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I.—THE HAWAIIAN HEPATICÆ OF THE TRIBE TRIGONANTHEÆ.

BY C. M. COOKE, JR.

THE tribe Trigonantheæ is represented in the Hawaiian Islands by twenty-five species belonging to six of the twenty-six genera enumerated by Schiffner and by a single species of the genus *Acromastigum* recently proposed by Evans. None of the peculiar genera, such as *Protocephalozia*, *Pteropsiella*, *Mytilopsis*, *Arachniopsis*, etc., found in tropical America by Spruce, have representatives among the Hawaiian members of this tribe. The genera represented are *Lepidozia* (three species), *Acromastigum* (one species), *Bazzania* (ten species), *Kantia* (four species), *Odontoschisma* (three species), and *Cephalozia* including *Cephaloziella* (five species).

Of the twenty-six species seven are unpublished—one in *Lepidozia*, two in *Bazzania*, and four in *Cephalozia*. Three of the last belong to the subgenus *Cephaloziella* and one to the subgenus *Eucephalozia*. No species of *Cephaloziella* have before been reported from the Hawaiian Islands.

A large number of the Hawaiian Trigonantheæ are related to North American and West Indian species and apparently not so many to East Indian, Asiatic, or South Pacific species. Some of the Hawaiian species related to North American and European species are: *Lepidozia australis* to *L. reptans*, *L. Hawaica* to *L. setacea*, *Bazzania Baldwinii* to *B. triangularis*, *Kantia bifurca* to *K. Sullivantii*, *Odontoschisma Sandvicense* to *O. Sphagni*, and *Cephalozia Baldwinii* to *C. leucantha*. Two of those related to West Indian species are: *Lepidozia Sandvicensis* to *L. commutata*, and *Bazzania patens* to *Mastigobryum Cubense*. *Cephalozia Kilohanensis* is closely related to *C. exiliflora*, of New Zealand, *Bazzania emarginata* is very close to *B. fallax*, of the East Indies, and *Kantia Tosana* is found in Japan.

The larger species of *Bazzania* are very conspicuous in the woods and on the higher mountain-ridges. They form large mats on the ground, sometimes many feet in diameter, and also cover the trees along with other bryophytes. The writer has only collected on the islands of Oahu and the lower ridges of Kauai. Undoubtedly the high mountain ranges of Hawaii, Maui, Molokai and Kauai offer a very rich field for the hepaticologist, especially in the smaller forms. The conditions are most favorable for the growth of hepatics.

The writer acknowledges his greatest thanks to Dr. A. W. Evans for his kind help in the preparation of this paper and for the use of material from the herbarium of Yale University, including several type-specimens sent by Herr F. Stephani and Mr. W. H. Pearson. Much thanks is also due Mr. D. D. Baldwin, of the Hawaiian Islands, for specimens of all the hepatics which he has collected.

The descriptions of the tribe and of the different genera are largely based on those of Spruce in his "Hepaticæ of the Amazon and Andes" and in his paper "On Cephalozia."

The tribe Trigonantheæ is a fairly natural one, and was first proposed by Spruce.[1] It is characterized by the trigonous perianth (except in *Kantia* and *Marsupidium*), which is usually borne on a short postical, specialized branch (rarely on a main branch or on the stem). This perianth is flattened antically and in every case there is a more or less pronounced postical keel, although apparent exceptions are found in certain species of *Cephaloziella*, where many of the perianths bear from one to three supplementary keels. In the tribe Epigoniantheæ the third keel is antical, while in the Scapanieæ and the Raduleæ the perianth is often so flattened that the upper and lower surfaces are in contact. In *Kantia* and *Marsupidium* the place of the perianth is taken by a large cylindrical perigynium. *Kantia* is distinguished from other saccate genera by its incubous leaves, but in the position of the sterile archegonia it agrees with *Acrobolbus*, a member of the Epigoniantheæ. In both these genera the calyptra is adnate (about three-fourths) with the perigynium and is crowned at the top by the sterile archegonia. In *Marsupidium*, which agrees with *Adelocolea* in its vegetative characters, the sterile archegonia surround the mouth of the perigynium; this condition finds its counterpart in *Tylimanthus*, another member of the Epigoniantheæ.

The plants of the Trigonantheæ vary greatly in size and also in color, being green, yellow, brown, white or sometimes reddish. The stems are simple or variously branched. In some genera the vegetative branches are lateral, while the specialized postical branches bear the ♂ or ♀ organs or else are reduced to flagella. In other genera all the branches are postical, while in *Anomoclada* the vegetative and sexual branches are antical and the flagella are postical. The lateral branches are commonly exogenous in origin, while the postical branches are usually endogenous and are axillary to the underleaves whenever the latter are present. In the genus *Acromastigum*, how-

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[1] On Cephalozia. 1882.

ever, the postical branches are exogenous in origin and are borne at the side of a reduced underleaf. The branching of *Cephaloziella* approaches that of some of the Epigoniantheæ.

Leaves are always present, though sometimes restricted to the sexual branches. They are usually alternate, rarely opposite, and are incubous, succubous or transverse. They exhibit various forms, being sometimes undivided and sometimes deeply parted, while their margins are entire or denticulate. The leaf-cells vary considerably in size in the different species and their walls are variable in thickness. Trigones may usually be demonstrated and are sometimes very large. Underleaves are usually present, though absent in certain species; they are minute to very large, in *Lepidozia* and *Acromastigum* being nearly equal in size to the leaves.

The inflorescence is usually dioicous, but is sometimes autoicous, and rarely paroicous or heteroicous. The ♀ bracts are tristicous in two to six series; they are broadly to narrowly ovate, deeply bifid to quadrifid and are usually larger than the leaves; sometimes they are highly connate with the bracteoles. The apex of the perianth is somewhat constricted, and the mouth is entire, dentate, ciliate or laciniate. The calyptra is pyriform and sometimes fleshy. The capsule is subglobose to subcylindrical, borne on a short or long stalk, four-valved to the base, two to five cells thick, the innermost cells being armed with semiannular thickenings. The spores are minute, round, and smooth or verruculose. The andrœcium is most often a short postical branch, but is sometimes terminal or intercalary on a leafy branch or on the main stem. The bracts are usually orbicular to ovate, closely imbricated, sometimes subcomplicate. The antheridia are usually solitary, but in certain species of *Bazzania* occur in pairs.

Key to the Hawaiian Genera of the Trigonantheæ.

Vegetative and specialized branches usually postical (sometimes lateral in *Cephaloziella*).
  Perianth present; leaves succubous or transversely inserted.
    Leaves succubous, undivided. *Odontoschisma.*
    Leaves succubous or transversely inserted, bilobed. *Cephalozia.*
  Perianth lacking, sporophyte developing instead within a cylindrical perigynium; leaves incubous. *Kantia.*
Vegetative branches usually lateral, specialized branches postical.
    Stems pinnately branched, often plumiform, in a few species bearing postical, endogenous flagella; leaves deeply lobed or parted; underleaves nearly as large as leaves. *Lepidozia.*

Stems sparingly branched, postical flagella exogenous; leaves transversely inserted, undivided; underleaves similar to leaves but slightly smaller. *Acromastigum.*

Stems pinnate or falsely dichotomous, postical flagella endogenous; leaves subfalcate, usually tridentate at the apex, rarely entire, bidentate or quadridentate; underleaves smaller than leaves. *Bazzania.*

Lepidozia Dumort., 1835.

Plants rather large or rarely small, pale or yellow-green, rarely bright green, densely cæspitose, in depressed, rarely erect or pendulous mats: stems usually strong, plumose, pinnately or bipinnately branched; leafy branches as a rule lateral, more or less curved downwards, sometimes attenuated and rooting at the apex; in small species, chiefly, postical branches present, which are normally leafy or frequently reduced to radicelliferous flagella: leaves incubous, small or minute, often broader than long, obliquely or transversely inserted, the antical margin longer and more rounded than the postical, decurved-convex or fornicate, usually 4-lobed or parted, rarely 2-, 3-, 5- or 6-lobed, lobes subulate, either entire or bearing at the antical base a few teeth, sometimes the whole margin dentate: cells small or minute, quadrate-hexagonal or oblong-quadrate, elongated at the base of the leaves, scarcely thickened at the corners: underleaves similar to leaves but smaller: dioicous or monoicous: ♀ inflorescence borne on a short postical branch from the main stem, rarely from a branch; bracts in 3 to 5 rows, appressed, concave, much larger than the stem-leaves, apex 2- to 4-lobed, margin denticulate to spinose; archegonia 20 or less, the sterile persisting at or near the base of the calyptra; perianth elongated, ovoid to narrowly fusiform, obtusely trigonous above, fleshy or unistratose, mouth entire, denticulate or ciliate-laciniate; calyptra one-half to one-quarter as long, pyriform or oblong, fleshy at the base: capsule oblong-cylindrical, 4-valved to the base, cells of outer layer furnished with parietal columns, innermost layer with semiannular thickenings; elaters slender, bispiral; spores minute, smooth or verruculose: andrœcium usually occupying a small postical branch, rarely terminal on a lateral branch; bracts in 5 to 10 pairs, suborbicular, concave, apex bidentate; bracteoles about half as large as bracts: antheridia borne singly.

Leaves obliquely inserted, 0.45^{mm}x0.35^{mm}. *L. australis.*

Leaves transversely inserted, less than 0.45^{mm}x0.35^{mm}.

  Plants large; leaves 0.3^{mm}x0.4^{mm}, closely appressed to stem. *L. Sandvicensis.*

  Plants small; leaves 0.13^{mm}x0.05^{mm}, slightly spreading. *L. Hawaica.*

Subgenus **Eulepidozia** Spruce, 1876.

Plants rather large, cæspitose, pinnate, more or less plumose: leafy branches nearly always lateral, in a few species rarely postical and flagelliform: leaves incubous, quadrifid about one-half: perianth fleshy, 2 to 4 cells thick, mouth subentire or denticulate, rarely ciliate.

Lepidozia australis (Lehm. & Lindenb.) Mitt.

Jungermannia australis Lehm. & Lindenb., Pug., vi, 28, 1834.

Lepidozia reptans australis G. L. & N., Syn. Hep., 205, 1845. Lindenb. & Gottsche, Sp. Hep., vi, 32, pl. V, figs. 18–23, 1846.

Lepidozia triceps Tayl., Lond. Journ. Bot., v, 369, 1846.

Lepidozia australis Mitt.; Seemann, Flora Vitiensis, 406. 1871.

Mastigophora triceps Trevis., Mem. reale Ist. Lomb. di Sci. e Lett., III, iv, 416, 1877.

Lepidozia reptans Evans, Trans. Conn. Acad., viii, 256, 1892 (not *Lepidozia reptans* (L.) Dumort.).

Plate I.

Monoicous: depressed-cæspitose, pale green: stems pale green, oval in section, about six by eight cells, cortical cells (in about 16 longitudinal rows) and internal cells about the same size, with uniformly thickened walls: lateral branches attenuate, flagelliform, rarely blunt: postical flagella infrequent; rhizoids frequent, colorless, borne in small clusters at the base of the underleaves: leaves approximate, obliquely inserted, spreading, plane, quadrifid (trifid, rarely bifid) about one-third; lobes subulate to narrowly triangular, acute, parallel, about 4 cells broad at the base and 8 cells long, usually ending in a row of 2 cells; sinuses separating lobes subacute or obtuse; leaves on branches approximate or slightly imbricated, similar to stem-leaves but smaller, usually trifid; leaves on attenuated branches minute, usually bifid; leaves subtending branches oblong, quadrate-ovate, bifid, lobes spreading, subulate: stem-underleaves about half the size of the leaves, distant, subquadrate, quadrifid about one-fourth; lobes subulate, parallel, 2 to 4 cells long, 1 to 2 cells broad; sinuses separating lobes obtuse; branch-underleaves smaller than those of stem, similar, quadrifid: cells in the middle of leaf arranged in rows, cavities with rounded corners, walls thickened, trigones small: cells in the middle of underleaf similar to those of leaf: ♀ inflorescence borne on a short branch; bracts usually in three pairs; innermost bracts broadly orbicular, denticulate at apex, teeth (usually 4) composed of 2 to 4 cells, rounded or acute, terminal cells verruculose ; sinuses separating teeth lunate ; cells near middle of bract oblong, with uniformly thickened walls : bracteole similar to bract ; bracts of second row orbicular, similar to innermost bracts but smaller ; bracteole of second row similar to bracts ; perianth broadly fusiform, 2 cells thick to a little above the middle, the rest 1 cell thick, terete below, irregularly 3-keeled above, mouth irregularly lobed, the lobes subdenticulate with teeth formed by sightly projecting obtuse cells: ♂ spike usually occupying a short postical branch, sometimes terminal on a lateral branch ; bracts in 4 to 7 pairs, concave or almost complicate, broadly ovate, bifid about one-third with triangular, acute lobes and acute sinus ; bracteoles ovate, bifid about one-fourth with subulate, parallel lobes and obtuse sinus.

Stems 0.23^{mm} in diameter ; leaves $0.45^{mm}x0.37^{mm}$; leaf-cells at edge of leaf $25\mu x20\mu$, at middle $32\mu x30\mu$, at base 38μ, at middle of underleaf $38\mu x24\mu$; underleaves $0.24^{mm}x0.21^{mm}$; innermost bracts $0.95^{mm}x1.1^{mm}$ and $0.82^{mm}x0.7^{mm}$; innermost bracteole $0.96^{mm}x0.96^{mm}$ and $0.8^{mm}x0.8^{mm}$; bracts of second row $0.45^{mm}x0.55^{mm}$; perianth 2.15^{mm} to $3.25^{mm}x1.3^{mm}$–1.7^{mm}; ♂ bracts $0.37^{mm}x0.3^{mm}$; bracteoles $0.24^{mm}x0.18^{mm}$.

Hawaii (Menzies). West Maui (Baldwin).

Lepidozia australis differs from *L. reptans* (G. & R., Hep. Eur., No. 479) in the following characters : the stems are more robust, the branches rarely branching and usually attenuate; the cells of the stems have much thicker cell-walls ; the leaves and underleaves are not as deeply lobed; the leaves are more obliquely inserted and spreading (while in *L. reptans* the leaves are concave, the lobes strongly incurved), the lobes are much narrower, usually only 4 cells wide (in the European species the lobes are usually 6 to 12 cells wide); the leaf-cells are larger, with much thicker cell-walls and with larger trigones ; the mouth of the perianth has shorter teeth.

Subgenus **Microlepidozia** Spruce, 1876.

Plants usually small, depressed-cæspitose, sometimes larger and pendulous : leaves transversely inserted, deeply divided or parted : perianth unistratose ; mouth ciliate-laciniate.

Lepidozia Sandvicensis Lindenb.

Lepidozia Sandvicensis Lindenb.; G. L. & N., Syn. Hep., 201, 1845. Lindenb. & Gottsche, Sp. Hep., vi, 12, pl. I, figs. 1–5, 1846.

Lepidozia filipendula Tayl., Lond. Journ. Bot., v, 369, 1846.

Mastigophora Sandvicensis Trevis., Mem. reale Ist. Lomb. di Sci. e Lett., III, iv, 415, 1877.

Mastigophora filipendula Trevis., l. c., 416.

PLATE II; FIGURES 1–12.

Plants loosely cæspitose, pale green: stems pale green becoming brown with age, pinnately branched, branches often bi- to tri-pinnatifid, flagelliform, main stem about 20 cells in diameter, cortical cells in about 60 longitudinal rows, internal cells hexagonal in cross-section, with uniformly thickened colorless cell-walls, cortical cells subquadrate, walls of about the same thickness as those of the internal cells, outer wall much pigmented; rhizoids wanting: leaves distant, almost transversely inserted, closely appressed to stem, slightly convex, subquadrate, slightly unsymmetrical, the antical edge longer than the postical, 12 to 18 cells wide at base, quadrifid (rarely bifid) more than one-half; lobes subulate, 4 to 6 cells broad, 6 to 10 cells long, ending in a single cell or a row of 2 or 3 cells, sinuses separating lobes acute, rarely obtuse: underleaves similar to leaves, but smaller, 8 to 10 cells broad at base; lobes usually 2 cells broad, 4 to 6 cells long; leaves of branches much smaller than stem-leaves, subquadrate, 6 to 8 cells broad at base, usually trifid, rarely quadrifid, lobed below the middle; lobes subulate, 1 or 2 cells broad at base, 2 to 4 cells long; underleaves of branches similar to branch-leaves, more often quadrifid: leaf-cells subquadrate, cell-walls uniformly thickened, cell-cavities with corners slightly rounded: leaves subtending branches ovate, deeply bifid about one-half; lobes triangular-subulate, acute, parallel or spreading: inflorescence unknown.

Stems 0.5^{mm} in diameter; cortical cells 30μ long, 27μ broad, 21μ thick; leaves of main-stem antical length 0.3^{mm}, postical length $0.2^{mm} x 0.4^{mm}$ (breadth at base); underleaves $0.22^{mm} x 0.25^{mm}$; leaf-cells at edge of leaf $29\mu x 25\mu$, at middle $35\mu x 25\mu$.

Hawaiian Islands (Tolmie). West Maui (Baldwin).

Lepidozia commutata Steph.,[1] of the West Indies, is very close to the Hawaiian species. The comparison has been made with specimens from the island of Guadaloupe (G. & R., Hep. Eur., No. 565). The two plants differ in their branching, the Hawaiian species having the branches pinnately or bipinnately branched, while in the West

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[1] Hedwigia, xxvii, 293, 1888.

Indian species they are simple or rarely pinnate; the cortical cells of the latter species are longer, narrower and with much thicker cell-walls, the leaves are not as closely appressed to stem, and those of the main stem are smaller with much smaller cells and thicker cell-walls, the leaves of the branches are larger and much more deeply lobed and their lobes are longer with much smaller cells. These differences hold also in the underleaves. In general appearance the two plants differ so that they can easily be distinguished by the naked eye, *L. Sandvicensis* being more robust and the stems appearing smooth. In *L. commutata* the plants are slender and the branches are rough, this appearance being due to the slightly spreading leaves.

Lepidozia Hawaica sp. nov.

Plate II: figures 13–24.

Dioicous: plants green, densely cæspitose or scattered among mosses and other hepaticæ: stems light green, pinnately branched, branches blunt or sometimes attenuated and flagelliform; stems about 4 cells in diameter, the internal cells with uniformly thin cell-walls, the cortical cells (in about 9 longitudinal cell-rows) with much thickened walls, the outer wall convex, giving the stem a fluted appearance; flagella scattered, postical with minute and closely appressed leaves; rhizoids wanting or found in small clusters of 2 to 4, at the base of the underleaves of the flagella or of the attenuated branches: leaves of main stem distant or subimbricated, transversely inserted, convex, suberect or slightly spreading, deeply 3-parted (rarely 4-parted) to within one or two cells of the base; base 4 or 5 cells broad; lobes spreading or parallel, often decurved, narrowly subulate, 1 or 2 cells broad, 3 to 5 cells long, with acute or obtuse sinuses; leaves of branches bi- or tri-parted, agreeing in other characteristics with the leaves of the stems: underleaves bipartite to within one cell of the base; base 2 to 4 cells broad, lobes most often parallel, narrowly subulate, 1 to 2 cells broad, about 4 cells long with obtuse sinuses: leaf subtending a branch subulate, 1 or 2 cells broad, about 4 cells long: leaf-cells subquadrate, with uniformly slightly thickened walls: ♀ inflorescence borne on a very short postical branch; bracts in 3 to 5 pairs; innermost bracts ovate, bifid about one-third, the upper portion ciliate or dentate; teeth 1 to 3 cells long, lobes generally divided, divisions subulate, 4 to 7 cells broad at base, about 9 cells long, ending in a row of three or more cells, cell-walls thin, apex of the end-cell usually verruculose; innermost bracteole similar to bracts; bracts of second row similar to innermost bracts but smaller; bracteole similar to bracts of second row; perianth broadly fusiform, terete below, many keeled above, mouth slightly contracted, irregularly lobed, lobes laciniate, laciniæ 4 to 6 cells long, 2 to 4 cells broad, cells of laciniæ slightly verruculose : ♂ spike usually occupying a short postical branch, rarely terminal on a lateral branch; bracts in 4 to 8 pairs, imbricated, concave or subcomplicate, broadly ovate, unequally bifid about two-thirds or one-half; lobes irregularly dentate, subulate, spreading, 3 or 4 cells broad at base, 6 or 7 cells long, ending in a row of about 3 cells, the apical cell slightly verruculose, the postical lobe broader than the antical; bracteoles similar to the stem-underleaves : capsule oval, dark brown; elaters blunt, bispiral.

Stems 0.07^{mm} in diameter; leaves 0.13^{mm} long x 0.05^{mm} broad at base; leaf-cells of lobes $23\mu \times 16\mu$, at base of leaf $18\mu \times 14\mu$; innermost bracts $0.7^{mm} \times 0.4^{mm}$; perianth 0.9^{mm} to $1.7^{mm} \times 0.4^{mm}$ to 0.5^{mm}; spores 12μ in diameter; elaters $150\mu \times 12\mu$; ♂ bracts $0.22^{mm} \times 0.15^{mm}$.

West Maui (Baldwin). Oahu: Nuuanu (Cooke).

This species is abundant in the latter locality, growing on the ground or fallen logs, on the shady lateral ridges.

Lepidozia setacea (Web.) Mitt. is very close to this species. For comparison specimens from G. & R., Hep. Eur., No. 502, were used. The Hawaiian species has leaves which are usually 3–parted, while in the European species the leaves are usually 4-parted; in the Hawaiian species the lobes are never 2 or 3 cells broad for 3 or 4 rows, but are shorter and narrower than the lobes of *L. setacea;* the leaf-cells have slightly thinner cell-walls and the terminal cell is not verruculose as in the European species; the underleaves of the Hawaiian species are usually bipartite, while in the European species they are usually tripartite; the leaves subtending branches in *L. Hawaica* are made up of a single row of cells, while in *L. setacea* these leaves are bipartite; the perianth of the Hawaiian species is smaller, and the innermost bracts and bracteoles are smaller and not so deeply lobed.

Acromastigum Evans, 1900.

Plants medium-sized, scattered among other hepatics, yellowish green, becoming brownish with age: stems stiff and wiry, mostly ascending or erect, sparingly branched: vegetative branches of three kinds: terminal branches from the lateral segments, terminal branches from the postical segments (flagella), intercalary branches axillary to the underleaves (very unusual): rhizoids not abundant: leaves distant or subimbricated, transversely inserted, undivided: underleaves a little smaller than the leaves, undivided: leaf-cells with thickened walls: sexual branches intercalary, arising singly in the axils of the underleaves: ♀ branch very short, its leaves reduced to the three to five rows of bracts; perianth long and slender, the three keels distinct except at the cylindrical base, separated by grooves; unfertilized archegonia borne at the base of calyptra: ♂ spike oblong; bracts in several pairs, strongly concave; antheridia occurring singly; paraphyses wanting; bracteoles similar to the underleaves but smaller: sporophyte not seen.

Acromastigum integrifolium (Aust.) Evans.

Mastigobryum? integrifolium Aust., Bot. Gazette, i, 32, 1875.
Bazzania? integrifolia Evans, Trans. Conn. Acad., viii, 255, 1892.
Acromastigum integrifolium Evans, Bull. Torr. Club, xxvii, 103, pl. I, 1900.

Dioicous: general characters of stems and branches given above; rhizoids whitish, simple or irregularly branched at the ends, very scanty on ordinary vegetative axes and occurring singly or in small clusters at the bases of some of the underleaves, more abundant on the flagella and less definite in position: leaves spreading widely from the stem, usually curved upward in the outer parts, ovate from a broad base, obtuse or more commonly acute, entire or nearly so, rarely with an indistinct angular tooth near apex: underleaves strongly squarrose, ovate or oblong, truncate or rounded at apex, entire or nearly so: leaf-cells with a very thick verruculose cuticle and conspicuous often confluent trigones but no intermediate thickenings; cell-cavities stellate: bracts very small and similar to ordinary leaves at base of branch but becoming rapidly larger toward the perianth; innermost bracts broadly ovate, gradually narrowed from near the base, shortly dentate or laciniate at apex (usually less than one-fourth the length) with slender teeth, otherwise entire or nearly so; innermost bracteole similar; perianth linear-fusiform, composed of a single layer of cells except at the very base, cells more uniformly thickened than the leaf-cells, mouth of perianth contracted, laciniate, the laciniæ long and slender, straight or irregularly curved and distorted, sometimes denticulate, composed of a single row of cells above and usually two or more toward the base: ♂ bracts in about 6 pairs, strongly concave, ovate, shortly bi- or tri-denticulate at the apex, the teeth 1 to 3 cells long, otherwise entire or nearly so; bracteoles similar to ordinary underleaves but smaller.

Stems 3 to 8^{cm} long; 0.25^{mm} in diameter; leaves $0.7^{mm} \times 0.4^{mm}$; underleaves $0.5^{mm} \times 0.3^{mm}$; leaf-cells at edge of leaf 14μ in diameter, in middle 18μ, and at the base $28\mu \times 23\mu$; innermost bracts $1.7^{mm} \times 1.0^{mm}$ (on robust specimens with perianths); perianth $4.0^{mm} \times 0.85^{mm}$: bracts $0.45^{mm} \times 0.25^{mm}$: bracteoles $0.35^{mm} \times 0.15^{mm}$.

Mixed with other hepatics. West Maui (Baldwin). Oahu: Konahuanui (Cooke). Type-specimen in Herb. W. H. Pearson.

Bazzania S. F. Gray, 1821.

Plants usually robust: stems depressed or pendulous, falsely dichotomous, compressed slightly from the front; cortical and interior cells of the stem similar, somewhat smaller than the leaf-cells; leafy branches lateral, very rarely postical; postical branches usually short and floriferous or elongated, microphyllous and radicelliferous: leaves incubous, alternate or very rarely opposite, more or less imbricated at the base, decurved, sometimes (in dry specimens principally) secund, always obliquely inserted, often falcate, twice as long as broad, subcordate at base or ligulate, apex usually truncate, tridentate, in rare cases 4-dentate or entire, sometimes equally bidentate or unequally bilobed, margin entire in most species, in a few dentate at the postical base: cells small, subequilateral, thickened at the corners, near the postical margin with 6 to 12 rows of elongated cells; subtending leaf antical, ovate-subulate, entire: underleaves always present, half as long as the leaves or less, usually wider than the stem, mostly subrotund, or quadrate, rarely elongate; apex truncate, usually 4-crenate to incised, rarely subentire, margin subentire or dentate, base cordate: dioicous: ♂ and ♀ flowers cladogenous on postical branches; ♀ bracts in 3 to 5 pairs, often shorter than leaves, concave, ovate to orbicular, rarely ovate-lanceolate, apex at least bilobed, laciniate or ciliate and more or less denticulate; archegonia 10 to 16; perianth narrowly ovoid, somewhat fleshy at the base, terete below, 3 keeled above, mouth subciliate: calyptra half the length of perianth, pyriform to cylindrical-oblong, 3 cells thick at base, 2 cells thick above: capsule half as long as calyptra, subcylindrical, the wall about 5 cells thick, outer layers with parietal columns, innermost having semiannular thickenings; elaters thin, subobtuse; spores minute: andrœcium shortly incurved; bracts in 5 to 10 rows, ovate, concave or subcomplicate, apex bifid or bidentate, rarely entire: antheridia usually in pairs, rarely solitary.

Underleaves ovate to orbicular.

Apex of leaves rounded or subtruncate. *B. Nuuanuensis.*

Apex of leaves tridentate or bidentate.

Leaf-cells at apex thick-walled, with or without small trigones. *B. Sandvicensis.*

Leaf-cells at apex thin-walled, trigones large.

Leaves broadly ovate ; plants robust, branching frequently.

Leaves tridentate, 1.4^{mm}x1.1^{mm}; leaf-cells at margin 15μ in diameter. *B. cordistipula.*

Leaves tridentate or bidentate, 0.85^{mm}x0.6^{mm}; leaf-cells at margin 25μ in diameter. *B. Didericiana.*

Leaves lanceolate, always bidentate ; plants slender, seldom branching. *B. emarginata.*

Underleaves subquadrate or quadrate.

Leaves lanceolate to ovate ; underleaves not connate with the leaves.

Leaves obliquely truncate, 0.9^{mm}x0.5^{mm}. *B. Baldwinii.*

Leaves acute or bidenticulate, 0.6^{mm}x0.4^{mm}. *B. minuta.*

Leaves ligulate ; underleaves sometimes connate with the leaves on one side.

Leaves large, 1.95^{mm}x0.85^{mm} ; leaf-cells at apex about 40μx30μ, with walls slightly thickened. *B. patens.*

Leaves 1.0^{mm}x5^{mm} ; leaf-cells at apex about 30μx20μ, with walls slightly thickened. *B. inæquabilis.*

Leaves small, 0.75^{mm}x0.4 ; leaf-cells at apex 20μ in diameter, with much thickened cell-walls. *B. Brighami.*

Bazzania cordistipula (Mont.) Trevis.

Herpetium cordistipulum Mont., Ann. des Sc. Nat., II, xix, 252, 1843. Voyage de la Bonite, Botanique, i, 242; atlas, pl. CXLIX, fig. 1, 1846.

Mastigobryum cordistipulum G. L. & N., Syn. Hep., 224, 1845. Lindenb. & Gottsche, Spec. Hep., vii, 65, pl. XI, figs. 1–5, 1851.

Bazzania cordistipula Trevis., Mem. reale Ist. Lomb. di Sci. e Lett., III, iv, 414, 1877.

Bazzania falcata Evans, Trans. Conn. Acad., viii, 255, 1892 (not *Bazzania falcata* (Lindenb.) Trevis.).

PLATE III ; FIGURES 1–14.

Plants yellowish brown or green, densely cæspitose: stems robust, falsely dichotomous, branches rarely attenuated or flagelliform; flagella postical, numerous, long-attenuate, microphyllous: leaves closely imbricated, alternate, subfalcate, spreading, obliquely ovate, the antical margin much more rounded than the postical, obliquely truncate, unequally tridentate; teeth broadly triangular to subulate, acute, acuminate or apiculate, antical tooth usually the longest, 5 to 13 cells long 4 to 7 cells broad, postical tooth 3 to 7 cells long 3 to 4 cells broad; sinuses obtuse to lunate; antical base arching over stem; postical margin slightly dilated near the base; line of insertion curved slightly inwards: underleaves imbricated, more than twice as broad as stem, orbicular, apex subretuse or repand, sometimes irregularly dentate, base cordate, lateral margins entire and somewhat reflexed: cells at apex of leaf thick-walled, with irregular cavities and large, sometimes confluent trigones, in the middle with elongate, substellate cavities and large triangular to orbicular, often confluent trigones, at the base with large, stellate cavities and large trigones; cells of underleaves similar to those of leaves: ♀ inflorescence borne on a very short branch; ♀ bracts in about 5 pairs; innermost bracts about the length of the leaves, broadly ovate, upper half irregularly denticulate, teeth 1 to 3 cells long, apex deeply 2 to 4 laciniate (about one-fourth), innermost bracteole similar to bracts; perianth ovate, terete below, many keeled above, mouth somewhat contracted, irregularly lobed, lobes laciniate, laciniae denticulate, 8 to 10 cells long, 4 to 6 cells broad, ending in a row of 4 or 5 cells; cells of perianth elongated, with much thickened walls: capsule oval, dark brown; spores light brown, minutely verruculose; elaters tapering toward the ends, blunt.

Stems 0.3^{mm} in diameter; leaves, antical axis 1.3^{mm} to 1.55^{mm}, postical axis 1.0^{mm} to 1.2^{mm}, breadth (greatest) near base 0.9^{mm} to 1.1^{mm}, at apex 0.35^{mm} to 0.4^{mm}, leaf-cells at base of median tooth 26μx19μ, in middle of leaf 26μx21μ, just above base 42μx24μ, extreme base 45μ, antical edge 15μ; underleaves 0.7^{mm}x0.85^{mm}; cells of underleaves 38μx22μ; perianth 2.2^{mm}x1.5^{mm}; innermost bracts 1.5^{mm}x0.9^{mm}; bracts of second row 1.2^{mm}x0.75^{mm}; spores 20μ; elaters 400μx15μ.

Hawaiian Islands (Gaudichaud, Hillebrand, Tolmie, Douglas). Hawaii (Beechey, Macrae). West Maui (Baldwin). Oahu (Mann & Brigham); Nuuanu, Konahuanui (Cooke). Kauai: Kilohana (Cooke); base of Pohokupili (Wawra). Very common from 1000 to 5000 ft., growing on the ground.

This species is closely related to *B. falcata*, of Nepal. A part of the type-material, from the herbarium at Kew, has been used for comparison. *B. falcata* differs from *B. cordistipula* in its larger leaves (length, antical 2.7^{mm}, breadth at base 1.6^{mm}, at apex 0.35^{mm}), which are much more falcate and bear one or two teeth at the postical base; the leaf-cells also are much larger with stellate cavities and larger trigones, measuring at apex 27μ, in the middle 45μx30μ, at the base 45μx38μ, and along antical edge 27μ.

Bazzania Sandvicensis (Gottsche) Steph.

Mastigobryum Sandvicensis Gottsche; Steph. Hedwigia, xxv, 207, pl. II, figs. 19–23, 1886.

Bazzania cordistipula Evans, Trans. Conn. Acad., viii, 255, 1892 (not *Bazzania cordistipula* (Mont.) Trevis.).

Bazzania Sandvicensis Steph., Bull. de l'Herb. Boissier, v, 841, 1897.

PLATE III: FIGURES 15–22.

Plants yellowish brown, densely cæspitose: stems ascending, long, robust, irregularly pinnately branched, branches sometimes attenuate, flagelliform; flagella numerous, very long, slender, microphyllous: leaves imbricated at the base, apex free, subfalcate, spreading, narrowly obliquely ovate, antical base curved, arching over the stem, postical not decurrent, line of insertion curved slightly inward, apex obliquely truncate, tridentate, teeth broadly triangular, acute, sometimes apiculate, about 4 to 8 cells broad, 6 to 14 cells long and ending in a row of 2 to 5 cells, sinuses obtuse or lunate: underleaves approximate or distant, suborbicular, apex truncate, rounded or slightly retuse: leaf-cells at apex with uniformly thickened walls, in the middle oblong, thick-walled, with small trigones, at middle of base large, with substellate cavities and large trigones, cells at antical edge oblong, with long axis perpendicular to edge, thick-walled, trigones small: cells of underleaf similar to those of leaf: ♀ inflorescence borne on a very short branch; ♀ bracts in about 5 pairs; innermost bracts broadly ovate, the upper portion denticulate, bifid to quadrifid, lobes subulate, 2 to 4 cells broad, 6 to 10 cells long, ending in a row of 4 to 6 cells; cells of bract elongated with thickened walls; innermost bracteole similar to bracts; bracts and bracteole of second row similar to those of innermost row but smaller; perianth ovoid-cylindrical, terete below, many keeled above, mouth deeply lobed, lobes laciniate, laciniæ about 4 cells broad, 6 to 20 cells long, denticulate at the base, ending in a row of 2 to 4 cells; cells of perianth elongated, with numerous intermediate thickenings: capsule oval, borne on a short stalk; spores minutely verruculose, light brown.

Stems 0.3^{mm} in diameter; leaves antical axis 1.4^{mm}, postical axis 1.15^{mm}, breadth at apex 0.35^{mm}, near base 0.75^{mm}; underleaves 0.55^{mm}x0.6^{mm}; leaf-cells at base of median tooth 17μx15μ, at middle of leaf 29μx20μ, near base 50μx19μ, at middle of base 45μx40μ, at antical edge 11μx15μ; innermost bracts 1.9^{mm}x1.0^{mm}; bracts of second row 1.25^{mm}x0.7^{mm}; perianth 3.2^{mm}x1.2^{mm}; spores 18μ.

Hawaiian Islands (Remy, Gaudichaud). Hawaii (Baldwin). Molokai (Baldwin). Oahu: Nuuanu, Konahuanui (Cooke).

This species is rather close to *B. cordistipula*. The plants are longer, the stems are rarely dichotomously branched, the leaves are narrower, less imbricated, the underleaves are smaller and are not imbricated, the leaf-cells are thicker walled, with smaller trigones, and at the apex are much smaller.

Bazzania Nuuanuensis sp. nov.

PLATE III: FIGURES 23–31.

Plants green, loosely cæspitose: stems more or less ascending, falsely dichotomous; flagella numerous, slender: leaves alternate, closely imbricated to the apex, spreading, subfalcate, broadly ovate, antical base arching over the stem, subcordate, postical base not decurrent, line of insertion curved slightly inward, apex truncate to rounded, margin slightly undulate: underleaves more than twice as broad as stem, transversely or subobliquely inserted, approximate, orbicular, cordate at the base, apex retuse or truncate; leaf-cells at apex of leaf thick-walled, cavities slightly irregular, trigones large, often confluent, in the middle somewhat elongated, cavities substellate, trigones large, at the base elongated, with intermediate thickenings and large, more or less orbicular trigones, cells along margin similar to those at apex.

Stems 0.3^{mm} in diameter; leaves 1.15^{mm}x1.1^{mm}, leaf-cells at apex 22μx20μ, at middle 35μx27μ, at middle near base 50μx28μ; underleaves 0.6^{mm}x0.8^{mm}, cells at middle of underleaf 30μx24μ.

Oahu: western ridge of Nuuanu (Cooke).

This species is closest to *B. cordistipula* among the Hawaiian species: it is easily distinguished by its apex not being toothed; its leaves also are broader in proportion to their length, the cells are slightly larger, and the underleaves are slightly smaller and not so closely imbricated.

Bazzania Didericiana Steph.

Mastigobryum Didericianum Steph., Hedwigia, xxiv, 249, pl. III, fig. 2, 1885.
Bazzania Didericiana Steph., Bull. de l'Herb. Boissier, v, 841, 1897.

PLATE IV; FIGURES 1–13.

Plants yellow-green, densely cæspitose: stems robust, sparingly branched, ascending; flagella numerous, slender, microphyllous: leaves imbricated, spreading, subfalcate, obliquely ovate, antical base arching nearly across the stem, postical base not decurrent, line of insertion lunate, apex obliquely truncate, tri-(bi- or quadri-) dentate, teeth broadly triangular, acute ; sinuses separating teeth lunate : underleaves twice the width of the stem, approximate or slightly imbricated, orbicular, apex retuse, crenulate or dentate, base subcordate : leaf-cells with stellate cavities, walls thin, trigones large, sometimes nearly as large as the cavities ; cells of underleaves similar to those of leaves : ♀ inflorescence borne on a very short branch ; bracts in 3 or 4 pairs ; innermost bracts ovate, the upper half denticulate, apex bifid to quadrifid, lobes subulate, margins denticulate ; cells with thickened walls, those at margin with outer walls thin, trigones small ; innermost bracteole similar to bract but narrower and slightly shorter ; bracts and bracteole of second row much smaller, bifid to quadrifid, lobes subulate, sparingly denticulate ; perianth ovoid-cylindrical, terete below, irregularly keeled above, mouth contracted, irregularly lobed, lobes laciniate, laciniæ 2 to 4 cells broad, 5 to 8 cells long, ending in a row of 2 to 5 cells: capsule oval, dark brown; spores round, verruculose ; elaters slender, blunt.

Stems 0.3^{mm} in diameter, leaves 0.85^{mm} long, 0.6^{mm} wide near the base, 0.25^{mm} at the apex; underleaves $0.35^{\mathrm{mm}}\mathrm{x}0.5^{\mathrm{mm}}$; leaf-cells at base of median tooth 25μ, at base of leaf $57\mu\mathrm{x}33\mu$, antical edge 24μ, at middle of underleaf $40\mu\mathrm{x}30\mu$; innermost bract $1.6^{\mathrm{mm}}\mathrm{x}1.1^{\mathrm{mm}}$; innermost bracteole $1.6^{\mathrm{mm}}\mathrm{x}0.8^{\mathrm{mm}}$; perianth $2.9^{\mathrm{mm}}\mathrm{x}1.0^{\mathrm{mm}}$; spores 20μ; elaters 160 to $240\mu\mathrm{x}12\mu$.

Hawaii: Kilavea (Didrichsen). Hawaiian Islands (Baldwin). Oahu: Nuuanu (Cooke).

This plant is easily distinguished from *B. cordistipula*, its nearest Hawaiian relative, by its shorter and much less frequently branched stems, by its much smaller leaves and underleaves, and by its slightly larger leaf-cells with stellate cavities and much larger trigones.

An aberrant form of this species is found in the same locality but not mixed with typical specimens. The stems branch much more frequently, the leaves are nearly half again as long and twice as broad, deeply bidentate, the lobes triangular, acute or acuminate, 4 to 6 cells broad, 6 to 8 cells long, connivent or spreading, the sinus acute or obtuse, and the underleaves are larger and less toothed. The cellular structure, however, agrees with that of typical specimens.

Bazzania emarginata (Steph.).

Mastigobryum Didericianum, var. *emarginatum* Steph., Hedwigia, xxiv, 249, 1885.

Plate IV; figures 14–27.

Plants yellowish brown, growing in loose tufts on the trees and on the ground, often mixed with other hepaticæ; stems very slender, sparingly branched, often pendulous; flagella scattered, very slender: leaves distant, rarely approximate, spreading, subfalcate, lanceolate, antical base arching about half way over the stem, postical base not decurrent, apex bidentate or emarginate, teeth subulate, divergent or parallel, 3 to 6 cells broad, 4 to 12 cells long, ending in a row of 2 to 6 cells, antical tooth often longer than the postical; sinus acute or obtuse: underleaves distant or approximate, twice as broad as stem, broadly ovate, base slightly curved, apex truncate, retuse or erose-dentate: leaf-cells at apex large, thin-walled, cavities stellate, pits long, trigones large, sometimes confluent, cells at margin small, elongated, perpendicular to edge, at the middle of the base oblong, trigones large, often confluent; at middle of underleaf similar to those of leaf: ♀ inflorescence borne on a short branch; bracts in about three rows; innermost bracts ovate, the upper portion denticulate, apex bifid to quadrifid, lobes subulate, denticulate at the base, 2 to 4 cells broad, 5 to 8 cells long, ending in a row of 3 to 5 cells; innermost bracteole similar to bracts; bracts of second row ovate sparingly denticulate, bifid, teeth 2 to 4 cells long, 2 to 4 cells broad; bracteole similar to bracts; perianth ovoid-cylindrical, terete below, many keeled above, 2 cells thick near base, mouth contracted, irregularly lobed, lobes laciniate, laciniæ 2 to 4 cells broad, 4 to 7 cells long, ending in a row of about 4 cells: capsule oval, purplish brown; spores brown, verruculose: ♂ spike occupying a short postical branch; bracts in about 6 pairs, concave, broadly ovate, apex irregularly dentate, teeth 1 or 2 cells long, 1 or 2 cells broad; bracteoles much smaller, broadly ovate, apex emarginate, lobes triangular, rounded; antheridia borne singly.

Stems 0.2^{mm} in diameter; leaves 1.3^{mm} long, 0.25^{mm} broad at apex, 0.5^{mm} broad at base; underleaves $0.45^{\mathrm{mm}} \mathrm{x} 0.4^{\mathrm{mm}}$, leaf-cells at apex 33μ, at middle of base $57\mu \mathrm{x} 28\mu$, at antical edge $20\mu \mathrm{x} 31\mu$, at middle of underleaf $45\mu \mathrm{x} 30\mu$; innermost bract $1.2^{\mathrm{mm}} \mathrm{x} 0.65^{\mathrm{mm}}$; bract of second row $0.75^{\mathrm{mm}} \mathrm{x} 0.45^{\mathrm{mm}}$; outermost bract $0.25^{\mathrm{mm}} \mathrm{x} 0.25^{\mathrm{mm}}$; perianth $2.4^{\mathrm{mm}} \mathrm{x} 1.0^{\mathrm{mm}}$; ♂ bracteole $0.25^{\mathrm{mm}} \mathrm{x} 0.3^{\mathrm{mm}}$; spores 22μ.

Hawaii: Kilavea (Didrichsen). East Maui (Baldwin). Oahu: Konahuanui (Heller, Cooke); Lanahuli (Cooke).

This species is very common on the higher mountain ridges, where it completely covers the trunks, branches and twigs of the lower stunted trees, sometimes along with *Herpocladium* and *Herberta*, which it closely resembles to the naked eye. Of the Hawaiian *Bazzaniæ*, *B. Dideriaciana* is nearest to *B. emarginata*. The stems of the latter are much longer and slenderer, the leaves are usually distant, are longer, narrower and more falcate, the apex is bidentate, the underleaves are smaller and narrower in proportion to their length, the leaf-cells are much larger.

B. emarginata is very close to *B. fallax* (Sande-Lac.) Schiffn., of the East Indian archipelago. Unfortunately the writer has been unable to procure specimens of the latter species. The comparisons are therefore made from the descriptions and figures.[1] The Hawaiian species differs from the East Indian in the following characters: the leaves are longer and narrower, with much longer and more subulate teeth, the underleaves are much shorter and broader, the leaf-cells are somewhat larger, the innermost bracts are longer, narrower and with much fewer and shorter lobes.

Bazzania Baldwinii Aust.

Bazzania Baldwinii Aust.; Evans, Trans. Conn. Acad., viii, 255, pl. XXII, figs. 4, 5, 1892.

Bazzania deflexa Evans, l. c., 255 (not *B. deflexa* (Nees) Underw.).

PLATE V; FIGURES 14–33.

Plants loosely cæspitose, yellowish green: stems slender, sparingly branched, sometimes with leafy branches given off from axils of underleaves, oval in section; flagella few, scattered, very slender: leaves distant, approximate or imbricated at the base, subfalcate, when dry concave, sublanceolate to obliquely ovate, antical base curved, arching nearly over the stem, postical base not decurrent, obliquely truncate, tri-(bi-)dentate, antical tooth the largest, 3 to 6 cells long, 2 to 4 cells broad, median and postical teeth usually containing from 3 to 5 cells; sinuses obtuse or lunate: underleaves remote, wider than stem, ovate-quadrate, apex truncate, undulate or erose-dentate, with obtuse teeth: leaf-cells at apex thin-walled,

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[1] *Mastigobryum Borneense* De Notaris, Epatiche di Borneo, 303, tab. XXXI, 1874. This species is referred by Schiffner to *B. fallax* (vid. Conspectus Hepaticarum Archipelagi Indici, 158, 1898).

corners rounded, trigones small, triangular, at base larger, thin-walled, corners rounded or slightly indented, trigones small, triangular, at margin similar to those at apex; cells of underleaf similar to those of leaf: ♂ spike occupying a short postical branch, dark brown; bracts in 5 to 10 pairs, closely appressed, concave, suborbicular, apex usually bidentate, teeth small, triangular; bracteole ovate, bidentate, teeth similar to those of bracts; antheridia borne singly, oval.

Stems 0.25^{mm} in diameter; leaves 0.9^{mm} long 0.2^{mm} wide at the apex, 0.5^{mm} at the base; underleaves 0.4^{mm}x0.35^{mm}, leaf-cells at apex 20μ, at base 38μx30μ, at antical edge 13μx17μ; ♂ bracts 0.5^{mm}x0.5^{mm}; bracteoles 0.5^{mm}x0.4^{mm}.

East Maui: Haleakeala (Baldwin). West Maui (Baldwin).

This species is closely related to *B. triangularis* (Schleich.) Lindb. (= *B. deflexa*), of Europe, North America and Asia. For comparison specimens from G. & R., Hep. Eur., No. 634, have been used. The leaves of *B. Baldwinii* are much less concave, narrower and frequently bidentate, the leaf-cells have thinner walls and smaller trigones, the cells at the base are somewhat larger, the underleaves are more oblong.

Bazzania minuta (Aust.) Evans.

Mastigobryum minutum Aust., Bull. Torr. Bot. Club, v, 17, 1874.
Bazzania minuta Evans, Trans. Conn. Acad., viii, 255, 1892.

PLATE V; FIGURES 1–13.

Plants loosely cæspitose, yellowish green: stems slender, sparingly branched; leafy branches lateral, sometimes postical from the axil of an underleaf; flagella scattered, very slender: leaves approximate or distant, spreading, lanceolate-ovate, apex bidenticulate, sometimes acute or apiculate, antical base curved, arching partly over the stem, postical base not decurrent: underleaves distant, a little broader than the stem, base subcordate, apex obtuse or truncate, bidentate, retuse or erose-dentate, lateral margin sometimes unidentate: leaf-cells at apex thin-walled, cavities with irregular outline, trigones small, at base larger, but agreeing in other points with those of apex, at margin similar to those at apex; cells of underleaves smaller than those of leaves and with smaller trigones.

Stems 0.15^{mm} in diameter; leaves 0.6^{mm}x0.4^{mm}; underleaves 0.15^{mm} x0.12^{mm}; leaf-cells at apex 23μx21μ, at base 34μx28μ, at antical edge 17μ; cells of underleaves 22μx17μ.

Hawaiian Islands (Hillebrand). East Maui (Baldwin).

Bazzania minuta is more closely related to *B. Baldwinii* than to any other Hawaiian *Bazzania*. They are easily distinguished by the difference in size of the plants and by the form and size of the leaves and underleaves.

Bazzania patens (Mont.) Trevis.

Herpetium patens Mont., Ann. des Sc. Nat., II, xix, 295, 1843. Voyage de la Bonite, Botanique, i, 242; atlas, pl. CXLIX, fig. 2, 1846.

Mastigobryum patens G. L. & N., Syn. Hep., 221, 1845. Lindenb. & Gottsche, Spec. Hep., vii, 48, tab. VIII, figs. 1–4, 1851.

Mastigobryum parvistipulum Aust., Bull. Torr. Bot. Club, v, 16, 1874.

Bazzania patens Trevis., Mem. reale Ist. Lomb. di Sci. e Lett., III, iv, 414, 1877.

Bazzania Beecheyana Steph., Hedwigia, xxxii, 204, 1893.

PLATE VI; FIGURES 1–10.

Plants depressed, loosely cæspitose, green: stems prostrate, falsely dichotomous; flagella short, blunt; rhizoids borne in clusters at the base of underleaves, long, colorless: leaves slightly imbricated, subfalcate, truncate, tri-(rarely quadri-)dentate, teeth broadly triangular, 2 or 3 cells long, acute; sinuses separating teeth broadly lunate: underleaves slightly broader than the stem, subquadrate, apex irregularly 4 to 6 dentate, teeth triangular, often divided, 2 or 3 cells broad, 3 to 5 cells long, lateral margins often dentate: leaf-cells at apex large, walls slightly thickened, trigones small, at middle of base very large, oblong-polygonal, walls slightly thickened, trigones small; cells of the underleaves oblong, smaller than those of leaves, with thinner walls and smaller trigones.

Stem 0.4^{mm} in diameter; leaves 1.95^{mm}x0.85^{mm}; underleaves 0.4^{mm} x0.5^{mm}; leaf-cells at apex 40μx30μ, at middle of base 52μx40μ, antical edge near base 22μ; cells of underleaves 43μx32μ.

Hawaiian Islands (Gaudichaud, Andersson). East Maui (Baldwin). Oahu (Beechey, Mann and Brigham); Nuuanu (Cooke). Kauai: Kilohana (Cooke).

B. patens is close to *Mastigobryum Cubense* Gottsche.[1] It differs however in the following points: *B. patens* is a larger plant, the leaves being nearly twice as large, the cell-walls are thinner and the trigones are smaller and are not confluent, the cells at the base are larger and their trigones are smaller and are not confluent, the underleaves are smaller and have thinner cell-walls and smaller trigones.

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[1] Stephani, Hedwigia, xxiv, 249, pl. III, fig. 1, 1885.

Bazzania inæquabilis Steph. Ms.

PLATE VI: FIGURES 11-25.

Plants loosely cæspitose, green: stems subascending, robust, frequently branching dichotomously, branches lateral, sometimes postical from the axil of an underleaf; flagella scattered, short: leaves densely imbricated, spreading, subfalcate, ligulate, antical base slightly dilated, arching partly over the stem, apex transversely or obliquely truncate, tri-(rarely bi- or quadri-)dentate, teeth triangular to subulate, parallel or spreading: underleaves approximate, scarcely broader than stem, subquadrate, usually connate on one side, apex truncate, irregularly dentate: leaf-cells at apex subquadrate, corners rounded, walls slightly thickened, trigones small, at middle of base larger, oblong, corners slightly rounded, walls slightly thickened, trigones small; cells at middle of underleaves oblong, with slightly thickened walls, trigones small: ♀ inflorescence borne on a very short branch; bracts in about 3 rows; innermost bracts ovate, upper portion irregularly denticulate, deeply bilobed, lobes subulate, denticulate at the base, acuminate or bifid at the apex; innermost bracteole similar to bracts; cells of innermost bracts elongated thin-walled, trigones lacking: perianth ovoid-cylindrical, terete below, irregularly keeled above, mouth contracted, lobed, lobes ciliate, cilia 2 to 4 cells broad, 6 to 8 cells long, ending in a row of 3 to 5 cells; cells of perianth elongated, with scarcely thickened walls: ♂ spike occupying a short postical branch; bracts in about 5 rows, broadly ovate, apex usually bidentate, teeth broadly triangular.

Stems 0.35^{mm} in diameter; leaves about 1.0^{mm}x0.45^{mm} to 55^{mm}; underleaves 0.3^{mm}x0.35^{mm}, leaf-cells at apex 30μx21μ, at middle of base 37μx25μ, at antical edge near base 18μ, cells of underleaf 34μx25μ; perianth 2.9^{mm}x0.9^{mm}; innermost bracts 1.3^{mm}x0.55^{mm}; cells of perianth 80μx20μ, of innermost bracteole 75μx30μ; ♂ bracts 0.4^{mm} x0.35^{mm}; cells of ♂ bracts 32μx20μ.

Oahu (Lauterbach); Pauoa (Heller); Nuuanu (Cooke). Kauai: Lihue (Cooke).

B. inæquabilis is a much smaller plant than *B. patens*, the stems branch much more frequently, the leaves are smaller, more closely imbricated, less falcate, sometimes spreading almost at right angles to the stem, the apex is much more deeply toothed, the underleaves are longer in proportion to their breadth, less deeply toothed, and the cells of the leaves and underleaves are smaller throughout.

Bazzania Brighami (Aust.) Evans.

Mastigobryum Brighami Aust., Bull. Torr. Bot. Club, v, 16, 1874.
Mastigobryum ligulatum Sande-Lac.; Steph., Hedwigia, xxv, 202, pl. I, figs. 13, 14. 1886.
Bazzania Brighami Evans, Trans. Conn. Acad., viii, 255, 1892.

PLATE VII.

Plants loosely cæspitose, green or yellow-brown: stems slender, creeping or ascending, branching frequently and dichotomously; branches blunt, rarely attenuated or flagelliform; leafy branches sometimes arising postically from the axils of underleaves; stems about 8 cells in diameter, all the cells of about the same size, walls much thickened, cortical cells in about 20 longitudinal rows, their walls pigmented; flagella numerous, slender, sometimes branching; rhizoids borne in clusters at the base of underleaves: leaves approximate or slightly imbricated, nearly opposite, spreading, subfalcate, ligulate to broadly ovate, antical base slightly dilated, arching halfway over stem, apex truncate, tridentate, teeth broadly triangular, acute to apiculate, sometimes rounded, 1 to 3 cells long; sinuses separating teeth broadly lunate: underleaves distant or approximate, much wider than the stem, usually connate with the leaf on one side, sometimes connate on both sides, subquadrate to broadly ovate, apex truncate, irregularly quadridentate, teeth triangular acute or apiculate, often bifid: leaf-cells at the apex with much thickened cell-walls, cavities small, subquadrate, at middle near base subvittate, the cells oblong, thick-walled, trigones small; cells of underleaves oblong, walls slightly thickened, the base of the underleaf showing one or two rows of very small cells with uniformly much thickened walls and irregularly oblong-quadrate cavities: ♀ inflorescence borne on a short branch; bracts in 3 to 5 pairs; innermost bracts broadly ovate, the upper part of margin irregularly dentate or denticulate, deeply bifid to quadrifid, lobes subulate, irregularly denticulate at the base; innermost bracteole similar to bracts, usually less deeply lobed; cells oblong, with slightly thickened walls; bracts of second row ovate, bifid: perianth fusiform, terete below, irregularly keeled above, mouth lobed, lobes ciliate, cilia 4 to 6 cells long, 1 or 2 cells broad, apical cell minutely verruculose: ♂ spikes borne in the axils of underleaves, sometimes on flagella, often curved; bracts in 5 to 10 pairs, concave, broadly ovate, apex bidentate or bidenticulate, teeth triangular, apiculate, sometimes acute, apical tooth minutely verruculose, lateral margins entire or sometimes bearing 1 or 2 teeth; bracteoles ovate or subquadrate, apex truncate or rounded, bidenticulate, teeth separated by a broadly lunate sinus, margin entire, sometimes bearing a lateral tooth on one or both sides; cells of bracts and bracteoles polygonal, walls slightly and uniformly thickened.

Stems 0.18^{mm} in diameter ; leaves 0.75^{mm}x0.25^{mm} at apex to 0.4^{mm} at base; underleaves 0.25^{mm}x0.35^{mm} ; leaf-cells at apex 20μx18μ, at middle 20μ, at base 35μx25μ, at antical edge 12μ, underleaf-cells at middle 20μx15μ, at base 12μ ; perianth 2.4^{mm}x0.8^{mm} ; innermost ♀ bracts 1.1^{mm}x0.7^{mm} ; cells at middle of bracts 75μx25μ ; ♂ bracts 0.3^{mm} to 0.45^{mm}x0.13^{mm} to 0.22; cells at middle of ♂ bract 32μx24μ.

Hawaiian Islands (Herb. Sande-Lac., Baldwin). Oahu (Mann and Brigham) ; Nuuanu, Mt. Tantalus, Konahuanui (Cooke). Kauai : Kilohana, Molokoa (Cooke).

Specimens of *Mastigobryum ligulatum* from Herr Stephani agree perfectly with the type-specimens of *M. Brighami* collected by Mann and Brigham. This species is very distinct from the other Hawaiian *Bazzaniæ*. Perhaps *B. inæquabilis* is the most closely related. *B. Brighami*, however, is a much smaller plant, the leaves are smaller and the sides more parallel, the leaf-cells are smaller, with much thicker cell-walls.

Of great interest in this species is the occurrence of antheridial spikes on the flagella. This tendency was found on several plants which came from the same log. It may be compared with the position of male spikes on the ventral branches of *Kantia*, since the flagella are modified postical branches. Leafy branches occur postically on *B. Brighami* but no male spikes were found on them. That male spikes occur on flagella is mentioned by Lindenberg[1] and by Pearson.[2] In *B. Brighami* sometimes as many as three spikes were found on a single flagellum.

Kantia S. F. Gray, 1821.

Plants rather small to large, dark green to pale green, depressed-cæspitose or scattered among other bryophytes : stems prostrate or assurgent at the sometimes gemmiparous apex, subsimple or rarely branching ; branches postical, blunt or attenuated ; rhizoids long, colorless, borne in clusters at the base of the underleaves: leaves closely imbricated to approximate, incubous, alternate, spreading narrowly ovate to suborbicular, entire, apex rounded or retuse, sometimes cuspidate, bidentate or bilobed : leaf-cells large, mostly isodi-

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[1] G. L. & N., Syn. Hep., 214, 1845.

[2] The Hepaticæ of the British Isles, 129, 1900. The species here referred to is *B. trilobata*.

ametric or oblong-hexagonal, thin-walled or with walls scarcely thickened, trigones small or lacking: underleaves always present, usually large, broadly ovate, suborbicular or broadly reniform, apex entire, retuse or bilobed, lobes often equally or unequally bifid: dioicous, autoicous or paroicous; sexual branches axillary to the underleaves: ♀ bracts in 2 or 3 rows, very much smaller than the leaves, subrotund, ovate or lanceolate, entire or 2 to 4 lobed, subconnate; bracteoles similar; perianth lacking; archegonia less than 12: perigynium developed from the ♀ branch, pendulous, subterranean, carnose, many cells thick, radicelliferous, clavate or subcylindrical, the apex crowned by the persisting bracts and bracteoles, the interior surface papillate; calyptra nearly as long as the perigynium, adnate almost to the apex, the free portion bearing the sterile archegonia: capsule cylindrical, the four linear, spirally wound valves 2 cells thick, the inner layer with numerous semiannular bands, which are nearly lacking in the outer layer; "involucellum" highly developed, finally adnate to the calyptra and reaching to the line of separation of calyptra and perigynium walls, its cells elongated and sinuous: elaters long, slender, blunt, bispiral; spores minute, about the diameter of the elaters.

Apex of leaves subtruncate or rounded, verruculose; underleaves retuse. *K. Baldwinii.*

Apex of leaves usually cuspidate; underleaves deeply bifid, lobes triangular. *K. cuspidata.*

Apex of leaves usually bidentate.
- Leaves large, $1.25^{mm}x1.1^{mm}$, teeth 1 to 3 cells long; underleaves bifid about two-thirds. *K. Tosana.*
- Leaves small, about $0.65^{mm}x0.5^{mm}$, teeth 3 or 4 cells long; underleaves bifid to within a cell of the base. *K. bifurca.*

Kantia Tosana Steph.

Calypogeia Trichomanis Mitt.; Seemann, Flora Vitiensis, 407, 1871 (not *Kantia Trichomanis* (L.) S. F. Gray).

Kantia bidentula Evans, Trans. Conn. Acad., viii, 256, 1892 (not *Jungermannia bidentula* Web.).

Kantia Tosana Steph., Hedwigia, xxxiv, 54, 1895.

PLATE VIII; FIGURES 1–8.

Polyoicous: plants in loose, depressed mats: stems prostrate, frequently branching, the branches obtuse or sometimes elongate-flagelliform, often gemmiparous; branches similar to stems; flagella lacking or rarely present; rhizoids long, colorless, borne in clusters at the base of underleaves: leaves alternate, spreading, obliquely inserted, imbricated, rarely approximate or distant, ovate, antical base arching partly over stem, postical base slightly decurrent, apex bidentulate, rarely obtuse or acute, teeth small, acute or obtuse, 1 to 3 cells long : cells of leaf polygonal, thin-walled, cavities angular, trigones lacking; cells at base oblong-polygonal : underleaves distant, twice the width of stem, subtransversely inserted, decurrent, broadly reniform, deeply bifid (about two-thirds), lobes entire or unequally cleft, divisions acute or obtuse, sinus separating lobes obtuse or lunate ; cells of underleaves similar to those of leaf but somewhat smaller : ♀ inflorescence usually borne singly, sometimes two ♀, a ♂ and a ♀, or a ♀ and a vegetative branch borne from the axil of the same underleaf ; bracts in two or three pairs, small, broadly ovate, usually bifid ; bracteoles similar to bracts : andrœcium a short branch, usually borne singly but sometimes in pairs from the axils of the underleaves : ♂ bracts in 4 to 8 pairs, ovate, deeply bifid (about one-half), lobes subulate : capsule long, oval ; spores light brown, minute, round ; elaters blunt, bispiral.

Stems 0.45^{mm} in breadth ; leaves $1.4^{mm}x1.1^{mm}$ to $1.25^{mm}x1.1^{mm}$; underleaves $0.35^{mm}x0.8^{mm}$ to $0.3^{mm}x0.5^{mm}$; leaf-cells at apex 45μ, at base $90\mu x45\mu$, at margin near postical base $90\mu x30\mu$, near antical base $75\mu x35\mu$; perigynium $3.9^{mm}x0.8^{mm}$ to $5.75^{mm}x0.9^{mm}$; elaters $300\mu x15\mu$; spores 18μ.

West Maui (Baldwin). Oahu: Nuuanu (Cooke). Kauai: Kilohana (Cooke).

This species is very common in damp, shady valleys, growing on the ground. It is about the same size as the widely distributed *K. Trichomanis*, of Europe and North America, but its leaves are narrower, more acute, and almost always bidentulate ; the leaf-cells also are much larger and with thinner cell-walls, and the underleaves are wider in proportion to their length.

Kantia cuspidata Steph.

Kantia cuspidata Steph., Bull. de l'Herb. Boissier, v, 846, 1897.

PLATE VIII ; FIGURES 9–14.

Sterile : plants greenish yellow, loosely cæspitose, depressed : stems short, prostrate, rarely branching ; true flagella lacking ; rhizoids long, colorless, borne in clusters at the base of the underleaves: leaves imbricated, alternate, obliquely inserted, spreading, plane, ovate, antical base arching partly over stem, slightly rounded, postical base slightly decurrent, apex obtuse or cuspidate : leaf-cells at margin thin-walled, just inside the marginal row polygonal, at base polygonal-oblong, cuticle smooth: underleaves distant, somewhat broader than stem, broadly ovate, deeply bifid about three fourths, the lobes triangular, acute, parallel or spreading, 6 to 8 cells broad, 8 to 12 cells long; sinus separating lobes acute or obtuse; cells of underleaves similar to those of leaves.

Stems 0.25^{mm} to 0.3^{mm} in breadth; leaves $1.05^{mm}x0.9^{mm}$; leaf-cells at apex 33μ, at base $62\mu x 35\mu$; underleaves $0.4^{mm}x0.45^{mm}$; cells at middle of lobe of underleaf $62\mu x 35\mu$.

Oahu (Heller); Nuuanu (Cooke).

Kantia cuspidata is a smaller plant than *K. Tosana*. The leaves are cuspidate or obtuse, never bidentulate; the underleaves are more deeply bifid, and their lobes are never truncate or bilobed.

Kantia bifurca (Aust.) Evans.

Calypogeia bifurca Aust., Proc. Acad. Nat. Sci. Phil., 223, 1869.
Kantia bifurca Evans, Trans. Conn. Acad., viii, 256, 1892.

PLATE IX: FIGURES 1–10.

Autoicous: plants small, scattered, pale green: stems pale green, slender, weak, prostrate, ascending at the tip, often gemmiparous, rarely branching except at the base, attenuate or blunt, oval in section, about 7 by 5 cells, ventral surface more convex than the dorsal, cortical cells (in about 12 rows) subquadrate, thin-walled, dorsal cells slightly larger than ventral, interior cells polygonal, thin-walled; a row of large elongated cells is found on each side of the stem where the bases of the leaves are attached; branches similar to stem, more often attenuate; rhizoids borne in clusters at the base of the underleaves: leaves tender, alternate, spreading, obliquely inserted, imbricated or approximate, becoming distant on attenuated stems or branches, decurrent postically to about the middle of the next leaf, antical base arching halfway over the stem, broadly ovate, apex truncate-bifurcate or bidentulate, lobes spreading, triangular, acuminate, 1 or 2 cells broad, 3 or 4 cells long, ending in a row of 2 or 3 cells; sinus separating teeth lunate: leaf-cells at apex subquadrate with slightly thickened walls, at middle of base oblong-polygonal with thin walls, at margin elongated, with slightly thicker walls than interior cells: underleaves distant, minute, deeply bifid to within a single cell of the base, which is 5 or 6 cells broad, each lobe bearing a single tooth on its outer margin, spreading, subulate, 2 cells broad, 4 or 5 cells long, ending in a row of 3 or 4 cells, the lateral tooth composed of 1 or 2 cells; underleaf-cells with slightly thickened walls: ♂ and ♀ flowers borne on very short branches, singly or in groups of 2 to 5 from the axils of consecutive underleaves, rarely 2 sexual branches borne from the axil of the same underleaf, in such a case both being of the same sex; ♀ bracts 2 or 3 pairs, much smaller than the leaves, innermost bracts ovate, unequally bifid to the basal row of cells, slightly verruculose, lobes subulate, connivent; bracts of second row larger, one-third the size of leaves, ovate, with a single marginal tooth, bifid about three-fourths, lobes spreading or connivent, sometimes unequal; bracteoles similar to bracts; perigynium undeveloped: ♂ bracts 2 to 4 pairs, concave to subcomplicate, ovate, bifid about one-half, lobes incurved, subulate, spreading.

Stems 0.18^{mm} in breadth; leaves 0.65^{mm}x0.5^{mm}; leaf-cells at apex 55μx45μ, at middle of base 60μx30μ, at margin (near base) 80μx20μ; large lateral cells of stem 105μx60μ; ventral cortical cells 80μx25μ; ♀ bracts of second row 0.45^{mm}x0.3^{mm}; ♂ bracts 0.24^{mm}x0.17^{mm}.

Hawaiian Islands (Hillebrand). Oahu: Pauoa (Heller); Nuuanu (Cooke). Kauai: Kilohana (Cooke).

Kantia Sullivantii (Aust.) Underw., of North America, agrees very closely with the Hawaiian species. It differs, however, in the following characteristics: the teeth of the leaves are usually longer, broader and parallel, and are separated by a deeper sinus; the terminal cells of the leaf are smaller, and those of the basal margin are shorter and broader, all the leaf-cells having slightly thicker walls.

Kantia Baldwinii (Aust.) Evans.

Calypogeia Baldwinii Aust., Bot. Gazette, i, 32, 1875.
Kantia Baldwinii Evans, Trans. Conn. Acad., viii, 256, 1892.
Kantia rotundistipula Steph., Bull. de l'Herb. Boissier, v, 846, 1897.

PLATE IX; FIGURES 11-17.

Dioicous (?): plants yellow-brown, depressed, cæspitose or scattered among other bryophytes: stems slender, simple or rarely branching, sometimes (very rarely) bearing true flagella, prostrate, ending obtusely or attenuated, flagelliform; flagella short; rhizoids borne in clusters at the base of the underleaves: leaves approximate, imbricated at the base, apex free, obliquely inserted, obliquely ovate, verruculose, antical base arching partly over stem, postical base decurrent, antical margin dilated, apex subtruncate or rounded, sometimes slightly retuse: leaf-cells with slightly thickened walls, trigones minute: underleaves distant, twice as broad as stem, broadly ovate-subrotundate, subcordate at the base, apex retuse; underleaf-cells similar to those of leaves: ♀ bracts arranged in 2 rows, minute; the innermost bracts the largest, about twice the size of an underleaf, broadly ovate, denticulate, apex obtuse; cells verruculose; bracteoles similar to bracts but narrower: perigynium undeveloped.

Stems 0.2^{mm} in diameter; leaves $0.7^{mm}x0.6^{mm}$ to $0.9^{mm}x0.7^{mm}$; underleaves $0.2^{mm}x0.4^{mm}$; leaf-cells at apex 25μ, at middle of base $55\mu x30\mu$, at antical margin $45\mu x18\mu$; bracts $0.6^{mm}x0.45^{mm}$.

West Maui (Baldwin). Oahu: Konahuanui (Cooke). Hawaiian Islands (Herb. Spruce).

K. Baldwinii is very close to *K. nephrostipa* Spruce, of South America. The leaves of the latter are more densely imbricated, longer in proportion to their breadth, the apex is usually crenulate, the cells have thicker cell-walls which are not verrucose, and the underleaves are broader and more deeply bifid.

Compared with *K. cæspitosa* Spruce, of South America, *K. Baldwinii* has the following differences: the plants are smaller; the stems branching much less frequently; the leaves are smaller and less imbricated, and the apex not so rounded; the leaf-cells have thinner cell-walls and smaller trigones; the underleaves are much smaller and broader in proportion to their length.

Odontoschisma Dumort., 1835.

Plants medium-sized, green, sometimes reddish, rarely white, growing in broad, flat mats, often mixed with mosses or other hepatics: stems strong, subterete, either prostrate or arching at intervals and free from the substratum; flagella postical or terminating leafy branches; leafy branches usually postical, similar to the stem: leaves obliquely to nearly longitudinally inserted, broadly ovate or suborbicular, retuse or rarely emarginate, usually concave and entire; cells rather small to minute, isodiametric, often with a verruculose cuticle: underleaves commonly minute and soon obsolete: ♀ inflorescence cladogenous; bracts bifid, rarely trifid or quadrifid; bracteoles always present; perianth large, narrow, mouth ciliate to denticulate: capsule cylindrical-oblong, in other characteristics agreeing with that of *Cephalozia*: andrœcium postical, small, amentiform, colorless, rarely larger and terminal.

Leaves strongly concave. *O. subjulaceum.*
Leaves slightly concave, more often spreading.
    Plants rather large; leaves longer than broad, trigones small or lacking. *O. Sandvicense.*
    Plants slender; leaves usually broader than long, trigones large. *O. gracile.*

Odontoschisma subjulaceum Aust.

Odontoschisma subjulaceum Aust., Bull. Torr. Bot. Club, vi, 303, 1879.
Jungermannia caudifera Tayl. Ms., ex parte; Aust., l. c. (as synonym).

PLATE X; FIGURES 10–26.

Dioicous: plants small, green, or reddish near the apex, growing in dense or scattered tufts on fallen logs or on the ground: stems simple, rarely branching, short, apex ascending, usually attenuated and gemmiparous; flagella borne near the base of stems, radiculose; rhizoids scattered, at the base of stems or on the flagella: leaves strongly concave, apex arching over the stem, closely imbricated, decreasing in size on the attenuated portions of stems and branches, broadly ovate, apex entire, rounded, ventral base slightly rounded, dorsal base not decurrent; leaves in upper part of gemmiparous branches small, spreading, narrowly ovate from a broad base, margin irregularly denticulate: leaf-cells thin-walled, with large sometimes confluent trigones and stellate cavities: underleaves rudimentary, minute, distant, usually bifid, near the base of branches much larger, unsymmetrically ovate or ligulate, obtuse or bidentulate: on gemmiparous branches similar to the leaves: cells of underleaves thin-walled, with or without very small trigones; cells of underleaves near the base of branches similar to those of leaves: gemmæ oval, composed of 1 or 2 cells: ♀ bracts in 2 or 3 pairs; innermost bracts ovate from a broad base, bifid from one-fourth to two-thirds, lobes triangular-subulate, acute-acuminate, often denticulate, innermost bracteole similar to bracts, but with shorter and more rounded lobes; cells of bracts and bracteole elongated, thin-walled, trigones small, upper marginal cells verruculose: ♂ bracts in 4 to 6 pairs, orbicular-ovate, strongly concave, unequally bifid one-third to one-fifth, lobes obtuse, verruculose at the apex.

Stems 0.15^{mm} in diameter; leaves 0.6^{mm}x0.58^{mm} to 0.4^{mm}x0.38^{mm}; leaf-cells at apex 24μx23μ, at middle of base 32μx35μ, trigones 10μ, cells at margin 21μx25μ; innermost bracts 0.75^{mm}x0.4^{mm}; ♂ bracts 0.2^{mm}x0.17^{mm}, rudimentary underleaves 0.06^{mm}x0.05^{mm}, cells 24μ.

West Maui (Baldwin). Hawaiian Islands (Bailey). Oahu: Nuuanu (Cooke). Kauai: Waimea (Heller); Kilohana, Lihue, Hanalei (Cooke).

Odontoschisma subjulaceum differs from *O. Sphagni* (Dicks.) Dumort., of Europe and North America, in being a much smaller plant and in producing numerous gemmæ; its leaves also are not decurrent ventrally and are much more convex with stellate cell-cavities and larger trigones.

Odontoschisma gracile (Mitt.) Steph.

Sphagnœcetis gracilis Mitt.; Seemann, Flora Vitiensis, 405, 1871.
Odontoschisma gracile Steph., Bull. de l'Herb. Boissier, v, 843, 1897.

PLATE X: FIGURES 1–9.

Sterile: plant brown when dry: stems slender, prostrate, long, rarely branching, branches often attenuate, flagelliform, rarely gemmiparous; true flagella rarely present, borne at base of stems; rhizoids in scattered clusters on postical surface of stem: leaves obliquely inserted, plane or nearly so, slightly imbricated or approximate, broadly subrotund, antical base rounded, postical base sometimes very slightly decurrent: leaf-cells with thin walls, very large trigones and stellate cavities: underleaves rudimentary, distant, minute, composed of 2 to 4 cells, underleaves at the base of branches larger, subligulate, composed of 7 to 10 cells; cells small, walls slightly thickened, cavities round or oval.

Stems 0.1^{mm} to 0.12^{mm} in breadth; leaves $0.4^{mm}x0.45^{mm}$; leaf-cells near apex $25\mu x27\mu$, trigones 10μ, cells near middle of base $45\mu x27\mu$, trigones 13μ; underleaves at base of branches $0.09^{mm}x0.045^{mm}$ to $0.09^{mm}x0.06^{mm}$, cells 24μ; cells of rudimentary underleaves 19μ.

Hawaiian Islands (Gaudichaud). Known only from the type-material, a portion of which is preserved in the Kew herbarium.

Odontoschisma gracile differs from *O. subjulaceum* in being longer and more slender; its leaves also are smaller and less imbricated, more spreading, broader in proportion to their length and with the postical margin much more curved; the leaf-cells have much larger trigones, and those at the base are longer and with narrower and more stellate cavities.

Odontoschisma Sandvicense (Ångstr.) Evans.

Sphagnœcetis Sandvicensis Ångstr., Öfver. af Kongl. Vet. Akad. Förhandl., xxix (No 4), 22, 1872.
Odontoschisma Sandvicense Evans, Trans. Conn. Acad., viii, 256, 1892.

PLATE XI.

Dioicous: plants green, rarely red, loosely cæspitose: stems appressed, branching irregularly, apex ascending, obtuse, sometimes gemmiparous, rarely flagelliform; flagella borne at base of stem or branches; rhizoids borne in clusters on postical surface of stems or branches: leaves slightly concave, obliquely inserted, ovate-subquadrate, apex subtruncate or rounded; verruculose, postical base slightly rounded, antical base not decurrent, leaves on attenuated gemmiparous branches small, ovate from a broad base, acute or obtuse: leaf-cells at apex and along margin oblong-quadrate, thin-walled, perpendicular to edge, cell-cavities with slightly rounded corners, trigones minute, cell-cavities sometimes slightly stellate with small trigones, cells in middle and at base thin-walled with cavities irregular or rounded and trigones minute or small: underleaves minute, rudimentary, consisting of a few cells; on gemmiparous branches similar to leaves; at the base of branches well developed, broadly ovate, obtuse or bifid; cells of the underleaves thin-walled with minute trigones: gemmæ oval, composed of 1 or 2 cells: ♀ inflorescence borne on a short branch; ♀ bracts in 3 or 4 rows; innermost bracts about the length of the leaves but narrower, ovate from a broad base, upper half irregularly denticulate, apex irregularly bifid about one-third, lobes ovate, apiculate or subulate, sometimes cleft, irregularly denticulate, terminal cell verruculose; innermost bracteole similar to bracts, but less deeply bifid: perianth fusiform, usually curved, terete below, irregularly keeled above, 3 or 4 cells thick at base, 2 cells thick to near the middle, 1 cell thick above, mouth irregularly lobed, lobes dentate-laciniate, laciniæ sometimes denticulate, 2 or 3 cells broad at base and ending in a row of 1 to 4 slightly verruculose cells: elaters bispiral; spores small, round, brownish yellow.

Stems 0.15^{mm} to 0.18^{mm} in diameter; leaves 0.9^{mm}x0.85^{mm}; leaf-cells at dorsal margin 17μx22μ, near apex 21μx25μ, at middle of base 39μx28μ; rudimentary underleaves 0.05^{mm}x0.07^{mm}; cells of underleaves at base of branches 30μx25μ; perianth 2.5^{mm}x0.6^{mm} to 3.0^{mm}x0.8^{mm}; innermost bracts 1.1^{mm}x0.4^{mm}; innermost bracteole 0.9^{mm}x0.35^{mm}; elaters about 250μx10μ; spores 9μ.

Hawaiian Islands (Andersson). Oahu: Nuuanu (Cooke).

Odontoschisma Sandvicense differs from *O. Sphagni* in having gemmæ and in its larger leaves, which are decurrent antically; the cells at the base of the leaves are also larger. From *O. subjulaceum* it differs in its larger size and green color; the leaves are larger, more quadrate, narrower in proportion to their breadth, more spreading, and less concave; its cell-cavities are more regular in outline, never as distinctly stellate, and its trigones are much smaller.

Cephalozia Dumort., 1835.

Plants usually small, sometimes minute, rarely large or robust, branches usually postical, rarely lateral: leaves succubous, rarely transversely inserted, more or less concave, often bilobed or subcomplicate, margins never reflexed, entire or denticulate: underleaves much smaller than leaves, in some species partly or wholly lacking: dioicous, autoicous or paroicous: ♀ inflorescence usually borne on a short branch, rarely terminal on a vegetative branch, sometimes variable in position in the same species; bracts in about 3 rows, bilobed (rarely trilobed or quadrilobed), often connate, yet free from the perianth; bracteoles always present: archegonia about 20, rarely fewer: perianth elongated, usually trigonous, rarely 5- or 6-keeled, mouth variously laciniate to denticulate, rarely entire; calyptra free, surrounded at the base by the sterile archegonia: capsule more or less oblong, walls 2 cells thick, cells of the inner layer furnished with semiannular thickenings; elaters long, bispiral; spores minute, about the diameter of the elaters, smooth or verruculose: andrœcium amentiform, usually occupying a short postical branch, or intercalary on a main branch; bracts in several pairs, bifid, monandrous.

- Stems weak, postically branched; cortical cells larger than interior; leaves more or less obliquely inserted; bracts not connate or only slightly so.
  - Plants rather large; leaves approximate or slightly imbricated; mouth of perianth laciniate; autoicous. *C. Sandvicensis.*
  - Plants minute; leaves distant; mouth of perianth ciliate; paroicous. *C. Baldwinii.*
- Stems rigid, sometimes laterally branched; cortical cells similar to interior; leaves transversely inserted; bracts connate.
  - Innovations lacking; leaf-cells with much thickened walls; ♀ inflorescence cladogenous; innermost bracteole not bifid. *C. Kilohanensis.*
  - Innovations present; leaf-cells with slightly thickened cell-walls; inflorescence acrogenous or cladogenous; innermost bracteole bifid.
    - Underleaves lacking; leaf-cells at margin 12μx10μ. *C. Lilæ.*
    - Underleaves present; leaf-cells at margin 20μx15μ. *C. heteroica.*

Subgenus **Eucephalozia** Spruce, 1882.

Plants variable in size, green, rarely yellow, sometimes reddish: stems mostly weak or fragile, rarely rigid, simple or sparingly branching; branches more or less postical, sometimes flagelliform: leaves obliquely inserted, often somewhat broader than long, concave or subcomplicate, margin entire, apex bifid: cells as a rule large, pellucid, quadrate-hexagonal or quadrate, smooth: underleaves, when present, entire or bifid: monoicous or dioicous: ♀ inflorescence in some species constantly cladogenous or acrogenous, in others variable in position; bracts rather large, 2- to 4-lobed, entire or often dentate, spinulose or incised; bracteoles always present; perianth fusiform, sometimes almost linear, trigonous, mouth constricted, denticulate, setulose, ciliate or laciniate: capsule more or less oblong: andrœcium spicate or amentiform, variable in position, rarely hypogenous; ♂ bracts similar to ♀ bracts but smaller.

Cephalozia Sandvicensis (Mont.) Spruce.

Jungermannia Sandvicensis Mont., Ann. des Sc. Nat. II, xix, 249, 1843. Voyage de la Bonite, Botanique, i, 259; atlas, pl. CXLVI, fig. 1, 1846.

Jungermannia crassifolia Lindenb. & Gottsche; G. L. & N., Syn. Hep., 685, 1847, according to Spruce.

Cephalozia connivens Aust., Bull. Torr. Bot. Club, v, 15, 1874 (not *Cephalozia connivens* (Dicks.) Dumort.).

Blepharostoma Sandvicense Trevis., Mem. reale Ist. Lomb. di Sci. e Lett., III, iv, 417, 1877.

Cephalozia Sandvicensis Spruce, On Cephalozia, 46, 1882.

Cephalozia multiflora Evans, Trans. Conn. Acad. viii, 256, 1892 (not *Cephalozia multiflora* Spruce).

PLATE XII.

Autoicous: plants depressed, pale: stems colorless, sparingly branched, branches blunt or attenuated, stems oval in section, about 6 by 5 cells, the ventral surface more rounded than the dorsal; interior cells with thickened walls, cortical cells in 10 to 12 rows, those of the dorsal surface about three times as large as those of the ventral; rhizoids scattered on the ventral surface of the stem, long, colorless: leaves slightly imbricated at the base or approximate, almost longitudinally inserted, spreading or slightly concave, antical base decurrent, broadly ovate, unequally bifid (about one-half), lobes subulate, spreading or connivent, postical lobe broader, with outer margin more dilated, 3 to 5 cells broad, 4 or 5 cells long, usually ending in a row of 2 or 3 cells, antical lobe about 3 cells broad (rarely 2 or 4), 4 or 5 cells long, ending in a row of 2 or 3 cells: cell-walls thin, corners rounded, trigones very small: underleaves wanting: ♀ inflorescence borne on a short branch; ♀ bracts usually in 3 pairs; innermost bracts ovate, deeply bifid (about two-thirds), the lobes usually unequally cleft, the outer division much the smaller, sometimes with supplementary divisions or subequally 4 or 5 lobed, the inner lobes subulate, 8 to 10 cells long and about 4 cells broad, ending in a row of 2 to 4 cells, outer lobes 2 to 8 cells long; innermost bracteole similar to bracts, scarcely connate with them, the lobes usually less deeply cleft; bracts of second row shorter, deeply lobed (about one-half), sometimes with subdivided lobes; perianth usually curved, fusiform, 1 cell thick, 3-keeled above, terete below, mouth contracted, about 12-laciniate-ciliate, laciniæ with denticulate bases, 10 to 12 cells long, 3 to 6 cells broad, ending in a row of 4 to 6 cells: ♂ spike a short postical branch, sometimes terminal or intercalary on a main branch; bracts in 4 to 8 pairs, imbricated, concave or subcomplicate, broadly ovate, bifid (about one-half), lobes equal, spreading, acute or acuminate, about 4 cells broad, 4 or 5 cells long, ending in a row of 2 or 3 cells; sinus separating lobes subacute; bracteoles minute, linear-subulate, 3 or 4 cells long, 1 to 3 cells broad: cells thin-walled: capsule oval, purplish brown; spores round, brownish with minutely verruculose wall; elaters blunt.

Stems 0.15^{mm} in diameter; leaves 0.35^{mm}x0.3^{mm}; leaf-cells at margin 52μx40μ, at middle 59μx41μ, at base 59μx65μ; innermost bracts 1.1^{mm}x0.55^{mm}; bracteole 1.0^{mm}x0.5^{mm}; perianth 2.8^{mm}x0.6^{mm}; ♂ bracts 0.23^{mm}x0.22^{mm}; spores 12μ; elaters 180μx12μ.

Hawaiian Islands (Gaudichaud). Oahu (Mann and Brigham); Nuuanu (Cooke). The writer has had the privilege of examining the type-specimens in the Montagne herbarium.

Compared with *C. lunulæfolia* Dumort. (= *C. multiflora*), of Europe, North America and Asia, there are the following differences: the Hawaiian species is monoicous while the other is dioicous, the leaves of *C. Sandvicensis* are less orbicular and much more deeply bifid, the perianth is 1 cell thick throughout, and its mouth is laciniate instead of being dentate.

C. Sandvicensis is very close to *C. connivens* in its vegetative characters, but its sexual characters differ somewhat. In the former the lobes of the bracts are much shorter and are neither dentate nor denticulate, in the latter species the bracteole is much more connate, the mouth of the perianth is more deeply laciniate in the Hawaiian species.

C. forficata Spruce, of tropical America, agrees most closely with our species, but is dioicous; in *C. Sandvicensis* the leaves are more deeply bifid, with a more or less acute sinus; in *C. forficata* the lobes are narrower and are separated by a lunate sinus. Spruce in his comparison between *C. Sandvicensis* and *C. forficata* uses the words "fere constanter strictis (nec conniventibus)" as a characteristic of *C. Sandvicensis.* The writer has found a great variation in the position of the apices of the lobes; on the same stem leaves can be found with the lobes overlapping, connivent, parallel or spreading.

Cephalozia Baldwinii sp. nov.

PLATE XIII; FIGURES 1–9.

Paroicous: plants minute, pale green, scattered among other hepaticæ: stems very slender, pale green or colorless, rarely branching from the postical surface, 5 or 6 cells in diameter, cortical cells (in about 9 longitudinal rows) much larger than internal cells, the latter with uniformly thickened walls; rhizoids long, colorless, in scattered clusters on the postical surface: leaves distant, minute, subtransversely inserted, slightly spreading, ovate, unequally bifid (about two-thirds), the antical lobe longer and narrower than the postical; lobes subulate, spreading, connivent or overlapping, antical lobe 2 or rarely 3 cells broad, generally 4 cells long, ending in a row of 2 or 3 cells, postical lobe 3 or 4, rarely 2, cells broad, usually 4 cells long, ending in a row of 2 cells or in a single cell; sinus obtuse or rounded: underleaves wanting: leaf-cells small, cell-walls thin, colorless, trigones lacking: ♀ inflorescence borne on a short postical branch; ♀ bracts reduced to a single pair, broadly ovate, deeply bifid (about one third), bearing a short lateral tooth, lobes triangular acute, sinus obtuse; bracteole ovate, bifid, lobes triangular, acute; perianth cylindrical, without distinct keels, 1 cell thick, mouth contracted, ciliate, cilia 1 or 2 cells long: ♂ bracts hypogynous, in 2 or 3 pairs concave, appressed to stem, ovate, bifid, lobes triangular, acute, sinus acute or obtuse.

Stems 0.75^{mm} in diameter; cortical (antical) cells 54μx21μ; leaves 0.15^{mm}x0.1^{mm}; leaf-cells at middle 25μx19μ, at postical margin 24μx15μ; innermost bracts 0.4^{mm}x0.35^{mm}; bracts of second row 0.4^{mm}x0.3^{mm}; perianth 1.1^{mm}x0.4^{mm}.

West Maui (Baldwin), creeping over *Lepidozia Sandvicensis.*

This species was found among some hepatics collected by Baldwin in 1875. Unfortunately only a single well developed perianth and two or three young flowers could be found. The younger stages show conclusively that the species is paroicous. *C. Baldwinii* is intermediate between Spruce's *Eucephalozia* and *Cephaloziella*, with a larger number of characters in favor of the former subgenus.

Spruce mentions only two paroicous species of *Cephalozia*, *C. Jackii* Limpr. and *C. myriantha* Lindb., of Europe, both of which belong to *Cephaloziella*. *C. leucantha* Spruce, of northern regions, is nearest to the Hawaiian species but differs in its more distant and more deeply bifid leaves, with narrower unequal lobes, in its dentate bracts, and in its dioicous inflorescence.

Subgenus **Cephaloziella** Spruce, 1882.

Plants small or minute, often mixed with mosses or other hepatics: stems usually robust, cortical and interior cells similar, in many subrhizomatous at the base, bearing flagella; leafy branches postical or more rarely lateral: lower leaves succubous, upper leaves crowded, transversely inserted, rarely exceeding the stem in breadth, often cuneiform, bifid one-half or more, carinate, segments subcomplicate or diverging, entire or subdenticulate, rarely spinulose: cells small or minute, subquadrate: underleaves (when present) small, entire or bifid, sometimes present or lacking in the same species: ♀ inflorescence acrogenous, cladogenous, or variable in position; bracts rather large, bilobed, lobes denticulate or spinulose; bracteoles always present, connate with the bracts; perianth narrow, rarely only 3-keeled, often 3- to 6-keeled in the same species, mouth denticulate, rarely ciliate: andrœcium borne on stems or larger branches, intercalary or terminal, rarely amentiform; bracts similar to stem-leaves, rarely smaller.

Cephalozia Lilæ sp. nov.

Plate XIII; figures 10–20.

Dioicous? plants scattered, pale green: stems pale green or nearly colorless, branching postically, oval in section, about 5x7 cells, walls slightly uniformly thickened, internal and cortical cells similar, the latter in about 18 longitudinal rows, rhizoids long, colorless, scattered at the base of the stem or branches: leaves distant, obliquely-transversely inserted, widely spreading, slightly concave, ovate or subquadrate, equally bifid (about one-half), lobes entire, spreading triangular, acute, about 7 cells long, 5 cells broad, usually ending in a row of two cells; leaf-cells with slightly uniformly thickened walls: underleaves wanting: ♀ inflorescence borne on main stem or branch, often having innovations; ♀ bracts in one or two pairs; innermost bracts broadly ovate, bifid (about one-third), lobes triangular, acute, spreading irregularly denticulate; sinus acute; innermost bracteole shorter than bracts, highly connate on both sides, ovate, apex rounded, denticulate or bifid (about one-fifth), lobes apiculate, denticulate, sinus obtuse; bracts of second row smaller, broadly ovate, bifid (about one-third): perianth ovoid-cylindrical, unistratose, terete below, many keeled above, mouth slightly contracted, irregularly lobed, lobes denticulate.

Stems 0.06^{mm} in diameter; leaves 0.12^{mm}x0.11^{mm}; leaf-cells at margin 12μx10μ, at middle and base 17μ; innermost bracts 0.32^{mm}x0.24^{mm}; innermost bracteole 0.2^{mm}x0.1^{mm}; perianth 0.35^{mm}x0.2^{mm}.

Oahu: Nuuanu (Cooke).

This species is the smallest *Cephalozia* reported, so far, from the Hawaiian Islands. It was found scattered among other hepaticæ. It is rather close to *C. elachista* Jack, of Europe. The leaves of the Hawaiian species are less deeply bifid and the leaf-cells are smaller with thicker cell-walls. The Hawaiian species is probably dioicous as no male spikes were found, while *C. elachista* is monoicous and its perichætial bracts are blunter and less denticulate.

Cephalozia Kilohanensis, sp. nov.

PLATE XIV.

Autoicous: plants minute, cæspitose, reddish brown: stems prostrate, light brown, sparingly branched from the postical surface, about 5 cells in diameter, internal and cortical cells similar, the latter in about 12 longitudinal rows; rhizoids numerous, scattered on the lower surface of the stem: leaves near the apex of the stem imbricated, almost transversely inserted, concave, assurgent, subquadrate, broadly ovate, bifid (about one-half), lobes entire, spreading, 6 to 10 cells long, 4 to 7 cells broad, triangular-ovate, apex acute to obtuse; sinus usually obtuse: leaf-cells with much thickened walls, trigones lacking or minute: underleaves wanting: ♀ inflorescence borne on a short postical branch; bracts in 3 to 6 pairs; innermost bracts similar to the leaves but from 2 to 3 times as large, broadly ovate, bifid (one-third to one-half), lobes unequal, the postical the larger, acute or obtuse, sinus separating lobes acute or obtuse, margin entire or nearly so; innermost bracteole narrowly ovate, connate on one or both sides, apex acute, obtuse or bifid, when bifid the lobes are unequal, triangular, acute; other bracts similar but smaller than innermost bracts; other bracteoles narrowly ovate, acute or obtuse, slightly connate on one or both sides: perianth cylindrical, terete below, obtusely keeled near the apex, 1 cell thick, upper third hyaline, mouth contracted, irregularly denticulate: ♂ spike usually occupying a short postical branch; ♂ bracts in 5 to 10 pairs, similar to leaves, closely imbricated, concave, unequally bifid, lobes ovate, obtuse, entire; ♂ bracteoles rudimentary, minute, ligulate; cells of bracteole small subquadrate; antheridia borne singly: spores minute, round, purplish, verruculose; elaters blunt; bispiral.

Stems 0.08^{mm} in diameter; leaves $0.18^{mm}x0.15^{mm}$ to $0.3^{mm}x0.28^{mm}$; cells of stem 16μ in diameter; leaf-cells at margin $19\mu x 16\mu$, at base $24\mu x 18\mu$: innermost bracts $0.35^{mm}x0.3^{mm}$, bracteole $0.35^{mm}x0.15^{mm}$; perianth $0.95^{mm}x0.4^{mm}$; ♂ bracts $0.25^{mm}x0.2^{mm}$; spores 9μ; elaters about $160\mu x 9\mu$.

Kauai: Kilohana (Cooke), growing on the ground.

This species resembles *C. exiliflora* (Tayl.) Trevis. at first sight but differs in a large number of important characters. The Hawaiian species is autoicous while the New Zealand species is dioicous, the leaves of the former are larger, and more imbricated near the apex, the walls of the leaf-cells are slightly thicker, the ♂ and ♀ organs are not acrogenous but are borne on postical branches, and lastly the perichætial bracts are not denticulate.

Cephalozia heteroica sp. nov.

PLATE XV.

Heteroicous: plants green, loosely cæspitose: stems subsimple or branching from the postical aspect, prostrate at the base, apex ascending, circular in section, about 6 cells in diameter, internal and cortical cells similar, with slightly thickened walls, the latter in about 15 longitudinal rows; rhizoids colorless, scattered on the ventral surface: leaves distant, transversely inserted, squarrose, somewhat concave, subquadrate, bifid more than one-half, lobes spreading, ovate, acute, entire, separated by an obtuse sinus, about 7 cells long, 4 or 5 cells broad: leaf-cells with uniformly thickened walls, cell-cavities sometimes rounded, trigones minute or lacking: underleaves very small, about 4 cells broad at base, variable in form, lanceolate-ovate to broadly quadrate, apices acute, obtuse or bifid, with unequal, acuminate to obtuse, spreading to connivent lobes; cells of the underleaves small, with uniformly thickened walls: ♀ inflorescence usually borne on the main stem, with a sterile or floriferous innovation, sometimes on a short postical branch; bracts in 2 or 3 pairs; innermost bracts broadly ovate to broadly quadrate, bifid (one-fourth to one-third), lobes triangular, acute, denticulate; innermost bracteole suborbicular, connate on both sides, bifid, lobes triangular, acute, denticulate; bracts of second row broadly ovate, bifid (about one-third), lobes triangular-ovate, acute, spreading, slightly denticulate; bracteole of second row connate on both sides, ovate, bifid (about one-third), sometimes quadrified, lobes ovate, acute, slightly denticulate: perianth broadly fusiform, terete below, bluntly three-keeled above, mouth slightly contracted, irregularly lobed, lobes denticulate; innovations lateral or postical, arising just below the second bracteole or from the axil of a bract: andrœcium borne just below the female flower or intercalary on a vegetative branch; ♂ bracts in 3 to 10 pairs, imbricated, suberect, slightly concave, about twice the size of the leaves of the vegetative branches, bifid (about one-half), lobes broadly ovate-triangular, acute, widely spreading, sinus broadly lunate; bracteoles ovate, bifid (about three-fourths), lobes subulate, parallel; antheridia borne singly.

Stems 0.08^{mm} in diameter; leaves 0.15^{mm}x0.16^{mm}; leaf-cells at margin 19μx16μ, at middle of base 20μ; innermost ♀ bracts 0.45^{mm}x0.6^{mm}; innermost bracteole 0.38^{mm}x0.4^{mm}, ♀ bracts of second row 0.45^{mm}x0.5^{mm}; bracteole of second row 0.35^{mm}x0.3^{mm}; perianth 1.25^{mm}x0.45^{mm}; ♂ bracts 0.25^{mm}x0.25^{mm}.

Kauai; Kilohana (Cooke), growing on an exposed bank.

This species varies greatly in almost every character pertaining to the male and female flowers. In rare instances the ♀ inflorescence is borne on a short postical branch with the andrœcium median between the ♀ bracts and the main stem. Usually the ♀ inflorescence is borne on a main branch or an innovation and sometimes as many as three or four floriferous innovations are given off in succession. The ♀ bracts and bracteoles vary greatly both in size and form. The underleaves also vary greatly.

C. heteroica is nearest to *Cephaloziella Hebridensis* Steph., from the New Hebrides Islands.[1] This species differs in its dioicous inflorescence, in its carinate leaves with acuminate lobes, in its smaller leaf-cells, and in the entire mouth of its perianth.

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[1] Hedwigia, xxxii, 316, 1893.

EXPLANATION OF PLATES.

PLATE I.

Lepidozia australis (Lehm. & Lindenb.) Mitt., p. 5.—Fig. 1. Part of stem, postical view, ×30.—Fig. 2. Part of stem, antical view, ×30.—Fig. 3. Leaf subtending bract, ×30.—Fig. 4. Cells of tooth of leaf, ×270.—Fig. 5. Cells at middle of underleaf, ×270.—Fig. 6. Perianth, ×30.—Fig. 7. Innermost ♀ bract, ×30.—Figs. 8–10. Consecutive ♀ bracts, ×30.—Figs. 11–13. Consecutive ♀ bracteoles, corresponding to Figs. 8–10, ×30.—Fig. 14. Apex of perianth, ×200.—Fig. 15. ♂ bract, ×80.—Fig. 16. ♂ bracteole, ×80. All drawings from specimens collected by Mr. Baldwin on West Maui (No. 150).

PLATE II.

Lepidozia Sandvicensis Lindenb., p. 7.—Figs. 1, 2. Leaves of main stem, ×75.—Figs. 3–5. Underleaves of main stem, ×75.—Fig. 6. Leaf of branch, ×75.—Fig. 7. Underleaf of branch, ×75.—Figs. 8–10. Leaves subtending branches, ×75.—Fig. 11. Cells of lateral tooth of leaf, ×195.—Fig. 12. Cells of lateral tooth of underleaf, ×195. Drawings from specimens collected by Mr. Baldwin on West Maui (No. 69).

Lepidozia Hawaica Cooke, p. 8.—Fig. 13. Part of stem, postical view, ×75.—Fig. 14. Leaf, ×265.—Fig. 15. Underleaf, ×265.—Fig. 16. Perianth, ×30. Figs. 17–20. Consecutive bracts, ×75.—Fig. 21. Apex of perianth, ×105.—Fig. 22. ♂ branch, ×75.—Figs. 23, 24. ♂ bracts, ×75. All drawings from the type-specimens, collected by the writer in Nuuanu, Oahu.

PLATE III.

Bazzania cordistipula (Mont.) Trevis., p. 12.—Fig. 1. Leaf, ×24.—Fig. 2. Underleaf, ×24.—Fig. 3. Part of stem, antical view, ×12.—Fig. 4. Leaf-cells at base of median tooth, ×215.—Fig. 5. Leaf-cells at antical edge, ×215.—Fig. 6. Cells at middle of leaf, ×215.—Fig. 7. Cells at middle of base of leaf, ×215.—Fig. 8. Perianth, ×12.—Figs. 9–13. ♀ bracts in order, ×24.—Fig. 14. Apex of perianth, ×80.—Figs. 1–7 drawn from specimens collected by Mr. Baldwin on West Maui (No. 12); Figs. 8–14 drawn from specimens collected by the writer on Konahuanui, Oahu.

Bazzania Sandvicensis (Gottsche) Steph., p. 14.—Fig. 15. Leaf, ×24.—Fig. 16. Underleaf, ×24.—Fig. 17. Cells of median tooth of leaf, ×215.—Fig. 18. Cells from middle of leaf, ×215.—Fig. 19. Cells at antical edge of leaf, ×215.—Fig. 20. Perianth, ×12.—Fig. 21. Apex of perianth, ×62.—Fig. 22. Cells of perianth, showing intermediate thickenings, ×215.—Figs. 15–19 drawn from type-specimen; Figs. 20–22 drawn from specimens collected by Mr. Baldwin on Molokai (No. 212).

Bazzania Nuuanuensis Cooke, p. 15.—Fig. 23. Part of stem, postical view, ×12.—Fig. 24. Part of stem, antical view, ×12.—Figs. 25, 26. Leaves, ×24.—Figs. 27, 28. Underleaves, ×24.—Fig. 29. Leaf-cells at apex, ×215.—Fig. 30. Leaf-cells at middle of leaf, ×215.—Fig. 31. Leaf-cells at middle of leaf near the base, ×215. All drawings from the type-specimens, collected by the writer on Oahu.

PLATE IV.

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II.—THE BERMUDA ISLANDS. PART IV.—GEOLOGY AND PALEONTOLOGY, AND PART V.—AN ACCOUNT OF THE CORAL REEFS.

BY ADDISON E. VERRILL.

THE writer published a preliminary paper on the geology of these islands in 1900,* giving the results of his studies there in 1898. During another visit to the islands, in 1901, he had opportunities to make many additional studies and to obtain additional photographs, especially of some excellent sections laid bare by the great hurricane of 1900. The present report, which contains these later results, has been delayed, partly because of his desire to again visit the islands to study some points more fully. But as there may not be such an opportunity, at present, it is now thought best to print it. Imperfect as it must be, it will be of value to some of the numerous students who now annually visit the islands.

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* American Journal of Science, ix, pp. 313–40, with cuts in text.

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I. GEOLOGY:

1. Character of the Rocks.

The geology of the Bermudas, so far as the visible structure is concerned, is very simple and is identical with that of the Bahamas, except that the coral reefs are of greater importance in the latter. The rocks in both are all limestone and the red clays resulting from its decomposition.

Figure 1.—The original Gurnets Head of Castle Island, showing typical æolian limestone formation. On the summit are the ruins of the ancient fort (*a*) called King's Castle; *b*, ruins of ancient Southampton fort.

Nearly all the rocks of the Bermudas, above sea-level, and to a considerable depth below it, are made up of wind-drifted shell-sand (figs. 1, 4–6), with very little materials derived from corals and other organisms, such as foraminifera, bryozoa, corallines, etc. These materials, when consolidated, form a true æolian limestone, sometimes friable, but in some places very hard and compact.

Figure 2.—Wreck Hill, as seen from the Sea, bearing N. ¾ East; the hills to the right are those west of Gibb's Hill Light, 100 to 175 feet high; after Findlay.

The only exceptions to this origin are small local deposits of limestone, near tide-level, having a laminated beach-structure, and containing larger fossil marine shells, barnacles, etc, of existing species. The latter are underlaid, as well as overlaid, by æolian limestones.*

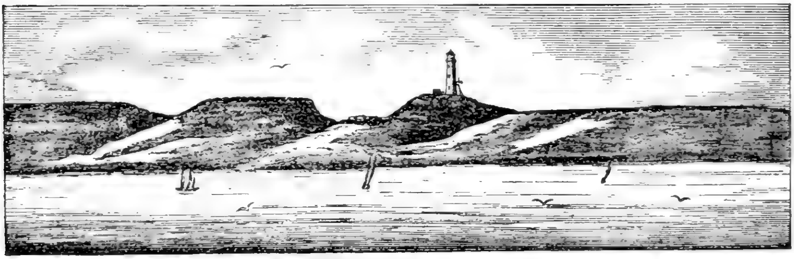

Figure 3.—Hills west and east of Gibb's Hill Light, bearing north, 150 to 240 feet high; after Findlay.

The islands are diversified by rather high hills and deep valleys. The higher hills are mostly toward the southern side of the main island and are conspicuous when the islands are approached from the south or southwest (figs. 2, 3). Some of them, like Wreck Hill,

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* See plates xvi to xviii; also fig. 11, p. 79.

appear regularly rounded or somewhat conical; others form more or less long ridges. Some are partly bare of vegetation, near the shore, and appear whitish in the distance.

These hills are all ancient sand-dunes, of which the sands are mostly consolidated. The height of these dunes is remarkable, considering the small extent of the land. Some are now 200 to 268 feet high. Nevertheless it is certain that the islands have subsided at least 80 to 100 feet,—probably more,—since these hills were formed. If we add this to the present height, it will be evident that they must have been at one time over 350 feet high, allowing nothing for the great amount of erosion that they have suffered during a long period of time, which would doubtless have amounted to 100 feet or more.

In modern times the sands have not been observed to drift more than 180 feet high,—and very seldom even to 100 feet. Therefore it is evident that the hills could not have reached their great height under present conditions. It would have required a much larger extent of sandy coast line and much more violent gales, unless the islands were undergoing a gradual elevation at the same time, which was probably the case.

These calcareous sands are easily and quickly consolidated by the percolating rain-water, which contains calcium bicarbonate in solution. Therefore, after being once slightly consolidated, they are not liable to be much eroded by the winds, though readily attacked by the rains.

These limestones almost everywhere show their wind-drift origin by their very irregular lamination and stratification. The layers are of unequal hardness and show very abrupt changes in dip in nearly every section, whether in the shore cliffs, road-cuts, or in the quarries (figs. 1, 4–6; and pl. xxii, figs. 1, 2). Owing to this structure and the very unequal hardness of the layers, the erosion of the clifts by the sea has brought about some very remarkable and picturesque forms. The topography and physiography of the islands have been so fully described and illustrated in my former article,* that it will not be necessary to dwell upon those features in this place, except as bearing directly upon geological changes. Many of the broader and more open valleys between the hills are probably the original valleys, formed when the hills were built up around them by the winds.

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* These Trans., vol. xi, part 2, pp. 464–490; and "The Bermuda Islands," pp. 52–78.

Such valleys may have since been partly filled up by the red-clay soils and calcareous sands washed down from the hillsides. When occupied by swamps, they are filled with thick accumulations of peat and muck, said to be 45 feet deep in some of the larger ones.

Many of the smaller and more abrupt valleys, both those on the dry land and those now beneath the sea, have certainly been made by the falling in of the roofs of more or less extensive caverns, aided by the subsequent erosion of the shores. Probably some even of the larger sounds and harbors, like Castle Harbor, Harrington Sound, etc., have had a similar origin, at least in part. This will be discussed more fully in the chapters on subsidence and erosion. These enclosed sunken areas or small valleys are like the "sinks" often found in the cavernous limestone regions of the United States and Europe, but they are unusually frequent in Bermuda, so that they become a notable feature. Those that are above the level of the sea usually contain rich soil and are locally called "banana holes," because bananas and other tender plants grow best in them, owing to the shelter from the winds and the richness of the soil.

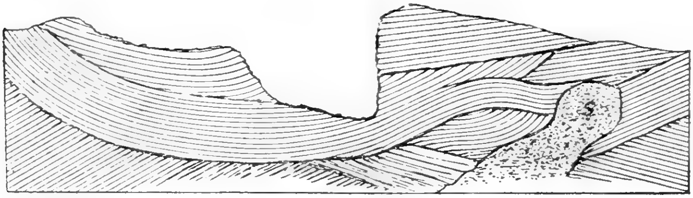

Figure 4.—Diagrammatic section of æolian limestone, as seen in Hamilton, showing irregular sand-drift structure; *s*, pocket of loose sand.

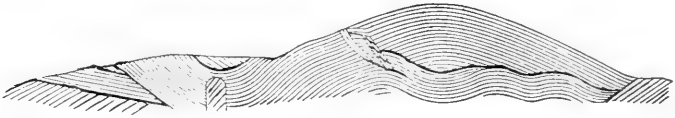

Figure 5.—Diagrammatic section of æolian limestone at Mt. Langton, showing very diversely stratified sand-drift structure. Both this and fig. 4 slightly altered and reduced from Rice.

Many of the sinks on the land extend below sea-level and then form small pools or larger ponds, often quite deep and filled with sea water, which may rise and fall with the tide. Some of those situated near the shore contain a variety of marine fishes, etc., which sometimes have entered through fissures, but in other cases, as at Devil's Hole, they have been put in by the proprietors. They make excellent fish and turtle preserves.*

Some of the smaller bays and harbors are evidently only sinks of this kind that have become connected with the sea by the erosion of the intervening rocks, in comparatively recent times. Others, like Peniston's Pond, are just beginning to be breached by the sea.

The soil of the islands is partly of reddish clay, partly of shell-sand, mixed with vegetable mold in most places. The reddish clay is the most important part. It is a mere insoluble residue or impurity, left after the decomposition and solution of the limestones by rainwater, during an immense period of time. It always contains, even where never cultivated, a notable per cent. of potassium salts, calcium phosphates, etc., and therefore forms a very fertile soil.†

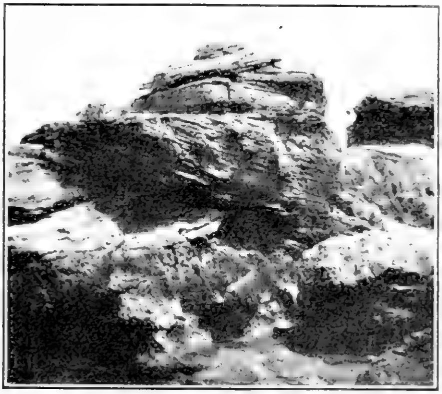

Figure 6.—A weathered and eroded shore cliff near Bailey Bay, north shore, showing abrupt changes in the inclination of the layers of æolian limestone.

Much of the interest in the geology of the islands is due to the various features of the erosion by the sea; surface erosion; and the subterranean erosion, which has formed extensive caverns, sinks, tunnels or passages for subterranean streams, etc. At present there are no streams or springs of fresh water, owing to the porosity of the rocks and the limited surface of the land.

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* For fuller descriptions see these Trans., xi, pp. 466–472; "The Bermuda Islands," pp. 54–60; also below, chapter on erosion.

† For analyses see these Trans., vol. xi, p. 493, and "The Bermuda Islands," pp. 81, 82.

2. *The Greater Bermuda.*

The present dry land must be regarded as a mere remnant of a much larger similar limestone island, of which the former extent is approximately indicated by the outermost of the surrounding reefs, but which has been nearly destroyed, partly by erosion and partly by subsidence, in former periods. This larger island, known as "Greater Bermuda" or "Pliocene Bermuda," was about ten times the size of the present dry land. It was broadly elliptical in outline, with the longer axis nearly northeast and southwest, or nearly the same as that of the present main island (figure 12, map I).

The area of this Greater Bermuda was probably somewhat more than 230 square miles. That of the present dry land is less than 20 square miles. The best estimates are about 19⅓ square miles or 12,373 acres.*

The elliptical area, now enclosed by the outer reefs, is about 22 miles long and 11 miles wide in the widest parts. There are good reasons for believing that nearly all of this area was dry land, with numerous more or less elevated hills, especially around the borders, in the period of Greater Bermuda. The evidences of this will be given later. The amount of subsidence is believed to have been at least 80 to 100 feet since the period of greatest elevation.

3. *The Bermudas not a true Atoll.*

The elliptical form of the outer reefs, more or less covered with corals and enclosing a broad shallow lagoon, with scattered islets and reefs within it, is so much like that of the coral islands or atolls of the Pacific Ocean in appearance that the earlier writers believed that the Bermudas formed a true coral atoll. But this has been shown by various more recent writers not to be the case.†

However, the careful recent investigations of the Pacific coral-islands, especially by Mr. Alexander Agassiz, have shown that many or most of the coral reefs of that region have a foundation of older eroded rocks, at no great depth, on which the modern coral reefs have been built up. Thus the conditions even there approximate more nearly to those at Bermuda than has been supposed by some recent writers. Perhaps the difference is mainly due to the less

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* See these Trans., xi, p. 465, and "The Bermuda Islands," p. 53, for areas of the various larger islands of the group.

† Lieut. Nelson, in 1840, was perhaps the first to demonstrate the true nature of the Bermuda rocks.

abundant growth of corals at Bermuda, and a less profound erosion of the submerged limestone banks and cliffs on which the recent corals have grown. In view of this, I have previously suggested that such a structure as that of the Bermuda reefs should be called a *pseudatoll.*

Probably the position of the more elevated rim of limestone reefs, and the ancient sand-dunes of which they are remnants, was largely determined by still older coral reefs of Tertiary age, but this cannot be ascertained at present.

4. Volcanic Character of the Bermuda Foundation.

All geologists admit that the Bermudas rest on the flattened and eroded summit of a vast submarine volcano. The geological period when this volcano was last active is, of course, very uncertain. It is, however, most reasonable to suppose that it corresponded in time with the last great volcanic eruptions of the nearest American mainlands. This would imply that the Bermuda volcano was formed or completed during the Triassic period or at its close. During that period, and at its close, immense outbursts of volcanic rocks took place all along the eastern coast of North America, from North Carolina to Nova Scotia, giving rise to enormous trap-dykes, such as the Palisades of the Hudson ; Mount Tom, Mt. Holyoke, Meriden Hills, and numerous other extensive outflows along the Connecticut River valley; and also the vast series of dykes in Nova Scotia, especially along the east side of the Bay of Fundy. As the Nova Scotian regions of eruption are only about 675 miles north of Bermuda and the immense dykes have a nearly north and south direction, it is not unlikely that the outburst at Bermuda was in direct relation with those of Nova Scotia.

The great Bermuda volcano has a height of about 15,000 feet, for the surrounding ocean is about 2500 fathoms deep. Its slope on all sides is very steep. Its form and height prove that it is a volcano. This is confirmed by the remarkable magnetic variations detected by the officers of the "Challenger" in different parts of the islands, which could hardly be caused by anything except iron-bearing volcanic rocks not far beneath the surface.

"The observations made by the Expedition showed that the variation differed in various parts of the island as much as 6°, ranging from 4° W. to 10° W., the smallest amount being found at a small islet just under the lighthouse on Gibb's Hill, and the greatest at the point on the west side of Clarence Cove." Such variations do not exist at sea, a few miles from the islands.*

Besides the main cone and crater, which form the foundation of the Bermuda Islands and reefs, there were two smaller connected peaks or side-cones, which lie a few miles to the southwest of Bermuda, and form what are known as Argus Bank and Challenger Bank, both having, in general, from 20 to 40 fathoms of water over their surfaces, but Argus Bank rises in one place to within 8 fathoms of the surface of the sea. (See fig. 7.)

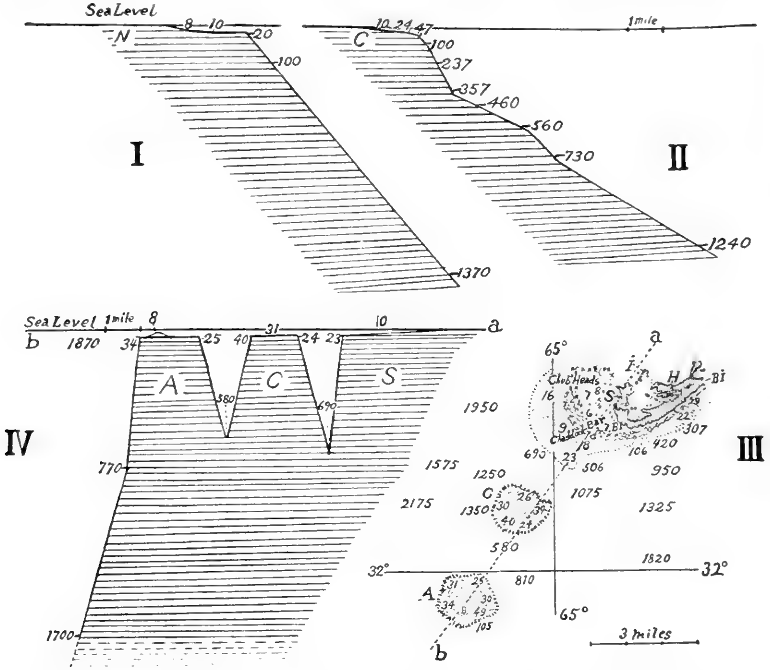

Figure 7.—I. Sectional diagram of submerged slope northward from North Rocks (N).

II. The same southward from Castle Harbor (C).

III. Sketch map showing the situation of Argus Bank (A); Challenger Bank (C); and southwestern end of the Bermudas; Somerset Island (S); Ireland Island (I); Main Island or Bermuda (B. I.); Hamilton town (H); *a*, *b*, line of the section shown in IV.

IV. Section through Somerset Island (S), Challenger Bank (C), and Argus Bank (A), along the line *a*, *b*, in III.

All soundings are given in fathoms. (Altered slightly from A. Agassiz.)

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* See "Voyage of the Challenger," Narrative, i, p. 140.

But their summits are now too far below sea-level for the growth of reef corals, though a few small corals are found on them.

The nearer is the Challenger Bank. It lies 13 miles S. 50° 14′ W. from Gibb's Hill light. It is about 10 miles in circumference. The distance from the 100 fathom line of Bermuda to its inner edge is not over four miles.

These two peaks and Bermuda are connected together by a ridge, covered with water only 580 to 690 fathoms deep, while the surrounding sea, on all sides, is from 1500 to over 2000 fathoms deep. The submerged slope of the Bermuda Mountain, on the north side, is steeper than that of any known large volcano upon the dry land. It falls off 1250 fathoms in 6 miles; that is at the rate of about 1250 feet to the mile. The slope of the Argus Bank is, on one side, 7620 feet in 10 miles. (See fig. 7.)

No doubt each of these peaks and craters, when they were most active, rose high above the level of the sea, like the volcano of Teneriffe, though not so large or high. Perhaps more like Martinique, St. Lucia, and Dominica Island, among the Antilles. The size was similar to some of the latter, and there may have been many eruptions as violent as the recent eruptions of Mt. Pelé and from as lofty a crater. In fact there must have been very many great eruptions to have built up such an immense cone from the bottom of the deep ocean.

After the volcano became extinct there followed a vast period of time during which the action of the sea undermined and levelled down the materials of the volcanic cones, filling up the craters, more or less completely, at the same time, in case any deep central pits remained. This period of erosion may have lasted through all the Jurassic, Cretaceous, and Eocene periods, with more or less oscillations of level. However, it is probable that during those periods more or less extensive reefs of corals and deposits of shell-sand were formed, for during the Jurassic period reefs of corals existed as far north as middle Europe, and the climate in the latitude of Bermuda, in the Cretaceous and Eocene, must have been much warmer than at present. In any case, the final result of the erosion of the larger volcanic cone must have been to form submerged banks or shoals at a suitable depth for the abundant growth of corals, mollusks, etc.

It is probable that direct erosion by the sea waves would not have cut down the cones very far below the level of low-tide, for the waves in storms of ordinary force have little erosive power beyond 20 or 30 feet deep. In violent storms the wave action may have some feeble effects to the depth of 100 feet or more, but hardly sufficient to move anything more than loose material like fine sand and mud.

George's Bank and Nantucket Shoals, off Cape Cod, maintain themselves in the face of the most violent storms. Although composed only of loose sand and gravel, their shallowest parts rise to within 25 to 30 feet of the sea-level. This indicates that the eroding action of the waves decreases very rapidly, even at such depths.

The Argus and Challenger cones were evidently truncated and roughly levelled by the erosion of the waves, but at the present time they are depressed so far beneath the sea that coral reefs do not grow upon them. Possibly they may have been dry land, with sand dunes and corals like those of Bermuda, in the period of Greater Bermuda. If so, the subsequent subsidence and simultaneous erosion of the limestones could have reduced them to their present depths.

If Jurassic or Tertiary coral reefs existed here, as is quite probable, they would certainly have grown best around the borders of the banks and shoals. Thus they might have initiated the atoll-like structure that has prevailed subsequently.

It is possible that during some of the former geologic periods, after the cones were formed, there may have been long periods of subsidence, in which the depth of water over them became too great for the growth of coral reefs,* as is now the case at the Argus and Challenger Banks.

5. *Emergence of the Land.*

At some period, perhaps after the close of the Miocene, when we know that many of the West Indian islands, with their Miocene corals, were upraised, as well as the eastern coast of the United States; or perhaps still earlier, in the Eocene, the Bermuda reefs and shoals, whether of coral or not, were so much raised that they formed dry land.† No doubt this land at first formed a group of low islands

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* Deep artesian borings at Bermuda might determine these questions with certainty. No doubt this will eventually be undertaken, as has been done elsewhere.

† That the dry land was as old as the middle Tertiary is probable, because of the long time that must have been required for the evolution of the endemic genus *Pœcilozonites*, with at least seven very diverse species that we find already there in the Pliocene. There must have been many earlier ancestral species that are unknown to us. See Paleontology.

along the rim of the partly enclosed lagoon, as is almost always the case with small oceanic islands of this type. Their sandy beaches and flats, alternately covered by the tide and exposed to the sun, afforded an abundance of dry shell-sand. From this time onward the shell-sand, derived mainly from the life and death of myriads of small mollusks on and about the reefs and shoals, must have been drifted by the winds, so as to form hillocks and sand-dunes, gradually increasing the height and extent of the islets and eventually uniting them together into larger ones. It is probable that this was favored and accelerated by the continued and gradual uprising of the volcanic basis, during a long period of time. But it is possible to account for much of the subsequent great growth of the islands, even without much elevation of the sea bottom, beyond what was necessary to lay bare the extensive shoals of fine shell-sand, periodically covered by the tide.*

6. *Evolution of Greater Bermuda; Pliocene Bermuda.*

From the evidences derived from the subsequent subsidence, it is probable that the highest sand dunes, eventually, in one period at least, attained the height of over 450 feet. It is hardly probable that this was due wholly to the drifting of the sand to that height, though it is not impossible. It seems more probable that the emergence of the land continued while the great sand dunes were forming. In that case the higher and larger sand dunes would also be the older ones and the deposits at the center and summit would be the oldest. If the height were wholly due to sand-drift, then the upper layers at the summits would be of later origin. The character of the rocks indicates, but does not prove, that the upper and central parts of the higher hills are the oldest. But fossils have not yet been found in them. Thus a long continued period of emergence was probable, with a constant loss of materials from the tops of the hills.

No doubt a very large amount of material has been removed from all the hills through solution and by mechanical erosion by rains, so that 450 feet for their greatest former elevation is probably too low an estimate.

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* Subsequent subsidence has buried the first formed limestones deeply beneath the sea,—probably at least 100 feet. We know the nature of the submerged rock to about 50 feet deep at Ireland Island dock, where it is a sand-drift limestone, associated with red clay soil.

I hope to demonstrate later that the rocks which I call the "Walsingham formation," and refer to the Pliocene period, now rise to the height of 60 to 70 feet and probably much more. If we add to this 100 feet for the later subsidence, those rocks must have formed hills at least 160 to 170 feet high in the Pliocene, even if we allow nothing for solution and denudation. Their interstratified red clays indicate a loss of more than 150 feet by solution. So it is probable that the islands were much higher and larger, even in the Pliocene, than at present.

It is certain that it took a very long period of time to bring about the elevation of the land and to accumulate the vast quantities of shell-sand and red clays contained in the hills. But the mere mechanical work of heaping up the sand by the wind is of secondary significance in this study. It might have gone on very rapidly at times if the winds were more violent than now. This may have been the case, especially in the time of the Glacial period.

What is of far greater significance is the enormous lapse of time required for the small shells and other small organisms to grow in quantities sufficient to build up all this land, with its high hills, in addition to the quantities, perhaps equally great, that were washed away into deeper water, and also the great bulk that was lost by solution to form the red soil of the dry land and the caverns.

When these considerations are taken into account, it is plain that the building up of Greater Bermuda must have required a vast period of time. Therefore, we are forced to believe that it had attained very much of its growth in the Pliocene or pre-Glacial times, and that it had acquired, before the Glacial period, a large flora and fauna of its own, of which some portions still exist, though the greater part may have been exterminated by the cooler and more stormy climate of that period.

Perhaps all those plants that are now peculiar to Bermuda (only about 8 species*) date from the Pliocene or earlier periods. The same is probably true of the few land snails peculiar to the islands, especially the genus *Pœcilozonites*, found nowhere else, and of which several of the species, including the largest, are known only as fossils, while others still survive in diminished numbers and feebler forms. Certainly they could not now exist in such places as small barren islands where they were once abundant.†

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* For lists of these see these Trans., vol. xi, p. 574, and "Bermuda Islands," p. 162, with figures.

† These matters will be more fully discussed in the chapter on paleontology.

If the higher land had become covered with luxuriant vegetation in the pre-Glacial times, this eventually would have had the effect of diminishing the accumulation of sand on the higher dunes. The drifting of the sand would have been more and more restricted to the vicinity of the shores, and therefore the bays and inlets would have been filled up more rapidly, except in face of strong currents.

It is not unlikely that the Bermuda cedar and the palmetto (which last is peculiar to Bermuda), with other trees now extinct there, may have then formed dense forests over most of the land, similar to those that existed when Bermuda was first discovered by Europeans. Indeed, from the great size and abundance of the fossil land snails, on small islands now barren and nearly bare of vegetation, it is evident that there was a former period when the climate was more moist and the vegetation much more abundant than in the present period. It is known that the Pliocene was really a period of greater elevation than the present, for I have myself found the large fossil land snails (*P. Nelsoni*, pl. xxvi) in limestone strata of the Walsingham period, in places now submerged beneath the sea. It is said to have been found in the limestones at the depth of about 48 feet below the sea at Ireland Island.

7. *Bermuda in the Glacial Period.*

That the advent of the Glacial period caused a marked change in the climate of Bermuda cannot be doubted. Huge continental ice-sheets existed over the whole of New England, Nova Scotia and Newfoundland, and their lofty frontal ice-cliffs, extending for hundreds of miles along the coast and reaching some miles south of the present shore lines, were dropping vast numbers of icebergs, doubtless of gigantic size, like those of Greenland, into the sea continually. Those ice-cliffs were not over 625 miles north of Bermuda, and doubtless the icebergs drifted much nearer. Possibly the Gulf Stream was stronger than now. If so, the icebergs may not have crossed it, but they must have gone far southward in the inshore Arctic current.*

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* In a former article (Amer. Jour. Science, ix, May, 1900), I suggested that the marine climate in the glacial period might have been warmer than now, because of the occurrence of fossil West Indian shells that no longer live there. But with the exception of *Livona pica* (fig. 60) carried inland by the hermit crabs, no marine fossils are known from the rocks that I now consider as preglacial and glacial. The beach formations, containing most of the marine shells

Therefore, it is certain that the northerly winds would have been cooler than at present and doubtless the contrasts in temperature between the northerly and southerly currents, both of air and water, would have been much greater than now. Therefore, we are safe in assuming that the climate would have been more stormy, with fiercer gales and much more rain than now. Probably there were also frosts regularly in winter, and perhaps some snow, for light frosts sometimes occur in Bermuda even now, and sometimes a few snow flakes also.

Such changes in the climate as I have named would have needed only a few degrees of decrease in the mean annual temperature. But they would have been sufficient to exterminate most of the tropical and subtropical life that may have existed there previously. The forests and other vegetation may have quite disappeared then from the exposed hills and highlands, even if partially retained in the sheltered valleys. Death of the vegetation and the increased violence of the winds would have set the sands in active motion again, perhaps far more energetically than ever before.

These, I suppose, were the conditions under which the land attained its greatest elevation and extent.

8. *Post-glacial Bermuda; Subsidence.*

During the decline of the long glacial period, the "Greater Bermuda," like the American coast north of it, underwent a gradual subsidence, as shown by many geological phenomena. This is believed to have amounted eventually to at least 100 to 120 feet, as will be shown in a later chapter.

This period probably corresponded to the Champlain or Lawrentian period of eastern North America. During this long period of subsidence there was an immense amount of erosion by the sea, and much of the lower parts of the previous dry land of the interior was finally covered by the sea, gradually bringing about the present condition of things. New sand-drift rocks were also forming during all this period. During this period, also, many species of plants and animals were introduced from North America and the West Indies

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then referred to, I now refer to the post-glacial or Champlain period. However, it is possible that the Gulf Stream waters were as warm in the glacial period as at present, and that owing to the elevation of the coasts of the boreal Atlantic, and probably of its entire sea bed, its current may have reached Bermuda more directly than at present, so as to offset the cold Arctic currents.

by winds, drift-wood, birds, etc., thus forming a new fauna and flora, combined with some remnants of those that had survival the glacial storms.

9. *Reëlevation of Bermuda.*

There is considerable evidence that these islands underwent a slight reëlevation of about six to ten feet, after the period of greatest depression. If this be true, its period corresponded, in all probability, to that in which Nova Scotia, Eastern Canada, and New England underwent a much greater reëlevation in post-glacial or Quaternary time.

Such a reëlevation, of small amount, would best account for the various local deposits of beach-rock, containing recent marine shells and corals, now found elevated from 6 to 15 feet above the sea. This will be discussed later.

10. *Consolidation of the Sands; formation of the Æolian limestones and "base rock."*

During the whole period of the accumulation of the shell-sands, a process of consolidation or cementation of the sands into softer or harder limestone has been going on beneath the surface of the land,* but not uniformly. This is brought about by the rain water, which always contains carbonic acid in solution, which dissolves a certain amount of the limestone as it percolates through the sands, forming calcium bicarbonate in solution. This solution, when exposed to the air, and especially when it evaporates, deposits calcium carbonate or crystalline calcite, either between the particles of sand, binding them together, or in the form of stalactites and stalagmites, when it drips into caverns, as is well known.

But in the rainy and warm climate of Bermuda, this process goes on with unusual rapidity. In fact, the sands and porous limestones, below a certain distance from the surface, seem to be saturated with the lime solution, for many of these limestones, which are so soft that they are quarried by large chisels and cut into regular building stones with ordinary saws, as easily as wood; become quite hard and suitable for building† after exposure to the air for a few weeks.

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* There is no evidence at Bermuda that the shell-sand and marl ever consolidate into limestone when wholly submerged beneath the sea. These materials are everywhere loose to a great depth, in the sounds.

† See these Trans., xi, p. 431, fig. 11; "The Bermuda Islands," p. 19, fig. 11.

So when the percolating waters meet cracks or fissures, where they will be exposed to air, they deposit the calcite on and near their surfaces, giving rise to sheets and blocks of harder material, which may later stand out in relief when erosion takes place. (See fig. 8.) The reticulated cracks, made by the air-drying of mud, are thus filled in some places, as well as the larger fissures. When such waters trickle down the surfaces of the stumps and roots of trees, the sands may be so hardened around them that complete molds of the roots, and even of the bases of the trunks, may be formed and preserved in the limestones. When the organic matters decay, casts may be formed in the molds. Some of the structures locally known as "fossil palmetto stumps" have possibly been formed in this way. These will be discussed later. (See chapter 24, pls. xix, xx.)

Figure 8.—Cliff of æolian limestone, south shore, showing the irregular stratification and the deeply pitted surfaces coated and infiltrated with calcite, characteristic of most of the cliffs that are exposed alternately to the action of the sea-spray and dry air.

When the percolating waters meet a nearly horizontal layer of impervious red clay, or a very compact layer of fine shell-marl, its downward course being arrested, it may collect in and consolidate more firmly the layers just above. The layers of hardened limestone will also vary in hardness according to the fineness and compactness of the shell-sand and calcareous mud composing them; according to their inclination and drainage; according to the amount of percolating water; and also according to their depth beneath the surface. Some of the beds of sand, even of considerable thickness, are still loose, with little or no consolidation, although of ancient origin with thick deposits of hard limestone rocks over them. Sometimes irregular masses or "pockets" of the loose sand occur in the harder limestones, fig. 4. When such loose deposits of sand happen to become exposed in the shore cliffs the soft contents are quickly washed away, leaving grottoes or cavernous places, large and small, in the cliffs. Probably the remarkable "Cathedral rocks" (fig. 9), on the west shore of Somerset Island,* have been formed mainly by the rapid

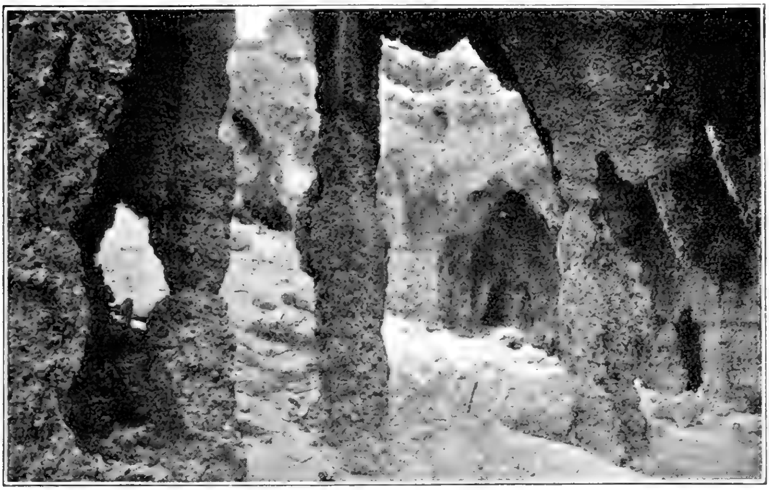

Figure 9.—Cathedral Rocks on Somerset Island; the ruins of an ancient cavern and water passages, partly broken down and dissected by the sea. The roof has partly fallen. The columns are hardened by infiltration and roughly pitted. The bottom, which is above high tide, is covered with shell-sand.

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* See pl. xxi; also these Trans., pp. 427, 473, and pls. lxxxviii, lxxxix; "The Bermuda Islands," pp. 15, 61, the same plates.

erosion of a thick bed of only slightly consolidated sand, in which many vertical fissures had allowed the percolating waters to consolidate the adjacent sand into harder rocks, which now stand up like pillars supporting the arches of overlying limestone. No doubt there was a time, before the erosion had progressed so far, when these archways and pillars formed the supports of a cavern of considerable extent. But the pillars are not true stalactites, as they are in some of the other caverns, but mere vertical masses of shell-sand, so impregnated and encrusted by stalactitic material that they are very hard and resistant. Some of the larger caverns on the islands have similar large columns which are so thickly covered with stalactitic material that their true nature cannot be ascertained without fractures or sections. But all intermediate conditions occur among the larger stalactites and pillars of the caves.

Figure 10.—Much eroded and undercut rocks and columns at Tobacco Bay, near Fort Catharine, as seen at low tide.

Probably the curiously and roughly eroded rocks and pinnacles of Tobacco Bay* and other similar localities had a similar origin, but have progressed farther toward destruction (fig. 10, and pl. xxiii, figs. 1, 2).

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* See also these Trans., p. 474, pl. lxxx, fig. 1, xc, fig. 2; "The Bermuda Islands," p. 62, plates the same.

Pulpit Rock (fig. 22) and the North Rocks (figs. 23, 31) probably owe their existence mainly to their resistance due to infiltration, while the softer surrounding rocks were washed away. The same is doubtless true, in a marked degree, of all the other boldly sculptured rocks and projecting crags, such as Lion Rock (fig. 20), and the cliffs shown in figs. 17, 22.

11. *Unconsolidated Sands; no consolidation below low-tide level.*

Why the masses of shell-sand, mentioned above, remain unconsolidated, imbedded in or between hardened strata of the same composition, has never been satisfactorily explained. The only suggestion that seems to me plausible, is that they were so situated that they were continually soaked in waters that were already saturated with calcium carbonate and from which no evaporation could take place, owing to the nearly impervious or hard rocks above and below them. Under such conditions they might have become water-bearing strata without alteration, either by solution or hardening. This would also explain the remarkably perfect preservation of delicate land shells, even with their colors perfect, in these beds.

I have already mentioned that there is no evidence that these shell-sands and marls, at Bermuda, ever become consolidated into lime when constantly covered by the sea, somewhat below low-tide level. In the excavations made at Ireland Island and elsewhere, 6 to 10 feet of such unconsolidated materials have been found, overlying æolian limestones. Stakes and probes can be driven down many feet into these sands almost everywhere in the harbors.

The same conditions are found all over the world where shell-sands and coral-sands form the bottom deposits. Also, in the deep sea where *Globigerina*-ooze occurs of great depth, it is never consolidated. Probably this is also due to the absence of evaporation. Perhaps violent agitation, in shallow water seas, may take the place of evaporation, to some extent, and cause some consolidation, just below low tide, by loss of carbonic acid.

But many geologists constantly refer to such shell-limestones and coral-limestones as if consolidated below sea-level. I do not know of any evidence that it ever occurs under ordinary conditions. A marked or rapid change in temperature, or contact with water of a different chemical composition, or the action of living organisms, might cause it, under unusual conditions.

12. *Surface Hardening and Infiltration by Sea Water and Spray.*

Wherever the limestones have been exposed for some time to the joint or alternate action of salt spray and the atmosphere, their surfaces becomes hard and deeply corroded, pitted, or rudely honeycombed, with the intervening portions rising up into sharp ridges, rough and ragged points, and other strange, rude, and irregular forms, so that they are very unpleasant to walk upon or climb over, for they are very destructive to shoes and clothing. (Pl. xxii.)

This is due partly to the solvent action of the sea water, eating out the pits, and partly to the infiltration and hardening of the intervening spaces by the evaporation of the calcareous water. As the intermediate ridges and points become higher they seem to act by capillary action, like wicks, to draw up the water from the pits and crevices, and the stalactitic material is deposited at their points and edges, building them up and making them very hard. (See figs. 8, 15, 22.) This action is going on everywhere along the cliffs. When the surface of the rocks becomes thus hardened, they are very resistant to erosion by the waves, and thus even limestones that are soft beneath the surface may endure for a long period.

Below high tide the action is somewhat different, for here the sharper projections are worn off, but the infiltration and hardening of the rock goes on to low-water mark, especially wherever it is alternately wet and partly dry. In such places the rocks usually become rudely pitted, partly by solution and partly by the mechanical erosion of the softer spots, but the pits are generally larger than above sea-level, and often form shallow tidal pools, large and small. Owing partly to this hardening of the rocks, nearly or quite to low-water mark, but not much lower down, and partly to the diminished force of the waves on the rocks while submerged, these hardened limestones often form nearly flat platforms or benches, at or just above low-water mark. Sometimes this is aided by the horizontal stratification of the rocks, by corals and other growths, and by other causes. But the infiltration of these partly exposed rocks, converting soft limestones into those that will ring under the blow of a hammer, has a great effect in preventing their rapid destruction by the waves.

13. *Compact Limestones; Building Stones.*

In its downward course all the percolating waters must eventually be stopped, by the layer of sea-water which everywhere fills the porous beds of limestone to near the level of mean-tide and sometimes above it. The rain water, being lighter, will rest upon the sea water and mix with it only very gradually in the pores of the rocks. Even in the shallow wells, often dug near the shore for cattle, nearly fresh water can be drawn from the surface during the ebb tide, though there may be salt water at the bottom.

The calcareous fresh water, thus arrested by the sea water, will therefore deposit much of its calcite in the strata just above the level of the salt water. As this level varies with the tide, a considerable thickness of harder limestone, often four to six feet thick, may eventually be formed about at the level of high water mark, if the land should remain at a given level for a long period of time. This appears to me to have been the mode of induration of many of the hard strata of limestone found in various places, just about at high tide level, as along the south shore, and of other hard limestones on the reefs.

Such hard compact limestones have been called by some writers the "base-rock," and some have believed that they represent an older formation, underlying the whole island.

Mr. A. Agassiz, however, considered them as formed from ordinary æolian limestones, of any age, indurated by the action of the sea water and air, and not indicating any particular period. Both views are true in part.

Superficial induration of the kind to which Mr. Agassiz refers is common enough, as described above, but it does not convert thick strata of limestone over wide areas, and above sea-level, into a compact marble-like limestone, of very uniform character; such as we find in much of the so-called "base-rock" of the south shores. Doubtless hard limestones of various periods have been massed together under the name of "base-rock," and the name is therefore misleading and better be abandoned.

Similar hard limestones occur locally at various higher levels, often much above the level of the sea, and they have often been quarried for building stones. Some of these belong to the earlier or "Walsingham formation" and are associated with the ancient red clay and extinct land shells. But others are of later origin and are only unusually hard and compact portions of the ordinary æolian limestones.

Perhaps the unusual induration of such layers, distinctly above sea-level, may be connected with the somewhat variable zone or level of underground fresh water in the rocks, for no doubt such a zone exists here, as elsewhere, in spite of the porosity of the rocks.*

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* Artesian wells on the higher lands have yielded water in a few cases.

Percolating calcareous waters would be arrested at such a level, and deposit, just above it, by cooling and evaporation, much calcareous material, for it would occupy a zone in which evaporation would be taking place in dry weather and through capillary action. This process, if long continued, would form strata of hard limestone, but not necessarily of any particular period.

The harder strata, especially of the "Walsingham formation," are usually overlaid by a bed of red-clay soil, which was probably orignally occupied by vegetation. The dead vegetable matter of such a soil may have contributed additional carbonic acid, and perhaps humic acids, to the percolating rain water, and this may have hastened the solidification of the underlying rocks.

Therefore it is evident that no very definite separation of these limestones into periods or formations can be safely made, merely on the hardness or compactness of the rocks, though in general the older ones are likely to be the harder. The sands have been continually drifting and consolidating, unequally and variously, ever since the first islands rose above the sea, and at all levels. So, likewise, the changes in elevation and subsidence have been so very gradual that they have produced no marked periods or changes in the rock formation, except locally. We can, however, distinguish an earlier period, by means of the extinct fossil land shells, during which the climate was more favorable for vegetation and land-snails than at present, as indicated above.

This we may provisionally refer to the Pliocene. It was, in my opinion, certainly pre-glacial.

14. Pliocene Bermuda; Walsingham Formation.

I propose the new name "Walsingham formation" to designate that portion of the older Bermudian strata of limestone and red clay characterized by containing several species of extinct land snails, of which the largest and most abundant is the *Pœcilozonites Nelsoni* (Nelson's snail; pl. xxvi, figs. 5–8).

a. Compact Limestones.

The most prominent and characteristic of the rocks are the compact and hard æolian limestones which have, in many places and over wide areas, become so highly infiltrated with calcite, that the original sand-drift structure has been obscured or lost, so that they sometimes appear to be in thick massive strata, forming durable building stones. But in many other places these rocks have remained friable or soft, with well marked sand-drift structure. In some cases they include layers or pockets of imperfectly consolidated, or loose, shell-sand. Between the layers of limestone are successive layers of "red-clay,"—a decomposition product, representing ancient soils, and often containing numerous extinct land-snails. The red-clay may be more or less indurated by the infiltrations of calcite, or stalactitic materials, with which, and the shells, it sometimes forms a breccia-like reddish mass (fig. 45). The fossil land-snails occur in the limestone, whether it be consolidated or friable, but are most abundant in those portions connected with the layers of red-clay, especially in and just above the latter.

Most of the larger caverns and sinks, like those of Walsingham and vicinity, have been formed in this formation, which seems to contain the oldest rocks now exposed to view on the islands, and to form the nuclei of the larger hills. It is found at all levels, from below low-tide mark to the elevation of 70 feet or more. Its hard compact layers, exposed in many places on the south side of the main island, just above high-water mark, are those that have been called "base rock" by Heilprin, Rice, and others,* and "the limestone" by Stevenson, but they are of the same nature as, and essentially contemporary with, those that occur elsewhere at greater elevations, as shown by the overlying red clay and extinct snails. The best examples of the so-called molds and casts of "palmetto stumps" also occur in this formation (see plates xix, xx), showing that the latter might have been due to some extinct and unknown plant or animal.

This formation outcrops in numerous places on the ancient Walsingham property, between Castle Harbor and Harrington Sound, hence the name given to it. It seems to form most, if not all, of the high neck of land separating those two bodies of water, for it out-

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* Professor Rice, op. cit., p. 9, 1884, stated that the so-called base rock "does not uniformly underlie the softer rocks, nor is there any evidence that it is older than they." He apparently referred to all the hard limestones of drift-sand origin, near sea-level, taken collectively. Agassiz, 1895, held essentially the same view.

But Stevenson, 1897, claimed that this rock, which he called "limestone," represented a distinct formation, underlying the ordinary æolian limestone, which he called "sandstone." However, he considered the limestones and red clays, containing extinct snails, around Castle Harbor and Harrington Sound, as a newer formation, "The intermediate deposit," of the same age as the beach-limestones. With this conclusion I do not agree.

crops by the roadside, nearer the Harrington House, nearly at the highest part of the ridge, perhaps fifty or sixty feet above the sea. Near the Walsingham house there are several deep sinks, filled with sea water, and used as fish ponds and turtle ponds, which are formed in these rocks.

The famous Walsingham caves (pl. xxi, fig. 2) with large stalactites,* Joyce's Cave, and several other similar caverns in this district are in this formation, for the hard limestone, near the entrances, contains the red soil and Nelsonian snails. There are many other outcrops of the same limestone, associated with red-clay breccia, and often completely filled with masses of the large Nelsonian snails, on the land of Mr. W. S. O. Peniston. The interesting Peniston cave,† with only one small entrance, which is on the top of a higher ridge, east of the Harrington House, also appears to be in the same rock, though I found no fossil snails just there. The cave dips downward with a steep slope to below sea level, for there is a pool of sea water in the bottom. The slope is said to be over 80 feet deep.

There is an excellent exposure of the Walsingham formation at the old quarry on the west side of Castle Harbor, and near Paynters Vale. Here the hard, compact limestone, formerly quarried for government works, is several feet above the sea-level.

The harder limestone is here overlaid as usual with a layer of red clay, which is more or less indurated in places, or united into brecciated masses mixed with stalagmitic material and several extinct land shells, especially the large Nelsonian snails (fig. 45–47; also pl. xxvi). With these land snails numbers of a large marine spiral shell (*Livona pica*, fig. 60) are often found here. These shells were carried from the beaches up over the hills in those days, just as they are today, by the large land hermit-crabs, who use them for shelter. Part of the red clay is here contained in pockets or cavernous places in the limestone. The fossil land snails occur here in the limestone as well as in the red clay material. At this quarry much of the harder limestone shows distinct sand-drift structure, which is still more evident in the rocks below and above it.

The Walsingham limestone, with red-clay breccias, outcrops at many other places on the southwest and south sides of Castle Harbor.

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* See these Trans., vol. xi, plates xc–xciii, and "The Bermuda Islands," p. 58, plates xc–xciii.

† See these Trans., vol. xi, pp. 438, 471, pl. xciii, and "The Bermuda Islands," pp. 26, 59, pl. xciii, figs. 1, 2. Also below, Chapter 16, B.

It seems to form most of the narrow neck of land that extends from Tucker's Town eastward to Castle Point. The extinct fossil land snails occur at many localities in this district.

Thus it seems to be continuous along the shores, from the point near Coney Island to Castle Point, a distance of several miles. Apparently most of the rocks of Hamilton Parish belong to this formation. It occurs also at Tuckers' Town and on the shores of Harrington Sound. Sharks Hole,* with the cliffs west of it, and Devil's Hole seem to be excavated in the Walsingham formation, though only very few imperfect fossils were found at those places. The hard rocks on Pear Island and Trunk Island are probably of the same age.

Mr. A. Gulick records a locality on the west side of Knapton Hill, near the west end of the sound, where a layer of red earth, about 8 to 10 inches thick, and containing several characteristic species of fossil snails, rests on a limestone of this formation.

It occurs along the roadside, from Bailey Bay to near the causeway, for I have found good specimens of *P. Nelsoni* in it at several places there. I also found it in the ledges outcropping near the shore at Mr. Seon's beach, Bailey Bay.

On Bailey Bay Island it occurs near the sea-level, on the north side, and extends to an unknown depth below it. At this place I have obtained *P. Nelsoni* from ledges submerged even at low tide. Similar hard rocks occur on other small islands, and on the shores farther westward, but as they have not yielded the fossil snail (*P. Nelsoni*), they cannot now be referred to this formation with any certainty. The same is true of the hard limestones forming the upper ledges on many of the higher hills. They may belong to the Walsingham formation, but this cannot be demonstrated until extinct fossil snails occur.†

It apparently outcrops on the northern side of Hamilton Harbor. On Ireland Island, Nelson described a cavern in it, containing great

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* These Trans., p. 438, pls. lxxi, lxxiii; "The Bermuda Islands," p. 26, same plates.

† Some of the species of *Pœcilozonites* that are found as fossils are still living. This is notably so in the case of *P. Bermudensis* (pl. xxvi, figs. 1, 2; pl. xxvii, figs. 1, *a–l*), which occurs both in the Walsingham formation and in the later ones. It is often very abundant in some of the later and softer limestones, retaining conspicuous bands of color. The fossil variety (variety *zonata*, pl. xxvii, fig. 2) is rather larger and thicker than the recent ones. This species, therefore, cannot be used for determining the age of these limestones.

numbers of *P. Nelsoni.** On Tucker's Island, in Great Sound, it contains a large cavern, supported by great stalactitic columns, and with several feet of sea water over its floor. I observed the red-clay and stalactitic breccia, containing the Nelson's snail, in the ledge near its entrance, and in other places on the island.

It has also been recorded as occurring on St. George's Island. I did not find the extinct snails in that vicinity, but had little time to search for them there.

Professor Rice, however, described a very hard limestone, of æolian origin and containing fossil land snails, as occurring at the old quarry at Stocks Point. It was overlaid by a local deposit of beach rock, containing many marine shells (see below, p. 75). This section, therefore, agrees completely with many of those on the south shore of the Main Island, described below.

Excellent exposure of the hard Walsingham limestone occurs at many places, just above high water mark, on the south side of the Main Island, from west of Tucker's Town to Elbow Bay, and perhaps further.

The best examples that I saw are at the foot of a low bluff, near Hungry Bay, where the harder layers had been quarried by blasting. A good series of photographs of the rocks along this bluff, some of which are reproduced in my plates, were made in the spring of 1901, by A. H. Verrill. A violent hurricane, not long before, had washed away the debris and cut away the softer overlying rocks, so as to show all the strata very beautifully† (see fig. 11).

The hardest stratum (*b*) at this place is about one and a half to two feet thick, and has been blasted off for building purposes. It is a very compact, white limestone, almost like marble in some places, and often with no trace of sand-drift structure, though showing this at times in the continuation of the same section. It is overlaid in some places by a thicker and somewhat softer stratum (*b'*) of the same nature.

The latter carries on its upper, nearly level, and somewhat eroded surface, portions of a firmly adherent layer of indurated red clay, commencing in which, at one place (plates xix, xx), there are large numbers of those cavities called molds of "palmetto stumps," mentioned above, some of which penetrate into the hardest stratum of

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* See his description of the cavern, quoted below, p. 82.

† See pls. xvi–xx; also these Trans., xi, pls. lxxxiv–vi; and "The Bermuda Islands," same plates. See discussion of their nature in chapter 24, Paleontology.

Walsingham limestone, while others only reach its upper surface, or fail of that even. The hardness of the rock seemed to have had no influence. They may have been formed before it was hardened.

Above the red clay surface there is here a deposit of beach-rock (*c*), three or four feet thick in some places, and containing many marine shells. The latter is irregularly laminated, and locally variable in thickness and character. It appears to have been a true marine deposit, formed below high-water mark, but now elevated five to eight feet above it.

This is overlaid, along most of this exposure, by a layer of drift-sand (*d*) which is only slightly consolidated and friable to the touch, especially in its upper part. Hence the storm, referred to above, readily cut it out into the cavernous or oven-like places, shown in some of the plates, under the overlying strata (*e*) of later æolian limestones, which are here well indurated. The unconsolidated layers contained, in the lower part, some fragments of marine shells. There were mostly small valves of *Mytilus* and other light bivalves, easily drifted by the wind, but in its upper part it contained the land snail, *Pœcilozonites Bermudensis* (plate xxvii), which is still living, and there were no extinct forms found with it.

Following this exposure westward the unconsolidated beds soon disappear or become so consolidated that they cannot be distinguished from the overlying æolian limestones, which continue. The beach-rock also disappears locally, so that the upper æolian limestones may rest directly on the Walsingham limestone, though unconformably.

The arrangement of this series of rocks is almost the same at various other places, as at Devonshire Bay. It was observed there, both by Rice (1884) and Stevenson (1897, p. 105), underlying the beach-rocks containing marine shells,. Professor Stevenson's description will be quoted below, under beach-rocks.

It happens that the hard limestones of this formation occur along much of the southern coast of the island, just above sea-level; between tides; or more or less submerged. In many places the strata lie nearly horizontally, though not always so. In case these nearly horizontal, compact beds outcrop between tides, or a little below low-water mark, they will resist the erosion of the waves much more effectually than the softer overlying limestones of later age. Thus they are sure to form, under such conditions, more or less extensive "benches" or shelves, between tides or lower down. The waves speedily wear away the layers of red clay and the unevenly corroded or pitted upper surface gives good opportunities for the commencement of the formation of "pot-holes," large and small, by the scouring action of the sand and rushing waters. Probably some of the deeper and narrower cups or pot-holes on the serpuline atolls are directly due to remodelling and enlarging the cavities called molds of "palmetto stumps," which often abound in this limestone much above sea level, as well as between tides. (See chapters 20 and 24, *b.*)

It seems evident to me that the vast number of durable flat reefs, littoral shelves, submerged benches, and serpuline atolls, all along the south coast, are due largely to the outcroppings of these hard, nearly horizontal limestone strata, which have just the right nature and position to easily yield such flat structures, by the erosive action of the waves. (See figures 11, 27–29.) But I do not wish to deny that similar structures can be, and often are carved from ordinary æolian limestones, especially when the layers are horizontal or nearly so, as Mr. Agassiz states.

I am, therefore, inclined to believe that most of the serpuline atolls and outlying flat reefs of the south coast are composed of the hard limestones of the Walsingham period. But I do not know that the characteristic, extinct, fossil land snails have as yet been found in these reefs. As a rule, these solid limestones, in this vicinity, are destitute of recognizable fossils.

b. Red Clay layers, with extinct Land Snails.

That the Walsingham formation, which I refer to the Pliocene, represents a long period of time, is evident, not only on account of the great thickness of its limestone strata, but also from the successive layers of red-clay soil interstratified with them, as described above. Each of these layers of soil indicates a long time for surface decomposition, and locally without sand-drifting. Six or seven of these layers of soil, varying in thickness, have been noticed in some sections; most of them are only 2 or 3 inches thick, but some are 8 to 10 inches or more.

It is thought that it would require the solution of at least 150 feet of limestone to form a single foot of this soil, not allowing anything for that portion which would naturally be washed away by rain. (See chapter 20, A.)

Prof. T. W. Goldie, in his printed lecture on the Geological Formation of Bermuda, 1893, pp. 14, 15, mentioned a "belt or layer" of "red clay" soil, 8 inches thick, underlying the æolian limestones near Hamilton. This layer was about 60 to 70 feet above sea-level and at about 130 feet below the surface of the hill. It was found in making a boring for a well at the military establishment on Prospect Hill. The layer of red clay was underlaid by strata of compact limestone. Perhaps this was a part of the Walsingham formation.

A similar layer of red clay outcrops between limestones on Bishop Street, in Hamilton. It is about 60 feet above the sea. From this layer the sample of "virgin red soil" was taken for analysis by Mr. Manning* (sample No. 3).

15. Beach-rock with Marine Fossils; Devonshire formation; Champlain Period.

That beach-rocks, containing the common marine shells of the shores and shallows, are still in process of formation locally, on many parts of the shores, is plainly to be seen by any one who observes such phenomena critically. They are formed of the sands, coarse and fine, which are tossed up toward and above high water mark by the waves, and often in their upper parts blended with finer sands that have dried and then drifted along the beaches with the winds. Exposed alternately to the action of the sea water, rains, and air, they often harden rather rapidly, as explained above, into compact masses of limestone, usually of small extent, and with thickness varying greatly within short distances. The larger marine shells found in them are mostly broken by the waves, but many are entire.

These modern deposits are seldom more than three or four feet above high tide, and are most frequent in partially sheltered bays and coves.

Many of them are constantly being washed away by more violent gales, or by waves from some different direction, so that only a few become permanent. At certain places the modern sand-dunes have encroached upon and buried such beach deposits.

It is evident that the same phenomena have been taking place in all previous periods of the geological history. But as the islands have subsided about 100 feet, it must be evident that all the older deposits of this nature must now be buried beneath the sea. The only beach deposits of much antiquity that we could expect to find would be those formed at some period when the islands stood at a slightly lower level than now, in the Champlain or post-glacial period (see p. 61).

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* See these Trans., xi, p. 493, table; also "The Bermuda Islands," p. 81.

a. Devonshire formation.

Some of the older and more elevated beach-rocks indicate that they were formed in such a period of depression. Some of these now lie 12 to 16 feet above the sea, and by the fine character of the materials and good condition of the shells, appear to have been formed in comparatively quiet waters, and not tossed up by hurricanes, as Mr. Agassiz supposed. No doubt some of the coarser deposits, with broken shells, only 3 or 4 feet above the sea, as described by him, may have been tossed up by violent gales, for we know that recent Bermuda hurricanes have thrown broken shells, as well as rocks of considerable size, to the height of 10 to 15 feet, or even more, above high tide. But their action is much more destructive than formative. No one has seen them leave regular thin-bedded deposits of fine materials and entire shells at any such elevations. The evidence, therefore, at present, is that the more elevated beach-rocks are of Champlain age, and were mostly deposited in partially sheltered bays and lagoons, where violent sea waves did not enter with great force. Yet in later times, the barrier reefs or islands protecting them having been worn away, some of them have come to be exposed on the outer shores, especially along the southern side of the main island (fig. 11). They are best displayed, perhaps, on the south coast of Devonshire Parish, and therefore I propose to call them the *Devonshire formation*, for a distinctive name.

Professor Rice (1884, pp. 10–14) studied these rocks with much care. But he did not, in all cases, distinguish between the beach-rocks and the underlying hard æolian limestones of the Walsingham formation. Moreover, he supposed, like Heilprin, that they belonged to an earlier period than I do, and that they underlaid the æolian limestones generally, just as the Walsingham limestones do, instead of being of much later origin than the latter, and localized, or of small extent, as I believe.

Stevenson, also (1897, p. 103), held a similar view. He called them "the intermediate deposits,"* believing that they were deposited directly over the Walsingham formation, and earlier than the ordinary æolian limestones. So far as their position is concerned, in many of the outcrops, their views were correct. But according to my observations, these rocks are much later and more local than they apparently supposed. Yet they are old enough to have

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* Part of the rocks to which he gave that name are of sand-drift origin and belong to the Walsingham formation.

been covered in some places by a considerable thickness of late æolian limestones, as shown in fig. 11.

Mr. Agassiz, however, took the extreme opposite view, and believed that they are all of modern origin, and formed since the islands attained their present level. He believed that all the materials, even of the most elevated beds, were carried up the beaches by the waves and winds, to the heights at which they are now found.

My own conclusions are intermediate, for I consider them local shore and shallow water deposits of different periods. The older and higher ones I believe to have been formed at a period when the land stood at least 10 to 15 feet lower than now, as explained above. Others are still forming. The older ones, especially, are worthy of more careful studies.

Lieut. Nelson, 1840, was the first to describe a genuine beach formation with marine fossils, at Bermuda. It seems to have been one of the older ones, resting on Pliocene limestone. His description was as follows :

"The most interesting organics with which I have met were in the rock now inclosed by the North Bastion at Ireland Island. Whilst cutting the escarp of this work, a large block of reef was discovered in the solid rock fifteen or twenty feet from the surface, and at about four feet above high water. This specimen contained *Mæandrina areolata*,* the common *Mytilus* of the coast [*M. adustus*], retaining its black colour, and a pink *Millepore* [*Polytremacis?*] very common in the serpuline reefs. This spot, conceiving the truncated strata of Ireland I. to be restored to their proper form, must have been at the very apex of the saddle, and is perfectly distinct from the loose, soft, and newer sandstones. Above the level of this spot lie the strata, *a*, *a*, fig. 8, which for some hundred yards along the north side, consist chiefly of a hard subcrystalline limestone."

"In the centre of this rock was a cavern ; and entangled amongst the stalagmitic lining (as well as in that of other caves and crevices), or else lying in heaps in the loose red earth within, we found abundance of a large and delicate *Helix* [= *Pœcilozonites Nelsoni*]."

This statement regarding the loose red soil and stalagmitic materials containing this extinct snail, indicates that the clay and underlying rock belonged to the Walsingham formation, for the

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* This specimen, which is still preserved in London, has been recently identified as *Mycetophyllia Lamarckana* by Gregory. I have referred this species to *Mussa* (these Trans., xi, p. 68, note). If correctly named by Gregory, it is not known to inhabit Bermuda at this time.

conditions are like those of the quarry at Paynter's Vale, described above (p. 70). This beach-rock was evidently a very local deposit. It must have been much later than the red clay and limestone below it. It could not have been of the same period, for we know that part of the older rocks containing fossil land shells occur submerged some 45 feet below the sea at the dockyard, in the immediate vicinity. Therefore the rock containing marine fossils must have been deposited at some period after the submergence of the Walsingham formation to at least that amount.

Among other instances, Nelson mentions a locality of beach-rock on Long Bird Island, not described by later writers:

"The last individual animal organic which I shall mention is a *Strombus*, which I chiselled out at Long-bird Island, and had the cavities in the substance of the shell filled with crystallized carbonate of lime. I may terminate this list comprehensively by saying that almost every shell now known in the surrounding sea may be found in the rock quite perfect, except with regard to colour, especially among the newer beds on the sea coast."

A local deposit of beach-rock or "conglomerate," with marine fossils, occurring at an old quarry on Stock's Point, St. George's Island, has been described by Rice, Stevenson, and others. It is said to have been of greater extent and height formerly. It varies from 1 to 6 feet in thickness. The marine shells contained in it are mostly broken. It lies in corroded hollows of the harder underlying limestone, and to the height of about 12 feet above the sea.

This deposit of beach-rock was described by Professor Rice, as follows:—

"The rock which has been quarried there, and which now appears in the base of the bluff, is a very hard rock of subcrystalline texture and of ferruginous color. It shows vestiges of irregular lamination, and contains fossil Helices and no marine fossils. It is undoubtedly a drift-rock, like that at Paynter's Vale. The upper surface of this rock is exceedingly irregular, giving evidence of much subaerial erosion preceding the deposition of the overlying strata. It is overlain by a remarkable conglomerate, evidently a beach-rock, containing fragments of the underlying hardened drift-rock, peculiar ferruginous nodules, compact lumps of 'red earth,' and pretty large marine shells. The upper surface of this conglomerate, unlike its lower surface, is quite regular—the usual plane of marine deposition. This conglomerate is overlain in places by a stratum of sand, like that observed at Devonshire Bay, containing shells of land snails in its uppermost layers. Above this sand, where the sand is present, in other places resting immediately upon the conglomerate, is the ordinary drift-rock."

b. Fossils of the Beach-rocks.

As mentioned above, marine shells are often abundant in these rocks. Most of them are species still living about the islands, though of these some are now rare and much smaller than the fossils. In the chapter on Paleontology, I shall give a rough list of these fossils hitherto recognized. Unfortunately collectors have not designated, in most cases, the exact localities where their specimens were obtained, so that they are probably of different periods. Few recognizable corals have occurred. The *Mussa* or *Mycetophyllia* obtained by Nelson is of the most interest. Near Hungry Bay, I found in these rocks fragments of a large barnacle (*Balanus*), which I have not seen living here.

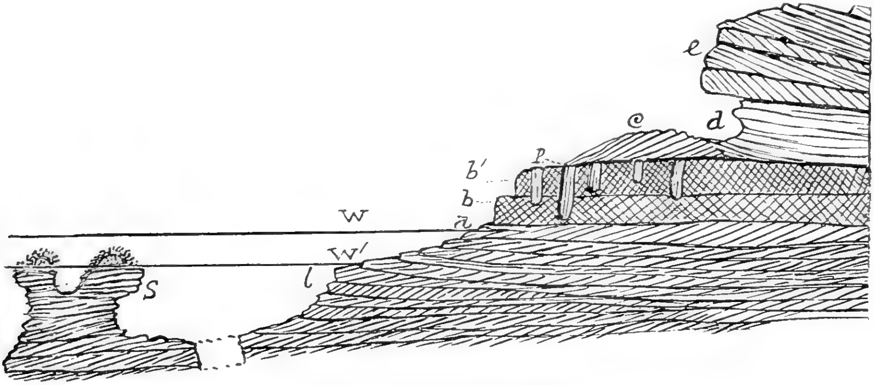

Figure 11.—Diagrammatic section west of Hungry Bay, south shore; *b*, *b′*, strata of hard Walsingham limestone, containing cylindric holes, *p*, commonly called molds of "palmetto stumps," and overlaid by indurated red-clay; *c*, Beach-rock or Devonshire formation, containing marine fossils; *d*, beds of imperfectly consolidated drift-sand, overlying *c*; *e*, later æolian limestones containing only recent land shells; *s*, diagrammatic section of small serpuline atoll, near the shore; *w*, *w′*, level of high-water and low-water mark. Original.

The best exposures that I studied were between Elbow Bay and Hungry Bay. These have been mentioned above (p. 72), and some of the exposures have been previously figured by me.*

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* Plates xvi–xx. Also these Trans., xi, p. 908, plates lxxxiv–lxxxvi; "The Bermuda Islands," p. 496, same plates.

At these places the beach deposits vary in thickness from 1 or 2 feet up to 4 feet or more. They are irregular and variable within a few hundred feet. They are rather hard, laminated, with pretty thin layers, which dip toward the sea at small but variable angles. They rest either directly upon the flat corroded surfaces of the hard Walsingham limestones, *b* and *b′*, or upon a layer of partially indurated red-clay that overlies the latter. They also overlie the surface of a hard limestone (*b′*), which at this place contains remarkably perfect examples of the "fossil palmetto stumps." (See plates referred to above.) These beach-beds contain numerous marine shells, mostly of common existing species.

The beach-limestones are marked *c* and *c′* in the plates and in the diagrammatic section (fig. 11). In the best sections they are overlaid by a bed of very imperfectly consolidated drifted sand, 3 to 6 feet thick, which was here washed out into cavernous places by the previous hurricane (see p. 72). But a short distance farther west these loose beds, or their equivalent, become gradually harder and in some places cannot be distinguished from the overlying æolian limestone (*e*, *e′*). The loose sand-bed contained in its lower parts a few separated shells of marine bivalves, mostly *Mytilus*, and numerous specimens of *Pœcilozonites Bermudensis* in good preservation, but no extinct species, so that it doubtless belongs to the newer series. In other shore sections, in continuation with those figured, the beach-rocks were lacking and the later æolian limestones, like *e*, *e′*, rested directly on *b′*.

Professor Stevenson's description of the locality at Devonshire Bay was as follows:—

"The intermediate deposit, or marine limestone, covers the broadly irregular surface of the limestone. It reaches to the water-level, on the southwest side of the old fort, but is seven or eight feet above it on the northerly side. The rock is hard in the lower portions, but becomes soft above, disintegrating readily and passing, as far as extent of consolidation is concerned, very gradually into the overlying deposit. It is slightly conglomerate in the upper portion. The structure is very similar to that of the sandstone, the laminæ being thin and inclined in all directions. The hardness of the rock is not due to spray, or to the washing of the present tides, since it is as marked on the northerly as on the southerly side of the fort. *Livona*, *Chama*, *Tellina* and *Arca* occur in prodigious numbers, the shells of *Livona* being as large and as perfect as those dredged in Castle Harbor, or in the shallows off the south shore.* The other shells give equal proof of having been deposited in comparatively still water. On the southerly side of the old fort, an apparently complete physical break between the intermediate rock and the sandstone is indicated by a horizontal line, yet the passage from the lower to the upper rock is extremely gradual, while above the line and within the *Helix* zone, *Arca* and *Chama* were seen perfectly preserved, the open valves of *Arca*, in one case, being still attached. The condition, for a time at least, must have been such as one sees at Tuckertown today, where the dune is encroaching upon the bay."

16. Evidences of Subsidence.

That these islands have undergone a considerable amount of subsidence, since the time of Greater Bermuda, is admitted by every geologist who has studied them, but they differ as to the probable amount. The evidence is partly derived from (A), the æolian limestones, peat bogs, red soil, land snails, etc., dug up from far beneath the sea at Ireland Island, and in dredging and blasting the ship channels; (B) from the fact that caverns, sinks, and peat bogs on the land now extend much below sea-level, although they must have been formed above it. Stalagmites and stalactites, formed in the air, are now found submerged in the sea water in the caves; (C) from the submarine sinks, sounds, and deep water channels, which give every evidence of having been formed by running water when the land was elevated above the sea. The latter are, no doubt, the more important evidences, but the former appeal more to those who are not geologists.

A. Evidences from submerged Æolian limestones and Peat bogs.

During the excavations made in 1870, at the dockyard on Ireland Island, to accommodate the great floating dock, series of æolian limestones were penetrated to the depth of 52 feet below low tide. At the depth of 46 feet below sea-level, a stratum of peat and "red-earth," 2 feet thick, was found, which contained vertical stumps of cedar trees. Below this were again strata of hard æolian limestones, at least 4 feet thick, containing fossil land-snails (said to have been *P. Nelsoni* by some; *P. Bermudensis* by others). I have not seen

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* Prof. Stevenson was probably misinformed as to its existence in these localities. So far as I know it is extinct in Bermuda.

these fossils. If this snail was really the extinct Nelson's snail, this lower hard limestone, and probably the associated red-earth, belonged to the Walsingham formation.

The peat and stumps may have belonged to a later period than the red-clay and the limestone below it, but according to some accounts the fossil snails and trees were all found in the layer of red soil.* Bones of an unknown bird are also said to have been found in this red soil. Probably these materials were not taken out with sufficient care by the workmen to enable any one to determine their exact relations.

In dredging out the channel in Hospital Bay, about 25 years ago, large numbers of the trunks of cedar trees, in pretty good preservation, were brought up. They were overlaid by a peat bog, and over this was a deposit of shell-mud and shell-sand, with foraminifera, etc.

Masses of peat, evidently derived from a submerged peat-bog, were dredged up by me and my party in 1901, in the channel of "The Reach," north of the Swing Bridge, where the depth of water was about 15 to 20 feet.

A bed of red-clay was found between layers of æolian limestones while blasting out the reefs to deepen the channel at the entrance of St. George's Harbor, in 1847–8.

Roots and stumps of cedar trees have been pulled up on the anchors of vessels several times, both in Hamilton and in St. George's Harbors. There is, therefore, good reason to believe that Hamilton Harbor, St. George's Harbor and the "Reach" were once marshes or peat-bogs, with cedar trees in the drier parts, like the Devonshire marshes, for example. By subsidence and the encroachment of the sea, the peat beds have been buried at the bottom of the harbors

Peat, as well as cedar wood, if buried under the salt-water mud, would last almost indefinitely. If openly exposed to the water, the cedar would soon be destroyed by the "ship-worms" (*Teredo*), which abound here.

Such peat bogs might have come to be below the sea-level by a long period of subsidence, before the encroachment of the sea, just as some of the existing peat bogs now extend far below sea-level. That was, indeed, probably the case, for otherwise the sea would have rapidly worn away the peat to which it had access on the shore.

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* See Jones, J. M., Visitor's Guide to Bermuda, 1876, p. 119. Also "Recent Observations in the Bermudas," Nature, vi, p. 262, 1872; ditto, Amer. Journ. Science, Ser. 3, vol. iv, p. 414, 1872. Reprint.

B. Evidences of Subsidence derived from Caverns and Sinks.

Among other structures indicating subsidence are the various caverns, with large stalactites and stalagmites, now depressed more or less below the level of the sea and filled with sea water, which is said to be at least 30 feet deep in some of them. The stalactites descend into the sea water in some cases, while stalagmites can be seen, through the clear water, rising up from the bottom.

a. Caverns containing Sea water.

In the large cavern on Tucker's Island, the bottom is covered by 6 to 10 feet of clear sea water, beneath which I saw, in 1901, many large pointed stalagmites standing upright, but not reaching the surface. Some of these were more than a foot in diameter. This cavern, which was then open to visitors on payment of a fee, has to be explored in a boat. Its roof is supported by large stalactitic columns, many of which are of hardened limestone, thickly encrusted with dull-colored stalactitic material, but most of them extend beneath the sea water to the bottom.

Lieut. Nelson, 1840, described a partly submerged cavern as follows :

"Tucker's Island cavern was a perfect bijou; with one splendid exception it has hitherto stood unrivalled among the caves of Bermuda. This little cavern had a length of eighty feet, a breadth of about fifty, a height above the little lake within of at most fifteen, and a depth below its surface scarcely exceeding fourteen. The stalactites were remarkably clear and beautiful, varying from the massive pendant of six or seven feet in length, to the slender incipient fragile tube, which crumbled at the slightest touch. It was a scene not to be readily forgotten, when we launched a little boat into the miner's first and narrow opening, through which the sun shone strongly, and reflecting its light from the face of the water upwards and with power to the sparry fretted ceiling of the vault, illuminated it in a way which can only be appreciated by those who have been eye-witnesses of such effects. This cave was shortly afterwards destroyed, as interfering with the safety of the works."

One of the most interesting caves, because of its peculiar situation and its elegant and profuse pure white stalactites and drapery-like sheets of stalactitic material, is Peniston's Cave, on the land of Mr. W. S. O. Peniston. It was not open to the public at the time of my visit, and partly on that account its stalactites retained their original purity of color. The entrance is near the top of a wooded hill somewhat south of the Harrington House, toward Castle Harbor. There is a large, dry, cultivated sink to the northward of it. The entrance is nearly perpendicular and barely large enough for a man to enter, it being only the wider part of a fissure. The fissure expands below to form the cave. The floor and roof both slope rapidly downward for about 80 feet. The open space is at times more than 50 feet wide. The height of the roof varies from 4 or 5 up to 10 or 15 feet. It is thickly covered in most places with multitudes of rather small stalactites, though large ones occur. These stalactites are still forming. Water was dripping from most of them. Many of the small and very slender ones were tubular and porous at the end, and had a drop of water hanging there, in which, with a lens, loose or but slightly attached crystals of calcium carbonate could be seen forming.*

In the bottom of this cavern there is a pool of very clear sea-water, about 8 to 10 feet deep, so that it goes below the level of Harrington Sound and Castle Harbor to that depth, but the connection with the sea is probably only by small crevices. No fishes live in it.

At several points on the west shore of Castle Harbor, opposite the Peniston Cave and others of this vicinity, several streams of clear salt water flow out from holes and crevices in the beach, exposed at low tide. Some of them are like springs, and of considerable volume. The water may come from the caves, or even from Harrington Sound. Such localities are excellent for collecting marine invertebrates.

The whole neck of land between Harrington Sound and Castle Harbor seems to be cavernous. Sharks Hole† at the southeast corner of Harrington Sound is a cavern in the form of a deep archway, partly submerged beneath the water, so that a boat can row in 50 feet or more. The bottom is covered with large broken rocks, among which many fishes may often be seen. The water under the arch is rarely more than 10 to 12 feet deep. Among other well known caves in this vicinity are Cooper's Cave and Paynter's Cave; Joyce's Cave, near Coney Island; Convolvulus Cave; and the Walsingham Caves.‡

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* See these Trans., pp. 438, 471, pl. xciii, figs. 1, 2; "The Bermuda Islands," pp. 26, 59, pl. xciii, figs. 1, 2.

† Its location is at S. H. on map II. See these Trans., xi, p. 438, pl. lxxiii; "The Bermuda Islands," p. 26, pl. lxxviii.

‡ See these Trans., xi, pp. 470, 471, plates xc–xcii; "The Bermuda Islands," pp. 58, 59, same plates.

b. Walsingham Caves and Sinks.

On the ancient Walsingham place, near the northwestern shore of Castle Harbor, there are several rather large caves, excavated by percolating rain water and fresh water streams in the hard limestones of the Walsingham formation (see p. 70).

One of these, near "Tom Moore's Calabash Tree," has at present no sea water in it. It has two entrances, one of which is on considerably higher land than the other. From this the path descends rapidly into a long irregular colonnade, bordered on each side with large stalactitic columns, and hung with large stalactites. In some places it enlarges into vaulted rooms of considerable height. The second entrance opens at a much lower level into a very evident dry sink, covered at present with woodland.*

This cavern seems to have been at one time the subterranean channel of a stream of water of considerable volume. Probably it was connected directly with several other caves, some of which are now represented only by the adjacent sinks.

Near by, but on lower land, there is a large cave with a single room. It has a high sloping roof, from which hang great numbers of stalactites, some of them of large size, many over a foot in diameter and perhaps 6 to 10 feet long. This cavern† has a deep pool of sea-water covering most of its floor. It is said to be 15 to 20 feet deep in the deepest parts, which are not accessible without a boat. Certainly the bottom could not be seen, except close to the shallower side, when strongly illuminated. Some of the stalactites descend into the sea-water. Several other caverns in this district have the same general character, and some communicate with the sea so freely that the tides ebb and flow, and various fishes live in them. (See pl. xxi, fig. 1.)

Near these caves are several sinks with abrupt sides and nearly full of sea-water. They are evidently the ruins of caverns like those

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* It was from one of these caverns that a large stalagmite was taken in 1819, by Admiral David Milne, and sent to the museum of Edinburgh. It was 25 inches in diameter, where it was sawn off, 11 feet 3 inches high, weighed about 3½ tons and contained 44 cubic feet. (See Proc. Royal Society Edinb., v, p. 423; "Bermuda Pocket Almanac," 1888, p. 175; 1889, p. 149. But the attempts that have been made to estimate its age, by the rate of deposit now going on, are futile, for there is no possibility that the rate is the same now that it was formerly, nor that it was at all constant in any former period. The variations must have been very great.

† See these Trans., p. 471, pls. xci, xcii; "The Bermuda Islands," p. 59, same plates.

that remain. One, close by the Walsingham house, appears to be of considerable depth, but I had no means of sounding it. The bottom was not visible in strong sunshine. It may be 20 to 30 feet deep. When I visited it there were several large green-turtles swimming in it. A smaller sink of the same kind exists by the roadside on Coney Island. It may be 30 to 50 feet in diameter. Its banks are of limestone rocks, on all sides, either perpendicular or overhanging, and large flat slabs, evidently parts of the fallen roof, lie loosely on the bottom. The water is 6 to 10 feet below the brink and about 8 to 12 feet deep. Large numbers of snappers and other large fishes were seen in it.

The famous Devil's Hole, on the west side of Harrington Sound, is another sink of precisely the same nature, but much larger. It may be nearly 100 feet across. Its perpendicular walls rise 10 to 15 feet or more above the water. The water is said to be nearly 40 feet deep, but I know of no accurate measurements. It is walled around and kept as a show-place, on account of the large numbers of Hamlet groupers and other large fishes that are kept in it.*

Webb's Pond, near the Flatts, is another good example of a sink filled with the sea water. It is near the shore and is about 200 feet in diameter. It is said to be 14 feet deep.

When any of these caverns or sinks extend below sea-level, whether their stalactites and stalagmites are submerged or not, it is conclusive evidence of considerable submergence, for such caverns are always excavated by percolating or running rain-water, which also forms the stalactites by exposure to air. But to many persons the submergence of the stalactites seems more tangible and convincing evidence.

I shall show later that caverns and sinks exist which are entirely submerged beneath the sea.

c. *Peat-bogs and Marshes.*

Many of the peat-bogs and fresh-water marshes are known to be so deep that their bottoms are considerably below the level of the sea. In a region where the rocks are so easily permeable as in Bermuda, the land and fresh-water marsh plants of which the peat is composed could only have grown when the bottom of the valleys

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* It is located at D, on map II. See also these Trans., xi, p. 468; "The Bermuda Islands," p. 56. These sinks make excellent preserves for fishes and sea-turtles.

containing the peat was above sea-level. But a subsequent gradual subsidence would permit their growth on top, provided the surface remains always a few feet above the sea, for the fresh water of the upper layers will not readily mix with the brackish water below.

Pembroke Marsh, near Hamilton, is now but little above the sea, yet according to Governor Lefroy, who had it tested in 1872, the peat is, in places, 40 to 48 feet deep. This would show that the bottom of this valley or sink extends to at least 30 to 35 feet below the sea-level, and that the islands must have subsided as much as that, since the peat began to form. Several other bogs and marshes are known to extend below sea-level, but I am not aware of any reliable records of their depths. The instances given show well how peat beds happened to be buried in Hamilton and St. George's Harbors (see p. 81), by subsidence.

C. Evidences of Subsidence from submerged Sinks, Sounds, and Channels.

That sounds, sinks, and subterranean passages, due in part to the caving in of the roofs of caverns, exist here beneath the sea, just like those on the land, and formed in the same way by the solvent action of rain-water, when the land stood at a higher level, is certain. No doubt most of the smaller, deep, isolated sinks, harbors, sounds, and "holes" are of this origin. No other explanation of their origin is available. The same is true of many of the passages through and under the reefs. Probably, however, the larger ship-channels and the broader sounds were largely due to the erosion of the rocks by running streams during the time of Greater Bermuda, but many of those streams may have had underground channels, as they do in many limestone regions. The much greater extent of the land, at that time, and its height must have given rise to streams of considerable size and velocity, which would have cut away and undermined the soft limestones with great rapidity, whether above ground or underground. If the falling in of large caverns took place to form sinks, these would have been rapidly enlarged by the erosion of the shores, either by fresh water or sea water, according to their elevation.

Therefore, at the present time it is impossible to determine which factor was of the most importance in the excavation of the larger sounds. In either case the land must have been raised above sea-level to a height equal at least to the present depth of the deepest sounds and channels (12 to 14 fathoms), unless we admit that they have been eroded by the sea since their submergence. Erosion of the sea bottom seems not to have occurred here, unless in very shallow water, for the bottom is everywhere covered with a thick deposit of incoherent shell-sand and fine, white, calcareous mud, which is evidently accumulating faster than it can be removed by the sea. Where excavations have been made to deepen the inner channels, loose shell-sand has been found to be 6 to 8 feet thick, over the æolian limestones. Therefore it is probable that all the deeper sounds and channels have been very much filled up since the subsidence of the land. They may have been originally 40 to 50 feet deeper than now. But as some are still 12 to 14 fathoms deep, it is safe to assert that the islands were at least 80 to 100 feet higher than now, when those deeper places were eroded.

If we wish to trace the present terrestrial conditions downward beneath the sea, it will be necessary to first consider such evidences as exist in the shallower waters near the shore. These may be found in abundance. Only a few will be mentioned here, as examples:

a. Submerged Caverns and Sinks.

While blasting out the rocks to deepen the channel at Timlin's Narrows in Hamilton Harbor, in 1843, the drills suddenly entered a submarine cavern. When gunpowder was exploded in it, the depth suddenly increased from 15 feet to 22 feet. This cavern contained red clay and stalactites. J. M. Jones states that in deepening the channel into Hamilton Harbor, in 1869, a cavern was found at the depth of 36 feet below sea-level.*

"Blue Hole," on the west side of Castle Harbor, is a submerged deep sink, similar to "Devil's Hole" on the land. Many other similar sinks or deep "holes" exist here, under the sea. Very many more have, no doubt, been so entirely filled up with mud that they are no longer visible. Some of the abruptly deeper parts of Harrington Sound are of the same nature, as are also the deeper parts of Castle Harbor and Elies Harbor.

b. Submerged Sounds or eroded Valleys.

If we go into deeper water, we find several notable areas of water from 50 to 70 feet deep, surrounded on all sides by shallower areas. In a few such places the depth reaches 72 to 84 feet, as in a small

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* American Journ. Sci., Ser. 3, vol. iv, p. 415, 1872.

sound inside of Mills Breaker (*e*, map II). These deeper places, more than 45 feet deep, are mostly indicated by ruled lines on map I, fig. 12 (p. 92). A few of the smaller ones, less than two square miles in area, omitted on map I, are shown on map II, pl. xxxvii.

If the land were reëlevated to the height of 45 feet above its present level, all these areas would become enclosed sounds, like Harrington Sound. Very likely the tides and waves would soon clear the mud and debris out of their old channels, so that most of them would communicate with the outer waters by narrow channels, thus coming to resemble Castle Harbor, Great Sound, Elies Harbor, etc. But some would remain for a long time land-locked, unless the waters have unknown subterranean passages. The deeper part of Great Sound would thus form a completely land-locked sound, two square miles or more in area, and about 15 feet deep (VI on map I). It would resemble Harrington Sound in size and form. There would also be a much smaller area of water, about 10 to 20 feet deep, in the center of Harrington Sound.

All these sounds that would be left, after such reëlevation of 45 feet, would amount to about 40 square miles, but the dry land regained would be about 160 square miles, or about eight times the present area of the dry land.

The largest of the residual sounds would be that including part of Murray Anchorage and the longer and deeper North Rock Sound, now connected with the former by a channel of 8 fathoms depth. This sound would be about as large as all the present land of Bermuda, including Castle Harbor and Harrington Sound. Three other sounds without visible outlets (II, III, and V), each about the size of Harrington Sound, would remain. Another, similar in size to St. George's Harbor, is marked II on map I.

Again, if the reëlevation should amount to about 50 feet, the total area of dry land gained would amount to about 190 square miles, and the only bodies of water, of any notable size, that would remain are indicated by the heavy dotted or broken lines on map II. They would amount to about 12 to 14 square miles. All the flats, and the rest of the reef areas and great interior lagoons, would be laid bare. The pinnacles and cliffs exposed would be, on the lower lands, 45 to 50 feet high.

The largest sound that would now remain is the North Rock and Mills Breaker Sound (*e* on map II), which would have an area of 6 or 7 square miles, with depths of 16 to 22 feet in some small areas, but most of it would be only 4 to 10 feet deep. A small, irregular, bilobed sound (*a*), farther east, toward the Mills Breaker cut (xiv), would probably be connected with the former sound by an extension of its southern limb in the form of a narrow, deep, and crooked channel, in which there is now 48 feet of water. This sound would be about as large as St. George's Harbor. To the east of it would lie two smaller bodies of water, 10 to 34 feet deep. The larger of these (*c*) would probably remain connected with Mills Breaker cut (xiv) by means of a narrow deep channel, and probably also with the sounds (*a*) and (*e*). A shallow sound of about 3 square miles (*a*), would exist north of St. George's Island, in the eastern part of Murray Anchorage. It would be larger than the present Harrington Sound. One (*i*), about as large as Harrington Sound, would be enclosed in what is now Great Sound. It would have no visible outlet, and would be 4 to 10 feet deep. A few other small and mostly shallow lagoons or ponds, without outlets, marked *b*, *f*, *g*, *h*, would also exist with water only 4 to 10 feet deep.

A rise of 70 feet would cause very nearly all of these lagoons and sounds to disappear. As remarked above, these larger submerged sounds are due in part to erosion when they formed valleys on the dry land of Greater Bermuda. That they may, in some parts, have been formed by the falling in of great caverns in the still older limestones beneath them is quite possible, but that view, which has been advanced by others, is unnecessary and is also incapable of being proved, at present, for we, as yet, know nothing about the nature of the rocks that immediately underlie the sounds beyond 52 feet below sea-level.

However, the cavern theory does not seem adequate to account for valleys and sounds six to ten miles across, with very gently sloping bottoms. They, like the larger of those under discussion, are more likely to be the original valleys, formed between the primitive sand-dunes, for sand-dunes cannot exist without having valleys between them. Such valleys would have been the places where the waters flowed and then ordinary erosion would have done the rest.

c. *Outer Channels or "Cuts."*

1. *Position and depth of the Cuts.*

The outer circle of reefs "flats" and boilers forms an almost unbroken barrier around the islands, as shown on maps I and II.* They enclose a narrow strip of sea one-half to nearly two miles in width on the southern side, but six to nine miles wide on the western and northern sides.

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* Map II is printed on pl. xxxvii. Map I is fig. 12, p. 92.

Through the great border of reefs, extending from St. George's Island at the eastern end around the whole northern and western sides to the extreme southwestern part, a distance of some 40 miles, there are only six or seven narrow and crooked channels considered navigable for vessels even of small size. Only one of these, the "Narrows" or ship-channel (S. C., map II), is used by passenger steamers and naval vessels. The others are sometimes used by the smaller native fishing and coasting vessels. One of these, the "Hogfish Cut" (see viii, maps I, II), was considerably used by coasting vessels in early times, and could be easily improved. In a former work* I have quoted the sailing directions, given by Mr. A. G. Findlay, 1870–1895, for entering by several of these channels. But most of them are too dangerous to be attempted, except by experienced local pilots.

They are of importance geologically, because they are probably the more or less obstructed and filled up ancient channels by which the separated interior sounds, described above, were connected with the sea in the time of Greater Bermuda, and were eroded to their greatest depths at that time.

Beginning at the northeastern end of the islands, the first channel, off St. George's and less than a mile from the shore, in some places, is the main ship-channel or "Narrows" (S. C., maps I, II). This is long, narrow, and crooked, but has usually 6 to 8 fathoms of water. It leads into the Murray Anchorage. The next channel northward is Mills Breaker Cut (XIV, on map II, pl. xxxvii). This has 10 fathoms of water at the entrance. The branch that leads directly westward is 8 to 10 fathoms deep, and leads to the small, deep sound (*c*), which is 10 to 14 fathoms deep and about a mile wide. From this it leads into the longer sound (*a*), by a channel 8 fathoms deep, running west, about a mile into the large North Rock Sound (*e*, map II), which is 8 to 12 fathoms deep. This "cut" seems to be the most important one, from a geological point of view, because, according to the official charts, it is the deepest and one of the widest, and drains the deepest of the enclosed sounds.

Cut XIII, farther northeast, is of much less importance, for though 10 fathoms deep at the entrance, and 8 fathoms within, it is much obstructed by scattered reefs and rocks.

Cut XII, east of the "Great Breaker Flatts," also appears to be very much obstructed.

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* These Trans., pp. 486–489; "The Bermuda Islands," pp. 74–77.

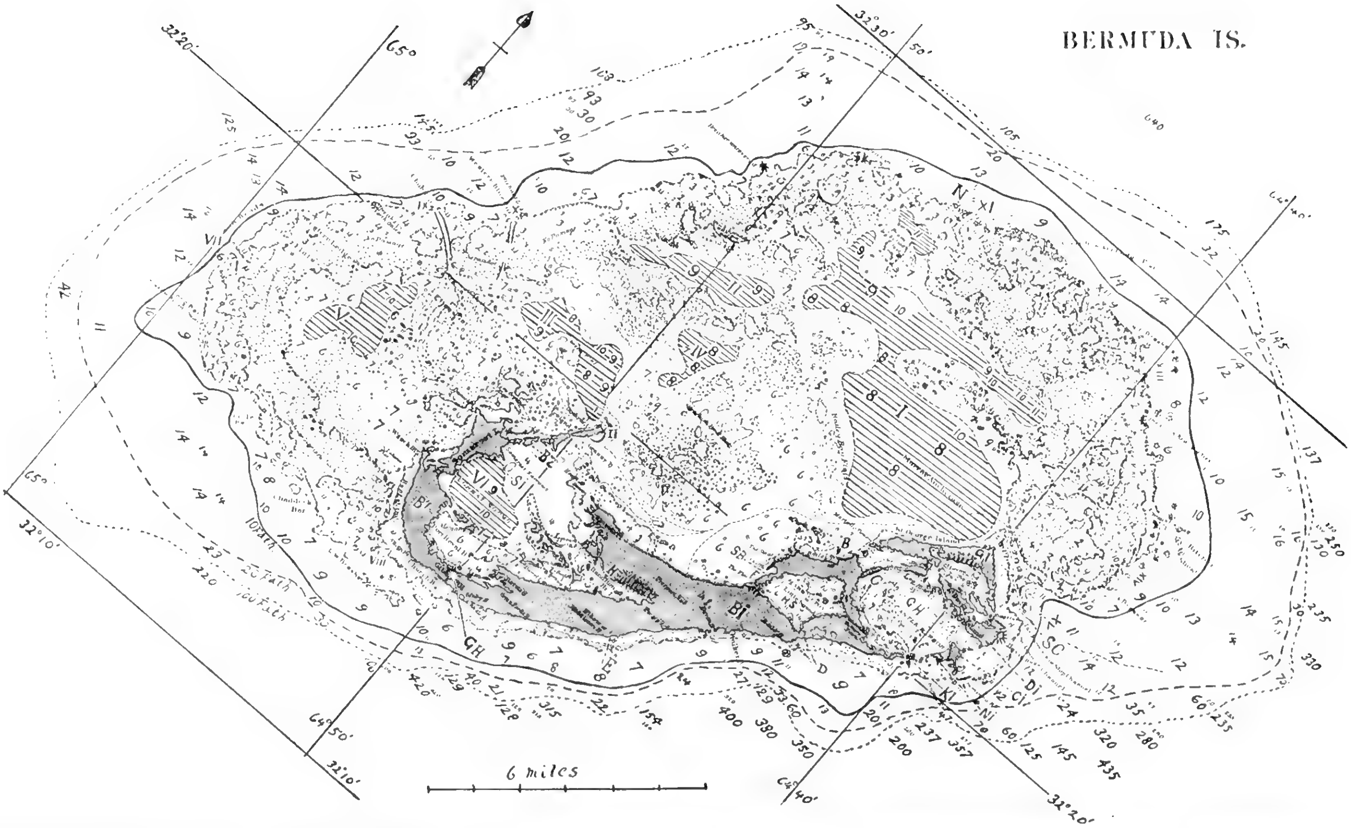

Figure 12, Map I. Bermuda Islands and Reefs, with contour lines of sea bottom.

Explanation of Map I; Figure 12.

The depths outside the reefs and in the lagoons are in fathoms; those on the reefs and shallows are in feet. The continuous line, outside the reefs, indicates the contour at 10 fathoms; the two dotted lines indicate 20 and 100 fathoms, respectively.

I. I.—Ireland Island with the Naval Station and Dry Dock. See pp. 71, 77 81, 109, 115, 151, 160.
BZ.—Boaz Island.
S. I.—Somerset Island. See pp. 63, 106, 109.
B. I.—Bermuda or Main Island, p. 108, 136.
B.—Bailey Bay. See pp. 51, 71, 110, 111, 138, 139, 142, 158, 159, 161.
H.—Hamilton, the capital and harbor. See pp. 50, 75, 82, 88, 144.
H. S.—Harrington Sound. See pp. 71, 84, 86, 88, 89, 98, 111, 112, 138, 144
S. B.—Shelly Bay. See pp. 111, 123, 151.
F.—Flatt's Village and the outlet of Harrington Sound. See pp. 111, 136.
E.—Elbow Bay, with modern sand dunes. See pp. 72, 79, 119, 151, 153.
G. H.—Gibb's Hill Light. See pp. 48, 55.
D.—Devil's Hole. See p. 86.
C.—Causeway, destroyed Sept. 12, 1899, by a great storm, and rebuilt. See pp. 127, 132.
C. H.—Castle Harbor. See pp. 70, 85, 88, 121, 127, 128, 135, 138, 159.
G. I.—St. George's Island and town. See pp. 70, 72, 104, 105, 109, 130.
G.—St. George's Harbor. See pp. 81, 82, 87, 89, 90, 94, 127, 136, 144.
S. C.—Main Ship-channel or entrance to Murray Anchorage. See p. 91.
D. I.—St. David's Island and Light. See pp. 109, 110.
C. I.—Cooper's Island. See pp. 106, 109.
N. I.—Nonesuch Island and Quarantine.
K. I.—Castle Island and ruins of King's Castle. See pp. 47 (cut 1), 94, 128.

The principal submerged sounds or drowned lagoons, over 45 feet deep, are shaded with parallel lines, and numbered I–VI. Their probable ancient outlets, called "cuts," are numbered VII to XV.

I.—Murray Anchorage. See pp. 88, 89, 90, 91, 138.
II.—Blue Cut Sound. See p. 94.
III.—Sound north of Ireland Island, or Western Chub Cut Sound. See p. 94.
IV.—Brackish Pond Sound. See p. 94.
V.—Chub Cut Sound or Western Ledge Sound. See p. 94.
VI.—Great Sound. See pp. 72, 88, 90, 138, 144.
VII.—Cut in Long Bar, leading to a large passage 3 miles long and 6 to 10 fathoms deep, running S.E. and N.W. inside Long Bar Reef. See p. 94.
VIII.—Hog-fish Cut, 7–10 fathoms deep, leading to Chub Cut Sound and Elies' Harbor, from the southwest. See pp. 91, 94.
IX.—Chub Cut, 3–8 fathoms deep, leading to Chub Cut Sound from the north. See p. 94.
X.—Western Blue Cut, partly obstructed by reefs, leading to Sound III. See p. 94.
XI.—North Rocks, Northeastern Cut, leading toward a small sound 11 fathoms deep, not numbered (North Rocks Sound). See pp. 91, 94, 115, 128–132.
XII. and XIII.—Ledge Flat Cuts, 7–9 fathoms deep, connected together inside the outer reefs. See p. 91.
XIV.—Mills Breaker Cut, 8–10 fathoms deep, leading towards Mills Breaker Sound, an irregular sound (not shaded), 9 to 14 fathoms deep, and about 2 miles long. See Map II. See pp. 91, 115.
XV.—Main Ship-channel or the Narrows, a narrow, deep cut leading to Murray Anchorage. See p. 91.

Note.—The map is altered from that of Mr. A. Agassiz by the addition of the three contour lines, at 10, 20, and 100 fathoms depths; by shading the deeper parts of the larger lagoons, where the depth exceeds 45 feet; and in some other respects. It is based on the Admiralty Chart, reduced by photography.

Cut XI, the Eastern North Rock Cut, is navigable for small Bermudian vessels with a good pilot, but is dangerous. It leads directly to the Great North Rock Sound, marked *e*, on map II, pl. xxxvii.

Cut XI*a*, the Western North Rock Cut, is larger and deeper, and is easily entered by vessels of some size with good local pilots. It runs southward into the great North Rock Sound. It has 6 to 8 fathoms of water in most of its course, but it is rather crooked.

Cut X*a*, the Eastern Blue Cut, leads into the sound numbered II, on map I; *f*, on map II. It is rarely used, except by fishing boats and other small craft, as it is much obstructed by detached reefs. It has depths of 5 to 8 fathoms.

Cut X, the Western Blue Cut, is not much better for navigation. It has depths of 4 to 6 fathoms. It leads to Ireland Island, and into the sounds numbered III and IV, on map I; *g*, on map II.

Cut IX, the Chub Cut, is navigable only for small vessels. Its depth is 3 to 7 fathoms. It leads into the sound numbered V, on map I; *h*, on map II.

Cut VII leads into a large sound, 7 to 10 fathoms deep, between Western Ledge Flats and Long Bar. (See map II.) In part of its course it is 10 fathoms deep.

Cut VIII is the Hog-fish Cut. It is very long, narrow, very crooked, and not far from the shore. It is badly obstructed near its entrance by Kitchen Shoals, but the Bermuda mercantile vessels formerly made much use of it to enter Elies' Harbor.

Besides these, there is a channel (XIII) into Castle Harbor, between Castle Island (cix, map II) and Southampton Island, which was much used by vessels in the early years of Bermuda history.

The channel that leads into St. George's Harbor is of the same nature. This was originally narrow, crooked, and too shallow, but it was much improved about 50 years ago by blasting out some of the worst ledges in its bottom. It badly needs additional improvements of that sort to safely admit modern vessels of larger size.

2. *Filling up of the Cuts and Channels.*

There can be no doubt that most, if not all, of these cuts through the reefs have very much filled up and obstructed since their submergence. If they drained the interior sounds and valleys of Greater Bermuda, they must have been at least equal to them in depth. Of course, some of them may have been of later origin than the sounds, and if so, may have served merely to help in the ebb and flow of the tides, like the present shallow outlet of Harrington

Sound, which is much shallower, and also of much later origin than the sound. But if the deeper sounds were excavated to their lower levels by running water, as it seems necessary to believe, then the channels must have been equally deep. That they should have been partly filled up after the subsidence is natural. Great masses of rock, broken by the storm waves from the high, bordering, submerged cliffs, would certainly fall into them from time to time. Shell sand and mud would collect in the interstices, and corals would grow on the fallen rocks, thus inevitably, but gradually, obstructing and filling them up.

The action of the sea waves, in 10 to 20 fathoms of water, is almost inappreciative, and not sufficient to remove coarse sand or small stones. The tides, also, are here not strong enough to produce much effect at the bottom, even of shallower channels, though in some cases it is able to remove fine loose mud and keep the projecting ledges bare. Reef corals, millepores, corallines, Gorgoniæ, and other organisms grow well in these channels, where there are rocks, and their debris helps to fill up the channels. It is, therefore, not unlikely that some of these channels were once 30 to 50 feet deeper than at preseut.

17. Broken Grounds outside the Reefs.

The outer borders of the outer reefs usually fall off suddenly, like submerged cliffs, into water from 30 to 40 feet or more in depth. In many places the outer reefs are undercut, so that their tops overhang their bases more or less, by the more rapid wearing away of the rocks below, owing either to their less hardened condition, or to less protection by living corals, algæ, etc., or perhaps to both causes combined, in most localities. In other parts they fall away with steep slopes, or with a succession of steps, indicating layers of different hardness, like the cliffs along the shores. These submerged steep cliffs are rarely less than 30 to 40 feet high, and are more or less covered with a profusion of coral-heads, especially the brain-corals and astræans, *Oculina*, *Millepora*, gorgonians, corallines and nullipores, *Sargassum* and other large sea weeds, all of which have a great effect in retarding the erosion by the waves. The reef-corals, which are usually abundant and large to the depth of about 25 to 30 feet, become small and scattered at about 40 feet, but the branching *Oculinas* and large *Gorgonias* extend down to 125 feet or more, where there are rocks for attachment.

The bottom slopes gradually form the bases of the submerged cliffs to the depth of 100 to 125 feet; beyond that it falls off more rapidly to about 300 feet, and then descends with a steep slope to 6,000 feet or more.

That portion of the bottom that lies between 30 or 40 feet and about 120 feet is irregular, rough, and more or less completely covered with ledges and blocks of stone, interspersed with patches of white shell-sand. As the depth increases the shell-sand predominates more and more, until at about 100 to 125 feet, and beyond, it covers most of the bottom.

The rough rocky zone, between about 40 and 120 feet, is called the "broken ground" by the fishermen. Many of the rocks scattered over this slope are doubtless great and small masses that have been torn from the outer edges of the reefs by the violent sea-waves, during the thousands of years since they were submerged. Others are probably eroded ledges of æolian limestone. These rocks are more or less covered, especially in the shallower parts, with an abundance of living organisms, such as corallines, nullipores, and other algæ; large branching corals of the genus *Oculina;* and large gorgonians, such as the sea-fan, *Gorgonia flabellum;* the sea-plume, *G. acerosa; Plexaura flexuosa; Plexaurella crassa*, *Verrucella*, etc. (See also chapter 29.)

This zone of "broken ground" is often two to three and a half miles wide off the eastern, northern, and western reefs; but usually only one-half to one mile wide off the reefs of the southern side.

It undoubtedly represents what were once the low lands, shores, and shallows of Greater Bermuda, to which have been added immense quantities of debris derived from the erosion and tearing down of the outer reefs by the violent oceanic waves that beat on the outer edges of these upright reefs with immense force during storms.

The character of the bottom over this zone, its slope, and its depth indicate a submergence of at least 100 feet, as do the cuts and sounds described above.

18. *Argus and Challenger Banks.*

The present very uneven surfaces of Argus and Challenger Banks are like those of Bermuda, and indicate erosion when they stood above sea-level. Some considerable parts of their summits are now 180 to 240 feet beneath the sea; other parts (Argus Bank) are only 8 feet (see fig. 7). Erosion by waves on such sunken banks would be a levelling process and does not extend, even in great storms, with noticeable effect, more than 100 to 125 feet below the sea-level. Hence it is probable that they have subsided at least 100 feet since they were eroded.

19. Evidences of Reëlevation of the Bermudas.

The evidence in regard to the reëlevation of the islands after their greatest depression, is not entirely conclusive.

The evidence depends largely upon the existence of elevated beach deposits, containing existing marine shells, at various localities, from 5 to 20 feet above high water mark, as described in chapter 15, on the Devonshire formation.

It appears to me probable that some of those beds were made below sea-level, and therefore do actually give evidence of elevation, as stated on p. 76. That they are not more extensive and general may be due partly to the abruptness of the shores in most places, and partly to their subsequent erosion, for they would have been powerfully acted upon by the sea during their emergence, when they were doubtless mostly unconsolidated beds of sand.

We might well expect to find such deposits around the low shores of certain land-locked bays and lagoons, where they are not now known to exist, had such an elevation taken place, even to the extent of 8 or 10 feet. Possibly such deposits may exist around Mullet Bay and other bays surrounded by low lands, but I am not aware that any one has made a careful search for them in such places. But it is possible that much of their bulk may have been carried away from such localities, by solution in rain waters, even if not much exposed to erosion by the sea.

The most elevated beds of this kind now known are not over 15 to 18 feet above the sea. Very few are more than 10 to 12 feet above it; ordinarily their elevation is only 5 to 8 feet above high tide.

Professor Rice adopted the view that an elevation, of small amount, has taken place since these beds were formed, but Mr. Agassiz took the opposite view. (See above, pp. 76, 77.)

Mr. Agassiz suggested that such materials could have been thrown by storm waves to such heights, and therefore that they do not prove elevation. This is no doubt true in exposed situations, but most of these beds are situated in partially sheltered harbors where such violent wave-action would probably not occur; moreover, the usual regular character of the beds and the condition of the contained fossils indicate rather quiet deposition, not storm formations.

Another suggested evidence that an elevation of several feet has occurred is the peculiar character of the erosion on many of the cliffs. A second very marked plane of maximum erosion can often be observed 8 to 15 feet above the one situated at or a little above the present high-tide level. In many cases the cliffs are thus undercut at two levels. This, however, might well be due to the action of violent gales, producing waves much larger and more powerful than the ordinary ones. Thus a single violent storm will often effect more erosion in one day than ordinary storms would do in several years.

In other cases cavernous places or "ovens" of large size have been excavated entirely above the reach of ordinary waves. This is the case on the islands in land-locked Harrington Sound as well as in more exposed situations. It seems at first hardly probable that occasional severe storms could effect this kind of erosion at such elevations.

But in many cases such erosions are excavated from beds or pockets that are unusually soft, or consist of nearly loose sand, so that the mere dashing of the spray, made in a severe storm, might be sufficient to rapidly wear away such materials at several feet above high tide. Still it must be admitted that the erosion of such places as the Cathedral Rocks (fig. 9); the pinnacles of Tobacco Bay (fig. 10 and pl. xxii, fig. 1); the Natural Arch; and many other places (pl. xxii, fig. 2), could be more easily explained if the islands have actually been raised several feet above their former level, in post-pliocene times. To suppose that this took place at a more remote period would imply a durability that these rocks do not possess, although their durability is very great. (See chap. 20, A.) This upper zone of erosion has apparently been removed by subsequent erosion on most of the more exposed cliffs, especially on the south side.

We might well expect, also, to find some evidences of wave erosion on the ledges around the borders of some of the enclosed lowlands and bays, where the sea does not now reach. It might have produced more or less distinct terraces in such places, if the land had remained a long time at a lower level than now. But of course, such terraces, had they once existed, may have been mostly or entirely removed or obscured by later erosion of the softer rocks and soil.

It seemed to me that there were some indications of such a terrace formation, in some places along the west side of Castle Harbor; around Mullet Bay and Hungry Bay; and in various other places. But I did not have sufficient time to make a careful study of this question. It would, perhaps, require many careful excavations in undisturbed localities, if such could be found. But as the soil has been constantly cultivated there for nearly 300 years, it probably would be hard to find localities with the soil in its original state. At any rate, I do not know that any careful studies of this kind have ever been made there.

As the question now stands, the elevated beach formations, which occur at numerous places, are the most important evidence, and they lead us to believe that a reëlevation has actually occurred, as claimed in a former chapter (pp. 76–78). If this be true, it is most probable that it was contemporaneous with the post-Champlain elevation of Nova Scotia and New England.

20. Changes due to Erosion.

The erosion of the Bermuda limestones has taken place chiefly in five ways: A, by the solvent action of the carbonic acid in rain water and salt spray; B, by the direct mechanical effects of rain; C, by the mechanical action of streams, either above ground or subterranean; D, by the mechanical action of the waves, both above and below sea-level; E, by the action of tidal currents and currents caused by the winds. The last is probably the least important.

A. Subaerial erosion due to carbonic acid in the rain-water.

In the Bermudas, owing to the equable climate and absence of frost, the phenomena of erosion and subaerial disintegration of the rocks are very much simplified, as compared with Europe and the greater part of North America. There is every reason for believing that the present conditions have continued for an immense period of time, without much change in this respect, though great changes in the amount of rainfall are probable. Therefore, observations that would give a fairly accurate measure of the present average rate of disintegration of the limestone would be of great value in determining the time required for the great changes that have taken place in past ages. We might, by a careful study of the formation of the "red soil," as a decomposition product, or insoluble residue left after the solution of the limestone, be able to estimate approximately the total age of the dry land of the Bermudas. At present we can only say that this process of accumulation of the red soil is an extremely slow one.

It probably requires the destruction of at least 150 to 200 feet of limestone to form one foot of soil, as shown by the chemical analyses of the shell-sands and rocks (see pp. 74–75). The amount of impurities in the limestone is very small—probably less than an average of 0.75 per cent. Some of this material in the limestone was probably of foreign volcanic origin (floating pumice and ash from the West Indian volcanoes perhaps), but some of it may have been derived indirectly from the ancient Bermudian volcano. Fragments of pumice are now rarely found on the shores. Probably the amount of this native soil on the island, if evenly distributed over the surface, would amount to at least two feet. Though there are large tracts where the average depth of soil is not over six inches, and also tracts of nearly bare rock, there are depressions and valleys between the hills where it is many feet deep. This light soil is easily washed from the hillsides into the valleys by the heavy rains, unless it be closely covered by grass or some other vegetation. On the contrary, as there are no brooks or streams of fresh water, comparatively little of it is now carried into the sea and wasted, though streams of considerable size probably existed in the time of Greater Bermuda. Hence it follows that unless these limestones disintegrate with unusual rapidity, it must have taken a very long period to form even one foot of soil.

This kind of decomposition of the rocks has been going on during the whole history of the islands, since the first dry land emerged, for we find numerous layers of the same red-clay interstratified between all the limestones ; even those of Pliocene age (see p. 74). Perhaps the amount still imbedded in the limestone may be actually greater than all the surface soils.

The limestone thus dissolved and carried away from the surface by the percolating rain-water, is afterwards partly deposited in the pores of the underlying rocks, making them harder and more compact; a smaller part is deposited in caverns, in the form of stalactites and stalagmites; other portions serve to harden the exposed surfaces of rocks and the surfaces of fissures, etc. But a large proportion is, without doubt, finally carried into the sea, in solution.

When unsaturated rain-waters or streams find their way into fissures or cavities of the rock, or into loose or soft portions, they will gradually dissolve away the rock and form caverns, large or small. In many cases their formation is partly a mechanical process of erosion, but in nearly all cases observed here it is partly or largely a solvent action (see pp. 70, 84).

Eventually the roofs of the broader caverns become too weak to support their own weight and they fall in, thus forming "sinks," which, by subsequent enlargement and blending together by erosion may, in some cases, form the basins of large ponds, marshes, harbors and sounds.

Slow rate of decay of limestones.

Some data that I obtained by examining the ruins of the old stone forts on Castle Island and other islands, some of which were probably built before 1620, show an unexpectedly slow rate of disintegration of the ordinary firm limestone used in the walls and buildings. This was confirmed by observations made at other places. These data would make the average rate of subaerial disintegration for the harder æolian limestones to be less than two inches in a century. This would require 120,000 years for the destruction of the 200 feet of hard limestone necessary to form one foot of soil.

But there are, in many places, areas of much softer limestones, which decay far more rapidly and furnish soil much more freely. Such tracts of soft limestones have, by their decay and solution, given origin, in many cases, to the sinks, ponds, marshes, and caverns that abound on the larger islands. This consideration would very materially reduce the time required to form the soil.

But many of the softer limestones, when exposed to the air, as in the road cuttings, become, in a few months, very much harder and more resistant to decay. It is rare to find in the extensive road-cuts any great portions of the nearly perpendicular side-walls that have fallen away by decay. On the contrary, their surfaces have become hardened by infiltrations and coatings of calcium carbonate, so as to resist weathering quite well.

My observations, therefore, on this point, though not satisfactory and far too few in number, point to a great antiquity for the Bermuda limestones, though recent in a geological sense.

Spanish Rock.

Some idea of the slowness of the subaerial decay of the limestone, where it has acquired a hard surface, may be gained from an ancient incised inscription on the rock known as "Spanish Rock" (fig. 13).

This inscription consists of a monogram, a rude cross, and the date, 1543. The date is, or was a few years ago, fairly distinct. It was originally cut, perhaps .50 to .75 of an inch deep,—possibly an inch. That it has remained visible so long may be due to the fact that the corrosion may have affected the incised lines quite as much as the surrounding surfaces. Still, it is remarkable that it should have been preserved at all. It is now much less distinct than 40 years ago, but this is largely due to vandalism of visitors.

As to the authenticity of the date, we have no positive proof. Local tradition makes it appear to have been known to the early settlers.

It is, perhaps, one of the mementoes of the supposed visits of the Spanish before the English settlement, mentioned by Gov. Butler, in 1619: "Witnesse certaine crosses left erected upon rocks and promontories." He also refers to old Spanish coins that had been found here by the early settlers.

The presence of numerous wild hogs on the islands in 1593, as narrated by Henry May, and in 1611, as described by the early settlers, proves that Spanish or Portuguese vessels had previously visited the islands and introduced them there.

However, I have not found any positive reference to the inscription on Spanish Rock before 1840, but the literature of the islands, before that time, and after 1640, is singularly bare of all references to the natural history of the islands. Those 200 years were the "dark ages" of Bermuda, in this respect at least.

I am not certain as to who, among modern writers, first mentioned it, but all agree that it had been known for a very long time, and that, from the first, it appeared ancient.

It has been attributed by most writers to Ferdinando Camelo, a native of Portugal, who received an abortive charter for the settlement of Bermuda from the King of Spain, about 1527. But there is no evidence that he personally ever visited the islands. If the monogram ever stood for his name the C has now disappeared by weathering. Quite possibly this has happened. At present, the monogram more resembles TK or FK or TR. It is more probable that it is the only known record of the survivors of some disastrous shipwreck in 1543, who may have lived for some time on these islands, and perhaps died here. The presence of a cross would rather exclude the theory that it was left by pirates or buccaneers.

If the date be genuine, it indicates a loss of less than an inch in depth from the surface in 362 years.

This, however, is rendered less improbable when we see the small amount of erosion and decay on some of the stone work of the ancient ruins of stone forts, built by the early settlers. The purity of the air and absence of the sulphur acids, derived from the combustion of coal, is favorable to the duration of such objects here, as contrasted with the rapid decay of marble in our large cities, or near factories and smelting works.

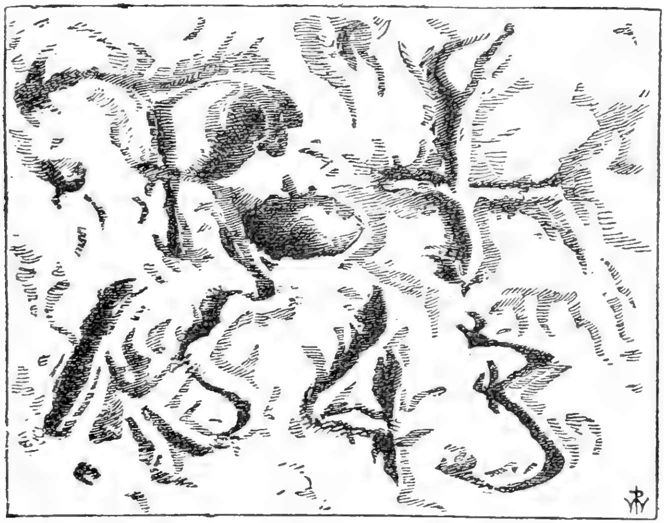

Figure 13.—Ancient inscription on "Spanish Rock," after Lefroy, 1879.

However, the remarkable durability of limestones of this kind, away from cities, and especially when hardened by the stalagmitic coating, is well known in other countries.

On the Mingan Islands, south coast of Labrador, and especially on Niapisca Island, there are many tall and often slender columns of Lower Silurian limestone, standing on and near the shore. The limestone forming them is in nearly horizontal strata of varying hardness, and some of them are mushroom-shaped at the top and undercut below, very much like some of the columns at Tobacco Bay, in Bermuda, but taller and larger, for some of those at Niapisca Island are 60 feet high. They were thus eroded during the Champlain period, when the land there stood much lower and those islands were submerged. So that at one time those columns must have been much like the tall narrow reefs off Murray Anchorage. That they have stood so many thousands of years, exposed to the storms and intense frosts of the Labrador coast, is good proof of their durability. A group of these columns is figured by Lyell in his Manual of Geology, p. 78, 1853, fig. 97. I saw the same columns in 1861.

Lyell, in the same work (pp. 74, 75), also describes limestone cliffs much eroded by the sea in the Pleistocene period, but now elevated 180 feet above the sea and situated inland, near Palermo, Sicily. They are pitted, encrusted, and infiltrated with stalactitic material near the base, like the Bermuda cliffs, and contain holes bored by marine bivalves (*Lithodomus*), the shells of which often still remain in the holes, when under the crust. But these cliffs contain sea-worn caverns in which are gravel deposits filled with the bones of extinct mammals, such as the mammoth, hippopotamus, etc., thus showing the great antiquity of the cliffs and caverns. They have evidently altered but little in the many thousands of years since the Pleistocene period, when they were raised from beneath the sea. Lyell describes other similar cases in the Morea and other regions, proving the remarkable durability of such cliffs.

Therefore it is not unreasonable to suppose that the date on Spanish Rock is genuine, nor to believe that the columns of Tobacco Bay, the Cathedral Rocks, etc., have remained much as they now are for thousands of years, or since the Champlain period, when they were probably elevated above the sea, like those of Niapisca Island.

B. Mechanical action of rain-water.

Bermuda has a large rainfall. At times the rains are frequent and violent. According to Lefroy's tables, covering eleven and sixteen years respectively, the annual rainfall was 54.66 inches at Ireland Island, and 48.61 inches at St. George's. The amount near Hamilton during later years has usually varied between 58 and 63 inches, but in 1898 it was only 48.19 ; and in 1900 it was 67.05 inches.*

The rainfall is usually pretty well distributed throughout the year, but is generally greatest in October and November and least in the summer months, when droughts are not uncommon, but seldom very prolonged. Usually more or less rain falls on from one hundred and ninety to two hundred and seven days. During July, 1896, the rainfall at the Prospect Observatory was 18.21 inches. On July 30th the fall was 4.42 inches.

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* See tables, these Trans., xi, pp. 500–502 ; "The Bermuda Islands," pp. 88–90 455.

Such copious rains wash large quantities of the red-clay soil, loose shell-sands, and other loose materials from the hillsides into the valleys, and on steep sea shores much may be carried into the sea.

The cutting away of the cedar forest and destruction of other native vegetation, even by the early settlers, very soon led to many of the hills becoming barren, and often nearly bare of soil over large areas, where the soil was at first fertile. This was especially the case on St. George's Island, which was first settled, for Governor Butler, in 1619, said that even then the land had become barren and of little or no value, except for pastures. Laws regulating and restricting the cutting of the trees, prohibiting the burning of the brush so as to kill young trees, etc., were made before 1630, mainly in consequence of the increasing barrenness of the soil.* More stringent ones were made in 1632, 1659, etc. But the islands were overpopulated, fuel and lumber were scarce, and the laws could not be enforced.

Although at the present time no permanent streams are formed, doubtless much of the copious rain finds its way into cracks and crevices of the rocks, and finally into larger passage ways, and thus into the sea. In a few hours after the hardest rains most of the water disappears from the surface of all the uplands.

C. Erosion by streams in former periods.

Although streams do not exist at the present time, there is evidence (see pp. 86–96) that in the time of Greater Bermuda, and later, they did exist, both above ground and in subterranean passages, leading into or through caverns, and finally reaching the sea. The agency of such streams in forming the great sunken or drowned sounds and their channels or cuts out to sea has already been discussed. (See pp. 87–94.)

No doubt the subterranean streams of Greater Bermuda were the principal agents in excavating the caverns that now exist on the land, as mentioned above, and consequently in forming the sinks, etc., derived from their ruins.

A number of the passage ways through which they flowed are also known. I have mentioned on p. 84, that the large dry cave of Walsingham was probably once such a passage-way for a large and rapid stream of water. A narrow and deep chasm, with a small

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* For details see these Trans., xi, pp. 421, 477, 593, 598, 602, 603; "The Bermuda Islands," pp. 9, 65, 181, 186, 190, 191.

natural bridge across part of it (fig. 14), on Cooper's Island, was probably also an underground passage. Basset's cave on Somerset Island, said to be over a mile long, but without stalactites, appears to have been another large passage-way for a stream, and there are many others.

Figure 14.—Chasm and natural bridge on Cooper's Island. This appears to have been an ancient underground water-way, now partly submerged, from which the roof has mostly fallen.

The small size of the present islands and the porous and cavernous nature of the rocks preclude the formation of streams with the existing amount of rainfall.

A certain amount of solvent action on the shore limestones and exposed reefs is also effected by the salt spray that dashes over them. This action extends considerably above high-water mark in exposed places. It results in eroding the limestone into a very rough, pitted, or honeycombed surface, coarse or fine. The intervening spaces run up into sharp edges and jagged points, and the whole surface becomes hard from secondary infiltration with calcium carbonate.*

D. Erosion by the waves.

This subject has been repeatedly referred to in the previous pages. A brief description will be given, in this place, of the various phases, or at least some of the more important ones, of the subject.

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* See figures 8, 9, 10, 15, 18, and pl. xxii, figs. 1, 2; also pp. 66, 67.

a. Erosion of the North Shore Cliffs, Islets, and Ledges.

This is, naturally, the most conspicuous phase of erosion by the sea. Its effects and the resulting forms depend upon several factors: such as the degree of exposure to the sea, and whether there be outlying reefs to break the force of the seas; the depth of water near the shore; the violence of the wind; the height of the cliffs and the inclination or dip of the layers of rock; the varying degrees of

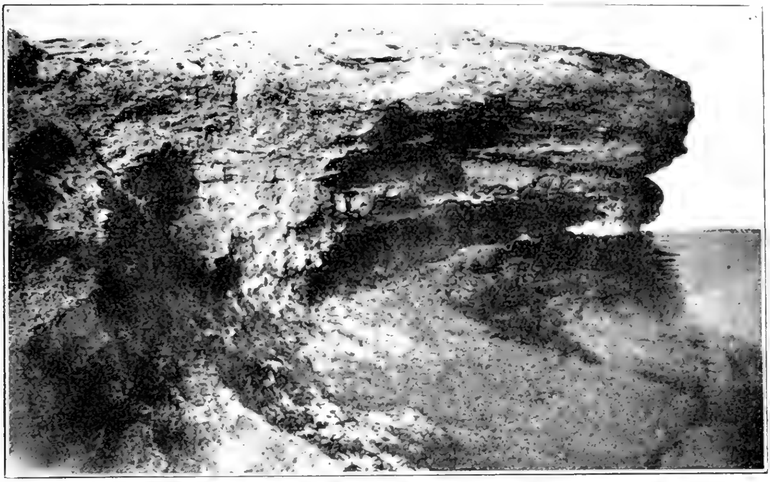

Figure 15.—Cliffs of æolian limestone on the north shore, showing two strongly marked planes of erosion, the upper one above high-tide level. The honeycombed rocks are hardened by infiltrations and coatings of calcite.

Figure 16.—Eroded cliff, near Bailey Bay, north shore, showing masses of limestone fallen from the cliff, and not yet much undercut.

hardness of the layers; the existence of pockets, beds, or layers of loose sand in the cliffs, etc.

The irregular stratification of the limestone, with layers of unequal hardness and sloping in all directions, which is characteristic of all such æolian limestones, causes this rock to be admirably suited for the ocean waves to carve into curious and fantastic forms. (Figs. 1, 6, 8, 10, 15, 16, 17, 22.)

Figure 17.—Pinnacle of æolian limestone on south shore showing sand-drift stratification above, and the deeply pitted, rough, hard surface below, infiltrated and coated with calcite. The cliff on the left is undercut.

Along most of the north shore of the Main Island, from near Hamilton to the eastern end of St. George's, the shore is almost everywhere formed by low or only moderately high limestone cliffs, which in many places have a talus of fallen rocks at the base, usually exposed at low tide (figs. 16, 25). But in many other places there are not many fallen rocks and the waves dash directly against the base of the cliffs, both at high-tide and low-tide. (Figs. 10, 15, 22, 33*a*, 33*b*.) In the latter case the cliffs are apt to be undercut, between tides, and usually somewhat above high-tide level, owing to the dash of the waves and spray in storms. The zone from about half-tide to 10 to 20 feet above is usually deeply pitted and very rough, as already described (p. 66).

If the strata are nearly horizontal and unequal in hardness the undercutting will vary in amount, making two or more projections and intervening grooves (figs. 15, 17). When the strata are irregular in position and variable in hardness the undercutting and consequent falling away of the cliffs in large masses give rise to all sorts of fantastic forms. (Figs. 8, 10, 17, 20, and pl. xxii.)

Sometimes, when the rocks vary greatly in hardness, due to the presence of large beds or masses of unconsolidated sand and to the hardening by infiltration of particular parts, as described above (p. 63), the rapid erosion of the softer beds or masses leaves the harder parts projecting in the form of partly or wholly detached pillars, pyramids, pinnacles, or columns, often of considerable height (figs. 10, 17; pl. xxii).

"Pulpit Rock," on Ireland Island, is a good example of such a detached pinnacle rock (fig. 22). It also shows well the irregular stratification of the æolian limestone. Some of these pinnacles stand out some distance from the shore, on the flat reefs, showing where an islet or the shore cliff once stood.

The formation of pinnacles and towers is well shown at the eastern end of the islands, especially at Tobacco Bay, on St. George's (fig. 10 and pl. xxii, fig. 1), and on the eastern shores of St. David's and Cooper's Islands, and at some points on the south shore (pl. xxii, fig. 2).

In many of these places every stage in the process of forming these columns can be seen, as well as their undercutting and final overthrow, by which high islets and shore cliffs become eventually converted into flat tidal ledges, and detached flat reefs, or even into serpuline atolls (figs. 27–29; pl. xxiii).

The remarkable examples of erosion shown at "Cathedral Rocks" or "Old Church Rocks," on the western side of Somerset Island (fig. 9 and pl. xxiii), are similar in origin, but less broken down. They are probably largely due to great masses of loose sand that has been washed away from the hardened parts that now form the pillars and arches. Part of this may have been done at a former time, when the land stood 10 to 15 feet lower than now (see pp. 75–80).

Along many parts of these shores there are many outlying small rocky islets and numerous limestone ledges; some of them are close to the shore and evidently connected with the shore cliffs at no very distant period, while others are farther away. The submerged ledges, somewhat removed from the shore, are more or less covered with corals, but all bear quantities of large dark-colored seaweeds (*Sargassum*, etc.), so that they are conspicuous, even when wholly submerged. There are several of these small islands and ledges off Spanish Point; others, like the Staggs, east of the Flatts; and several in Bailey Bay, which are all good collecting grounds. Bailey Bay Island is the largest and highest of those in its vicinity, and bears some vegetation, such as stunted cedars, etc., but its summit is partly covered with fine drifting sand. Its shore ledges are very rough and deeply pitted (fig. 18), and its strata lie at all angles, so that there is here no approach to the formation of flat tidal benches or shelves, nor of serpuline atolls, such as are abundant on the south shores.

Figure 18.—Islets and ledges in Bailey Bay; showing the shattered and irregular rocks, deeply pitted and honeycombed above low tide.

b. Grottoes and cavernous places.

Small grottoes, due to the removal of soft materials, exist in the cliffs at Clarence Cove (figs. 33*a*, 33*b*), and in many other places. There is a grotto in the face of a cliff near the lighthouse on St. David's Island, that is said to contain a pool of fresh water, but I did not visit it.

Along the high shore cliffs there are many grottoes and caves that can only be entered from a boat, and sometimes only at low tide.

Two large dome-like grottoes of this kind, accessible only by a boat at low water, are situated close together in the shore-cliff a short distance east of Bailey Bay. One of them is lighted from above by a small chimney-like opening in the roof. Such grottoes often contain nests of the tropic bird.*

Small grottoes in the shore cliffs exist in many other places, and many are entirely submerged, under the reefs, and are the abode of innumerable fishes, octopi, and various other marine creatures.†

c. Natural Arches.

The formation of the well known "Natural Arches" at Tucker's Town beach‡ is evidently due, also, to the erosion of masses of softer limestone, leaving the harder parts to form the sides and central pillars of the arches. It stands just at high tide, but in heavy storms great waves dash under and through the archways with force enough to slowly cut away the softer limestones. The irregular strata of rock forming the arches are considerably broken and show distinct vertical fissures, as if due to settling. They are destined to fall at no distant time.

d. Sandy Beaches.

On the north side of the Main Island the line of cliffs is broken at Hamilton Harbor, at the Flatts, at Shelly Bay,§ where there is a good shell-sand beach, and at Bailey Bay, where there are two short sandy beaches.

e. Cliffs of Harrington Sound.

On the cliffs of Harrington Sound, which has usually less than a foot of tide, and which is so completely landlocked that it never has large seas, the erosion presents some different phases. The cliffs on the sound are often precipitous, and in some places, as at Abbot's Head (fig. 21), they are quite high.‖

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* These Trans., xi, p. 679, pl. lxxii, fig. 1; "The Bermuda Islands," p. 267, same plate.

† See pl. xxxvi; also these Trans., xi, pl. lxxii; "The Bermuda Islands," same plate.

‡ These Trans., xi, pp. 437, 473, pl. lxxxvii; "The Bermuda Islands," pp. 25, 61, same plate.

§ See these Trans., pl. lxviii, fig. 1; "The Bermuda Islands," same plate.

‖ See also these Trans., xi, pl. lxxi, lxxii; "The Bermuda Islands," same plates.

Many of these cliffs show, by their perpendicular fronts and the masses of fallen debris, that they are undergoing considerable erosion. This is mainly due to the peculiar undercutting effected by the small sharp waves, acting in one narrow zone, usually only a foot or less in breadth, doubtless aided by the solvent action of the water that is in constant contact with the surface undergoing erosion. This causes the waves to cut a narrow groove, like a huge saw-cut, deeply into the face of the cliffs, whether high or low, just about at high-water mark. I have seen such grooves cut into the bases of cliffs to the extent of 10 to 15 feet, and less than a foot wide (figs. 19, 20).

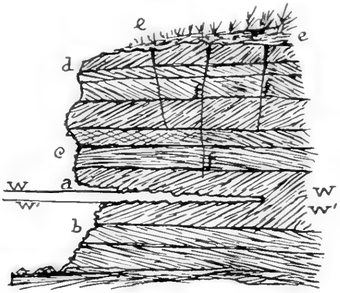

Figure 19.—Diagram of undercut cliff on Harrington Sound; *a*, groove about a foot wide; *w*, *w'*, high tide and low tide levels; *c*, *d*, æolian limestone cliff; *e*, *e*, soil; *f*, *f*, vertical fissures; *b*, submerged æolian limestones.

Figure 20.—Lion Rock, on the south shore of Harrington Sound,—a curiously eroded and hardened rock. The cliff in the middle distance is narrowly undercut, at sea level. (Phot. 1901, by A. H. Verrill.)

This goes on till a large unsupported mass of the cliff falls away by its own weight. The fall is often hastened by reason of vertical fissures or weak places in the cliffs. Great angular blocks of stone, thus fallen off, lie in front of the cliffs at the eastern end of the sound, and especially at the base of Abbot's Head (fig. 21). The latter are said to have fallen off only a few years ago, but I did not learn the date. They show, as yet, scarcely any wear, but those that are submerged are partly covered with corals, etc. As there are no violent waves in the sound, such masses are not so soon destroyed as on the exposed shores.

Figure 21.—Abbot's Head, on Harrington Sound, showing the recently fallen masses of rock at base.

In most photographs these narrow deep undercuttings show only as a dark line, looking like a dark shadow, at the foot of the cliff, as in fig. 20.*

Sharks Hole, at the southeastern end of the sound, is a large arch-way or tunnel, penetrating deeply into the cliff, and about half

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* See also pl. lxxi, these Trans., vol. xi, and "The Bermuda Islands," same plate, in which the long cliff, west of Sharks Hole, is shown to be thus undercut. Also pl. lxxiii, showing Sharks Hole.

submerged, so that boats can go in. It has apparently been made by the removal of a mass of softer limestone. It may have been a passage-way for an underground stream when the land stood at a higher level (p. 76). But large masses of stone have fallen from the sides and roof in modern times, due to undercutting, and many masses still lie on the bottom, in plain view.

There are also small grottoes on Trunk Island, above and below tide, due to the more rapid undercutting and removal of softer rocks.

In some cases, where this mode of undercutting occurs in hard flat ledges, just above high tide, the effects are very curious. I have observed such cases on the north side of Trunk Island and in other places. In some instances the portion of the ledge that is undercut may be only a few inches to a foot thick; the outer border may run out to an irregular edge only an inch or two thick, while the undercut groove may be several feet deep. This is quite unlike anything that happens on the open coast, where such projections would be soon broken off by the waves, even if they could be formed.

f. Erosion of the Outer Reefs and "Flats" off the northern and western shores.

The great barrier forming the broad outer border of the elliptical area, extending from off St. George's all around to the Long Bar, the most southwestern of the reefs, is formed of a series of almost continuous broad patches of flat reefs. They are nearly flat on top, and are mostly submerged from one to ten feet below low-water mark. In certain places they are close to the surface or partially laid bare at low tide, and the seas break heavily over them in stormy weather. Such portions of the reefs are designated as "breakers" on the charts. In certain places patches of reefs, large or small, stand somewhat apart and outside of the main border line. Some of these, where the seas break heavily, are called "boilers," as in the case of some of those to the east of Mills Breakers. A large number of outlying reefs exist outside the western border reefs.*

Among the most dangerous of these detached reefs are the Chub Heads, 9 miles from the shore at Wreck Hill; Long Bar, of which the south part is 6 miles W.S.W. from Gibb's Hill Light; and Southwest Breaker, on which the sea always breaks, and which lies

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* Mr. A. Agassiz has given very full descriptions of many of these outer reefs and "flats" from personal examination, and reference should be made to his memoir for more details.

1½ miles from the shore, and about south from the southwestern end of the Main Island.

The somewhat submerged reef or "flats" of the outer barrier are usually from one-fourth to a mile wide and very irregular in outline; in some places they may be over two miles wide. The great northern "Ledge Flats" are eight and a half miles long, from the cut west of North Rocks to Blue Cut, and from one to two miles wide. The "East Ledge Flat" is over seven miles long, with no important interruption, and seldom more than half a mile wide. Many of the others are as large as Somerset Island or St. George's Island.

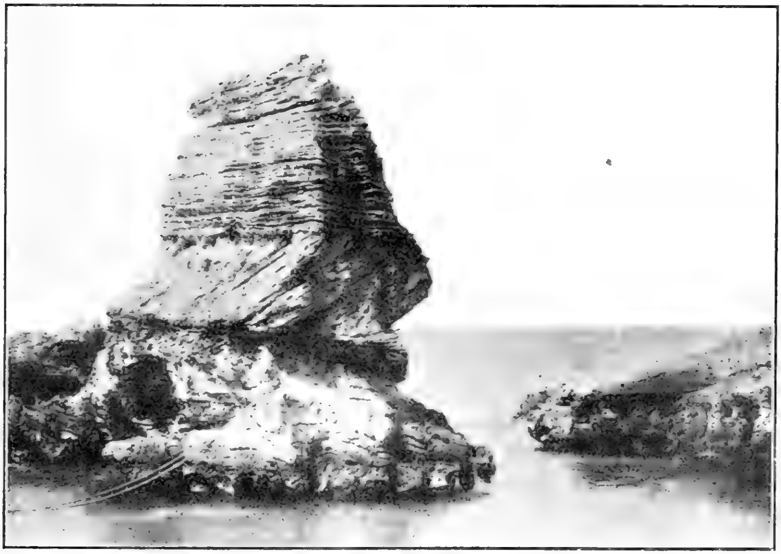

Figure 22.—Pulpit Rock, Ireland Island, showing characteristic, irregular, sand-drift stratification above; the lower part is undercut, infiltrated, and roughly eroded.

Among the most important "breakers" are "Mills Breaker," north of the eastern end of St. George's; "Great Breaker," east of North Rocks; and the breakers or flats around North Rocks, which are bare in places at low tide (fig. 24).

North Rocks (figs. 23, 31, 33) consist of a small group of pinnacles, the higher ones showing at high tide. They stand on one of those flat reefs that is partly laid bare by the tide, and are the only rocks that project above the general level of the outer reefs. The largest is only about 14 or 15 feet high, above low tide, and about

10 feet in diameter (fig. 23). They are undercut and eroded like the pinnacles near the shore (fig. 22); and like the reefs themselves, they are remnants of what were once islands, now destroyed by the sea.

These rocks are interesting historically as well as geologically, for it was in close proximity to these rocks that the "Bonaventura," with Henry May on board, was wrecked in 1593, as mentioned below. Therefore they were represented, with this wrecked vessel, on the reverse of the original seal of the Bermuda Company (fig. 32). They lie about 8 miles north of the Main Island and about 12 miles N.N.W. from Catherine Point, at the eastern end of St. George's Island. (See map II.)

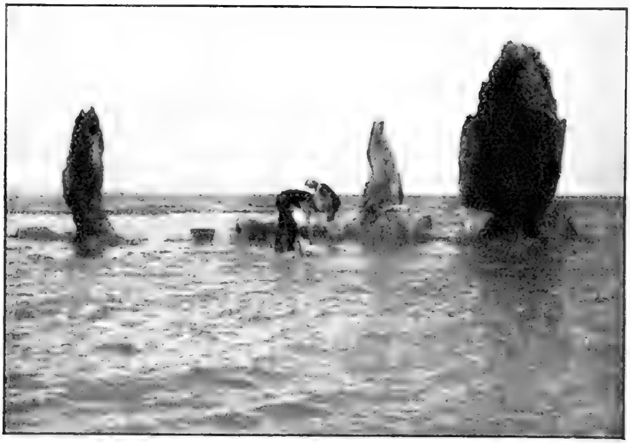

Figure 23.—North Rocks, a view looking southward, toward the main island, which is seen in the background. From a recent photograph by Phelps Gage. Loaned by Prof. E. L. Mark, from Proc. Am. Assoc. Ad. Sci., 1905.

Within the outer reefs and between the anchorages there are innumerable detached reefs and groups of reefs of various sizes and shapes, but often covering many square miles, where the water is so obstructed and filled with reefs that no vessels of any kind can pass through them, except small boats in pleasant weather. But in other places they are more openly arranged or scattered, with deep water and white bottoms in the wide and deep passages between them.

Beneath the sea the outer reefs and breakers, as well as most of those inside, are roughly eroded, with their sides perpendicular, or even so much undercut that the top often overhangs 6 to 10 feet or more. Schools of fishes, including many bright-colored species, often take refuge under the cavernous places (pl. xxxvi, fig. 1). Owing to the deep undercutting many of the detached reefs, standing in 30 to 40 feet of water, have a broad, flat-topped or mushroom-shaped form. So many of them are most undercut 20 to 30 feet below the surface of the sea, that it seems probable that the land remained stationary, or nearly so, for a long period of time, when about 30 feet higher than now, during the general period of subsidence.

So, likewise, there are reasons for believing that it stood for a long time at about 50 feet higher than at present, owing to the large areas of the lagoons or sounds that lie at, or are filled up to, near that depth, as well as to the erosion of so many of the reefs to about that depth. It is not probable that the erosion of the sea now reaches to much more than 20 feet below low tide, with any degree of force.

Figure 24.—Flats near North Rocks, at low tide. One of the men was Governor Lefroy. From a photograph made in 1875 by Mr. J. B. Heyl.

All these outer reefs and many of those nearer the shores are overgrown with corals of various kinds, sea plumes, sea-fans and other gorgonians, *Millepores*, serpulæ, mussels, *Chamas*, sponges, sea-weeds, corallines, nullipores, and many other living organisms, which greatly protect them from the wear of the waves, and on the outer parts raise the level considerably above that of the underlying limestone rock. Were it not for this protective covering, the reefs would be worn away and destroyed far more rapidly.

Among the reef-corals* that are most efficient, both in protecting and building up the surfaces of the reefs, are the "brain-corals"

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* For a fuller account and illustrations of the reef-corals and gorgonians, see Chapter 29. Also my articles in these Trans., xi, pp. 63–206, pls. x–xxxv; also, Verrill, Zoölogy of Bermuda, i, articles 11, 12, pp. 63–206; same plates.

(*Mæandra*), the "star-corals" (*Orbicella* and *Siderastræa*); "rose corals" (*Mussa*); *Porites astreoides* (plate xxix); and the "finger-coral" (*Millepora alcicornis*, plate xxx, A). The latter is very abundant on all the reefs and rocks, including those near the shores, for it grows in very shallow water. It forms large and handsome clusters of elegantly branched fronds, often projecting from the edges of the reefs. It is dark russet-brown in color when living. The common brain-coral (*Mæandra labyrinthiformis*) is the largest and most abundant reef-coral. It may grow in broad crusts 3 to 8 inches in thickness, and 6 to 8 feet across, due to the grafting together of many small colonies, or it may form rounded or hemispherical masses, 1 to 6 feet in diameter. It is orange or yellow when living.

The most important protective sea-weeds are large, olive-colored species of "gulf-weed" of the genus *Sargassum*, "rock weed" (*Fucus*), etc., also various calcareous pale red algæ, belonging to the genus *Lithothamnion*, and others related to *Corallina*.

If the Bermuda Islands could be suddenly reëlevated to the height of 45 feet, the greater part of Greater Bermuda would become dry land. The parts that would remain covered by water, in the form of lagoons and sounds, are shown, with the exceptions of a few small ones, by the ruled areas on the map (fig. 12, map I).

The dry land that would thus be gained, amounting to about 160 square miles, would have a very remarkable appearance, something like some of the much eroded ancient table-lands of Colorado and other parts of the western United States, though on a much smaller scale.

Most of the land would lie in the form of long, narrow, irregular, curved outer islands, often 5 to 8 miles long, with nearly perpendicular or even overhanging cliffs, about 40 feet high. Hundreds of smaller, irregular islands, and detached pinnacles, spires, columns, and mushroom-shaped cliffs, rising from the shallow waters and the broad and nearly level, enclosed sandy plain, to the height of 40 to 45 feet, would lie within the outer row of islands, both scattered and in groups. Between them would be intricate passages, some of which might be deep enough to allow the tides to reach several of the enclosed sounds. These columns and cliffs would be more or less coated and covered, on the sides and top, with massive corals and other growths. But seen from below they would, in many places, present appearances similar to the much smaller eroded cliffs and pinnacles of Tobacco Bay and other localities on the present shores, as seen at low tide (pl. xxii).

In nature, however, such changes in level rarely if ever occur suddenly, to anything like this amount. Such an emergence would be likely to cover centuries of time. In that case the bizarre cliffs and pinnacles would be greatly eroded, as fast as they emerged above the sea, and by the time the entire elevation had been accomplished only a part would remain, and these mostly much reduced in height and size. Channels would be eroded, at the same time, to allow the tides to flow freely into the larger sounds. Meantime the vast areas of fine loose sands, gradually uncovered, would afford immense quantities of materials for the wind to drift into sand-dunes on the newer as well as on the older lands.

g. Erosion of the South-shore Cliffs and Reefs.

Along the south side of the Main Island the shore cliffs are almost continuous and are usually higher and more precipitous than on the north side. In most parts the waves at high tide, at least in storms, dash against the bases of the cliffs. But at low tide there may be a wide beach of shell-sand exposed in front of the cliffs, as near Tucker's Town, Elbow Bay, and many other places. Or these may be nearly flat, broad benches, or smooth shelves of hard limestone, laid bare in front of the cliffs by the tide. At several points, as at Elbow Bay and Tucker's Town, there are extensive sand beaches. The erosion of the cliffs on this side is similar to that on the north side, but on a larger scale, owing to higher cliffs and to the greater violence of the storms, though the outlying lines of reefs and serpuline atolls serve to more or less break up the heavy seas, and thus give considerable protection in many places. However, owing to the fact that the harder limestones of the Walsingham formation (pp. 72–74, fig. 11) outcrop in thick, nearly horizontal beds, at and below tide-level in many places, the erosion has been materially modified in certain ways, especially in the formation of the flat tidal ledges, and flat-topped outer reefs and serpuline atolls, so characteristic of this shore, as mentioned on a former page.

h. Pot-holes.

The hard flat beds have also been favorable for the formation of pot-holes, both on the tidal ledges and on the reefs. Some of the shallow pot-holes have, apparently, been started in slight depressions and eroded spots in the surface, and then worn deeper by the plunging and whirling action of the waves and the stones carried by them.

Some of these may eventually become of large size and several feet deep before they are broken through and spoiled (see fig. 25).

But I believe that many of the deeper and more regular pot-holes are simply the ancient fossil structures familiarly known as fossil molds of "palmetto stumps," originally contained in the hard flat ledges and filled with softer sand. When the sea encroaches upon such a ledge as that shown in plates xix, xx, for example, if it were below tide, it would at once begin to wear and enlarge the holes already existing and they would soon become wider at the top and more cup-shaped; many would blend their margins together; some would have one side of the rim worn off, forming crescent-shaped or horseshoe-shaped pot-holes, etc., just as we now find the smaller and more regular pot-holes on many of the submerged ledges and reefs (fig. 26).

Figure 25.—Cliff and pot-hole on south shore. The upper part shows æolian limestone not much altered; other parts are rudely honeycombed, encrusted, and infiltrated. The pot-hole, on the right, contained a loose mass of limestone.

Mr. Agassiz attributed all such pot-holes to the direct action of the sea. But he also believed that the so-called "palmetto stumps" were real pot-holes formed by the action of the waves. Those that he mentioned, however, happened to be in shore rocks, within reach of the tides at least. However, those that I have figured (pls. xix, xx) are decidedly above the tides, and if they were ever worn by the waves, it must have been in a period of greater subsidence, the existence of which Mr. Agassiz does not admit. But they have sharp edges; are surrounded by still adherent red-clay soil; their inner surfaces are nearly smooth, and they cut uniformly through the harder and softer layers, which are characters not found in real pot-holes. Moreover, just the same structures occur in limestones, apparently of the same age, at least 60 to 80 feet above the sea. Therefore they can hardly be pot-holes, and those that are in the sea must, at any rate, have preëxisted in the limestones before the present submergence of the rocks. See chapter 24*b*, for a discussion of the mode of origin of these structures.

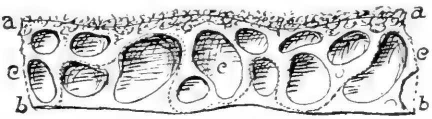

Figure 26.—Diagram of group of small pot-holes on edge of reef; *a*, the dotted line, shows how some may become crescent-shaped by erosion, as *c*, *c*. Altered from A. Agassiz.

i. *Serpuline Atolls or "Boilers."*

Along nearly the whole southern shore of the islands the reefs are situated much nearer to the shore than on the northern and western sides. Most of them are not more than half a mile to a mile away, though in some places they may be more than a mile from the shore. Along this coast most of the outer reefs are usually flat on the top and well covered with living corals, sea-fans and other gorgoniæ, mussels, barnacles, serpulæ, and sea-weeds. A few of them, as Southwest Breaker, are uncovered in places at low tides. Their sides are steep, often perpendicular, and frequently undercut. They often fall off into deep water by flat steps or benches of hard limestone. They seem to be formed, in most places, of the hard, nearly horizontal beds of the Walsingham limestone (see above, pp. 73, 74).

The inner line of reefs that exists along most of this coast is peculiar in being made up largely of a special form of reefs, usually known as "serpuline atolls," a name given by Lieut. Nelson in 1840.*

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* See pl. xxiii; also these Trans., xi, p. 486, pls. lxxvii, lxxviii; "The Bermuda Islands," p. 74, same plates.

The serpuline atolls are detached, rounded, elliptical, crescent-shaped, or irregular reefs with a raised rim and excavated or cup-shaped central part. They vary in size from those only a few feet in diameter up to those of 100 feet or more. Many are very regularly rounded. The rim is formed by a solid, raised, living crust, made up of the hard, convoluted, shelly tubes of serpulæ and *Vermetus*, barnacles, small black mussels, nullipores, corallines, and some true incrusting corals, such as *Porites astreoides* and a few others, with more or less seaweeds, etc.

The living rim of these atolls is usually laid bare by the ebb tide, wholly or in part. The rim is usually higher and larger on the windward side, because the organisms live best in the swash of the pure water, and are liable to be killed off on the lee side by the sand and debris, often washed out from the central pool. The growing rim, therefore, is often lacking at one or more places on the lee side, so that the edge is lower, and the water that is thrown into the central pool by the waves rushes out over the low lee side in a miniature cataract, when there are large waves. The rim may rise from a foot to nearly two feet above low tide, because such organisms as compose it can endure an exposure to the air of two or three hours, especially as the sea or spray usually dashes over them, and they retain water in their interstices. (Plate xxiii.)

The living organisms usually have not built up the whole height of the raised rim, but they have protected it from erosion to a lower level, and have added something to its height by their own growth.

These serpuline atolls are composed, like the reefs farther out, of hard æolian limestones, usually in nearly horizontal beds, probably of Walsingham age (see pp. 73–74). The hardness and horizontal position of the beds of this limestone are eminently favorable for their formation, though they probably are often formed of other limestones, especially when they are in hard and nearly flat layers. If the layers happen to be much inclined, the atolls become irregular and imperfect, owing to the very uneven erosion that results.

The submerged sides of the atolls are usually undercut, or at least very steep. They are situated at various distances from the shore, but are mostly within half a mile of it, and usually with not more than 10 to 15 feet of water between. Many are in water not more than 2 to 4 feet deep at low tide. In some places many of them are even connected with the shore ledges, at low tides, as "fringing reefs," especially around the outer small islets, but in such places the rim is covered more by seaweeds, etc., than by serpulæ.

At certain places along the south shore, as at Whale Bay and Great Turtle Bay, various stages in the process of eroding the projecting ledges and cliffs into detached pinnacles can be seen: and the undercutting of these, between tides, until they fall over, leaving flat-topped ledges, which are converted into the serpuline atolls by the formation of the living rim over which the waves dash to excavate the central cup or pool. This is excavated partly by the impact of the descending and whirling water and the sand carried with it. and partly by the solvent action of the water. As intimated above (p. 74), the waves may often find the beginnings of the pot-holes already existing in these limestones. The accompanying diagrams are intended to illustrate some of the phases of these methods of erosion.

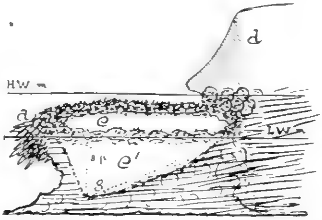

Figure 27.—Diagram of shore cliff, *d*, with connected serpentine atoll, *c*; *a*, *a*, living rim of the latter; *c'*, cavity 8 feet deep. HW*m*, and LW*m*, high and low-water levels. Slightly altered from A. Agassiz.

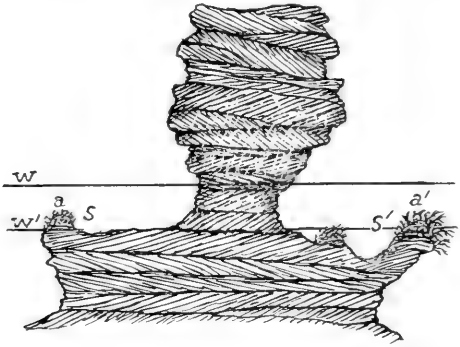

Figure 28.—Diagrammatic section of incipient serpuline atoll with central undercut pinnacle of æolian limestone still remaining; *a*, *a'*, sections of rim consisting of living serpulæ, etc.; *s*, *s'*, the enclosed lagoon or cup; *w*, *w'*, tide-levels. Original.

Figure 27 represents a cliff or ledge (*d*) eroded at base into a flat bench, on the borders of which the serpuline rim (*a*) has already begun to grow, while the waves have scooped out a deep pool or cup (*c*, *c*), which, in this case, is 8 feet deep at the center. This would form a fringing atoll.

Figure 28 represents one of the detached pinnacles of æolian limestone, in nearly flat beds, at a stage when it has become strongly undercut at the base, while the rim of the serpuline atoll (*a*, *a*′) is already growing and the central pool (*s*, *s*′) is being excavated by the waves. Such a pinnacle would eventually be overthrown, and then the atoll would be more deeply excavated near the middle, thus assuming the typical form, which is shown in section in figs. 11, *s*, and 29.

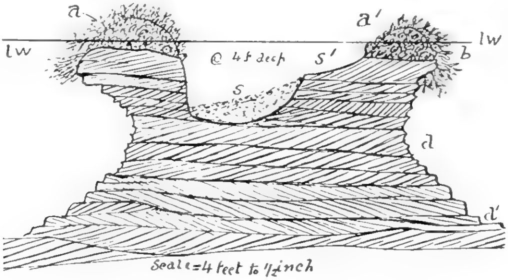

Figure 29.—Diagrammatic section of completed, small serpuline atoll; *a*, *a*′, rim of living organisms; *c*, central cup, 4 feet deep; *s*, accumulation of sand and gravel; *d*, *d*′, undercut submerged æolian limestones; *lw*, low-tide level. Altered from A. Agassiz.

The submerged sides (*d*, *d*′) of such structures are also being eroded by the dash of the waves, especially at low tide and in stormy weather, so that most of them are undercut or perpendicular below the protecting rim of organisms. Thus, in course of time, many of them will be broken off on one side, forming crescents, or all around, and thus they will eventually be changed into ordinary submerged ledges or reefs. Many such isolated reefs, without the rims, occur all along this coast, often mixed with the atolls.

Similar serpuline atolls occur at a few places and in small numbers inside the great bordering reefs of the north side. Some of these are to the northeast of Ireland Island and north of St. George's Island. Perhaps they occur there because the character and horizontal position of the limestone are favorable.

Mr. Agassiz believed that these reefs and atolls were formed out of the ordinary æolian limestones, superficially hardened over the surfaces and edges by the local action of the sea-water itself. If, as I believe, these limestones were already much hardened, nearly throughout, long before they became submerged beneath the sea, and had also in most cases a horizontal stratification, as they now do on the adjacent shores (fig. 11 and pls. xvi–xx), the whole problem of the formation of the remarkable serpuline atolls along this shore becomes much simplified.

However, I do not wish to deny that such reefs and atolls can also be formed by the cutting away of ordinary æolian ledges, when the strata are favorable, as Mr. Agassiz states, for I have seen the same process. But as we find hundreds of these remarkable atolls along this south shore, and very few in other places, it seems reasonable to connect the littoral outcrops of a suitable, hard, horizontally stratified limestone with the parallel line of atolls and flat reef at a little distance from the shore. Indeed, it is possible, at low tide, to wade out to some of the atolls figured in my plates, as was done to obtain the photographs. In other cases the atolls are actually connected with the flat benches of limestone exposed between tides, or with the shore cliffs.

j. Cutting Channels; forming Harbors and Bays.

In many cases the gradual erosion of the sea-cliffs by the waves and the encroachments of the sea have connected sinks and low valleys with the outside waters by means of narrow or wide chan-

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* At the Island of Anticosti, Gulf of St. Lawrence, I have studied the action of the waves over a large expanse of nearly flat reefs that extend along the shore for a great many miles, between tides, or barely submerged. They are formed of hard layers of Silurian limestones, nearly horizontal in position, from which the overlying softer strata have been removed by the undercutting of the cliffs between tides, and above, by the violent action of the sea-waves, aided no doubt by the frosts of winter, and by the existence of layers of soft shales, between the limestones. The flat reefs are often 100 to 200 yards wide. Their surfaces contain irregular depressions, and shallow pools of water, large and small, are left in them at low tide, but very few deserved to be called "pot-holes." The shore cliffs there vary from 20 to 300 feet or more high, and the summit of the higher ones usually overhangs the base. The outer edge of the flat reefs, below low tide, is also undercut or abrupt in most places, just like many of those at Bermuda. In fact, the phenomena of erosion are in many respects similar to those of the south shore of Bermuda, though on a much grander scale. But the organisms for forming coral-encrusted reefs and serpuline atolls do not exist in northern waters.

nels, thus forming partly enclosed harbors, lagoons, sounds, or bays, as they are variously called. Every stage in this process can be seen in progress. There is a little landlocked cove on Coney Island, with a shell-sand beach, but connected with the open water only by a narrow channel, between limestone ledges, barely wide enough for a row-boat to pass through (fig. 30). A similar miniature harbor may be seen near the roadside between Bailey Bay and Shelly Bay. It is said to have become connected with the sea, in quite recent times. Peniston's Pond is a larger body of water, separated from the sea only by a low bar, over which the waves pour a large amount of water in storms.

Figure 30.—Cove at Coney Island, with a narrow entrance through the shore ledges.

It is evident that the sea will soon cut a channel through the bar and convert it into a small bay or harbor. This has already happened at Hungry Bay, farther west, which was evidently shut off from the sea formerly by a similar bar, which has been breached by erosion. The tide now flows in and out, through a narrow channel, in a rapid current. This bay is shallow and the inner end terminates in a dense mangrove swamp of considerable extent.

Elies' Harbor and the "Scaur" are other good examples of the same action.

It is easy to see that this same process, when it opens up larger valleys, or sinks, will give rise to larger lagoons and sounds.

St. George's Harbor and Castle Harbor are examples of the same kind of erosion done on a larger scale and much longer ago; probably, also, much aided by subsidence of the land. The two causes operate together and in most of the older cases cannot be considered separately.

21. *Rates of Erosion by the sea; modern changes slow.*

Most observers, seeing the evidence of great erosion on all sides, and considering the softness of the rocks, have naturally supposed that the erosion has taken place far more rapidly than is the case.

In my studies of the rate of erosion by the waves, as shown on the masonry of the causeway leading to St. George, and in other places, this rate of erosion was found to be unexpectedly slow, under ordinary conditions, owing to the absence of ice and frost; also because there are no deposits of very hard sand, gravel, and pebbles on the shores, which the storm waves can pick up and use as tools of destruction, by dashing them against the bases of the cliffs and against each other, as they do on our rocky coasts. It is only during the severe storms and hurricanes, which occasionally occur, that rapid erosion is accomplished.

The causeway between the main island and St. George's was completed in 1871.* It was about a mile long, and fairly well built of native limestone blocks of considerable size. It included an iron drawbridge and several smaller bridges, under which were strong tidal currents, flowing in and out of St. George's Harbor and Castle Harbor. It is so situated in the passage between the islands that it is partly sheltered by the outlying small islands and reefs, and ordinarily it is not exposed to the full violence of storms. By an examination of the masonry of this causeway, in 1898, at various places, I found that during the 27 years that it had been built, the erosion by the sea rarely amounted to an inch in depth, where most active, and the average erosion was less than half an inch, between tides; most of this, also, had evidently been effected within the first few years after its erection, before the stones had acquired their hard superficial coat of infiltrated calcite. It is true that these stones were selected from the harder beds of limestone and therefore had more than the average resisting power, but after any of the soft limestones become infiltrated by calcite, the surface is resistant, so that the differences in power of resisting erosion by the sea, between tides, is much less

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* It was totally destroyed by the great hurricane of Sept., 1900, but has since been rebuilt in a different way.

than it would otherwise be. Allowing the average to be even an inch in 25 years, it would have required at least 25,000 to 30,000 years for the sea to have eroded the high cliffs of the islands facing on Castle Harbor to the extent that they have been eroded.

I did not obtain any reliable data as to the rate of erosion of the exposed cliffs of the south shore, except the observation that on Castle Island the ancient sea-walls of the forts were often built with their foundations on the edges of the cliffs (fig. 1) or even on a shelf of limestone some distance below the original brow of the seaward cliffs, and they have not yet been undermined, but stand firmly where they were put many years ago.* So, likewise, the Cathedral Rocks show scarcely any changes since the earlier photographs were made, about 30 years ago. I compared an excellent photograph, made by Mr. J. B. Heyl, about 1875, with the condition of the rocks as they were in 1901, and could find no changes worthy of note.

Figure 31.—North Rocks. From a photograph taken by Mr. J. B. Heyl in 1875.

North Rocks in former times.

A comparison of several photographs taken at various times within the past thirty years shows but little modern alteration in the North Rocks, but some very severe storm might suddenly overthrow them. They are situated near the extreme edge of the outer reefs, about

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* Although the first stone fort was built here about 1620, the present ruined walls may date no farther back than 1812.

eight miles north from the islands. They stand on an extensive patch of flat reef, part of which is laid bare by low tides. The larger one is about 14 to 15 feet high, the second in size is about 10 feet. They are evidently the remains of an island of considerable height and extent that has been nearly worn away to the sea-level by erosion. But the ancient engravings indicate that the erosion, even in this exposed situation, has not been rapid.

Figure 32.—Reduced facsimile of the reverse of the ancient seal of the Bermuda Company, engraved on Norwood's map of Bermuda, published in 1626. It shows the wreck of May's vessel in 1593, alongside of North Rocks, which then appeared much as at present, but apparently higher and the two parts more nearly equal.

On Norwood's map of 1626,* in the two lower corners, are engravings of the seal of the original Bermuda Company. On the reverse side of the seal (fig. 32) there is a view of a wrecked vessel alongside of two high rocks, which are easily recognized as the two peaks or lobes of the main North Rock. The vessel, with broken masts, stands upright between the large rock and a small one that exists to

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* The map particularly referred to was made by Richard Norwood, before 1622. "A mapp of the Sommer Islands, once called the Bermudas." London, 1626. Reprinted from an original engraving in the British Museum, by Governor Lefroy in "Memorials of the Discovery and early Settlement of the Bermudas or Somer's Islands," London, 1877 (end of vol. I). A much less complete edition of this or an earlier map was published in 1624, in Capt. John Smith's "General History of Virginia, New England, and the Summer Ils."

A later survey and map by Norwood, completed in 1633, has also been reprinted by Gov. Lefroy, in the work cited, p. 644, but the shore lines are much coarser and less accurate in the latter, which was made mainly with reference to the transfers of land and the boundaries of estates.

the right and is therefore concealed by the hull of the vessel. In a photographic view (fig. 31) taken in 1875 by Mr. J. B. Heyl, a man stands where the vessel stood and the two views are apparently from nearly the same point. The two peaks of the rock are represented as being nearly equal in height, but now one is decidedly lower than the other. This ancient sketch, imperfect as it naturally is, corresponds fairly well with the outlines of the rocks, as seen in the photograph. It proves that these rocks have undergone no great change in general form and size since the early settlement of Bermuda, for this seal was probably engraved as early as 1618–20.

The sketch was very likely made by Mr. Norwood, for he was a man of good ability as a draughtsman, and was making his first survey in 1617. The scene evidently commemorates the wreck of a French vessel, the "Bonaventura," on the 17th of Nov., 1593, on board of which was one English seaman, Henry May, who published, after his escape to England, in 1594, an account of his experiences and a fairly good but brief description of these islands, which, up to that time, were known in England only as dangers to be carefully avoided. Those of the crew who were saved (about 26 persons), brought ashore their provisions, tools, and fittings of the vessel "before she split." They remained on the island five months, while they built a small cedar vessel of 18 tons, with which they sailed to the Banks of Newfoundland and joined the fishing fleet and were thus taken back to Europe. May, in his narrative, stated that when they went on the rocks, in the night, they supposed they were on the shore of the island, because of the "hie cliffs," but in the morning they found that they were "seven leagues" away from it. He also said that after building a raft they towed it ashore, "astern of their boat," and that "we rowed all the day until an hour or two before night yer we could come to land."

Several writers have been misled by this statement and have even imagined that they must have been wrecked on some far more distant island which has since been worn away or submerged.* But it is evident that May meant that it was seven leagues *as they had to row*, for they could not cross the reefs at that point, in the surf, and must have rowed along outside the reef till they reached the present ship channel and there entered the bay and landed, probably on St. George's Island. This would have caused them to row about seven

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* See Lefroy Memorials, vol. i, p. 9. Also Jones, Recent Observations in the Bermudas, and his Visitors' Guide, 1876.

leagues and would doubtless have taken all day with the boat heavily laden and towing a raft astern.

That there was no islet in the place of the North Rocks when the islands were first settled (1611) is evident from the fact that none is mentioned by the early chroniclers and none is represented on Norwood's accurate map of 1626. Indeed, it is recorded that Governor Moore (1612) made a voyage out to sea in order to find, if possible, an outlying island, but without success.* An island at this locality, even if small, could easily have been seen from the main island. Hence it would be safe to believe that the North Rocks were then not much larger than now, even if we did not have Norwood's sketch to prove it.

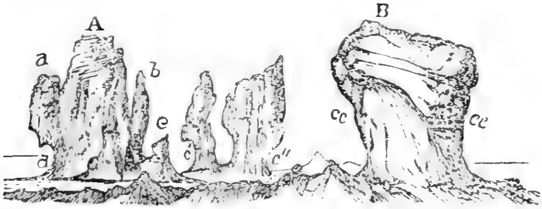

Figure 33.—North Rocks as drawn by Lieut. Nelson, about 1830, and published by Lyell, 1853. A, The largest rock, then 16 feet high, with two conspicuous side-lobes, *a*, *b*, and a small rock, *c*, near its base; *c'*, *c''*, two smaller rocks where but one now stands. B, Next to largest Rock, then about 12 feet high, strongly undercut at *cc*, *cc*.

In Lyell's Manual of Geology,† the author has reproduced a very interesting drawing of the North Rocks, made, as he stated, by Lieut. Nelson. Therefore, it dates from about 1830, for Nelson was the engineer in charge of the governmental works at Ireland Island in 1827 to 1833. This figure (see my fig. 33), if correct, shows that the North Rocks have changed somewhat during the past 75 years. The small rock, *c*, seems to still exist.

. The main rock has lost something from the height of the smaller peak (*a*, *a*), and one side-lobe seems to have been lost. One of the two rocks near it (*c'*, *c''*) has apparently disappeared; the only one that appears in that vicinity in the recent photographs (fig. 23) has a crooked form like *c'*. The rock *c''* seems to have been destroyed. The rock B, in the foreground of this sketch, is represented as rela-

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* See these Trans., xi, pp. 664, 665; "The Bermuda Islands," pp. 252, 253.

† Lyell, Sir Charles, Manual of Elementary Geology, several editions; in the American reprint of the 4th ed., 1853, the figure is on page 78.

tively larger than in the photographs, but this is evidently to give perspective for artistic effect. It has nearly the same shape as at present, but may have been somewhat larger. Lyell stated that it was then 12 feet high, while the main rock was 16 feet high. These are rather more than their present heights. Unfortunately the point of view in this sketch is not the same as in any of the photographs, so that no very close comparison of the cuts can be made. A comparison of the sketch, on the spot, with the actual rocks, would be useful. But it is evident that at least one of the smaller rocks has disappeared. The wonder is that the changes have been so small in this very exposed situation.

This drawing, therefore, confirms my conclusions, derived from other evidence, that the rate of erosion is here very much slower than has been supposed.

Great Storms ; Hurricanes.

The Bermudas are frequently visited by severe storms, and occasionally genuine West Indian hurricanes reach these islands and do great damage to buildings, shipping, trees, crops, etc. But as the dwellings are almost all of limestone blocks, and solidly built, they are seldom entirely demolished and for that reason there is seldom any loss of life, though in the storm of Sept. 28, 1903, two men were killed.

Such storms are of special geological importance, for they effect more changes in the shore cliffs and beaches in a few hours than would occur in many years of ordinary weather. Unfortunately no geologists or other persons sufficiently interested have been on the spot to record such changes as have occurred along the shores and outer reefs, at such times. Such facts as are recorded usually relate mostly to the damage to property, or to the shores of the more sheltered harbors.

In Part I of this series* I have given some details of the effects of the hurricane of Sept. 12, 1899, in which the long causeway was destroyed (see also, p. 127, above), and much other damage was done all over the islands. But yet there is scarcely anything recorded of the changes that it wrought on the exposed cliffs, though such effects were sufficiently obvious a year later, all along the southern shores.

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* These Trans., xi, pp. 442, 496, 497: "The Bermuda Islands," pp. 80, 84, 85 where other similar hurricanes are also recorded.

A later great storm or hurricane occurred Sept. 28, 1903.* Though it was of comparatively short duration, it also did a great amount of damage. At the height of this storm, which was about noon (12.30 P. M.), the wind had a recorded velocity of 74 miles, from the northeast; after it shifted to the northwest it had a velocity of 40 miles, at 3 P. M. It was accompanied by a very heavy rainfall, which washed away the roadbed in many places. Large numbers of cedar trees were uprooted, many large palmettoes were broken off, the banana crop was ruined, and numerous public buildings and private dwellings were damaged. A number of stone docks and sea walls were badly damaged or destroyed, and many boats were wrecked. Not much was said in the papers of the effects on the shore cliffs, but in the Royal Gazette for Oct. 10th the following item appeared:

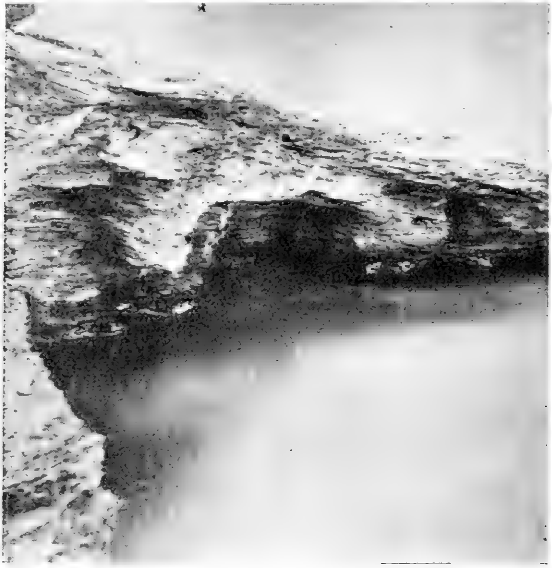

Figure 33*a*.—Undercut cliffs at Clarence Cove, near the location of the great landslide of Oct. 6, 1903.

"On the North shore of Pembroke Parish—from Spanish Point toward the Ducking Stool—the rugged cliffs in several places show the effects of the fierce onset of mighty billows during the late hurricane. Huge pieces, wrenched up and swept away, have left

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[*] See "The Colonist," of Sept. 30, 1903, and "The Royal Gazette," vol. xxxviii, No. 80, Oct. 7, 1903, p. 1, for details.

white, staring gaps in the dark rocks as a reminder, for many a day to come, of the visitation."

A week after this storm the great landslide at Deep Bay occurred, hastened, no doubt, by the effects of the great sea-waves of the storm. (See below.)

During such storms, and even in those of much less violence, the fine calcareous mud of the shallower bays and sounds is so thoroughly stirred up that the water becomes milky white everywhere, and when this sediment settles it must make layers of notable thickness.

Landslides.

Owing to the undercutting of the cliffs, great masses weighing many thousands of tons sometimes suddenly slide off into the sea, causing a great commotion. One of the latest of these landslides happened at Deep Bay, near Hamilton, Oct. 6, 1903, a week after the hurricane of Sept. 28.

Figure 33*b*.—Cavernous and undercut cliff at Clarence Cove.

An account of it was published in the Royal Gazette for Oct. 10, 1903, as follows :—

"At 'Deep Bay,' near Admiralty House, on Monday, about midnight, (just one week after the storm) a large portion of the cliff, some 60 feet deep, and from 35 to 40 feet in width, toppled over into the sea with a thundering reverberation, resembling very much the sound of a shock of earthquake. For years—in fact beyond the memory of the oldest heads in the vicinity—there has existed an irregular-edged crevasse at the place where the final break occurred, nearly semicircular in shape and some eighty feet in length, and from two to three feet wide at the top, locally known as 'the crack,' and although it could not but be evident to the most casual observer that the fracture of the rock was complete throughout, its collapse was regarded as a far remote possibility by the North-siders, notwithstanding its very perceptible inclination seaward, no one of whom feared to step across on to the leaning cliff, and walk, amid sage-brush and scrub-cedars, to its dizzy edge, even children fearlessly invading it in their gambols."

The fallen masses of stone at other places indicate similar landslides, but I was not able to learn the dates of any others of importance. They often seem more recent than they really are, and most of them have apparently not occurred within the remembrance of the inhabitants. Among those that appear to be comparatively recent is the mass of angular blocks at the base of Abbot's Head (fig. 21).

Earthquake shocks, even if not very severe, might loosen many of these undercut masses. But, as stated in my former work,* very few earthquakes have occurred here in modern times, and those were of but little importance. Those recorded occurred in 1664, 1801 and 1843. According to the local newspapers† a slight earthquake occurred on July 27, 1903, between 5 and 6 A. M., at Paget East.

Silting of Harbors; Ancient Maps.

That some local changes in the depth of certain harbors have taken place since the early settlement of the islands is certain. In some cases this has been connected with the drifting of sands from the land into the sea, as at Tucker's Town, where the sands from the dunes on the south shore drift across the narrow neck of land into Stokes' Bay, on the Castle Harbor side. This small bay or harbor is now very shallow, with broad sand flats exposed at low tide. It is said that in the early days of Bermuda small vessels in the West Indian trade could anchor in this harbor.

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* These Trans., xi, p. 510; "The Bermuda Is.," p. 98.

† See Royal Gazette for July 28, 1903.

The changes in Shelly Bay, referred to by Nelson, also seem to have been connected with the drifting of sand and will be referred to under that head (Chapter 23).

The small harbor at the Flatts has been subject to many changes, owing to the swift tidal currents, which are continually moving the sands, combined with the effects of storm waves, which often work against the tides. There have been periods in the past when it was used as a harbor for trading vessels, but it is now much obstructed by sand bars. However, in very early times the same thing occurred, for in 1629 there is a record of the payment of 50 pounds of tobacco to Thomas Emmet for "digging the channel at the Flatts mouth," which had become obstructed by the formation of a sand bar, even then.* Nelson, 1840, said of it:

"The Flatts Inlet, entrance to Harrington Sound, is perceptibly filling, notwithstanding the benefit it receives from the Sound as a backwater." The same condition still exists. It is a locality of shifting sand bars.

Nelson, 1840, also made the following observations, which are still applicable:

"Thus at the head of Crow-lane, Bermuda or Main Island, within the memory of the present generation, ships of some burthen used to lie at wharfs, where now scarcely a large boat can repair at all tides. The same has occurred in the narrow channel between Ordnance Island and the Market-wharf at St. George's, but to a far greater extent."

However, on the whole, the changes since the first accounts were written, about 300 years ago, have been small and local, and entirely insufficient to materially alter the general form and character of the islands and reefs. The following account† applies perfectly well at present. It is also of special importance as indicating the condition of the outer reefs and channels at that time, thus showing that there cannot have been any notable changes in level, nor any extensive changes by erosion:

"And thus conditioned rest thes small ilands, in the midst of a huge maine ocean, whose violence is borne of and broken in the north-east side by infinite numbers of uncertaine rocks, being shallowely hidd for three leagues out at sea. As to the southwarde of

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* See these Trans., xi, p. 435: "The Bermuda Islands," p. 23; Lefroy, Memorials, p. 489.

† Published in 1610, by Wm. Strachy. (A true Repertory, etc.)

them is found a continued ledge of the same mettall within halfe a league of the shore, servinge to the same purpose on that side, the which betwixt them (leavinge noe open approach to any part of the shore which vessels of any burthen, save only through thoes two channells which greatly, gently and peaceably conveye the benefitt of the sea through the straight and narrowe mouthes of the two harbours into the large bosome of the firme and rocky earth) prove thereby so terrible and sure a fortification against all invasive attempts that waye, as by haveinge some sort art added unto them at the harbours mouthes since the plantation, they cause the whole peece to become as fully impregnable, and as easily to be defended against any ennemye as (I think) any one in that nature of Christiandome."

Ancient Maps.

Strachy refers to a map of the islands, made by Admiral Somers while detained there by the shipwreck, in 1609.* That map was never published and was probably lost soon after it was made. It would be of great interest now.

But Richard Norwood, a very competent surveyor, was employed by the Bermuda Company from 1615 to 1622, to make a careful survey and map of the islands. His first map, published in 1626, and a later one, made by him before 1633, are still in existence, and both have been republished.†

I have carefully compared these early maps with the most recent Admiralty charts and with other maps made during the past century. The changes in outlines are very slight. In some cases small bays or coves have been converted into lagoons by the formation of sandbars across the mouth. In other cases such bars have apparently been washed away, converting a small lagoon into an open cove. These are phenomena that are common on all sandy shores, and may take place during a single severe storm.

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* "For no greater distance is it from the Northwest Point to Gates his Bay, as by this Map your Ladyship may see, in which Sir George Summers, who coasted in his Boat about them all, tooke great care to expresse the same exactly and full, and made his draught perfect for all good occasions, and the benefit of such, who either in distresse might be brought upon them, or make saile this way."

† See page 129, foot note, for more details of these maps. A later careful survey was made about 1730 by Lempriere, whose first edition I have not seen. It was republished in "The West Indian Atlas," by Thos. Jeffreys, London, 1780.

The variations from the present outlines are, in most cases, no greater than might be due to slight inaccuracies of the surveyor or engraver. Thus the maps confirm the conclusion that changes due to erosion are here very slow.

22. *Origin of the Shell-sands.*

Until quite recently most writers called the calcareous sands of Bermuda "coral sands." Nelson was probably the first writer to definitely state that the sands are mainly derived from small shells. Mr. A. Agassiz considered them as mostly derived directly from the disintegration of the æolian limestones of the reefs and cliffs, though ultimately derived from shells, corallines, etc. According to our studies, the sand and mud of the sounds, bays, and shores are mostly shell-sand, whenever the materials are coarse enough to be identified. But in the deeper parts of the harbors and sounds there is a large admixture of calcareous mud, so finely divided that its origin cannot be determined directly.* As all gradations exist between such fine particles and those that can be recognized as fragments of minute shells, it is pretty safe to assume that a corresponding percentage of the fine material is also of shell origin. That a considerable part of the sand and mud is, in many places, the detritus of eroded rocks, especially near the shore cliffs, is very evident, but the proportion is probably much smaller than Mr. Agassiz supposed. Therefore there is reason to believe that the total mass of material is increasing, not diminishing as some have supposed.

We collected large amounts of the bottom materials from numerous localities for study, with reference to their origin. Among the localities were Murray Anchorage, Bailey Bay, Great Sound, Harrington Sound, Castle Harbor, etc., in depths of 1 to 10 fathoms, as well as on the shores.

They were all rather similar, though differing much in fineness, and especially in the relative amount of impalpable mud. When the fine mud is washed out through fine sieves, the sand-like material that remains consists, in nearly every case, mainly of small broken shells, together with many entire specimens, living or recently dead.

More than 50 species of these small shells can often be picked out from a single sample of mud, after washing. In most cases the small

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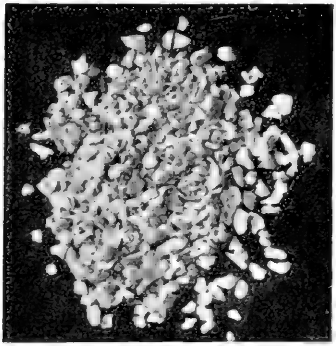
* See also Verrill, Notes on the Geology of Bermuda, Amer. Journ. Science, ix, pp. 328–331, figs. 8, 9, 1900, and Moseley, Notes by a Naturalist on the Challenger, 1879.

bivalves are in excess of the univalves, though more of the latter are entire.* (See figures 34*a*, 34*b*, and pl. xxiv, figs. 1, 2.)

Part of the small shells are the young of larger species, but the greater number never grow large. Such small species (pl. xxiv) are probably annual, or at most biennial, and reproduce rapidly, so that their total increase in bulk is greater than that of larger shells with slower rates of growth and reproduction. But fragments of larger shells are also found in considerable numbers in most samples, especially in those from the shores and very shallow waters.

34*a*.



34*b*.

Figure 34*a*.—Washed shell-sand from off Bailey Bay, in 4 fathoms. ×1½.
Figure 34*b*.—Washed shell-sand from main Ship Channel, in 6 fathoms. ×1½.

In many localities, near the reefs and rocks, fragments of *Vermetus* and allied genera occur in considerable quantity. One of these, *Tenagodus*, or *Siliquaria*, *ruber*, is red and often imparts a reddish tint to the sand. In other cases the reddish tint is due mostly to fragments of *Spondylus*, *Tellina* and *Chama*, and to the sessile foraminifer, *Polytrema miniaceum*, which is common on dead corals.

In nearly all the samples of fine sand a very small percentage of diatoms, spicules of gorgoniæ and of sponges, and shells of ostracodes could be found, and also, occasionally, a few radiolarians, but such organisms collectively would usually not make up a tenth of one per cent. of the material.

Fragments of corallines, or calcareous algæ, of the genera *Halimeda*, *Udotea*, *Lithothamnion*, etc., are usually common, especially near the reefs, and often form an important element. Foraminifera

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* Numerous species of these small shells were described and figured by Verrill and Bush,—these Trans., vol. x, pp. 513–544, pls. lxiii–lxv, 1900; and "The Zoölogy of Bermuda," article 3, reprint.

of several species are also common,* and also fragments of starfishes, echini, and other echinoderms. Fragments of calcareous worm-tubes of the Serpula family are also common in the deposits from near ledges and reefs.

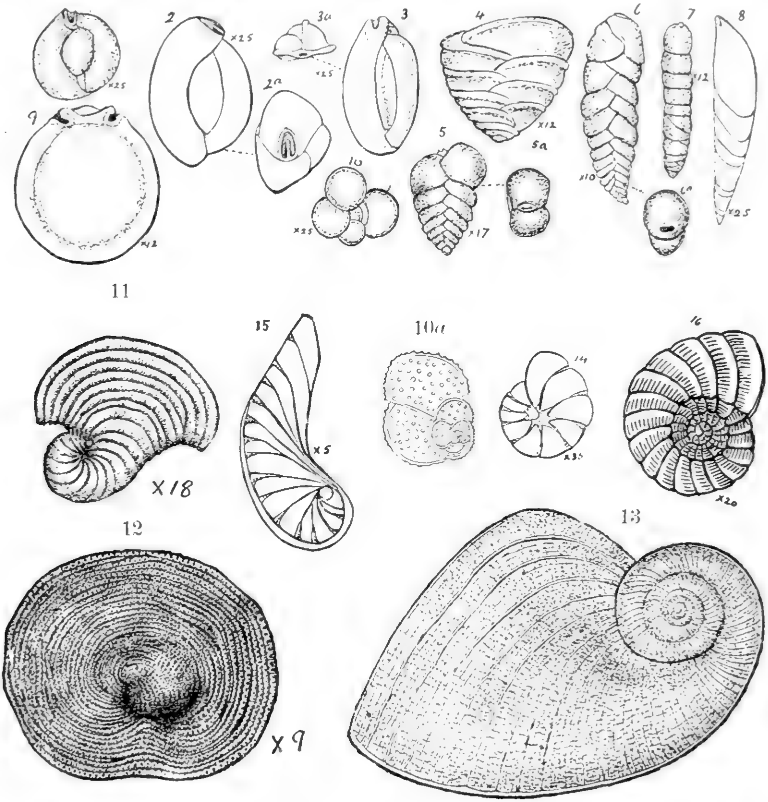

Figure 35.—Bermuda Foraminifera. 1, *Miliolina circularis*, side view; 2, *Miliolina seminulum*, side view; 2*a*, end view; 3, *M. pulchella*, side view; 3*a*, end view; 4, *Textularia trochus*, side view; 5, *T. concava*, side view; 5*a*, end view; 6, *T. luculenta*, side view; 6*a*, end view; 7, *Clavulina communis*, side view; 8, *Nodosaria mucronata*, side view; 9, *Biloculina ringens;* 10, *Globigerina bulloides*; 10*a*, the same, with bases of spines remaining; 11, *Orbiculina adunca*, young; 12, the same, adult; 13, *Cornuspira foliacea*, × 8; 14, *Nonionina depressula;* 15, *Cristellaria compressa;* 16, *Peneroplis pertusus;* Figs. 1–10, 14–16, after Brady; 11–13 after A. Agassiz.

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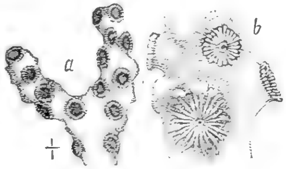
* Among the common species are *Orbiculina adunca*, *Orbitolites marginalis*, *O. duplex*, *O. complanata*, *Orbulina universa*, *Miliolina circularis*, *M. venusta*, *M. seminulum*, *M. pulchella*, *Cornuspira foliacea*, *Textularia concava*, *T. luculenta*, *T. trochus*, *Ammodiscus tenuis*, *Clavulina communis*, *Peneroplis pertusus*,

Fragments of corals are usually few in number, even in the vicinity of the reefs. The most common form is the slender branched hydroid coral, *Millepora alcicornis* (fig. 36 and pl. XXX A), which is abundant on all the reefs and is easily broken. Of the true corals, fragments of the slender branched *Oculina diffusa* (fig. 36*a*) are occasionally found, and in some localities the thin edged shade-coral, *Agaricia fragilis*, occurs in the form of thin fragments. Fragments of the more solid or massive genera, such as *Porites*, *Mussa*, *Mœandra*, *Orbicella*, etc., are rare in the mud and sand, even near the reefs.

36

36*a*



36*b*

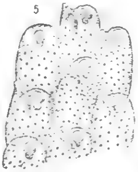


Figure 36.—*Millepora alcicornis*, branches, $\frac{2}{3}$ natural size.

Figure 36*a*.—*Oculina diffusa*, branch with expanded polyps, natural size; *b*, the same, more enlarged. After Agassiz.

Figure 36*b*.—*Schizoporella Isabelliana*, group of cells, much enlarged.

Bryozoa of several kinds are often met with in some localities. One of the most common forms is a thin encrusting species of *Biflustra*, which grows abundantly on the stems and fronds of floating *Sargassum*. Another common species is *Idmonea atlantica* (fig. 36*c*), which grows abundantly on the reefs in slender branched forms with tubular calicles. Some larger or more solid foliaceous species also occur not infrequently. Among these is a species that at first forms thin crusts on rocks and dead corals, but later often becomes massive, or has tubular, pink-tipped branches (36*b*).

In shallow water near the shores land-shells are rather common in the sand. Among those found were *Pœcilozonites bermudensis*, *P. circumfirmatus*, *Polygyra microdonta*, *Subulina octona*, *Rumina decollata*, *Helicella ventricosa*, *Helicina convexa*, *Truncatella cari-*

Biloculina bulloides, *B. ringens*, etc. For much longer lists of the Bermuda Foraminifera, see Woodward, Journal New York Microscopical Society, 1885, p. 147, and Brady, Voyage of the Challenger, Zoology, vol. ix, with a volume of plates. Most of the species are described and figured by the latter. The thin circular and subcircular disks of *Orbitolites*, *Orbiculina* and *Peneroplis* are among the largest and most common forms. For fossil species, see chapter 24.

bœensis. All these are common species which can easily be washed into the sea by rains or blown by the winds. Seeds of land plants occurred in small numbers in the same localities.

Near the ship-channels there was usually a considerable per cent. of small fragments of coal and cinders. The latter were usually decomposed, partially or wholly, to small reddish lumps of red clay, often soft enough to be easily crushed between the fingers. In some samples from off Bailey Bay, such fragments of cinders constituted about 10 per cent. of the washed material.

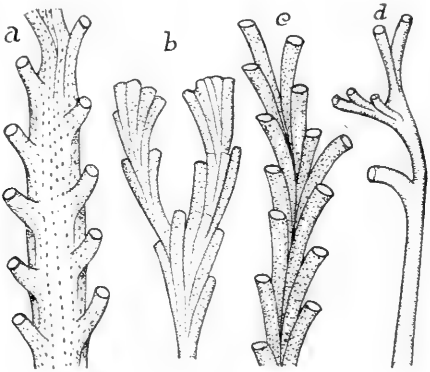


Figure 36*c*, *a–d*.—*Idmonea atlantica*, branches of different sizes and shapes; much enlarged. Drawn by A. H. Verrill.

An average sample of the bottom from Bailey Bay, in 6 fathoms, had about the following proportions; Impalpable and very fine mud, 60 per cent.; coarse materials, such as fragments of larger shells, bits of limestone, etc., 5 per cent.; shell-sand stopped by the finer sieves, 35 per cent.

The washed shell-sand was estimated to consist of the following average percentages:

Small shells, entire and broken	65
Corals, Millepora, etc.	3
Corallines	8
Bryozoa	1
Echinoderms	0.5
Foraminifera	5
Other organisms	0.5
Limestone detritus	8
	100

In some samples the shells formed at least 90 per cent. Of course such estimates can be only approximate, for no two lots would be just alike. Some of the most abundant species of small shells commonly found are shown on plate xxiv, figures 1, 2.

In the channels and passages between the islands, and especially on shallow bars, where there are active currents and wave action, the fine calcareous ooze is washed away more or less completely and the bottom usually consists, in such places, of nearly clean shell-sand, which may contain numerous living and dead foraminifera, amounting, in some cases, to 10 or even 20 per cent., while in the immediate vicinity of reefs the fragments of calcareous algæ may sometimes amount to 25 per cent. or more, and in such places the fragments of *Millepora, Oculina*, etc., may rise to 20 per cent. or more, in some instances.

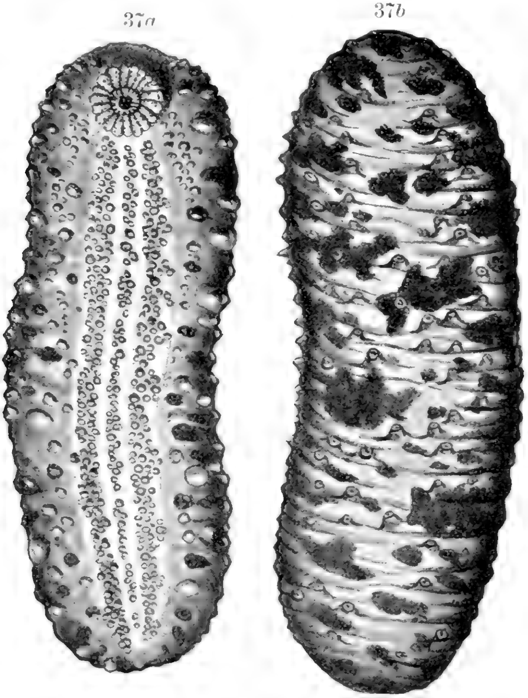


Figure 37*a*.—*Stichopus Möbii*, spotted variety, ventral side, ⅓ natural size.
Figure 37*b*.—The same, dorsal side. Drawn from life by A. H. Verrill.

In the sheltered harbors and more or less enclosed lagoons, especially in the deeper parts, where there is but little wave action, the fine ooze that is washed out from other places settles down and forms a soft, more or less coherent, whitish, grayish, or yellowish mud, that Mr. Agassiz called "marl." In such localities there are comparatively few living organisms, except some small foraminifera, though the common sea-urchin (*Toxopneustes*), the black holothurian (*Stichopus*), and various annelids may also flourish in large numbers. Such bottoms occur in Harrington Sound, Hamilton Harbor, Great Sound, St. George's Harbor, etc.

In some cases part of this ooze or mud has probably been washed in from the shores by rains, and in that case it comes from the old æolian limestones, as Mr. Agassiz claimed. But I am disposed to believe that most of it is recent and of the same origin as the coarser particles. The rocks and soil here are so porous that there is but little running water, even during rains. But during heavy storms, especially when of some duration, the water over all the sounds often becomes milky with this fine ooze that is stirred up from the bottom by the wave-motion. It sometimes does not clear up for a day or two. At such times great quantities of the fine sediment is deposited in those places where the water is most quiet and thus the ooze sometimes accumulates very rapidly.*

The broken condition of the larger part, even of the smaller shells, and the finely comminuted mud are probably largely due to the fact that the shells, and even the mud in bulk, are the food of various marine animals. Indeed, it is probable that most of this sand and mud has more than once passed through the digestive organs of the mud-dwelling forms of life, and in this way the shells have been broken into small fragments or reduced to powder.

One of the most important species, for this kind of geological work, is a large holothurian (*Stichopus Mōbii*),† which occurs in great numbers on all the white muddy bottoms. (Figures 37*a*, 37*b*.)

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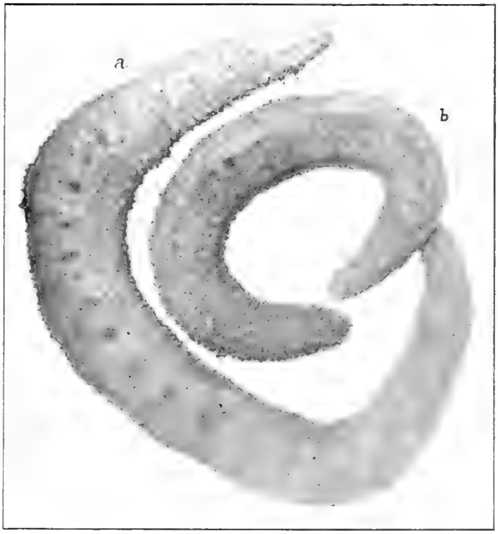
* This fine calcareous mud is carried out to sea many miles by the tides and currents, for it largely covers the submarine slopes of the Bermuda mountain at all depths down to 2475 fathoms, and as far away as 43 miles, according to Thomson. He states ("The Atlantic," i, p. 289), that the Challenger sounded on the slopes of Bermuda at 120, 780, 950, 1820, 2250, and 2475 fathoms, and at all these places the bottom material consisted largely of "soft, white, calcareous mud, evidently produced by the disintegration of the Bermuda reef and of the multitude of pteropod shells that sink down from the surface."

† Several other names have been given to this species. The scarcer variety, which is yellowish or brownish with large black spots, agrees best with *Möbii* Semper, of the West Indies. It was later named *S. xanthomela* by Heilprin. The abundant black variety was named *S. diaboli* by Heilprin, but it seems to be only a color variety. The name, *diaboli*, may well be retained to indicate the common black form, as a variety.

This is usually nearly or quite black in color, though sometimes spotted, and is 10 to 15 inches long and 3 to 4 inches broad. It is, therefore, very conspicuous when the white bottom is viewed with a water-glass.

This creature, like all the larger holothurians, has a large convoluted intestine, which is always found crammed full of the bottom mud, from which it digests out any nutritive material that it may contain, but the inert residue is passed out in great quantities and mostly in a state of fine division. Another large holothurian, but much more slender (*Holothuria Rathbuni*) lives buried in holes beneath the surface of the mud, but feeds in the same way. It is often 15 inches in length and pale rusty brown in color with darker brown blotches.*

38



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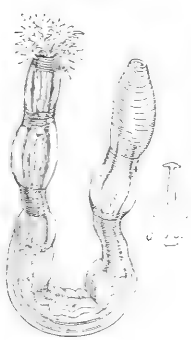

Figure 38.—*Holothuria Rathbuni*, 1/3 natural size. Phot. by A. H. Verrill.

Figure 39.—*Synapta roseola*, Pink Synapta, about 1/2 natural size; *a*, one of the dermal anchors much enlarged.

Several other smaller and more slender burrowing holothurians, which commonly occur, belong to the genera *Synapta* and *Chirodota*.

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* These Trans., vol. xi, p. 37, pl. i, figs. 6, 7; Verrill, Zoölogy Bermuda, I, art. 10, pl. I, figs. 6, *a*, *b*, 7, 1901.

Among them are *S. roseola* (fig. 39), *S. inhærens*, *S. acanthia*, and *C. rotifera*. All of these swallow the mud in bulk, picking it up with their oral tentacles, which they use like hands while feeding.

Some of the sea-urchins which live on these bottoms have the same habit of feeding on mud and sand in bulk, while others select with more care the small living mollusks. The most important of these is *Toxopneustes variegatus* (fig. 40), a round species, 2 to 4 inches in diameter, thickly covered with dark purple, violet, or brown spines. It is everywhere abundant on the muddy and sandy bottoms, often associated with the large *Stichopus*, feeding in the same way. A larger but much less common species, *Hipponoë esculenta*, has the same habit. Its spines are shorter and nearly white.

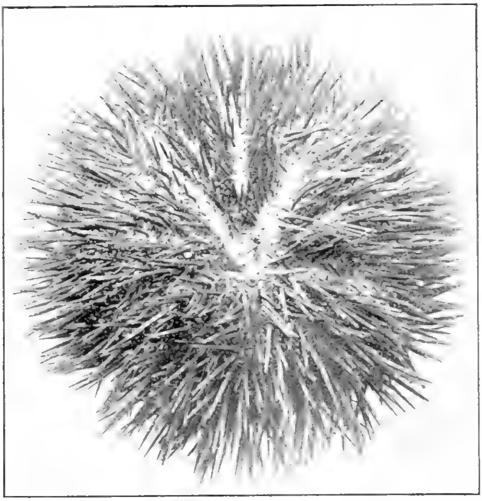

Figure 40.—*Toxopneustes variegatus*, ⅔ natural size. Phot. by A. H. Verrill.

In certain localities a flat "cake-urchin" or "sand-dollar," with six perforations (*Melitta sexforis*), is abundant and feeds on the sand.

A large starfish, with five long flat rays, is common in some places, living under the surface of the sand. It is remarkable for the rapidity with which it can glide along, using its numerous large ambulacral feet as paddles or oars for swimming or gliding, while concealed just under the loose sand. It feeds on small mollusks. This is the *Luidia clathrata*, common also on the Carolina coasts. A very common ophiuroid (*Ophionereis reticulata*), with long, slender arms and a pale yellowish body, reticulated with brown lines, also lives in the sand and under stones.

Annelids of many kinds* also swallow the mud and sand with little selection, while others pick out, with their prehensile organs, the small living mollusks, etc. Among the larger forms burrowing in the sand are *Arenicola cristata* (fig. 41) and *Eupolymnia magnifica* (plate xxxv, fig 1, *a*); also the "blood-drop" *Enoplobranchus sanguineus* Ver.

The first is often 12 to 15 inches long and nearly an inch in diameter. Its color in life is dark olive-green or blackish green, with dark red plumose gills. It is common on most of the sandy bottoms in shallow water and at low tide. It makes large and deep burrows, which often have large coils of mucus at the entrance. The second is nearly white, with a body more than a foot long. Its numerous white, slender, prehensile tentacles, which spread out in every direction, are often more than a foot long. Its intestine is usually so filled with mud and sand that the delicate walls of the body will burst when it is taken from its burrow. It builds in the burrow a large and rather delicate tube usually consisting mostly of small bivalve shells, both entire and broken, loosely cemented together. The tube is concealed in the sand or under stones in sandy places. It selects such materials with its tentacles and puts them in place with the same organs.

Figure 41.—*Arenicola cristata; a*, profile; *b*, dorsal view; ⅓ natural size: Phot. by A. H. Verrill.

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* Many of the annelids were described by me in these Trans., vol. x, pp. 595–670, 1900.

Another large species (*Cirratulus grandis*) is olive-green or yellowish brown, with numerous long reddish cirri (fig. 42). The large *Pectinaria regalis*, which constructs a remarkable portable, cornucopia-shaped tube of shell-sand, the particles regularly cemented in a single layer, is common.* Many smaller species, with similar feeding habits, are abundant in the mud and sand, and must make large contributions to the deposits of fine materials.

Many species of crabs found there, and also other crustaceans, feed largely on small mollusks, usually crushing the shells with their strong claws, thus contributing to the shell-sand. Many of the univalve mollusks (*Gastropoda*) feed on bivalves, usually drilling a hole in the shell through which they suck the blood. The well-known "drill," which is so destructive to young oysters on the American coast, is a good example. Many related species with similar habits are found in Bermuda. There are also many fishes, abundant there, that feed on small mollusca and other calcareous bottom organisms and thus contribute to the formation of the fine mud.

Figure 42.—*Cirratulus grandis* V., nat. size. Drawn from life by A. E. Verrill.

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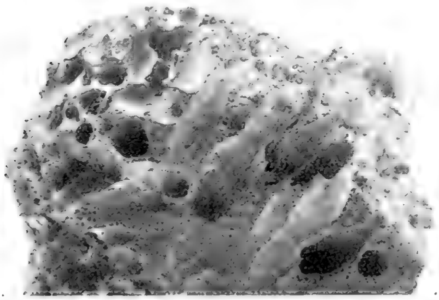
* These Trans., vol. xi, p. 38, pl. viii, figs. 6, 7, 1901.

The rough and corroded appearance, often noticed on the surface of broken shells, is due, without much doubt, in nearly all cases, to the action of the digestive fluids of fishes and other animals that swallow the mollusks. In some instances similar effects may be due to acids generated by decaying vegetable matters, with which they have been in contact at the bottom.

That no appreciable loss of the coarser bottom materials occurs through solution is evident, for if the carbonated waters were not already saturated, they would surely first dissolve the impalpable calcareous mud, which is everywhere present in larger or smaller proportions, and thus speedily become saturated with lime. Nor is there evidence that solidification of these sediments is taking place anywhere beneath the sea, by the deposition of the calcium carbonate from solution.

43



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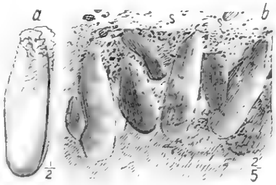

Figure 43.—Borings of *Lithophagus appendiculatus*, in hard limestone, about ½ natural size.

Figure 43*a*.—The same ; *a*, one of the shells removed.

The breaking up of the massive corals and the larger shells is due largely to the action of various kinds of boring creatures, which penetrate the basal and older parts of the corals and the thicker parts of shells and gradually weaken them till the action of the waves can reduce them to fragments. Specimens of the common brain-coral are sometimes found five to six feet in diameter. These are probably more than 150 years old.* They would doubtless grow

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* So far as known there is no definite limit to the duration of the life of the large compound corals. Were it not for accidents and enemies, such as borers, they might live a thousand years or more, for aught that we know to the contrary. As it is, some of the Pacific massive corals become 20 to 30 feet or more in diameter, indicating ages of 500 to 800 years.

much larger were it not for the undermining of their bases by boring sponges, mollusks, annelids, etc.

Among the most common and important of the borers are bivalve mollusks of the genus *Lithophaga*. One of these, a dark brown or black species, about 2 inches long (*L. nigra*), is very common in the bases of large corals. Other species with the same habits are *L. appendiculata* (fig. 43, 43*a*) and *L. bisulcata*. Other boring bivalves common here are *Gastrochæna rostrata* and *Coralliophaga coralliophaga*.*

Several species of annelids are constantly found in irregular burrows and tubes in the dead or partly dead corals, but it is uncertain, in most cases, whether they make the burrows or simply occupy those made by sponges and mollusks. Several large species of *Leodice*, *Marphysa*, *Nicidion*, etc., are particularly common and with other forms found in corals will be referred to later, in discussing the life of the reefs. See chapter 30.

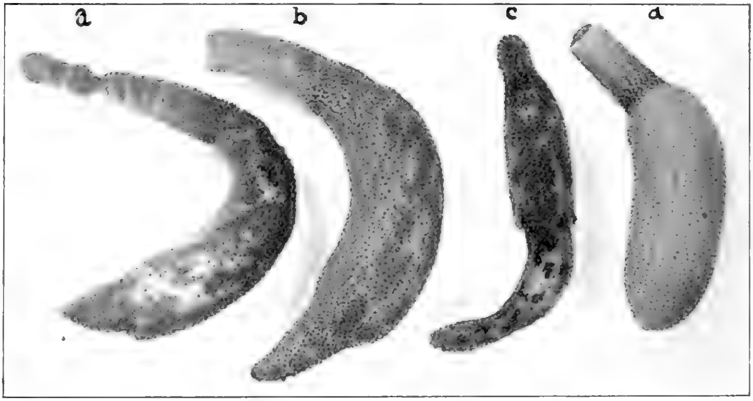

Figure 43*b*, *a–d*.—*Physcosoma varians;* from corals, showing different color varieties and states of contraction. Phot. by A. H. Verrill.

Several species of Gephyreans also occur. One of these, *Physcosoma varians* (fig. 43*b*), which is very common, seems to be a true borer, but may be only an intruder.†

Certain species of siliceous sponges are among the most destructive of the boring animals that attack corals and shells. They make

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* See these Trans., vol. x, pl. lxiii, figs. 9, 10.

† See these Trans., vol. x, p. 669; Verrill, Zoölogy of Bermuda, art. 9, p. 669, 1900.

irregular branched burrows of all sizes, finally reducing the coral, shell, or even hard limestones, to a mere honeycomb, easily crumbled by the waves. They mostly belong to the genus *Cliona.* One such species (*C. sulphurea*), common on the American coast, from Cape Cod to Florida, is famous for its destructive borings not only in the shells of oysters, etc., but even in hard marble.

The related Bermuda sponges have not yet been determined specifically, but they are abundant and destructive.

One of the common reef dwelling sea-urchins (*Echinometra subangularis,* pl. XXXIV, A, has the remarkable habit of forming cavities or holes for itself in the solid limestones. Even when it becomes 3 to 4 inches in diameter the holes just fit its form.

23. *Modern Sand Dunes and Peat Bogs.*

In recent times the activity of the drifting sands has been quite variable, depending mainly on the effects of the vegetation that borders and encroaches upon the dunes.

It is singular that none of the early settlers, who wrote such full descriptions of most of the other features of Bermuda, say anything definite about the drifting sands, which later became a conspicuous feature. Neither are areas of barren sands indicated on the early maps of Norwood (1626–1663). Though there is mention of some barren sandy lands on Ireland Island in the early records,* the district about Tucker's Town was cultivated, and from the records appears to have been fertile, for it is mentioned that Governor Tucker (1616) planted figs and pomegranates there.

Therefore it is probable that at the time of the first settlement of the islands (1611) the native vegetation, especially the cedars, had so fully covered the soil that the sands no longer drifted to any great extent, except close to the shores, and so did not attract attention. At the time when Lieut. Nelson wrote (1833–37) the drifting sands had attained considerable importance, and he mentions that the drifting, in the vicinity of Elbow Bay, had begun about 70 years previously (about 1763), and at Tucker's Town about 1773. His account is as follows:—

"The proprietor of the principal part of the land of this bay, the venerable Captain Lightbourne, remembers an attempt about seventy years ago, when the inhabitants expected an attack from the French and Spaniards, to form a breastwork along the sand hills which

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* See these Trans., vol. xi, pp. 476–479; "The Bermuda Islands," pp. 64–67.

then, as at Shelly Bay, skirted the coast. In doing so they cut through the natural protections given by the sea-shrubs and creepers which usually abound in such places. From that day the sand, supported by constant supplies from the sea, has steadily proceeded up the hill to the very summit, a height of 180 feet. It is, however, surprising to observe the singular state of arrest under which the invader stands before the children of the soil. A few straggling cedars, widely scattered in advance of the wood which now bounds the space, have been passed by this sand flood, yet the dazzling, dry, and almost snow-white sand is checked, before the front rank of the trees, in a steep bank, varying from ten to twenty five feet in height, and so remarkably well defined that scarcely a particle is scattered beyond a distance of 20 yards. Although this inroad commenced so long ago, yet the principal advance has been since 1807, from which date about 200 yards have been gained on the eastern side. Before I left the colony in March, 1833, the sand had reached the northern corner of a cottage belonging to a man called Ned Keel (on Mr. Butterfield's estate) and the top of the bank, eight feet high, was on a level with the eaves of the shed. During the last fourteen years it has progressed, at this point, only about forty yards, in a bed from four to eight feet deep, in consequence of the repulsive action

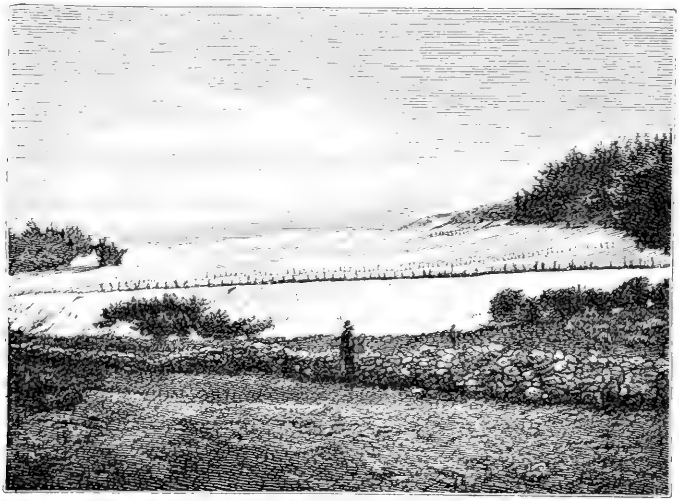

Figure 44*a*.—Drifting sand, or advancing "sand glacier," at Elbow Bay, about 1873. After Thomson.

of a thin belt of cedars just below. Very near this spot also, is a small circular group of the same trees, which the sand has passed, and imbedded to the depth of from six to eight feet; but the space within has been so perfectly screened, that the bottom of this little oasis is the natural green-sward."

"There is another encroachment at Tucker's town, said to have taken place about sixty years ago; it has crossed the neck between Harrington's Sound and the sea; but beyond this it does not seem inclined to move. The sand has not been stopped at the eastern extremity of this beach, where the bluffs commence, by their very considerable declivity,—though it has been most effectually at the crest of the slope, by a natural fence of sage bush, growing partly in the soil and partly in the sand; which as it ascended, seems to have thus rolled on with the seeds of destruction to its progress in its own bosom."

When J. M. Jones wrote (1866–72), the drifting sands were still quite active near Elbow Bay, as quoted in my former paper (vol. xi, p. 474), and nearly the same conditions evidently existed at the time of the visit of the Challenger, in 1873. When Jones wrote, a small cottage had been buried by the sand, the top of the chimney alone being visible.* This chimney and the moving sand dune or "sand-glacier" were figured by Thomson in the Voyage of the Challenger; The Atlantic, vol. i, p. 310–13, figs. 74–76.

But Jones stated that even in his time the activity of the moving sands had greatly diminished, as compared with 1850, owing to the vegetation. Stevenson, in 1897, stated that the sand had advanced but little at Elbow Bay in the previous 20 years.

Probably the modern activity in the drifting of the sands was brought about in most cases by the reckless cutting of the cedars and the burning of the brush, combined, perhaps, with the disturbance of the surface soil to make roads or build forts, near the shore.

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* The description of this locality by Jones, 1876, p. 81, is as follows:

"On arriving at the north-east corner of the sand-hills, the encroachment of the drifting sand will at once be perceived; as the mass, some ten feet in depth, is now gradually covering a small garden. According to the observations made by persons residing close to, this overwhelming body has advanced over the cultivated land about eighty yards, during the last twenty-five years. At the N.E. corner of the hills, will be seen among some oleander trees near the top, the chimney of a cottage which formerly stood there, inhabited by a coloured family. It is now wholly buried in the drifting sand, save the chimney; which alone rises above the mass to show the position of the structure."

Lieut. Nelson also described the changes that had occurred at Shelly Bay, as follows:

"In 1801 Shelly Bay scarcely existed: what is now the mouth, was at that time a row of sand hills; and the road on the north side lay close within. Some free blacks who lived there, being in need of fuel, cut down the plants which kept these sand hills in a solid state. Being no longer duly opposed, the sea quickly broke through, and now retains possession of the ground at least 100 yards in rear of the old road, traces of which are still visible. The Mangrove Swamp between the beach and the present road was until then a garden." . . .

The condition of Shelly Bay appears to be still nearly as described by Nelson.* As to its previous condition, I know of no earlier description in which the sand hills across its mouth are mentioned. On the contrary, on the early maps of Norwood it is represented with nearly its present outline. In the earliest accounts it is mentioned as a bay abounding in fishes (1610), discovered by Mr. Shelly, one of Admiral Somers' party, in 1609. Therefore, unless Lieut. Nelson was misinformed as to its condition in 1801, the sand hills across its mouth must have been formed after the settlement, which seems improbable. I am disposed to think that the change was not nearly so great as Nelson was led to believe.

As to Tucker's Town, the sand still continues to drift in that district, and sand-dunes are still forming near the shore (see pl. xxi, fig. 2), though the area of drifting sand seems to be much less than formerly, owing to the great increase of native sand-dwelling vegetation and the introduction of additional species.†

One of the most important species growing here in the sand close to the shore is *Scævola lobelia*, a low shrub which has thick, leathery leaves and long creeping root-stalks. It is the species shown on the sands in my plates.‡ A little farther away from the shore the "Sage-bush" (*Lantana*) becomes important, and the seaside morning-glory (*Ipomœa pes-capræ*), with several seaside grasses, especially *Cenchrus tribuloides*. At the edges of the advancing sand the oleanders and cedars, with other plants, form barriers to its advance. In

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* For a view of Shelly Bay, see these Trans., xi, pl. lxviii; "The Bermuda Islands," same plate.

† See these Trans., vol. xi, pp. 474–479, pls. lxxv and lxxvi; "The Bermuda Islands," pp. 62–67, same plates.

‡ See pl. xxi, fig. 2. Also these Trans. pl. lxxv and lxxvi; "The Bermuda Islands," same plates.

fact, at the times of our visits the sand was drifting but little at any place except near Tucker's Town, owing to the vegetation.

An unusually long drouth, by injuring or destroying the vegetation, might cause the sands to drift again in many localities. It was also noticed that in several limited areas the drifting sand did not come from the beaches, but was derived from the crumbling of old æolian rocks.

Peat Bogs.

Deposits of peat of considerable extent occur in several of the swamps in Bermuda. The most extensive are in Devonshire Swamp and Pembroke Marsh. These swamps occupy deep valleys between the hills of æolian limestone and their bottoms are many feet below the present sea-level, so that the water in them is more or less brackish below the surface. Governor Lefroy is reported to have tested the depth of peat in Pembroke Marsh, in 1872. It is said that he found that it was 42 feet or more deep.*

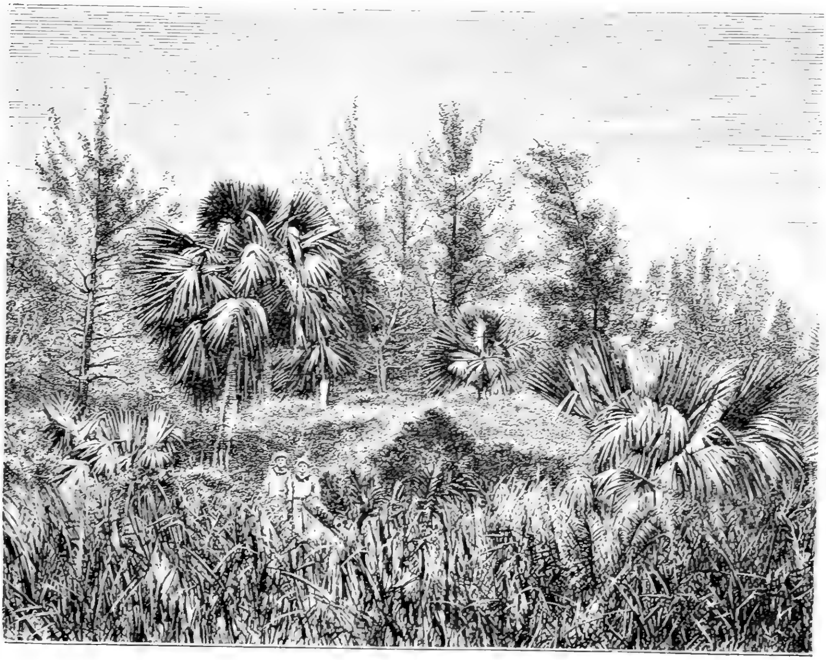

Figure 44*b*.—View in Devonshire Swamp. From a photograph, after Thomson.

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* See p. 87; and "The Bermuda Islands," p. 55. Also J. M. Jones, Visitor's Guide, p. 121. For view of Pembroke Marsh, see "The Bermuda Islands," p. 159, cut 32.

The lower portions of these peat beds must be of great age, while the upper portions are very modern. A careful exploration of the lower parts might afford the remains of plants, birds, insects, snails, etc, which are now extinct in Bermuda. The only records that I have seen in regard to this is the statement that cedar trees five feet in diameter have been found buried in the peat, but this is not much larger than some found growing by the earliest settlers. The peat of these bogs is not composed, to any great extent, of the remains of *Sphagnum* and other mosses,* as in cold climates, but mainly of the leaves, stems, and roots of larger plants, such as several large ferns that grow luxuriantly, and to the height of 6 to 8 feet,† reeds, sedges, palmetto, cedar, with vines and shrubs of various kinds. (See figure 44*b*.)

This peat, where purest, resembles superficially the ordinary peat of colder climates, and burns equally well when dried. In some localities it has been dug for a fertilizer. I am not aware that its microscopic structure has been studied by any one for scientific purposes. Eventually it may yield many facts of much scientific interest. The deposition of peat in some of the swamps is still going on, but in many places the swamps have been partially or wholly drained and are now cultivated.‡

Additional note on Bottom Deposits.

Chapter 22 was in type long before I had seen the following valuable paper :—The Shoal Water Deposits of the Bermuda Banks, Proc. Amer. Acad. Arts and Sci., xl, No. 15, 1905, pp. 559–592. (Cont. from Berm. Biolog. Sta., No. 5.) By Henry B. Bigelow.

In this work the author has given a pretty detailed account of the character of the bottom deposits that he examined from numerous localities, representing about all the varieties of bottom to be found, within the outer reefs. His results agree pretty closely with my own, though he found foraminifera more abundant in several places

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* Several species of such mosses do occur, though of relatively small importance. Among them are: *Sphagnum cymbifolium*, *S. cuspidatum*, and *Isopterygium tenerum*.

† Among the larger and more abundant swamp ferns are *Acrostichum aureum*, *Pteris aquilina*, *Osmunda regalis*, *O. cinnamomea*, *Woodwardia virginica*, *Aspidium coriaceum*. See also, "The Bermuda Islands," pp. 162–166, for some of the rarer species.

‡ For section at Ireland Island, showing ancient submerged bed of peat, see figure 58.

than I did anywhere. He also gives a somewhat greater percentage to the calcareous algæ, in certain places, than I have done. He follows Mr. A. Agassiz in attributing the fine mud and marl entirely to the erosion of the rocks and sands of the shore and reefs, overlooking the very important part that living animals take in the grinding up of the shells, etc., as explained in the preceding pages. He apparently overlooked the early studies of Nelson, Moseley, and others on this subject, and does not refer to them or to my own paper (Notes on the Geology of Bermuda,* 1900), even in his bibliography. In my paper of 1900 there was a fairly good though brief discussion of the subject, with figures of the sands from photographs. He informs me that it was accidentally overlooked.

One of the most novel and interesting parts of his paper relates to the character of the deposits on the Challenger Bank. The bottom was found to be covered with rounded pebbles composed of the nullipore, *Lithothamnion ungeri*, on all sides, and carrying serpulæ, small corals (*Madracis*), bryozoa, etc. From this he concludes that wave-action with force sufficient to roll these masses over (some were 6 inches in diameter) extends to the depth of 30 to 40 fathoms, which is quite contrary to the current scientific belief.

To me his conclusion that they are continually turned over by wave-action seems unnecessary. Plants of that sort require so little light that the diffuse and reflected light enables them to grow on the lower shaded sides of rounded pebbles in shallow water, though not on the parts resting on the bottom. Fishes with burrowing and rooting habits may turn such pebbles over frequently and continually while searching for their prey, and so might the larger crabs and other crustacea, the *Octopus*, etc., thus causing them to grow on all sides and keeping them free of sediment.

In enumerating the most important genera of shells (p. 568) he places the well known bivalves, *Codakia*, *Cardium*, and *Gouldia* among the gastropods.

The fragments of "red *Serpula*" that he refers to on pp. 566, 567, probably are fragments of one of the Vermetidæ (*Tenagodus* (*Siliquaria*) *ruber* Schum.). I do not know any species of Serpulidæ with red tubes. (See above, p. 139.)

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* Amer. Journ. Science, ix, pp. 313–340, with cuts in text, 1900.

PART IV.—II. PALEONTOLOGY.

24. Fossils of the Walsingham Formation.

In a former chapter (pp. 68–74), I have discussed the occurrence of numerous fossil land-shells, nine of which are now extinct, in this formation. Besides the land shells we find in it the well-known large West Indian "whelk" (*Livona pica*, fig. 60). The latter is often abundant, just as it is in the later æolian limestones. It was undoubtedly carried up from the sea beaches to the sand hills by the land hermit crab (*Cenobita diogenes*, fig. 60), which is still found on the modern sand hills with the ancient fossil shells on its back, for these fossil shells are so commonly weathered out entire that they are always available. Many of these ancient specimens still retain the external color and the pearly luster of the interior nacreous lining. This species, though still common in the West Indies, seems to have died out in Bermuda in modern times. There is no authentic record of recent living specimens.*

a. Land Shells.

The most interesting of the fossil shells belong to a genus of snails peculiar to Bermuda, named *Pœcilozonites* by Pilsbry. It differs anatomically from all the related genera, but its nearest allies are found in eastern North America. It is by no means certain that all the extinct species referred to this genus really belong to it, but most of them strongly resemble the living forms. At the time when this formation was deposited the genus had already reached its maximum development and greatest differentiation, for at that remote time the largest known species (*P. Nelsoni*) was very abundant, while at the same time the smallest and most diversely formed species, such as *P. cupula* and *P. Dalli*, were in existence. Six species and five well marked varieties are now recognized. All the species and all but one of the varieties are found fossil in this formation. This proves that the genus had been established or had originated here at a period long anterior to the deposition of the oldest rocks now known on the islands, for such differentiation implies a very long period of evolution. Three species of the genus and four varieties are now extinct. The other associated species belong to well known American and West Indian genera.

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* See "The Bermuda Islands," p. 296; these Trans., xi, p. 708, for a discussion of this matter.

An important paper on the fossil land shells of Bermuda has recently been published by Mr. A. Gulick,* in which he has described several new species and has given many details of their occurrence. Most of his new species had been collected previously by us, in 1898 and 1901, but not described.

The following species have been found in this formation:

Pœcilozonites Nelsoni (Bland) Pilsbry.

Hyalina Nelsoni Bland, Annals Lyc. Nat. Hist., N. York, xi, p. 78, 1875 (as a variety of *H. bermudensis*).

Pœcilozonites Nelsoni Pilsbry, Proc. Acad. Nat. Sci., Philad., 1888, p. 290, pl. xvii, figs. J. K. L.; in Heilprin's Bermuda Islands, p. 197, pl. 16, figs. J. K. L.; Trans. Conn. Acad., x, p. 500, 1900. Verrill, op. cit., xi, p. 728; "The Bermuda Islands," p. 316. A. Gulick, Proc. Acad. N. Sci., Philad., 1904, p. 415, pl. xxxvi, fig. 4.

Pachystyla mauritiana in Bartram's List, Berm. Almanac, 1881, p. 125.

Plate XXV; Plate XXVI, figures 4–8. Also figures 45, 46, 47.

This large extinct species is remarkably variable in form. In some localities most of the specimens are conical, about as high as broad, or even higher, while in other localities the spire is much depressed or flattened. The original type of Mr. Bland was the low and flattened form to which Mr. A. Gulick has recently given the variety name, *discoides*. (See fig. 46.) But intermediate forms are not uncommon. Those specimens that have a large callus on the inner lip Mr. Gulick called variety *callosus*. The amount of callus is also inconstant, so that no sharp line can be drawn between these varietal forms. They sometimes occur together, but more commonly are found at different stations.

The surface, in all the varieties, is generally ornamented by low, oblique, curved ribs, as shown on plate xxv. Many of the specimens from some localities retain traces of the original color. It was usually yellowish brown, with irregular streaks or blotches of reddish brown crossing the whorls, and sometimes with a subsutural band and one or two wider peripheral bands of brown, much as in some existing specimens of *P. bermudensis*.

The mass of specimens figured on plate xxv, and fig. 45, came from the Walsingham district, between Harrington Sound and Castle Harbor, and near Paynter's Vale. They are cemented together by a

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* Proc. Acad. Nat. Science, Philad., 1904, pp. 406–425, pl. xxxvi.

hard, red, calcareous matrix, containing red clay. The shells in this cluster are all of the high, conical form, now named variety *conoides.* (See pl. xxvi, fig. 4.) Some of them show color markings, as described above. This species is common in the Walsingham district, all along the western and southwestern shores of Castle Harbor, as stated above (see pp. 68–70), and at many other localities. Mr. Gulick found it in the ancient sandy strata at his station 818, near Tucker's Town, but not in later deposits of the same kind. It was found in great abundance at Ireland Island by Lieut. Nelson (1840), who described its occurrence as follows:

"In the centre of this rock was a cavern; and entangled amongst the stalagmitic lining (as well as in that of other caves and crevices), or else lying in heaps in the loose red earth within, we found abundance of a large and delicate *Helix* [*P. Nelsoni*]. In another instance upwards of thirty bushels were recovered, without any earth among them: a circumstance easily accounted for by the common habit of these animals to shelter in holes wherever they can find them. I have never seen these creatures alive, nor have I ever heard of their having been seen in that state; but still they were found with a smaller *Helix* deep in the compact rock. This *Helix*

Figure 45.—Mass of breccia-like material, containing numerous shells of the extinct Nelson's snail (*P. Nelsoni*, var. *conoides*), imbedded in stalagmite and indurated red clay from the Walsingham formation. About ⅓ natural size.

[*P. bermudensis*], which is the common living snail of the island, I obtained in the hardest stone and in the loosest sand; sometimes lined with druses of carbonate of lime, sometimes filled with a solid cast, at other times slightly cemented together, and frequently retaining some colour; in which condition they are generally found, as before mentioned, in every part of the colony."

This rock was a mass of marine or beach limestone, containing fossil corals (see under Devonshire formation below). The fossil snails in the cavern with red soil indicate that a mass of soil and calcareous sands of earlier origin, and containing these fossil shells, was imbedded beneath this mass of beach rock, and by its subsequent decomposition, the shells and red clay contained in it were left in the space it had occupied.

This large species appears to have become extinct at the time of the great subsidence at the close of the Walsingham period, when great changes in the climate and vegetation must have occurred.

It occurs at almost all the quarries opened in the limestones of this formation, especially on the west and southwest sides of Castle Harbor, both in the hard limestone and the red-clay breccia filling cavities. Also at Bailey Bay, Knapton Hill, etc.

Pœcilozonites Nelsoni Bland, var. **Nelsoni** Verrill.

Pœcilozonites Nelsoni, var. *discoides* Gulick, op. cit., p. 416, pl. xxxvi, fig. 4, 1904.

P. Nelsoni Pilsbry in Heilprin, "The Bermuda Islands," p. 197, 1889, pl. 16.

FIGURE 46. PLATE XXVI, FIGURES 7, 8.

This variety, in its extreme form, has a low flattened spire, but in most other respects differs very little from the more elevated forms of the species. Intermediate states frequently occur. It is found associated with the high-spired variety, but more often alone, at several localities in the vicinity of Castle Harbor and Bailey Bay. The last whorls are often distorted.

Bland's original description applied strictly to this form, named *discoides* by Gulick. He gave the height as 19^{mm}; diameters 37×34^{mm}, which are almost exactly the proportions that Mr. Gulick gives for his variety *discoides*. He gives for one: height, 19^{mm}; diameter, 37^{mm}; for another, height, 19.5^{mm}; diameter, 39^{mm}. (See our fig. 46.)

Pœcilozonites Nelsoni, var. **callosus** Gulick.

A. Gulick, The Fossil Land Shells of Bermuda, Proc. Acad. Nat. Sci., Philad., 1904, p. 414, pl. xxxvi, fig. 5. *P. Nelsoni* (*pars*), Pilsbry, Proc. Acad. Nat. Sci., Philad., 1888, p. 290, pl. xvii, fig. K; reprint in Heilprin, "The Bermuda Islands," p. 197, pl. 16, fig. K.

PLATE XXVI, FIGURES 5, 6. ALSO TEXT-FIGURE 47, TYPE.

Several good examples of this variety, in excellent preservation, belonging to the American Museum, New York, were lent to me for figuring by Mr. R. P. Whitfield. They were collected by him at Bailey Bay, in a road-side cutting and in cavernous places in the hills west of Mr. Seon's house. I personally collected similar specimens, but not as perfect, in the same vicinity. I also found the same variety in a ledge below low-water mark at Bailey Bay Island, and in a road-cut near Castle Harbor. Mr. Gulick's specimens were from Knapton Hill and Tucker's Town. Specimens of the same kind were sent to me thirty years ago by J. M. Jones. Some of the figures of *P. Nelsoni* published by Mr. Pilsbry in Heilprin's Bermuda Islands, pl. 16, reprinted from Proc. Philad. Acad. for 1888, p. 290, pl. xvii, also represent this variety.

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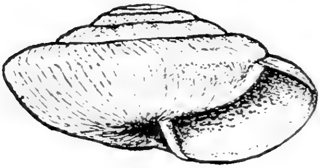

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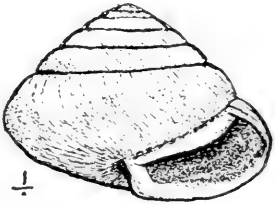

Figure 46.—*Pœcilozonites Nelsoni*, var. *Nelsoni*.
Figure 47.—*P. Nelsoni*, var. *callosus*, type. Both about natural size, copied from Gulick.

Mr. Gulick states that this variety is smaller than the ordinary form, but some of our specimens are much larger than his and exceed the diameter of his largest examples of the ordinary form, so that the size cannot be used as a varietal character. Its depressed form, thicker shell, the thickened outer lip, and thick callus of the inner lip are the only notable distinctions, but all these are variable characters in this species.

The following description of the larger Bailey Bay specimens was prepared several years ago, when I had also given it a varietal name in MSS.

Shell large and thick, with a rather low spire, the height usually less than two-thirds of the breadth. Base strongly convex. Umbilicus variable, but usually small and deep, and often partly covered by the slightly reflexed, angular edge of the lip. Body whorl obtusely angulated or obsoletely subcarinate. Sutures impressed, sometimes slightly canaliculate. Whorls 8 to 9. Spire sometimes much depressed, with an even slope, due to the flattened upper whorls, in other cases broad, conical, with the upper whorls a little more rounded.

The sculpture consists of numerous, very oblique and usually well-marked costulæ, parallel with the lines of growth; sometimes they are strongly developed and rather coarse, especially on the upper side of the body-whorl. Aperture somewhat irregular, transversely oblong-ovate, the outer end rounded, the basal side flattened, and the columellar end subtruncate, with a slight, excurved sinus, both at the basal angle and at the umbilical angle. The inner lip, in the older shells, is often much thickened, with a thick white callus; the thickening also affects the columella and outer part of the lip in most cases.

Color, when preserved, pale yellowish brown with a wide band of orange-brown, both above and below the periphery of the body-whorl, and sometimes with a narrower subsutural band of the same color. In some cases the upper surface is also flammulated with reddish brown.

Diameter of the largest specimen, 45^{mm}; height, 23^{mm}. Another has the diameter, 31^{mm}; height, 28^{mm}; length of aperture, 14^{mm}; its breadth, 7^{mm}. In Mr. Gulick's type the diameter was 33^{mm}; height 24^{mm}.

Pœcilozonites Nelsoni, var. **conoides** Verrill, nov.

FIGURE 45. PLATE XXV, TYPES. PLATE XXVI, FIGURE 4, TYPE.

This name is now proposed for the high-spired or conical form of this species, in which the height is from two-thirds to nine-tenths the diameter of the shell, or sometimes even equal to it.

It was figured by Pilsbry in Heilprin's "The Bermuda Islands," pl. 16, J.

It is the most common form of the species in many places in the vicinity of Castle Harbor, and was considered the typical form by Mr. Gulick. But Mr. Bland's original description, as stated above, applies only to the depressed form. The surface in many of the specimens is strongly costulate (see pl. xxv, *a*, *b*, *e*). The umbilicus is of moderate size or small. Many of the specimens are flammulated with brownish, and some have peripheral brown bands preserved.

This variety passes into the others by all intermediate gradations. One of the largest examples (see pl. xxvi, fig. 4) has the height 32^{mm}; diameter, 41^{mm}. The type specimens are from near the western shore of Castle Harbor in a mass of red-clay and stalagmite. It occurs in numerous localities in that district and near Paynter's Vale. Also on the shore opposite Coney Island, etc.

Pœcilozonites Bermudensis, var. **zonatus** Verrill.

These Trans., vol. xi, p. 728, 1902. "The Bermuda Islands," p. 316 [728], note, 1902. Gulick, op. cit., p. 418, pl. xxxvi, fig. 3, 1904.

PLATE XXVI, FIGURES 1, 2. PLATE XXVII, FIGURES 2, *a–l*, TYPES.

This variety occurs abundantly in the softer limestones and imperfectly consolidated sands of the Devonshire and Paget formations, in which its colors are often very well preserved. The examples figured are all of the latter period. Hence it will be more fully discussed under that formation.

It is found, however, associated with *P. Nelsoni* and other extinct species in the Walsingham formation, though in most cases far less abundantly than the latter.

The most productive localities are especially in the hard Walsingham limestones at the quarries near the west and south-west shores of Castle Harbor; we also found it near Bailey Bay and near Coney Island. Station 814 (Gulick).

It occurs both in the limestone and in the reddish breccia-like stalagmites containing red-clay, found in this district.

Pœcilozonites Reinianus (Pfr.) Pilsbry.

Helix Reiniana Pfeiffer, Malak., xi, p. 1, 1863.

Pœcilozonites Reinianus Pilsbry, Proc. Acad. Nat. Sci., Philad., 1888, p. 290, pl. xvii, I, D, reprinted in Heilprin, "The Bermuda Islands," p. 198, pl. 16, I, D (radula); these Trans., x, p. 500.

Verrill, these Trans., xi, p. 728; "The Bermuda Islands," p. 316 [728], 1902. Gulick, op. cit., p. 419, 1904.

FIGURES 66*a*, 66*b*.

This species is much smaller than the preceding; diameter, $9–11^{mm}$; height, $5–6^{mm}$. The spire is depressed (nearly flat in var. *P. Goodei*). The umbilicus is large, about one-third the diameter of the shell, and shows all the whorls. The whorls of the spire are somewhat convex, the apical one smooth; the body-whorl is rounded when adult. The shell is usually flammulated with chestnut-brown in recent specimens and some of the fossils show the same colors. There is no internal lamella. The fossil shells are usually somewhat larger than the recent ones. As a living species it is not abundant. Occurs not infrequently at the quarries of hard limestone near the shores of Castle Harbor with *P. Nelsoni*, and elsewhere, but usually in the form or var. *antiquus*. Gulick obtained his best specimens at locality 815, near Harrington House. It also occurs in the Devonshire and Paget formations.

Variety **Goodei** Pilsb.

Pilsbry, Proc. Acad. N. Sci., Philad., 1889, p. 85, pl. iii, figs. 12, 13; these Trans., x, p. 500; Gulick, op. cit., p. 419.

This living variety was distinguished merely on account of its nearly flat spire and larger umbilicus. Diameter, 9–10^{mm}; height, 3.25–4^{mm}.

It is reported by Mr. Gulick as found fossil at Town Hill (his station 819).

Variety **antiquus**, nov.

PLATE XXVI, FIGURE 3.

A single specimen of a peculiar form of *Pœcilozonites* was found imbedded in the stalagmitic mass of *P. Nelsoni* figured on pl. xxv, (see also fig. 45).

If it be not somewhat abnormal, it may represent a new species, in some ways intermediate between *P. Reinianus* and *P. circumfirmatus*, var. *discrepans*. It has rather the form of the first (var. *Goodei*), but it apparently had a faint internal ridge in the last whorl, unless due to injury during life.

The spire is almost flat, composed of about seven somewhat convex whorls, separated by impressed sutures. Surface rather strongly costulate; on the last whorl the costulæ are interrupted a little above the periphery by a slight groove. The solid stalagmitic cast of the interior shows, in spots where the shell is broken away, a very slight peripheral groove, as if there had been a very thin internal ridge, corresponding to the external groove. Probably this may have been produced by an injury during the growth of the shell. The basal side of the shell is wholly concealed. The last whorl is well rounded, not angulated at the periphery. The aperture is more lunate than in the existing varieties, owing to the more compressed whorls. It is larger than the living forms. Faint flammulations of red-brown color are preserved. Diameter, 10^{mm}; height, about 5^{mm}. Other similar specimens have the diameter, 13^{mm}; height, 6^{mm}. From a quarry near Castle Harbor. We found broken specimens of the same variety in a road-cut at Bailey Bay, but without the slight peripheral furrow.

It seems to be nearest to *P. Reinianus*, var. *Goodei*, but the latter is smaller and more delicate, has less evident costulation, and the whorls are less compressed.

Pœcilozonites circumfirmatus (Redf.) Pilsbry.

Hyalina circumfirmata Redfield, Am. Lyc. Nat. Hist., New York, vi, p. 16.
Pœcilozonites circumfirmatus Pilsbry, op. cit., 1889, p. 291, pl. xvii, figs. F, G, H (shell), A, B [radula and jaw]; same reprinted in Heilprin, "The Bermuda Islands," p. 199, pl. 16, 1889; these Trans., x, p. 500, 1890. Verrill, these Trans., x, p. 728, figs. 67, *a*, *b*, 1902; the same, "The Bermuda Islands," p. 316, fig. 67. Gulick, op. cit., p. 420, 1904.

FIGURES 48*a*, 48*b*.

This delicate species is similar to the last in size and form. Its diameter is usually 9 to 12^{mm}; height, about $6–7^{mm}$. The fossil shells differ but little from the recent ones. It is easily distinguished from others of the genus by the internal revolving lamina.

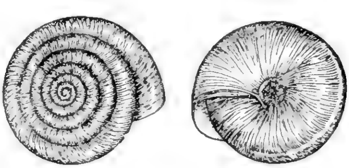

Figure 48.—*Pœcilozonites circumfirmatus; a*, upper, and *b*, under surfaces, × 2¼, from photographs of recent specimens by A. H. V.

Specimens were found by us at Bailey Bay in the interior of *P. Nelsoni*. It occurs at numerous localities in the Walsingham formation with *P. Nelsoni*, as well as in the later Devonshire and Paget formations. We found it common in the strata near Hungry Bay just above the Devonshire beach limestones. It is a common living species.

Variety **discrepans** (Pfr.).

This variety is separated only on account of its nearly flat spire. This is a variable character, as in *P. Nelsoni*, and intermediate forms are not uncommon. Mr. Gulick records it from the older hard limestones and red clay pockets at Knapton Hill and near Castle Harbor; also from ancient unconsolidated sands at Tucker's Town (his sta. 818). We took it from the sand inside a shell of *P. Nelsoni*, found in a road-cut at Bailey Bay, and also in strata immediately above the Devonshire beach-limestones at Hungry Bay. It is found living, but is not common.

Pœcilozonites cupula Gulick.

Op. cit., p. 417, pl. xxxvi, fig. 2, 1904.

FIGURE 49, TYPE.

Easily distinguished by its dome-shaped spire. It has about 8 whorls; diameter 16 to 20$^{\mathrm{mm}}$; height, 13 to 15$^{\mathrm{mm}}$. Some specimens show traces of subsutural and peripheral color bands.

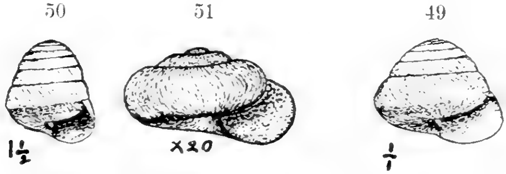

Figure 49.—*P. cupula*; 50, *Pœcilozonites Dalli*; 51, *Zonitoides Bristoli*. Types. All copied from Gulick.

Several specimens were found by Mr. Gulick at a quarry of hard limestone near Paynter's Vale, southwest shore of Castle Harbor (his locality 806), associated with other extinct species.

Pœcilozonites Dalli Gulick.

Op. cit., p. 417, pl. xxxvi, fig. 1, 1904.

FIGURE 50, TYPE.

This small species is higher than broad, with an elevated spire, rounded apex, and convex base. Diameter, 7 to 7.3$^{\mathrm{mm}}$; height 8.5 to 10$^{\mathrm{mm}}$. Whorls about 9, polished, whitish, with two brownish peripheral lines. Umbilicus small, partly covered by the reflexed columellar margin. Exact locality unknown.

Zonitoides Bristoli Gulick.

Op. cit., p. 421, pl. xxxvi, fig. 13, 1904.

FIGURE 51, TYPE.

A minute species, having three convex whorls, which are finely costulate and covered with fine and regular spiral lines. Diameter, 1.17^{mm}; height, 0.7^{mm}.

Recorded from the hard Walsingham limestone at station 807 by Gulick. Also from near Tucker's Town, in sand-pits at station 818* (type). It was not observed by our parties. Not known living.

Zonitoides minusculus Binney.

Pilsbry, op. cit., 1900, p. 501, pl. lxii, fig. 11. Verrill, op. cit., p. 317 [729], fig. 71, 1892. Gulick, op. cit., p. 421, 1904.

FIGURE 52, RECENT.

This well-known, minute North American species was recorded by Gulick, as found with the preceding at station 807. It is not uncommon as a living species in Bermuda. It is widely distributed in North America, ranging northward to New England and southward to the West Indies.

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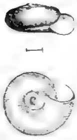
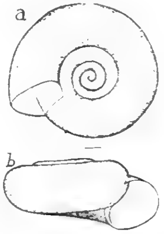


52*a*



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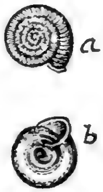

Figure 52.—*Zonitoides minusculus*, enlarged, after Binney.
Figure 52*a*.—*Thysanophora hypolepta*, much enlarged, after Pilsbry.
Figure 53.—*Strobilops Hubbardi*, enlarged 4 diameters, after Binney.

Euconulus turbinatus Gulick.

Op. cit., 1904, p. 420, pl. xxxvi, figs. 8, 9, 10.

FIGURES 55*a*, 55*b*, TYPES.

A small conical species with a high spire and blunt apex. Whorls 7½, narrow, nearly flat, umbilicus small Diameter 2.8 to 3^{mm}; height, 3.4^{mm}.

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* The sandy or unconsolidated strata at this station probably belong to the Walsingham formation, as the characteristic fossils occur in them.

Gulick records this species from the Walsingham limestones at station 806, near Castle Harbor, and at 807, Knapton Hill, and also from the sand-pits at station 818. Also from the Paget sand-pits (sta. 808). The specimen figured (55*b*) was from station 807. We found it in the red-clay breccia on the west shore of Castle Harbor, mostly as casts. It is not known to be living.

Thysanophora hypolepta Shuttl., Bern. Mitth., March, 1854, p. 129.

> *Helix* (*Microphysa*) *hypolepta* Pilsbry, Proc. Philad. Acad. Nat. Sci., 1889, p. 82, pl. iii, figs. 6–8; Pilsbry in Heilprin, "The Bermuda Islands," p. 200, pl. 16, figs. M. M.
>
> *Thysanophora hypolepta* Pilsbry, these Trans., x, p. 49, pl. lxii, figs. 2*a*, 2*b*, 1900. Verrill, these Trans., xi, p. 728, figs. 68, *a*, *b*; "The Bermuda Is.," p. 316, figs. 68, *a*, *b*, 1902. Gulick, op. cit., p. 413, 1904.

FIGURE 52*a*; RECENT.

This minute species is still living in Bermuda, but is not known from any other locality. It has a broader umbilicus than *Z. minusculus* and a rounder aperture. They are similar in size and appearance. Gulick records this from Knapton Hill, station 807, and near Paynter's Vale, station 806, but not from the Paget sands. We found it in the sand from the interior of *Pœcilozonites Nelsoni*, taken from a road-cut at Bailey Bay.

Strobilops Hubbardi (Brown).

> *Helix Hubbardi* Brown, Proc. Acad. N. Sci., Philad., 1861, p. 333.
>
> *Strobila Hubbardi* Tryon, Am. J. Conch., ii, p. 259, 1866. Binney, Terrest. Mol. U. States, v, p. 261, fig. 153, 1878.
>
> *Strobilops Hubbardi* Gulick, op. cit., p. 413, 1904.

FIGURE 53, RECENT.

This minute species, now living in the southern United States and Jamaica, was recorded by Gulick as found at station 806, near Paynter's Vale. It is not known as a recent shell in Bermuda. He gives the size of the fossil shell as diameter 2.8^{mm}; height, 1.2^{mm}.

Pupa (Bifidaria) servilis Guild.

> *Pupa pellucida* Bland, Am. Lyc. Nat. Hist., New York, vii, p. 351, 1861.
>
> *Pupa* (*Bifidaria*) *servilis* Pilsbry, these Trans., x, p. 497, pl. lxii, fig. 6, 1890. Verrill, op. cit., p. 729, fig. 74*a*, 1902; Bermudas Is., p. 317, fig. 74*a*.
>
> *Bifidaria servilis* Gulick, op. cit., p. 414.

FIGURE 68*a*, RECENT.

This is a minute species, still living in Bermuda, Cuba, the Bahamas, etc. It was found by Mr. Gulick in the imperfectly consolidated strata near Tucker's Town (station 818) which I refer to the Walsingham period.

Pupa (Bifidaria) rupicola (Say, not of Binney).

Pilsbry, these Trans., x, p. 498, pl. lxii, fig. 8, 1900 (description). Verrill, these Trans., xi, p. 729, fig. 74c, 1902; "The Bermuda Is.," p. 317, fig. 74c. *Bifidaria rupicola* Gulick, op. cit., p. 414, 1904.

FIGURE 68c; RECENT.

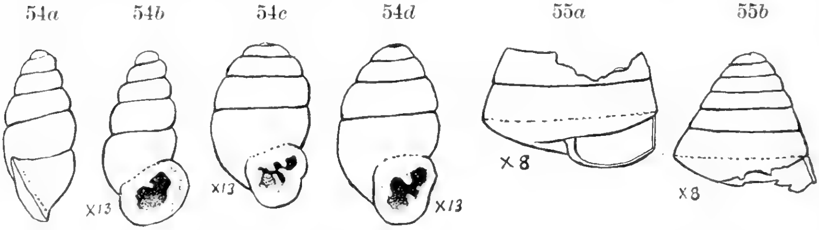
This was recorded from station 806, near Paynter's Vale, by Gulick, and also from station 808, in Paget sands. It is still living but not common in Bermuda. Also found in the southern United States and Cuba.

Vertigo numellata Gulick.

Op. cit., p. 413, pl. xxxvi, fig. 6, 1904.

FIGURE 54c, TYPE.

This minute extinct species is the most common of the fossil Pupidæ. Gulick recorded it from station 806, Paynter's Vale, and 807, Knapton Hill. We obtained it from sand in the cavity of *P. Nelsoni*, from near Bailey Bay, and from the red-clay breccia near Castle Harbor. It is not known from the Devonshire nor Paget formations, nor as a living species.



Figures 54a, 54b, *Carychium bermudensis* Gul., profile and front views. 54c, *Vertigo numellata* Gul. 54d, *Vertigo Marki* Gul. 55a, 55b, *Euconulus turbinatus* Gul. All reduced from Gulick's figures.

Vertigo Marki Gulick.

Op. cit., p. 414, pl. xxxvi, fig. 7, 1904.

FIGURE 54d, TYPE.

Slightly larger than the last. Diameter, 1^{mm}; height, 1.9^{mm}. Found by Gulick at the same stations as the preceding, but not so common. We found it in the sand from inside *P. Nelsoni*, Bailey Bay road-cut, with the last. Not known from newer deposits.

Carychium bermudense Gulick.

Op. cit., p. 415, pl. xxxvi. figs. 11, 12.

FIGURES 54*a*, 54*b*, TYPE.

This extinct species has about five convex whorls with the surface finely striate, corneous white. Aperture oblique, with a broadly expanded reflexed lip, thickened within, and with a slight prominence just above the middle. Columellar lamella minute and deeply situated. Diameter, 0.9^{mm}; height, 1.8^{mm}.

We took several good specimens from fine sand found in the interior of the shells of *Pœcilozonites Nelsoni* from road-cut near Bailey Bay. It was associated with the two preceding and other species. It also occurred, chiefly as casts, with several other species, in a red-clay breccia from the west shore of Castle Harbor. Gulick found it common in the red-clay deposits at his stations 806 and 807, and in the sands at station 818. He also records it from the Paget sands, stations 808, 809. It is not known to be living.

Succinea somersensis sp. nov.

Succinea bermudensis (*pars*) Gulick, op. cit., 1904, p. 421 (*non* Pfeiffer).

The ancient form, from the Walsingham formation, seems to be distinct from the recent species, which may have been a modern importation from the West Indies.*

The fossil species is larger and stouter—usually 12 to 13^{mm} long and about 7^{mm} in diameter; length of the last whorl about 9^{mm}. It is pretty regularly ovate, the breadth more than half the length. Surface nearly smooth, but showing delicate lines of growth. Spire small and acute. The shell is thicker than in the living form. Our largest specimen is 12^{mm} long; 7^{mm} broad.

Gulick gives for his largest example, length, 13^{mm}; diameter, 7^{mm}. It is seldom that the modern species becomes more than 10 to 11^{mm} in length, usually it is 8 to 9. Not uncommon in the Walsingham district. Mr. Gulick records it from his stations 806, 807, and 818. Whether his specimens from the sand-pits (Paget formation), at

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* The small species now living in Bermuda (see figure 70) has had several names. Some of the references are as follows:

Succinea barbadensis Guilding, Zool. Journ., iii, p. 532, Supl., pl. 27, figs. 4–6. Pilsbry, these Trans., x, p. 502. Verrill, these Trans., xi, p. 729, figs. 80, *a*, *b*, 1902; "The Bermuda Is.," p. 317, figs. 80, *a*, *b*.

Succinea bermudensis Pfeiffer, Proc. Zool. Soc. Lond., 1857, p. 110; Gulick, op. cit., p. 421, 1904.

stations 808 and 809, were of the same form as the earlier one I do not know. But we found one example in the beach rock (Devonshire formation) near Hungry Bay, associated with foraminifera and shells of *Cæcum*, etc.

b. "Palmetto Stumps" or "Sand Pipes."

FIGURE 56. PLATES XIX, XX.

In many localities and at various levels, often high above the sea, but especially in the firm Walsingham limestones, large cylindrical or cup-shaped cavities are found, often surrounded by a hardened wall, more or less infiltrated with stalagmitic material. They often occur in large groups and are frequently connected at the top by a layer of indurated red clay. (See above, pp. 62, 72, 120.)

They are generally believed by the natives to be the casts or molds of palmetto stumps, and this view has been adopted by several geologists. But Agassiz believed them to be "pot-holes" made by the sea.* Thomson considered them hollow stalagmites, made by dripping water in imaginary caverns. Such forms are not peculiar to Bermuda.

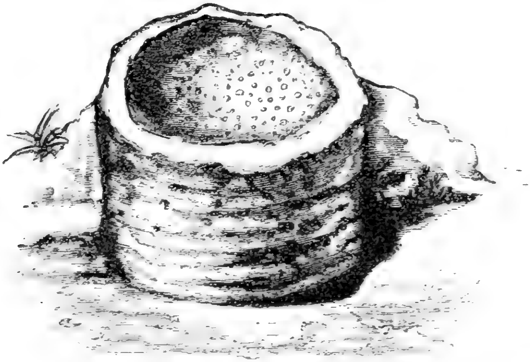

Figure 56.—A "fossil palmetto stump," which has partly weathered out from the surrounding softer stone, and shows internal pittings. After Thomson.

Structures very similar to these occur in the white chalk of England and in the calcareous rocks of Europe. In England they are called "sand-pipes" and "sand-galls." Examples of various sizes are figured by Lyell, in his Manual of Geology, ed. 4, p. 82, as

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* I have shown above (pp. 120, 121), that they are often converted into potholes, when they occur on the shore ledges.

they exist at Eaton, near Norwich. (Figure 57.) They vary in size there from a few inches to 12 feet in diameter, and in depth from a few feet to 60 feet. Most of those figured are pointed at the lower end. Lyell states that they are circular and very symmetrical in form. He believed that they are due to the solvent action of percolating rain water, but he does not explain why such solvent action should be concentrated, for long periods, upon such definite and circular spots, often close together, nor why the holes should preserve a circular form throughout their depth, without spreading laterally.

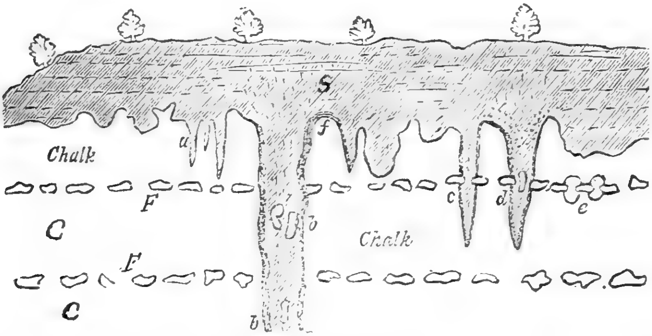

Figure 57.—Section at Eaton, Eng. After Lyell. C, C, white chalk; F, F, layers of flint nodules; S, sand and surface soil; *a-f*, "sand pipes" of various sizes.

The same difficulties are obvious in the Bermuda examples, for they often penetrate through layers differing in texture and hardness, without changing in size or form. If due wholly to the ordinary solvent action of rain-water, we should expect to find that such waters had spread laterally in the more porous layers and so produced irregularities.

It appears absolutely necessary to assume that there was at least some definite and specific cause to determine the position and circular form of the primary pit, if we admit that the solvent action was the active cause of the prolongation downward, for puddles of rain-water, on ordinary natural surfaces of soil, assume very irregular forms, and are rarely symmetrical and circular, like these holes. If we could explain the initial circular form of the pits, we might suppose that the solvent action had made them deeper and larger, especially if the pits had become filled with clay-soil and decaying vegetable matter.

Four possible causes for such circular pits,* originating, as they often do, in or beneath the red-clay soil, appear to me worthy of consideration at present:

A. There may have been living there in ancient times some burrowing animal that formed the pits, at least in part. The only creature that I can suggest as possible is a large burrowing land tortoise, like the gopher turtle of Florida. But I do not know that the gopher makes its holes so nearly perpendicular or so circular as these structures usually are. The sea-turtles scoop out pits, more or less circular, in which to deposit their eggs, but they are more irregular in size and form, and not so deep, and are made in the beach sands.

B. In ancient times the sands of Bermuda may have been the breeding place of some large gregarious sea-bird† that excavated its nests in the sand, in the form of round and shallow pits, suitable to be the starting point of these cavities. Or some such bird may have had the habit of "muffling" itself in the sand to remove vermin, after the manner of the domestic fowls, which often form shallow round pits in this way.

C. Some tree or other plant may have formerly existed here that had a large cylindrical, perhaps tuberous, root, which may have formed the initial pit. The rain-water trickling down all around such a root might, by its solvent action, after the death of the plant, continue the cavity downward in the same cylindrical form, especially if the rain-water should wash clay into the cavity as fast as it formed.

The trunk of the common palmetto is usually somewhat swollen or bulbous at the underground base, and not unlike some of these cavities in size and form, though usually not so cylindrical. But it sends off great numbers of tough rootlets, in every direction. Such rootlets ought also to have left casts, but I could find no traces of them in the structures that I examined.‡ But there may have been

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* In the next chapter (p. 178) some account is given of more irregular structures in the limestone apparently due to the stumps and roots of cedar and other trees.

† The considerable percentage of calcium phosphate in all the ancient red clays indicates that birds must have been abundant there in prehistoric ages, as they were when the islands were first settled. The presence of the salts of potassium also imply the existence and decay of abundant vegetation.

‡ Professor W. N. Rice mentioned finding indentations, looking like the casts of rootlets, in the bottom of some of the cavities that he examined. The structures

other plants there, in the pliocene, now extinct, that had fleshy or succulent roots of the right form, with rootlets too soft to be preserved. Some species of West Indian *Ipomeas* have huge, fleshy roots, as large as a man's body, and some of the extinct forms may have been even more remarkable.* It is not necessary to suppose that all the cavities were moulded around the stump of a palmetto or palm, living or extinct, if we believe them to be of vegetable origin, for there are many herbaceous plants with huge roots, and some of them are partial to sand dunes of this kind. That most of these cavities are in the ancient Walsingham limestone is significant, but similar ones occur in the later rock and at high altitudes.

It is also important to note that in the most typical cases, where a large group occurs (fig. 11, and pls. xix, xx), they all start downward from one particular level, usually a layer of red-clay soil, or an ancient "forest bed," though some may be deep and others shallow. This is contrary to what would have been the case if they had been due to stumps of the palmetto, buried in the drifting sands, for in that case the lower ends would have been nearly at one particular level, or in a layer of red-clay soil. In most cases we found no layer of red-clay at or near the lower ends. They usually terminated below in pure limestone, just as if dug out to variable depths by a mechanical tool.

It seems to me very probable that at least part of them were started by the thick root or base of some plant, and that in most cases they were enlarged and deepened by the solvent action of the rain water that naturally found its way into the crevice around the root, or around the core of loose material and clay that later filled the cavity, after the roots decayed.

D. The initial circular cavity may have been formed in the soil by mechanical means.

Rain water dripping at one particular spot from the branch of a tree will start, in loose soil, a circular cup-shaped cavity, which could easily be prolonged downward and enlarged by solvents.

The elastic stems of grasses, shrubs, and other plants growing in rather loose sandy soil and exposed to the winds will often, by their

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examined by him may really have been formed around the bases of palmettos, for they are probably not all of the same origin.

Thomson also refers to the pits on the inner surface of some that he examined (see his figs. 7, 9, and our fig. 56).

* Some of the West Indian species have fleshy roots 4 to 6 inches or more in diameter and many feet long, coiled in a regular tapering spiral, like a corkscrew, the coil often 10 to 12 feet long.

rotary motions, loosen the sand about themselves and thus cause the wind to excavate conical or cup-like cavities. Such cavities, if preserved by clay soil washing into them by rain, might be the starting points of deep cavities excavated by solution.

Whatever the cause may have been, in particular cases, such shallow cavities, if in a calcareous soil covered by clay, must have been filled by the red clay washed in by rain. The clay core on drying would shrink away from the surrounding materials, leaving a narrow crevice about it into which rain water would percolate and slowly dissolve away the surrounding limestone, redepositing part of it a little farther away, as the moisture evaporated. The enlarged crevices would be filled, again and again, by additional clay material, and so the clay core would be increased in size and length as the solvent action went on. Thus there would be no definite limit to the depth or size of the cavities, provided the time were very long and no insoluble obstructions were encountered. The ordinary effects of gravitation account, in this theory, for the extension downward being most rapid. The presence of clay deposited on the sides of the cavities accounts for the water not spreading much laterally in the more porous layers.

A similar effect may be seen when pebbles rest upon porous ice or snow in sunny weather. The ice melts away under and around the stone, but mostly beneath, so that the stone soon sinks into a hole but little larger than itself.

That the solvent action referred to will result in forming circular pits may be demonstrated experimentally by resting balls or cylinders of clay on shallow indentations in pieces of limestone and allowing very dilute acids to trickle very slowly over the surface of the clay, so that the solution will evaporate almost as soon as formed.

The best examples of these structures that I saw were near Hungry Bay on the south shore. See plates xix, xx. At this place there is a bench of hard limestone, believed to be of the Walsingham formation (see above, pp. 62, 72), just above high-tide, which has been quarried for building purposes. So that good sections of some of the cavities have been made, as in pl. xix.* The upper surface of this limestone is partially covered with indurated red clay, the softer parts of the clay stratum having been worn away by the sea. This surface is perforated by a large number of these cavities, most of them nearly round and a foot or more in diameter. If due

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* See also "The Bermuda Islands," plates lxxxiv–v, and these Trans., vol. xi, same plates.

to palmetto stumps there must have been a rather thick grove at this place. They terminate below at various levels in the hard limestone strata. The inner surface is rough and often stained to a dark manganese-brown color, but I could see no evidence of rootlets in these examples.

c. Plants ; Ancient Peat and Cedars.

On a former page (p. 81) I have mentioned the fact that a bed of peat, with red-clay soil and vertical stumps of cedars, was found, in 1870, at Ireland Island, in making the excavation for the floating dock. This fact has often been mentioned as evidence proving the subsidence of the land. A fossil species of land-snail (*Pœcilozonites*) is also said to have been found in the same bed or in the æolian limestone below it.

This bed of peat and soil was overlaid by layers of sand-rock and "coral-crust," of considerable thickness, as shown in the accompanying section, copied from Thomson.

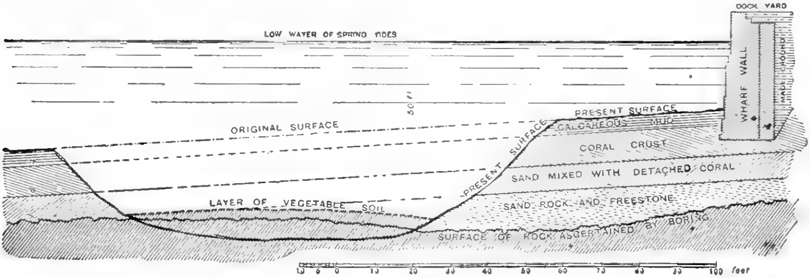

Figure 58.—Section made in the excavations for the dry dock at Ireland Island, showing the bed of peat and red clay with cedar stumps, etc. After Thomson.

The upper layer, about 25 feet below low-tide, was fine shell-sand and marl, 4 feet thick ; 2d layer, 8 feet thick, was "coral crust," containing shell-sand, fossil shells, and various corals, among them *Mæandra labyrinthiformis ;* 3d layer was shell-sand, mixed with corals, about 7 feet thick ; 4th layer, about 7 feet thick, was loosely coherent and harder shell-limestones ; the layer, of red earth and peat, with cedar stumps and bones of birds, was 2 to 4 feet thick, in a hollow eroded out of the latter ; 5th layer was hard æolian limestone, tested by borings to 52 feet, containing fossil land shells. The deepest part of the excavation was 50 feet. The upper surface of the red-soil bed was 44 to 50 feet below low-tide.

It is evident that this bed of peat and vegetable remains must have been deposited during the period of "Greater Bermuda," and therefore probably belongs to the Walsingham Period, though perhaps to the latter part of it, for the peat is underlaid by older æolian limestones.

It is unfortunate that careful microscopic examinations of this peat were not made, for it might have been possible to have identified specifically some of the plants and other organisms, which may have differed from those in the modern peat bogs.

The overlying beds of "coral crust" may have belonged to the Devonshire formation, and may indicate a subsidence, after the latter had been raised above the sea-level and hardened, for such materials do not appear to solidify in these waters, except when exposed more or less to the air.

25. Fossils of the Marine Devonshire Formation, or Beach Limestones.

The typical beach deposits of this period have been discussed above (see pp. 76–81), where it is also stated that the raised beach deposits may not all be of the same age, and that some of them may be very recent. But at present we have no positive means of determining this in most cases, for the fossil shells are generally all living species.

As the true Walsingham limestones were deposited at a time when the land was at a much higher level than now, we cannot hope to find, on dry land, marine deposits of that age.

A deposit of fossiliferous rock containing *Tellina*, *Lucina*, etc., situated 16 feet below low-tide mark, found in the excavations made in Tomlin's Narrows,* indicates by the nature of its solidification that it had been long exposed to the air and water above or between tides. It may represent a deposit of Devonshire beach-limestone made before the close of the first period of subsidence. But it may better be taken as one of the facts indicating that a small amount of subsidence must have occurred since the marine deposits were first elevated.† It is probably of the same age as the "coral crust" in the Ireland Island section, fig. 58. These submerged deposits deserve much more investigation.

In certain cases where extinct land shells of the Walsingham period have been found associated with red clay in cavities of the

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* See also, A. Agassiz, op. cit., 1895, p. 230.

† This would be in accordance with my belief that these Bermuda sands do not solidify into firm limestone except on exposure to the air. See p. 61.

beach-limestones, they appear to represent beds of the older formation that were buried in the later deposits and were afterwards removed by solution, leaving the shells and clay behind, as in the notable case at Ireland Island described by Lieut. Nelson in 1840. His description is quoted above on page 77.

In the mass of beach rock he found a cavity containing loose red earth with an abundance of *Pœcilozonites Nelsoni.* This occurrence seems to me an additional proof that the beach rock at this place was much later than the Walsingham limestone, as in the other localities described above, pp. 76–78.

The following list of fossils from the beach deposits is very incomplete, for I did not have time to make so large collections of them as I wished, and most other collectors have neglected them, because they are nearly all living species. Professor W. N. Rice (op. cit., p. 31, 1884) has given a much longer list of fossil shells than any other writer. Most of the species named by him were also obtained by my party; all those recognized are given in the following lists. Many others are too imperfect for identification.

Crustacea of the Devonshire Formation.

Balanus (large sp. like *B. tintinabulum*).

Fragments of a large barnacle were common in the beach-rocks near Hungry Bay. It must have been at least 1.5 to 2 inches in diameter. No such species is recorded as now living at Bermuda.

Cenobita diogenes (Linn.). Land Hermit Crab. Figure 60.

The fossil remains of this land crab have been found in a shell of *Livona pica.* It may, however, have been taken from comparatively modern sand dunes. It was sent by J. M. Jones many years ago, and the exact locality was not recorded on the label.

Marine Shells of the Devonshire Formation.

a. Gastropods.

Purpura hæmastoma Linn.

Near Hungry Bay; fragments.

Purpura deltoidea Lam.

Fragments only.

Nassa ambigua Montagu. Figure 59.

Not common. Recorded by Rice as *N. Candei* d'Orb.

Columbella mercatoria Linn. Figure 59*a*, *a*.

Common.

Columbella cribraria Lam. Figure 59*a*, *b*.

Common.

Oliva reticulata Lam.

Fragments only.

Olivella oryza Lam.

Recorded by Rice.

Fasciolaria distans Lam.

Recorded by J. Matthew Jones, a single instance.

59 59*a*

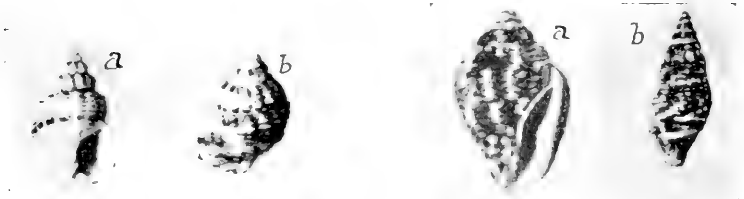


Figure 59, *a*, *b*.—*Nassa ambigua*; 59*a*, *a*, *Columbella mercatoria*; 59*a*, *b*, *Columbella cribraria*. All natural size, phot. A. H. V.

Natica canrena Linn.

Rare.

Trivia quadripunctata Gray.

Recorded by Rice as *T. rotunda*, which is now considered a variety.

Cypræa exanthema Linn.

Recorded by Heilprin from St. George's (as *C. cervus* Linn.).

Cypræa cinerea Gmel.

Recorded by Rice and by Heilprin.

Ultimus gibbosus (Linn.) Mtf.

Recorded by Rice as *Cyphoma gibbosa*; rare.

Strombus costatus Gmel.=**accipitrinus** Lam. Rare.

Nelson (see above, p. 78) recorded a *Strombus*, without specific name, from Long Bird Island. Heilprin mentions that the specimens of this species seen by him were antiquated in appearance. Probably they were fossil. I have seen no recent specimens from Bermuda, except in the collection of Miss Peniston, who had several fine ones in 1898, but not collected personally.*

Cerithium minimum Gmel.

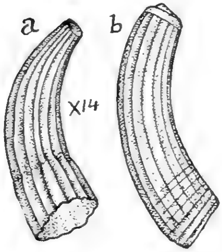
Not uncommon.

Cerithium variabile Adams.

C. ferrugineum Say, *non* Brug.

Common.

59*b*



59*c*

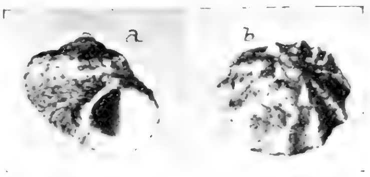


Figure 59*b*.—*Cæcum termes*; *a*, young; *b*, nearly adult. By A. H. V.
Figure 59*c*.—*Modulus modulus*, two examples, slightly enlarged. Phot. A. H. V.

Littorina angulifera Lam.

Near Hungry Bay.

Tectarius muricatus (Linn.).

Near Hungry Bay.

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* The late Miss Mary Peniston had a very valuable local collection of shells which she had obtained during many years. In 1898, I made a brief examination of her shells, intending to made a careful study of them a few days later, but was prevented from doing so by a severe illness. She died before my visit in 1901, and her shells were unfortunately not accessible then. She did not label her shells to any great extent, depending upon her memory as to the time and place of capture, etc. She had a considerable number of *exotic* shells, given to her by others as collected in Bermuda, which she personally considered doubtful. Among such, as noted by me at the time of my visit, were *Cypræa tigris*, *C. asellus*, *Voluta musica*, *Murex brassica*, etc. Such shells she kept on a separate shelf, but in the same case with the true Bermuda shells. Whether the *Strombus accipitrinus* was among those that she thought doubtful, my notes do not show. It was recorded by Krebs from Bermuda, 1864, as collected by Redfield.

Cæcum termes Heilprin. Figure 59*b*.

Several specimens in hard foraminiferous limestone, near Hungry Bay.

Vermetus lumbricalis Linn.

Fragments are common.

Tenagodus ruber (Schum.) Mörch.

Siliquaria rosea Blainv.

Fragments are common. They are also found in some of the modern beach-sands, to which they sometimes impart a reddish tint. Sometimes erroneously referred to the Serpulidæ as "*Serpula rubra*." First recorded from Bermuda by Mörch.

Scala, sp.

Bartram (Berm. Almanac for 1881, p. 126) recorded a species (erroneously as "*Scalaridæ scaberrima*" of Chenu), which he said was only found as a "sub-fossil." Chenu's figure of *Scala scaberrima* represents a *Scala* with numerous delicate varices, not unlike some of the living Bermuda species. Though Bartram's identification was doubtless wrong, it indicates that he had a true *Scala* from this formation, of which an outcrop occurs close to his former residence, at Stocks Point. In the same list he mentions other "sub-fossil" species as not found living now.

Livona pica (Linn.). Figure 60, p. 197.

Very abundant and perfect at Devonshire Bay (Stevenson). Common in the beach deposits and also in the older Walsingham formation, as well as in modern sand-dunes. (See above, page 158.) Not known as now living in Bermuda waters.

Astralium longispina (Lam.).

Near Hungry Bay; not common.

Modulus modulus (Linn.). Figure 59*c*.

Modulus lenticularis of many writers.

Not very common.

Nerita tessellata Gmel. Figure 61, 1, 2.

Not uncommon.

Nerita peloronta Linn. Figures 61, 3, 5.

Not common. Found by us near Hungry Bay; also recorded by Rice.

Nerita versicolor Meusch. Figure 61, 4.

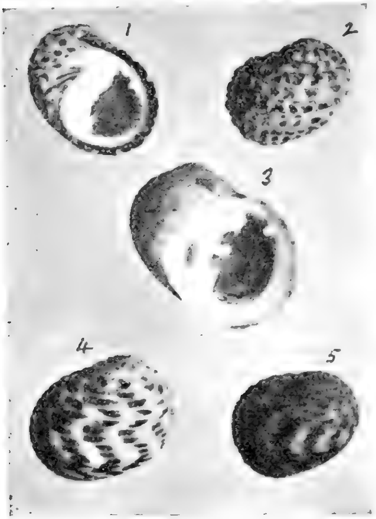
Not common; near Hungry Bay.

Fissurella (Cremides) barbadensis (Gmel.). Figure 62, *a*, *b*.

Fissurella barbadensis Gmelin=*F. antillarum* d'Orb., and of many others.

Recorded by Rice.

61



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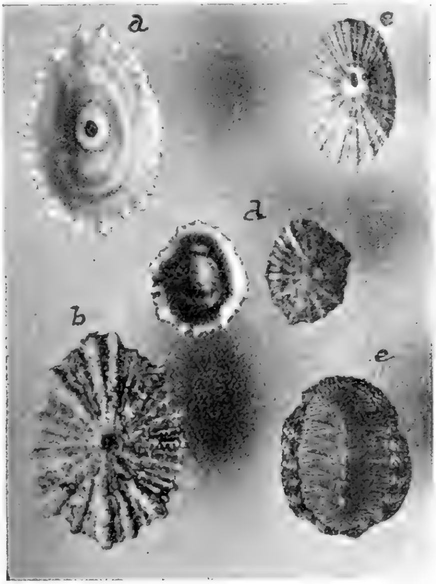

Figure 61.—1, 2, *Nerita tessellata ;* 3, 5, *N. peloronta;* 4, *N. versicolor.* Natural size ; phot. A. H. V.

Figure 62.—*a*, *b*, *Fissurella barbadensis ; c*, *Glyphis alternata ; d*, *Siphonaria alternata ; e*, *Chiton tuberculatus*, young. All about natural size. Recent. Phot. A. H. V.

Fissuridea alternata (Say). Figure 62, *c*.

Fissurella alternata Say=*Glyphis alternata* of many writers.

Recorded by Rice as *Fissurella græca*, which is a Mediterranean species closely related to *F. alternata*. Rice's specimens may have been *F. alternata*, which is the common recent Bermuda species of this group, or *F. Listeri*, which is very similar.

Bulla occidentalis Adams.

Bulla media of many authors (*non* Linn.).

Fragments are common.

b. Bivalves.

Tellina lævigata Linn.

Fragments, apparently of this abundant living species, are common.

Tellina (Angulus) promera Dall.

One specimen found at Hungry Bay, 1901.

Tellina, sp.

Fragments of one or more additional species were found, too imperfect to name. Fragments are abundant at Devonshire Bay.

Venus or **Chione**, sp.

In Bartram's list (see Berm. Almanac for 1881, p. 126), he identified a species, doubtless erroneously, as *Venus puerpera* from Chenu's figures, 351–354, which represent a rounded lamellose species. He states that it is only found sub-fossil. In our collection of the recent shells there are fragments of a similar large species.

Pullastra or **Callista** ?

In Bartram's list (op. cit., 1881, reprinted from previous years), he records a shell, only found as a fossil, under the erroneous name *Pullastra perovalis,* identified by Chenu's figure (vol. ii, p. 92, f. 411). The figure represents a regularly ovate, smooth shell unlike any recent Bermuda shell known to me. The fossil might be a *Callista maculata*, but needs reëxamination *

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* Mr. J. T. Bartram's collection of shells, birds, fishes, etc. was purchased by the Bermuda government, after his death, but it was not accessible at the time of my visits. In his lists, 1875 to 1881, many species entirely foreign to Bermuda are included, doubtless brought in by sailors. Among such are *Buccinum undatum*, *Fasciolaria tulipa*, *Terebra tigrina*, *Strombus peruvianus*, *Oliva porphyrea*, and many others. Moreover, many of the true Bermuda shells are wrongly named, from a superficial resemblance to the figures in Chenu, and in Woodward's Manual, which seem to have been the only illustrated works on shells that he had. He also published in his lists many (23) of his own manuscript names. He was a persevering collector, but uneducated and without any scientific training. He resided at Stock's Point for many years, but had previously been a sailor. If his collection had been carefully studied by a competent malacologist, it would have added much more to our knowledge of the Bermuda fauna than his lists indicate, for they are far too unreliable for scientific use, except in those cases when confirmed by later collectors. He also left a considerable amount of MSS. relating to his shells, but they have not yet been examined by a specialist to ascertain their value. J. M. Jones was personally acquainted with Mr. Bartram and certainly saw his collection and exchanged

Phacoides pennsylvanicus (Linn.) Dall, 1901.

Venus pennsylvanica Linn.; Nelson, 1840.
Lucina pennsylvanica of most writers.
Lucina speciosa and *L. grandinata* Reeve (t. Dall.).

Lieut. Nelson, 1840, recorded this as *Venus pennsylvanica*, and wrote as follows:

"A stratum of these, in indifferent preservation, is in the quarry whence the stone for the pier at St. George's ferry was obtained. This bed, however, is of trifling extent compared with an apparently corresponding one in the chain of islets reaching across the mouth of Crow-lane Harbour, beginning near Phyllis' Island, and continuing thence through every point till it reaches Harris's Island: it is about five feet thick and lies about six feet above the water."

Variety **somersensis,** nov. Figure 63.

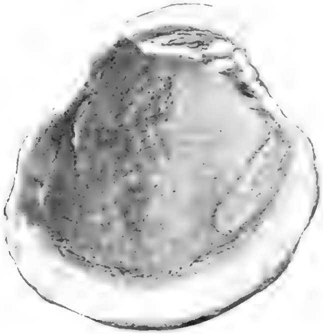

Figure 63.—*Phacoides pennsylvanicus*, var. *somersensis*, left valve, natural size. Type.

Two separate valves of this large and thick shell were found by me near Hungry Bay, 1901. It is thicker, more convex, and much more oblique than the typical form, with the umbo more prominent and the beak more incurved, and situated more anteriorly. The dorsal area is defined by a wide and rather deep groove; the lunule is large, strongly cordate, and sunken. The cardinal and

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specimens with him to some extent, as is shown by their correspondence, which I have seen, but Jones seems to have made very little use of Bartram's collection in compiling his own lists of 1864 and 1876, which are much more accurate than Bartram's later lists. Mr. G. Brown Goode also visited Mr. Bartram's place and saw his collection, but made very little use of it, except that he credits a few species of fishes to him, in his list of 1881 (Bermuda Almanac, p. 116).

lateral teeth are well developed. There is no radial sculpture, but the surface is covered with shallow unequal grooves or undulations, with larger ones at two resting periods. Height of figured valve, 55^{mm}; transverse elevation, 16^{mm}.

Codakia orbicularis (Linn.) Dall.

Codakia tigrina in most recent lists. *Lucina tigrina* (*pars*) auth. (*non* Linn.).

Fragments are common. Recorded by Rice as *C. tigerina.*

Codakia orbiculata (Mont., 1808) Dall.

Lucina pecten Lam., 1818.
Lucina imbricatula C. B. Adams, 1845.
Lucina pectinata C. B. Adams, 1852 (*non* Gmel.).
Lucina occidentalis Reeve, 1850.

Fragments are common.

Codakia costata (d'Orb.)=*Lucina antillarum* Reeve, 1850=*L. ornata* Adams, 1852 (*non* Reeve), Hungry Bay.

Chama macrophylla Chem. "*Rock Cockle.*" Plate XXXV B, figs. 4, 4*a*.

Common, mostly broken in small fragments. It has received many other names.

Chama lingua-felis Reeve.

Recorded by Rice. Probably only a variety of the preceding.

Arca noæ Linn. "*Mussel*" of the fishermen. Plate XXXV B, figs. 6, 6*a*.

Common.

Arca (Barbatia) dominguensis (Lam.).

Recorded by Rice.

Pectunculus undatus Linn.

Several valves of large size were found near Hungry Bay.

Modiola tulipa Lam. "*Black Mussel.*" Plate XXXV B, fig. 5.

Fragments near Hungry Bay.

Mytilus exustus Linn. "*Small Black Mussel.*"

Common; also found in the æolian limestones, just above the beach-rocks, associated with land shells, near Hungry Bay.

Spondylus americanus Lam. "*Rock Scollop.*" Plate XXXV B, figs. 1, 1*a*.

Fragments are common, often preserving the reddish colors. It has received a variety of other names.

Margaritophora radiata (Lam.). *Pearl Oyster.* Plate XXXV B, figs. 2, 2*a*.

Fragments retaining their pearly luster are occasionally found.

Ostræa frons Linn.

Fragments are not rare.

Corals.

? **Mycetophyllia Lamarckana** Edw. and Haime, (?)=*Manicina areolata* of Nelson (an incorrect determination).

The specimen, which is preserved in Coll. Geological Soc. London, has been studied by Gregory. If correctly named by him* (as *M. Lamarcki*), op. cit., p. 266, it is a scarce West Indian species, not now living in Bermuda.

If beach-worn, as is probable, I should suspect that it was rather one of the common Bermuda species of *Mussa*. (See p. 77, note.)

? **Mæandra areolata** (Linn.) Oken.

Verrill, these Trans., vol. xi, p. 81–84, pls. xi, xii, 1901.
Manicina areolata Lam. Lieut. Nelson, op. cit., 1840.

This common West Indian species is not now found living in Bermuda. I have formerly suggested that it was a mistaken identification of the last species, but this needs confirmation.

Found by Nelson in the beach-rock of Ireland Island.

Orbicella cavernosa (Linn.). Figure 87. Plate XXX A, fig. 2.

Verrill, these Trans., vol. xi, pp. 102, 171, 1901.

This species was recorded as a fossil from Bermuda, in Coll. Geolog. Soc. London, by Gregory (Proc. Geolog. Soc., li, p. 271), under the name, *O. radiata*.

Madracis decactis (Lym.). Figures 94, 95.

This species was recorded by Gregory, op. cit., p. 250, as found fossil in the beach-rocks. We did not find it, except living.

Agarica fragilis. Figures 101, 101*a*.

Agaricia undata Nelson, 1840.

Found with the last by Nelson. Small fragments of this common thin and fragile species are occasionally found, both in the beach deposits and in the later æolian limestones.

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* See these Trans., xi, p. 68, where, however, this identification was erroneously attributed to Dr. Vaughan. Whether it be Nelson's specimen may be doubtful.

Millepora alcicornis Linn. Figure 36. Pl. xxx A, fig. 1.

Fragments of the fragile branches are rather common in the beach deposits. It is now one of the most abundant reef corals.

Echinoderms.

Melitta testudinata (Klein)=*Scutella quinqueforis* Nelson.

This five-holed sand-dollar was recorded by Nelson from Ireland Island and the islands in Crow Lane, Hamilton. It has not been observed here by others, either living or fossil. The six-holed species (*M. sexforis*) is common, however. Possibly Nelson confounded the two species. Both are common on the sandy coasts of the Carolinas and Florida.

Foraminifera.

In some of the finer layers of beach-rock, near Hungry Bay, foraminifera of many species were common, but mostly too much worn to admit of specific determination.

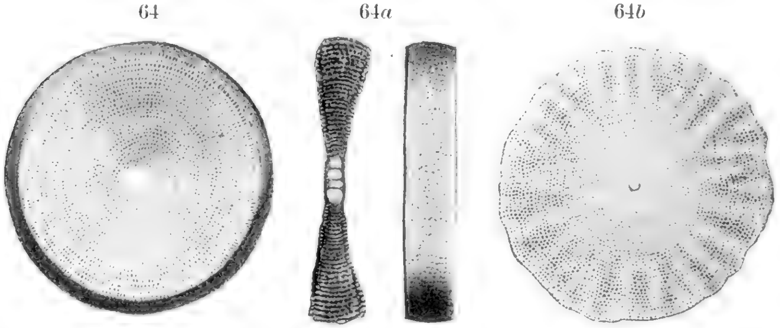

Figure 64.—*Orbitolites marginalis*, × 10; 64*a*, the same, profile and section; 64*b*, *O. duplex*, × 6. Both after Brady.

Among those recognized were *Orbiculina adunca* (see p. 140, fig. 35, 12); *Orbitolites marginalis*, fig. 64; *O. duplex*, fig. 64*b*; *Cornuspira foliacea* (fig. 35, 13); *Miliolina seminulum* (fig. 35, 3); *Biloculina ringens* (fig. 35, 9); *Textularia concava* (fig. 35, 5); *Peneroplis* (fig. 35, 16). But many other species were present.

Fragments of the common red sessile foraminifer (*Polytrema miniaceum*), which grows firmly attached to the under sides of dead corals and stones in warty and branched forms, are not uncommon. This is probably what Nelson referred to as a red *Millepora*. (See chapter 30 for figures.) Delicate shells of Mollusca (*Cæcum*, etc.) were found entire in the same layers, indicating that they were deposited in rather quiet water, either below low-tide or in a sheltered locality.

The species and varieties from these beds that are not certainly known to be living in Bermuda waters are the following:

?*Strombus accipitrinus.*
Fasciolaria distans.
Scala, sp.
Livona pica. Common.
Venus,—a large lamellose species.
Callista (?), like *C. maculata* in form.
Phacoides pennsylvanicus, var. *somersensis* Ver.
Balanus,—a large, massive species.
?*Mycetophyllia Lamarckana.*
?*Mæandra areolata.*
Melitta testudinata.

26. *Fossils of the Æolian limestones and sands of the Devonshire, Paget, and later formations.*

Certain portions of the æolian limestones must have been of the same age as the raised beach deposits, and seem to be continuous with them at some localities on the south shores, but others, and perhaps the larger part, are of later origin, down to modern times. In some places they rest upon the beach limestone unconformably. (See above, pp. 73–80, and plates xvi–xix.) At present it is impossible to determine the relative age of most of these æolian limestones. We know that some rest directly upon the older beach deposits or are continuous with them, and overlaid by thick strata of still later origin, yet it is not known that any characteristic differences can be made out in the fossils that they contain. Hence I have here grouped together all the fossils from these newer æolian deposits, whether supposed to be contemporary with the Devonshire beach deposits or later.

Although we have not, at present, sufficient evidence to prove any great change in the physical conditions between the Devonshire and Paget periods, there are certain facts that indicate greater changes of level than the few feet of elevation above the sea, now shown by the ordinary beach deposits. The discovery by us of a layer of hard marine limestone, near Hungry Bay, composed largely of foraminifera and small marine shells, such as we now dredge up from the depths of 3 to 5 fathoms, indicates that after deposition these beds may have been raised 20 to 30 feet or more, above their previous level. Moreover, the occurrence of hard limestones containing marine shells in the excavation for the dry dock (p. 177, fig. 58), and in the deepening of the harbor channels, at depths of 16 to 30 feet, indicates that such beds have at one time been elevated above the sea and subsequently subsided, for the loose materials apparently do not consolidate here except above low-tide level, where more or less exposed to the air (see p. 21). These facts go to show that a second period of subsidence, perhaps of 20 to 35 feet, followed the emergence of the Devonshire marine limestones. In that case, the changes in physical conditions and vegetation must have been considerable at that time, and doubtless enough to exterminate many species.

It is possible that the unusually thick layer of red clay that has been found to underlie the city of Hamilton and adjacent districts may eventually be found to mark best the distinction between the Devonshire and Paget periods. It certainly marks a very long period of surface decay of the limestone and probably of forest growth. In some of the sections it is at least two feet thick. In a boring for the military works at Prospect Hill, it was cut through at the depth of 130 feet, and at that point it was about 65 feet above sea level. At Hamilton it (or a similar layer) descends nearly to the shore. No fossils have been reported from it.

As it seems desirable to have a definite name to designate those limestones known to be newer than the beach deposits of Devonshire age, I propose to call them the Paget formation, because they are well displayed near Hungry Bay in Paget Parish, where my photographs, here reproduced, were made. This may be regarded as a typical example of these rocks. See plates xvii–xix. Their physical characters have been described above. (See p. 73 and fig. 11.)

a. Fossil Land Shells (*Pulmonata*).

Several of the extinct land shells of the Walsingham period are also found in the unconsolidated sands and soft shell limestones referred to the Devonshire period. In some cases it is possible that they had been weathered out of the older deposits and subsequently redeposited with other wind-drifted materials in the later sand-dunes. If so, we have at present no means of determining such instances.

There are, however, a few fossil species that have not been found in the older rocks, but are still living. The following species have been obtained from deposits believed to be of these later periods :

Pœcilozonites bermudensis, var. **zonatus** Ver. See p. 164.

PLATE XXVI, FIGURES 1, 2. PLATE XXVII, FIGURES 2, *a–l*.

Very common. In many of the banks of soft limestone by the roadsides, especially near Elbow Bay and Hungry Bay, it weathers out in large numbers and great quantities of the clean shells can sometimes be found at the base of the banks after rains. It was abundant in a bed of partially consolidated sands on the northwest side of Charles Island (or Goat Island), where the sea was undermining it. At this place many of the shells retained their brown color-bands, and some were curiously mounted on the summits of slender columns or pedicels of shell-sand, due to the protection afforded by the shells from erosion by the falling spray or rain. The shells figured on plate xvi, figs. 1–2, were from this locality.

At present this small barren island is nearly bare of vegetation and quite unfit for the existence of land shells of this kind. Probably these fossils date back to a period when this island, Castle Island, and the other adjacent small islands were much larger, wooded, and connected with the main island at Castle Point, thus forming a continuous barrier on the south side of Castle Harbor. There is no evidence whether Charles Island (also called Goat Island and Old Fort Island), was or was not wooded at the time of the first settlements, though a small stone redoubt was built on it at that time, of which the ruins still remain.*

This fossil variety (*zonatus*) is generally easily distinguishable from the recent specimens. The shells are usually distinctly thicker and heavier, the spire is usually more obtusely rounded, and the body-whorl less sharply angulated in the adult at the base. The inner lip nearly always has a thick callus in the adult. The umbilicus is generally decidedly smaller† than in the living form, being usually about 1^{mm}; sometimes only 0.5^{mm}, but is variable in both. The fossil shells are usually conspicuously banded with two peripheral brown bands, often separated by a white band on the keel, while the recent ones are generally blotched or transversely flammu-

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* See "The Bermuda Islands," p. 51, fig. 22, for what is known of the history of this ruin.

† By a typographical error it is said to be *larger* in my former article (these Trans., xi, p. 728, note ; and "The Bermuda Islands," p. 316).

lated with brown, as shown by the figures on plate xxvii. But some of the fossils, as fig. 2, *c*, *d*, are also slightly flammulated, similar to some of the living ones, while the living ones, as fig. 1, *c*, *g*, are often banded. The middle row of shells (figs. 1 and 2, *e* to *h*) in each figure show the range of variations in the umbilicus and base of each variety, while the lower row shows the range of variation in the form of the spire and aperture, and the angulation of the body-whorl. In fig. 2, *g*, the umbilicus is reduced to a small pore, while in fig. 1, *e* and *g*, it is large, yet all intermediate sizes occur, from .5 to 2^{mm}.

Average specimens are about 20 to 22^{mm} in diameter, and 12 to 14^{mm} high, but the larger ones may be 24 or 25^{mm} in diameter and 14 to 16^{mm} high. Some of those with a depressed spire measured 10^{mm} high and 19^{mm} in diameter; 10^{mm} high and 20^{mm} in diameter. All these are adults with a thick callus on the inner lip. The last body-whorl is usually distinctly angulated and sometimes almost carinate. In the young the spire is nearly flat, the last whorl is carinate, umbilicus larger, and the color is flammulated.

This variety would probably pass for a distinct species if intermediate forms were not found, or if it occurred in another region. The modern form seems to be a degenerate or depauperate descendant, altered by a less favorable environment.

The living form of this species has been erroneously referred to several genera, as shown by Pilsbry in Proc. Phil. Acad., 1888, p. 289, where he has figured the jaw, radula, and genital organs. The following references apply chiefly to the living form (var. *bermudensis*), which will doubtless be found in the more recent æolian limestones and dune sands, if sought for.

Pœcilozonites bermudensis Pilsbry (*pars*). Proc. Acad. Sci. Philad., 1888, p. 289, pl. xvii; the same in Heilprin, "The Bermuda Islands," pp. 196, 198, pl. 16, figs. E (young), C (radula); N, O, (genital organs), 1889.

Pilsbry, Proc. Phil. Acad. Nat. Sci., 1889, p. 85 (anatomy and synonymy); Trans. Conn. Acad. Science, x, p. 499, 1900.

Verrill, these Trans., xi, p. 728, 1902; "The Bermuda Islands," p. 316 [728].

Zonites bermudensis Binney, Annals N. York Acad. Science, iii, p. 86 (jaw and radula).

PLATE XXVII, FIGURES 1, *a–l*.

In our plate twelve recent specimens are figured from photographs. They show marked variations in color, elevation of spire, size of umbilicus, shape of aperture, and extent of angulation of the body-whorl.

According to Pilsbry (Phil. Acad., 1889, p. 86), this species was the type of the genera *Pœcilozonites* Bottger, 1884; *Bermudia* Ancey, 1887; *Juno* Mazyck, 1889. It has also been referred to many other genera.

Helix ochroleuca Pfr. is believed to be a pale, plain-colored variety of this species.

Pœcilozonites Reinianus. See p. 164. FIGURES 66*a*, 66*b*.

This living species, common in the older rocks, was also found by Mr. Gulick in the newer sandy deposits at his stations 808 and 809, near the Devonshire Marsh and barracks, associated with the last, and by us near Hungry Bay.

Variety *Goodei* Pilsbry has also been found by Gulick at Tower Hill. See p. 165.

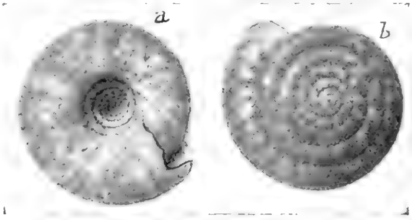

Figure 66.—*Pœcilozonites Reinianus*; *a*, under side; *b*, upper side of another specimen. Recent, × about 4. Photog. by A. H. V.

Pœcilozonites circumfirmatus. See p. 166. FIGURES 48*a*, 48*b*.

Found by Mr. Gulick at stations 808 and 809, with the two preceding.

Variety *discrepans* (Pfr.) has also been found in these deposits, by Mr. Gulick. (See p. 167.)

Euconulus turbinatus. See p. 168. FIGURES 55*a*, 55*b*.

This extinct species was found by Mr. Gulick at station 808, with the last.

Polygyra microdonta (Desh.). FIGURE 67.

Pilsbry, these Trans., x, p. 496, pl. lxii, fig. 3, 1900.

Verrill, these Trans., xi, p. 729, fig. 72; "The Bermuda Islands," p. 317, fig. 72. Gulick, op. cit., p. 413, 1904.

This species was recorded as a fossil of the "drift rocks" by Professor W. N. Rice (as *Helix*), but he did not give any special locality. It was not found as a fossil by our parties nor by Gulick. It is an abundant living species, found also in the Bahamas.

Pupa (Bifidaria) rupicola. See p. 170. Figure 68*c*.

One specimen was found by Mr. Gulick at station 808.

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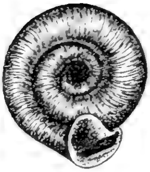

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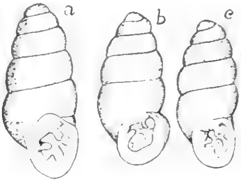

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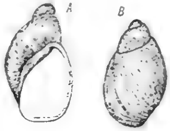

Figure 67.—*Polygyra microdonta*, enlarged; from photog. by A. H. V.

Figure 68.—*a*, *Pupa servilis*, ×9; *b*, *Pupa jamaicensis*, ×9; *c*, *Pupa rupicola*, ×9; after Pilsbry.

Figure 69.—*Pupoides marginatus*, nat. size and ×6½; after Binney.

Figure 70.—*Succinea barbadensis*, two recent specimens, ×2; from photog. by A. H. V. All from recent specimens.

Pupoides marginatus (Say). Figure 69.

Pupa marginata Say.

Pupoides marginatus Pilsbry, these Trans., x, p. 498, 1890, pl. lxii, fig. 16. Verrill, op. cit., p. 729, fig. 73.

This species, which is still living in Bermuda, was found by Mr. Gulick at station 809 (one specimen).

It has not been found in the older rocks.

Carychium bermudense Gulick. See p. 171. Figure 54, *a*, *b*.

This minute, slender extinct species was found in the sand-pits at stations 808, 809 by Mr. Gulick, as well as in the older formations.

Succinea somersensis Ver. See p. 171.

This species was found by us in the fine, hard, marine limestones near Hungry Bay, associated with foraminifera and marine shells. Mr. Gulick found a *Succinea* (recorded by him as the living form (*S. bermudensis*) in the Paget sands at his stations 808 and 809, which may have been the same as the older and larger species or variety. The existing species is figured here for comparison (figure 70).

b. Fossils Birds and Reptiles of the Paget Formation.

Up to the present time we have very little precise knowledge of the vertebrate fossils that have, from time to time, been found in these deposits.

The most important of these are probably the bones of birds. Several fossil bones of birds kept in the collection in the public building at Hamilton were seen by the writer, but they were too few and imperfect for identification, unless by long and careful comparisons with the skeletons to be found only in large museums. Other collections of birds' bones have been made, but not yet identified.

Several fossil birds' eggs have also been found, some of them quite recently, but they cannot be identified with certainty. Those that I have seen are about the size and shape of those of the tropic bird. Lieut. Nelson in 1840 mentioned the discovery of the bones and eggs of birds as follows :

"Returning to the cavern at the North Bastion (fig. 8). In the heap of red earth, which in this instance only had rather an unctuous feel, mixed with the large *Helix* [*P. Nelsoni*], were found quantities of birds' bones. From the best accounts, the caves at Ireland were frequented until lately by a sea bird, whose local name, derived from its peculiar cry, is Pim-li-co.* In hazy weather, or at night, this sound was always a warning for vessels from the West Indies to put about, and avoid the perilous southwest bar and reefs; but since the establishment of the dockyard at Ireland, these birds have almost left the Bermudas.

Whilst excavating a ditch near the cavern *b*, shown in fig. 5, p. 108, a small hole was discovered in a rather hard rock, composed of comminuted fragments, with the interstices not filled up; it was about twenty feet above the sea, thirty yards from it, and fifteen feet from the top of the hill, but without any apparent connection with the surface. In this hole were found an eggshell and many fragments of bones, similar to the preceding, but they were all, as well as the egg, coated with carbonate of lime.

Ireland however is by no means the exclusive mine for these fossils. Bones, apparently those of birds, have been found in the limestone on the coast of Harrington Sound by Mr. Hill, to whom I am indebted for the information. He obtained specimens fifty feet from the water, twenty feet above it, and four feet under the surface.

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* This is the Shearwater, *Puffinus cinereus* or *Anduboni*, which still breeds sparingly in Bermuda.

Three eggs were found close to the bones, and similarly imbedded. Another egg was found in a block of limestone near Hamilton."*

A fossil egg about the size of a hen's egg was found by Mr. H. J. Zuill of Orange Grove, Smith's Parish, Sept., 1903, in breaking stone by the roadside. (See Royal Gazette, Sept. 5, 1903.)

Mr. A. Agassiz mentions a fossil egg (as that of a tropic bird) found in a quarry by the Middle Road in Devonshire, formerly preserved in the government building. I examined the same specimen, but should be unwilling to say it was the egg of a tropic bird. It may have been a shearwater.

The most notable discovery of the bones of sea-turtles is that mentioned by Nelson, in 1840. There is no certainty as to their species and they may have been of recent origin:

"Turtle bones were also procured from the North Bastion coral rag, and from the sands at Elbow Bay. The turtles seem, like the poor bird before mentioned, to have been buried while depositing its eggs, as the two skeletons when first discovered were entire and undisturbed. Their dimensions were nine feet in length and seven in breadth, as I was informed by an eye-witness."

The earliest records of the Bermuda settlement mention the great size of the turtles as found living at that time.†

Probably they were the green turtle (*Chelonia mydas*), which ceased to breed here probably more than 200 years ago.‡

c. *Marine Shells in the Paget Formation.*

Livona pica and Cenobita diogenes (Linn.).

FIGURE 60.

This well known large, thick, pearl-lined, West Indian shell is one of the most common and conspicuous of the fossils of this formation. Where the rock is feebly consolidated or sandy, these shells often weather out in considerable numbers and are sometimes nearly perfect, the blotches of dark color still showing in many specimens. As stated above (p. 158), they were unquestionably carried up from the sea shores originally by the land hermit-crab (*Cenobita diogenes*), which is still living here in considerable numbers. But many of the shells have probably been used again and again, even after they have been weathered out of previous deposits.

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* See also Hurdis, Nat. Hist. of the Bermudas, p. 373, 1897.

† See Verrill, "The Bermuda Islands," p. 279 (691), 281.

‡ See Verrill, "The Bermuda Islands," I, p. 280, 1902.

In a few instances remains of the actual shell of the Hermit-crab have been found in the fossil *Livona.* Mr. J. Matthew Jones sent me a fossil crab of this kind from Bermuda, many years ago, which had the characteristic legs and claws in fairly good preservation. The exact locality where it was found was not recorded.

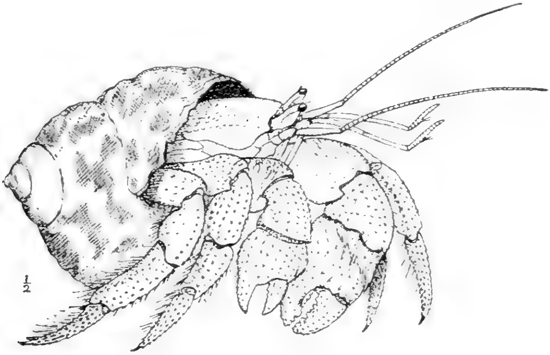

Figure 60.—Land Hermit Crab (*Cenobita diogenes*) in a fossil shell of *Livona pica*, ½ natural size. Drawn from life by A. H. Verrill.

The correct explanation of the presence of this shell in these elevated beds was first given by Lieut. Nelson, in 1840:

"The *Turbo pica* [= *Livona pica*) is very abundant, with the nacre and colors; but like the *Venus* [*Lucina*] *Pennsylvanica*, it is chiefly met with in sand-pits, and more recent formations, though without the slightest reference to the hardness of the stone containing it. It seemed difficult at first to account for these large shells (*Turbo pica*) being found on heights, where, from their weight, it was impossible to suppose they had been carried there by the wind; but a solution may be found in the habits of the Soldier Crab, which, on more than one occasion, I have seen running about in these shells."

The *Livona* appears to have become extinct at Bermuda in recent times, for its broken shells were found in the heaps of kitchen refuse at the ancient forts on Castle Island, as if used for food by the garrison there, probably during the war of 1812.*

Various other common marine shells, especially single valves of *Tellina*, *Mytilus*, *Lucina*, *Chama*, etc., are occasionally found in these deposits, especially in those that are but a few feet above the

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* See these Trans., pp. 463, 708; Verrill, "The Bermuda Islands," pp. 51, 296, for details.

level of the beach deposits. They were, without doubt, mostly carried up to those positions by unusually high winds or great storm waves, such as often occur in modern times. But crows and other birds habitually gather such shell-fish, sea-urchins, etc., on the shores and carry them inland for food, so that their shells may occasionally be found at any elevation.

d. Fossils of uncertain nature; Casts of Plants, etc.

In many localities irregular, cylindrical, tapered, and sometimes branched structures occur in the æolian limestones at various levels. Sometimes they are tubular with a cavity in the center, either empty or filled with loose sand. In many cases the walls are thick and not very firm ; in other cases, especially when small, the walls are hard and almost crystalline. These are generally supposed to be the moulds or casts of the roots, and sometimes of the stumps of trees and other plants. In some cases they resemble the stumps and roots of the common Bermuda cedar, but they seldom, if ever, show any organic structure. They appear to have been formed by the hardening of the sands around the roots by the rain water percolating through decayed roots or around living ones. (See p. 62, above.) According to J. M. Jones the process of forming these casts was still going on near Elbow Bay, when he wrote. His account was as follows:

"On the western side of the sand hills, there is now a plateau of about half an acre, or perhaps more, of hardened drift sand, forming gradually into rock. On its face are cracks filling with drift sand : showing that the sun doubtless affects this hardened surface. Elevated stumps of a foot or so in height, rise amid this plateau; having each a hole or depression at the centre. These denote the sites in which cedar trees formerly grew. At the east end of the hills may be seen the gradual decay of cedar stumps; exhibiting more clearly the several stages of change; which are the more worthy of study, in consequence of the light they throw upon the many curious chimney-pot looking structures everywhere to be met with on the Bermuda shores."

Perhaps these root-like structures are more abundant on Cooper's Island than elsewhere, but we observed them in many places. In some cases small tubular root-moulds were seen to come in contact with fossil snail shells and curve around them in clusters, just as living roots will do.

Some of the tubular forms may have been due to the consolidation of the walls of the burrows of animals, such as the land-crabs, earthworms, etc.

Synopsis of Bermuda Paleontology.

Three distinct formations can be distinguished by their fossils:

1st. The earliest rocks now visible above the sea probably belong to the Pliocene. They are here designated as the Walsingham Formation. They contain at least 17 species and 6 varieties of land shells (Pulmonata), of which 9 species and 4 varieties are extinct, besides one that still lives in the West Indies and southern United States, but not in Bermuda (*Strobilops Hubbardi*, fig. 53).

This formation contains all the known species (6) and most of the subspecies or varieties of *Pœcilozonites*, a genus peculiar to Bermuda. This genus had already attained its greatest development at that early period, for the largest and strongest species (*P. Nelsoni*), now extinct, was then very abundant, and all the other species and varieties were larger and heavier than their modern descendants.

In view of the great development of this genus at that time, it might well be called the *Pœcilozonites Period.*

No marine deposits of this age are visible, for it was followed by a subsidence of 100 feet or more.

2d. The second formation, here called the Devonshire, is composed in part of marine limestones or "beach rock," containing a large number of marine shells, corals, foraminifera, etc. It corresponds to the period of greatest subsidence. The marine limestones are now rarely elevated more than 8 to 12 feet above the sea and extend below low tide in some places. They have suffered greatly by erosion, and are now often of small extent. Æolian rocks of the same age occur. The marine fossils are mostly species still living in Bermuda waters. A few (about 10) are now extinct there (p. 189), but most or all still exist in the West Indies.

This period probably corresponds precisely with the Champlain or Leda-clay period of New England and Canada. It was followed by a period of elevation, probably of small amount (at least 12 feet, and perhaps 25 feet or more).

3d. The third formation, here called the Paget, was the period of reëlevation, probably to a height somewhat greater than the present. It consists chiefly of æolian limestones, unconsolidated shell-sands, and red-clay layers, resulting from decomposition. It contains at least 10 species and 3 varieties of land shells, of which 3 species and 1 marked variety are extinct.

It corresponds with the period of reëlevation on the American coast. There is some evidence, in the submerged hard limestones containing marine fossils, that there has been a period of subsidence of small amount, during this period.

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PART V.—CHARACTERISTIC LIFE OF THE BERMUDA CORAL REEFS.

The geological structure of islands surrounded by coral reefs is so largely dependent on the animals and plants occupying the reefs that a brief review of the principal forms of life seems to be highly desirable. The general character of the growths upon many of the Bermuda reefs was given by Mr. Agassiz in his valuable memoir,* but he usually mentioned only a few of the genera and families of the larger corals, gorgoniæ, etc., that he noticed, and without figures. My present purpose is, therefore, to give a more specific and detailed account of the principal living forms, with figures of many of them, so that students, with few other books, and also amateurs, when visiting the reefs, may be able to recognize many of the species, without much difficulty.

The outer reefs cannot be safely visited except in pleasant weather, with little or no wind, on account of the heavy surf that frequently covers them. But there are interesting and productive coral reefs in Castle Harbor which can be studied, even in somewhat windy weather, especially if the wind be from the west or northwest. Others, in and near Great Sound, Bailey Bay, etc., can be visited when the wind is southerly or off shore. The outer reefs are, however, of greater interest, because the corals and other groups grow upon them much more luxuriantly than elsewhere. Those off the south shore and the extensive areas off the western end of the islands have been least studied, owing to the almost continuous surf.

The reefs or "flats" near the North Rocks (see figs. 23, 24) are among the best localities for studying the life of the outer reefs, for

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* A. Agassiz, Visit to the Bermudas, March, 1894. Bull. Mus. Comp. Zool., xxvi, pp. 209–281, 29 plates.

they are often laid bare for two hours or more, at low-water of spring tides. But there are reefs much nearer the shore that yield nearly all the species found there, though less abundantly.[*]

The water is so transparent in pleasant weather that objects can easily be seen on the bottom to the depth of 20 to 30 feet or more, by using a water-glass, with which nearly all the boatmen are provided.

But many of the reefs, which are covered at low-tide by only 1 to 3 feet of water, can best be thoroughly explored by wading over them clothed only in a bathing suit[†] and stout boots, for the surface is apt to be very rough and unreliable.

To obtain very large corals we used large and strong steel double grapples, made for the purpose, and worked with a rope from a large row-boat.

The Bermuda lobster is often taken by the fishermen by means of a long-handled spear or "grains." But it requires considerable skill and much practice to use this instrument in deep water, owing to the strong refraction. Yet some of my party acquired great skill in its use. We took *Octopus*, large holothurians, etc., as well as the lobster, in that way.

The fishermen use large lobster-traps of a peculiar form[‡] in which they also often take various fishes, Spanish-lobsters (*Scyllarides*), crabs, etc. Such traps, slightly modified and suitably baited, would serve admirably for the purpose of catching the rarer forms of crustacea, carnivorous gastropods, etc., living among the reefs in deep water. For the deeper waters, "tangles" can sometimes be used to advantage, but among and near the actual reefs the bottom is apt to be too rough and rugged even for tangles.

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[*] The larger and better forms of corals, gorgoniæ, sponges, etc., must, as a rule, be obtained by the use of grapples. A form of grapples used there by the fishermen and called by them "nippers," is an excellent instrument for this purpose. It is attached to a pole about 20 to 24 feet long and is worked by a cord attached to the movable jaw.

[†] This was the method used by my students, during our visit in 1898. As all were expert at diving and swimming, the large boat could thus be rapidly filled with choice specimens in much better condition than those obtained by the use of "nippers," which often break delicate corals, etc. Still the nippers had to be used at depths beyond the reach of the divers, and for corals growing in inaccessible recesses and crevices ; also for objects that cannot safely be handled, like the long-spined *Diadema*.

[‡] See "The Bermuda Islands," i, p. 293, for a figure of the ordinary style of lobster-pot used there, and pl. xciv, fig. 1, for a figure of the "lobster."

ANTHOZOA.

Madreporaria; True Reef-corals.

In any examination of the reefs, the corals,* actinians, gorgoniæ, and bright colored sponges naturally attract most attention. Nearly all the corals, as well as most of the other forms of Bermudian reef animals and plants, are the same as those found on the reefs of

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* The more important recent systematic works relating to the corals of Bermuda are the following. Many other special papers and the general works of Ehrenberg, Dana, Edwards and Haime, etc., are quoted in the synonymy:

Agassiz, Louis.—Report on the Florida Reefs. Accompanied by illustrations of Florida Corals, 4to, 23 plates. Edited by A. Agassiz. Explanation of plates and names of the corals by *L. F. Pourtalès.* Mem. Mus. Comp. Zoology, vol. vii, No. 1, 1880.

The plates are remarkably good lithographs, mostly by Sonrel, and illustrate many of the species found at Bermuda, including also the very young of several species. It contains no descriptions.

Dana, J. D.—Corals and Coral Islands. In ed. 3, 1890, the list of Bermuda corals is on p. 114. (Determined by A. E. Verrill.)

Duchassaing, P. and *Michelotti, G.*—Memoire sur les Coralliaires des Antilles. Mem. R. Acad. Sci., Torino, ser. 2, vol. xix, pp. 89, 10 plates, 1860. Supplement to same, Mem. cit., vol. xxiii, pp. 112, 11 pl., 1866.

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——— Morphology of the Madreporaria, iii. The Significance of Budding and Fission. Annals and Mag. Nat. Hist., ser. 7, vol. x, pp. 382–393, 1902. No. iv. Fissiparous Gemmation, op. cit., pp. 141–155, 1903.

——— Aggregated Colonies in Madreporarian Corals. Amer. Naturalist, xxxvi, pp. 461–471, 1902.

——— West Indian Madreporarian Polyps. Mem. Nat. Acad. Science, vol. viii, No. 7, pp. 401–597, pls. i–xxv, 1902.

This is the most important work hitherto published on the anatomy and histology of the soft parts of reef corals, including their relations to the corallum. More or less of the embryology of several species is also given. About 26 species were studied, including 10 that occur at Bermuda.

——— The Coral Siderastrea radians and its postlarval Development. Publ. No. 20. Carnegie Inst., Washington, D. C., 130 pp., 11 plates, 1904.

Gregory, J. W.—Contributions to the Paleontology and Physical Geology of the West Indies. Quart. Journ. Geological Society of London, vol. li, pp. 255–312, pl. xi, 1895.

This is chiefly devoted to the fossil and recent corals and includes lengthy synonymy, which in numerous cases is erroneous, as Vaughan has shown. He recorded three fossil species from Bermuda and several recent ones. Among

Florida and the Bahamas. But many of the common Bahama species do not occur in Bermuda. Therefore the reefs-corals here are less varied and less luxuriant. The absence from Bermuda of the large branching and palmate forms of *Acropora* (or *Madrepora*)

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the latter, he erroneously recorded *Colpophyllia gyrosa*, due to the fact that he wrongly considered *Mussa fragilis* Dana a synonym of that species. His record of *Agaricia agaricites* is probably also due to his erroneous synonymy, for he did *not* record *A. fragile* from Bermuda, which he very likely confounded with the former.

Heilprin, Angelo.—The Bermuda Islands, 1889.

Gives a list of 19 species on pages 99–103. Several are synonyms.

Lesueur, M.—Descr. de plusieurs Anim. appar. aux Polypiers Lamellifères. Mem. du Mus. d'Hist. Nat., vol. vi, pp. 271–299, pl. 15–17, 1820.

Figures the polyps of several species; a number of new species described.

Pourtalès, L. F.—The Reef Corals. Illust. Catal. Mus. Comp. Zoology; Memoirs, vol. ii, pp. 65–93, 1871. See also *Agassiz, L.*

Quelch, John J.—Report on the Reef Corals. Voyage of Challenger, Zool., vol. xvi, 202 pp., 12 plates, 1886.

Enumerates nearly all the known corals of Bermuda, with descriptions of many. Admits too many species of *Isophyllia*, *Oculina*, and *Meandrina*.

Vaughan, T. Wayland.—Some Fossil Corals from the Elevated Reefs of Curaçao, Arube, and Bonaire. Samml. Geolog. Reichs-Mus., ii, 99 pp. 8vo, 1901.

Contains detailed descriptions and full synonymy of many recent West Indian species. Also a good bibliographical list of works relating to West Indian corals.

——— The Stony Corals of Porto Rican Waters. Bulletin U. S. Fish Commission, vol. xx, for 1900, pp. 290–320, 38 plates, 1901.

Contains descriptions and detailed synonymy of the species, with numerous figures from photographs. For the later views of Dr. Vaughan, on their nomenclature, see Amer. Journ. Science, xiii, p. 76 (note), Jan., 1902; and these Trans., vol. xi, p. 206, 1901.

Verrill, Addison E.—Bulletin Mus. Comp. Zool., I, No. 3, pp. 29–60, 1864. Records several Bermuda species.

——— On the Polyps and Corals of Panama, with descriptions of new species. Proc. Boston Soc. Nat. Hist., x, p. 323, 1866.

Contains a comparison of the West Indian Coral Fauna with that of Panama.

——— Comparison of the Coral Faunæ of the Atlantic and Pacific Coasts of the Isthmus of Darien. American Naturalist, iii, p. 499, Nov., 1869.

——— Additions to the Anthozoa and Hydrozoa of the Bermudas. Trans. Conn. Acad. Science, vol. x, pp. 551–572, pl. lxvii–lxix, 1900.

——— Additions to the Fauna of the Bermudas from the Yale Expedition of 1901. Trans. Conn. Acad. Sci., vol. xi, pp. 47, plates i–ix; 6 cuts in text, 1901.

muricata is particularly noteworthy, for the latter are often the most conspicuous of the corals on the West Indian reefs. One reason for their absence here may be the lower temperature of the water in winter. But it may be due in many cases to the short duration of the free-swimming larval stages* of such species, so that the young larvæ may all perish before arriving at Bermuda. The same causes have influenced most of the other marine animals.

Probably most of the Bermuda species have migrated in one way or another from the Bahamas. How long a time is required for drifting objects to travel from the Bahamas to the Bermudas is not known. The distance is rather more than 700 miles, but floating objects would not travel in a straight line. They would, most likely, travel at least 1,000 miles in such a journey. At the rate of 1 mile per hour the northward drift would be 1008 miles in 42 days, or 720 miles in 30 days. Probably the average rate of the current, in this region, may not be much greater than that.

Verrill, Addison E.—Variations and Nomenclature of Bermudian, West Indian, and Brazilian Reef Corals, with Notes on various Indo-Pacific Corals (105 pp., plates x–xxxv; 8 cuts in text). Trans. Conn. Acad. of Science, vol. xi, part I, pp. 63–168, 1901.

Contains figures and descriptions of most of the Bermuda corals with details of synonymy, etc.

——— Comparison of Bermudian, West Indian, and Brazilian Coral Faunæ, op. cit., pp. 169–206, cuts in text, 1901.

Includes a list of all Bermuda corals then known.

——— Zoölogy of the Bermudas, vol. i, 427 pp., 45 pl., 1903.

Includes the four preceding papers, as articles 5, 10, 11, 12.

——— Review of The Stony Corals of Porto Rican Waters by T. W. Vaughan, Amer. Jour. Science, vol. xiii, pp. 75-78, 1902.

Relates to synonymy and changes in nomenclature, and contains the later views of Dr. Vaughan (note p. 76).

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* Dr. J. E. Duerden has shown that many of the common reef corals, including some of those found at Bermuda, remain in the free-swimming larval condition only a short time,—sometimes but few days. This adds very much to the difficulty of explaining their migration across wide seas. Possibly some corals may have drifted long distances attached to drift-wood or other floating objects, but it is rarely that they are found attached to drift-wood. I have seen a branched *Oculina diffusa*, over 6 inches high, taken from the bottom of a vessel at Bermuda, after a cruise in the West Indies. It is even possible that some of the common Bermuda corals were accidentally introduced into Bermuda waters by the vessels of the early settlers. Unfortunately the early writers on Bermuda do not mention the existence of corals on the reefs.

At present I am able to recognize only 22 Bermuda species of true corals (exclusive of the deep-water forms, of which several are known.)* They belong to 10 genera, as now classified.

Quelch, in his report (Voyage Challenger, xvi), gave a longer list, for he described, as distinct species, many trivial variations of *Mussa* (as *Isophyllia*), *Mæandra*, *Favia*, and *Oculina*. But seven of the genuine species here described were not known to him, so that he really had but 15 genuine species. Doubtless others will yet be found on the extensive south-western reefs, which have been as yet very little explored by zoologists.

Some of the common Florida and West Indian species† that are lacking on the reefs here, so far as known, are as follows:

Mussa angulosa.
Mæandra clivosa.
Mæandra (*Manicina*) *areolata.*
Dendrogyra cylindrus.
Colpophyllia gyrosa.
Meandrina meandrites.
Dichocœnia Stokesi.
Eusmilia aspera.
Cladocora arbuscula.
Phyllangia Americana.
Solenastræa hyades.
Acropora muricata.
Var. *cervicornis.*
  " *prolifera.*
  " *palmata.*
Porites furcata.
Agaricia agaricites.

On the other hand, certain genera and species seem to be more abundant and luxuriant here than anywhere in the West Indies. This is especially the case with the genus *Oculina*, with its several species, and with the genus *Mussa* of the *Isophyllia* type, of which there are here five species and numerous varieties. *Agaricia fragilis*, so common here, is comparatively rare elsewhere.

It is doubtful if any of the species are really restricted to Bermuda, though a few of the recently described species have not yet been recognized from other localities.

The most conspicuous, largest, and also one of the most common of the true reef corals is the brain-coral (*Mæandra labyrinthiformis*, figs. 71–71*c*), but on the outer reef the massive *Porites* (*P. astreoides*, pl. xxix, 1), is quite as abundant, while in some places the common star-coral (*Siderastræa radians*, pl. xxix, 2) is more

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* For a list of these, see Trans. Conn. Acad., xi, p. 182; and Zoology of Bermuda, i, article 12, p. 182.

† For detailed descriptions, synonymy, and numerous figures of most of the Bermuda and Florida corals, see my articles in these Trans., vol. xi, pp. 63–206, plates x–xxxv, 1901; and The Zoology of Bermuda, articles 11, 12, same plates.

abundant than any other coral. The hydroid coral (*Millepora alcicornis*, pl. XXXA) is, perhaps, more generally diffused and more abundant than any of the others, for it lives under a great variety of conditions and seems to grow very rapidly. The "rose-corals" (*Mussa fragilis*, and other species of that genus, figs. 76–84) are also very common, both on the reefs and close to the shores, and are notable on account of the large size and bright colors of their living polyps. The branching *Oculinas* are chiefly found in sheltered places and at some depth; also in the sounds, especially in Harrington Sound.

The green, olive, yellow, and yellowish brown colors, so prevalent in the colors of the reef corals and actinians, are in most cases chiefly due to the presence of unicellular algoid plants (*Zoöxanthellæ*) living as parasites or symbiotically in the tissues of the polyps, chiefly in the cells of the endoderm. These plants give out oxygen, when exposed to sunlight, which may be utilized by the tissues of the coral and thus serve as a sort of respiration for them. Corals well supplied with such oxygen-producing plants can live a long time in aquaria without change of water, if exposed to sunlight part of the time.

The varying colors depend partly upon the relative abundance of the *Zoöxanthellæ* and partly upon the colors of the latter, for there seem to be several kinds, with different tints.

Mæandra labyrinthiformis (Linn.) Oken. *Brain Coral.* Figs. 71–71c.

Diploria cerebriformis Edw. and Haime, and of many later writers.

Mæandra labyrinthiformis Verrill, these Trans., xi, pp. 70–73. Pl. x, figs. 1–3; pl. xii, fig. 5, 1901.

This species, when living, is usually lemon-yellow or orange-yellow in color. When it grows under favorable conditions, with plenty of room, it forms large hemispherical or dome-shaped masses, sometimes 5 to 8 feet or more in diameter. Such specimens must be several hundreds of years old,* for colonies of this and related species, of known age, in the Yale Museum and elsewhere, which were measured from time to time while living, grew about $\frac{1}{8}$ to $\frac{1}{4}$ of an inch annually, in the warmer waters of Key West and the Tortugas.†

But such large examples are seldom perfectly regular, owing to various injuries received from storms, etc. Those that are 1 to 2

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* See above, p. 149, note.

† See also Dana, Corals and Coral Islands, ed. 3, pp. 253, 418.

feet in diameter are often remarkably symmetrical. When growing near together two masses often come in contact by mutual growth and then they will often completely unite together by a grafting process, leaving only a thin line of epitheca to indicate the place of union.* I have one large and nearly symmetrical specimen consisting of three masses perfectly united together. When large numbers of the young start close together they may so unite that they form broad, irregular, crust-like growths, several feet across and only 2 to 6 inches thick. When it starts near low-water mark it cannot grow upward to any great extent, as it is killed by a brief exposure to air and sunshine, and therefore it spreads out in flattened, cake-like forms, often dead in the center.

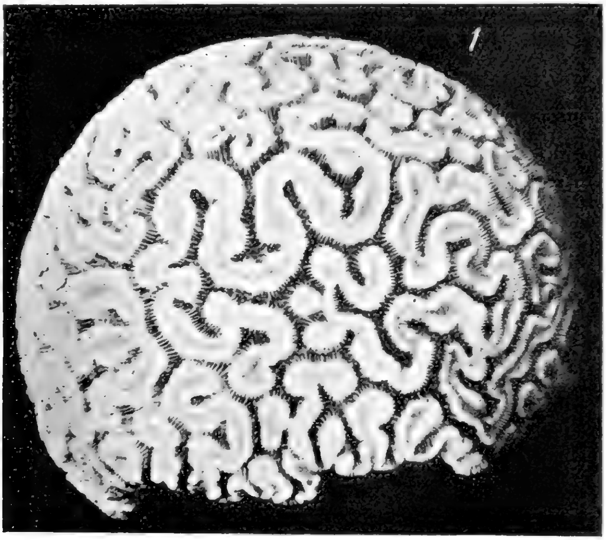

Figure 71.—*Mæandra labyrinthiformis.* Common Brain Coral. Young colony, somewhat reduced. Phot. A. H. V.

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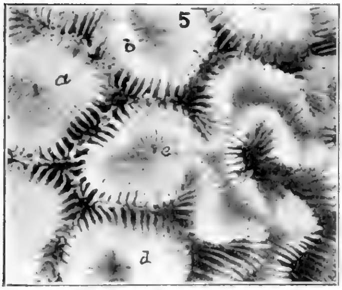
* This property is not confined to this coral, but is common to all the species of *Mæandra*, *Favia*, *Mussa*, *Agaricia*, *Siderastræa*, and doubtless to most other compound reef corals. I have personally observed it in numerous genera and species. Mr. Duerden has recently made some very interesting observations on the complete growing together, in the same way, of the recently attached and very young individuals of some of these corals, especially of *Siderastrea*. In such cases no evidence of such union can be detected in later stages. Amer. Naturalist, xxxvi, 1902; also Mem. Nat. Acad., viii, pp. 495, 523; and Carnegie Inst. Publ. No. 20, pp. 59, 60, 1904.

It varies greatly in the form and breadth of the ridges between the grooves. Young specimens, 2 to 4 inches thick, often have very wide and double ridges (var. *Stokesii*, fig. 71*a*); later on, the wide ridges divide and new grooves grow in between them. The wide ridges may also appear in larger specimens, either over the whole coral or in some particular places.*

71*a*



71*b*

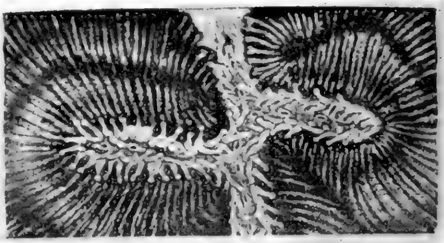


Figure 71*a*.—*M. labyrinthiformis* var. *Stokesii*, slightly enlarged: *a*, *b*, *c*, *d*, places where buds were about to develop.

Figure 71*b*.—*M. labyrinthiformis*, partially expanded polyps, enlarged; phot. from colored drawing.

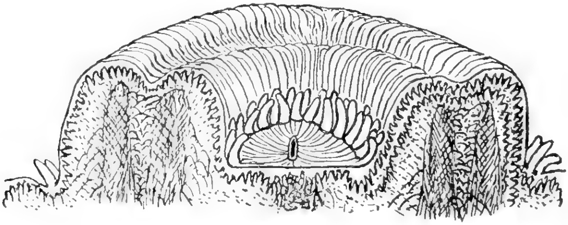


Figure 71*c*.—*M. labyrinthiformis*, a calicle at the end of a series, with a nearly contracted polyp, and a diagrammatic sectional view of the coral, to show the relation of parts. Drawn by the author from the living coral.

In full expansion the disks of the polyps rise up to or somewhat above the level of the summits of the collines, so that the bounding furrows may be seen above their walls while the disks become much wider than in their partly contracted condition, so as to occupy

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* For a fuller account and illustrations of these variations, see these Trans., vol. xi, pp. 70–73, pl. x, figs. 1–3; and Zoology of Bermuda, article 11, same plate.

nearly the whole breadth of the valleys, and the tissues become much more translucent. In contraction the column-walls of the polyps fold inward and downward over the septa, while the disk contracts to the breadth of the floor of the valleys, the tentacles having their bases over the groove outside the paliform lobes, as in fig. 71*c*.

The tentacles of the living polyps (fig. 71*c*) are not very long, rather slender, tapered, knobbed or obtuse at tips, alternately larger and smaller; the outer ones are the smaller, more erect, and have whiter tips. Mouths small, oblong or elliptical, with a whitish border. Disk deep yellow with faint white radiating lines. Cœnenchyma and polyp columns lemon-yellow to orange-yellow, sometimes dark ocher-yellow. In partial or complete contraction the septa and costæ show through as whitish radial lines.

It is common on the inner as well as on the outer reefs. On the reefs in Castle Harbor it is abundant, but seldom grows to great size there. It apparently does not occur in Harrington Sound. It is also common on the Florida reefs and keys, and throughout the West Indies.

Mæandra cerebrum (Ellis and Sol.). *Brain Coral.* Figs. 72–72*b*; 73, 73*a* (6–9).

Madrepora cerebrum Ellis and Solander, Hist. Zooph., p. 163, 1786.

Mœandrina sinuosa Verrill, Bull. Mus. Comp. Zool., i, p. 49, 1864 (*non Meandrina sinuosa* Les., Mem. Mus. Hist. Nat., vi, p. 278, pl. xv, figs. 4–9, 1820; with varieties *viridis, rubra, vineola, limosa, appressa*, most of which evidently belong to *clivosa*.

Mœandrina labyrinthica, M. labyrinthiformis, and *M. sinuosissima* of many writers.

Mœandra cerebrum Verrill, these Trans., xi, p. 74, plate x, fig. 4; pl. xii, fig. 4; pl. xiv, figs. 4, 5; pl. xix, fig. 7.

Mœandrina strigosa Dana. Pourtalès, Florida Reef Corals, p. 74; in L. Agassiz, Florida Reefs, pl. ix, figs. 6–9, 1880.

Platygyra viridis Vaughan, op. cit., p. 306, plates ix–xiii, 1901 (*non* Lesueur).

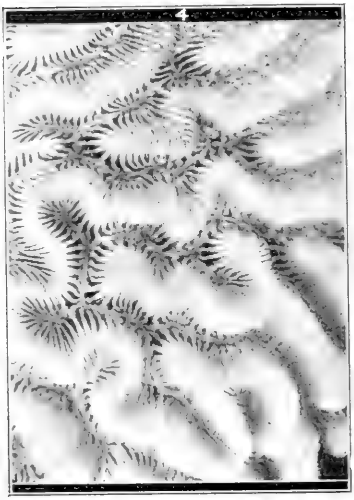
Mœandrina labyrinthica Duerden, Mem. Nat. Acad. Science, viii, pls. xx–xxii, figs. 138–147, anatomy and histology, 1902.

This closely resembles the preceding in form and modes of growth and may become equally large and hemispherical, but the collines between the grooves are always narrow and not double. Its color in life is variable,—often pale ocher-yellow, sometimes dull brownish yellow, but so far as I observed it does not assume the bright orange-yellow color of the preceding species, nor have I seen it green, though Duerden reports specimens with green colors, due to an abundance of Zoöxanthellæ in the endoderm.

The disk and tentacles are usually dark yellowish or greenish brown. In contraction the membrane of the disk becomes rough or wrinkled in radial lines, as in the other species of the genus.

When fully expanded the polyps rise a little above the crests of the collines and the disks expand to the width of the upper part of the calicinal valleys ; the adjacent column walls then become nearly vertical, leaving only narrow grooves between them, over the crests of the collines. The tentacles form two cycles, the inner ones a little larger; they are small, rather short, obtuse or slightly knobbed and whitish at the tip. In contraction the disk sinks to the bottom of the valleys and the column walls cover the septa, becoming uneven over their teeth. The tentacles can be introverted in full contraction.

72



72*a*

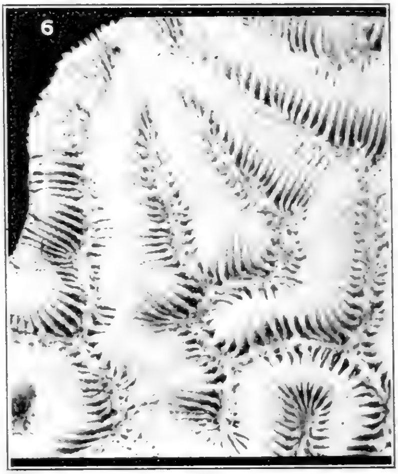


Figure 72.—*Mæandra cerebrum*, var. *sinuosa*. Brain Coral. Portion of a young colony, about natural size.

Figure 72*a*.—The same. Portion near the margin of the same specimen, enlarged about 1½. Both phot. by A. H. Verrill.

It is much less common than the last and is rarely found except on or near the outer reefs. It seldom grows close to the surface, but is more frequent in 6 to 20 feet of water.

It is a common West Indian and Florida coral, and often grows to great size there.

The common form of this species (figs. 72, 72*a*) in which the collines are of moderate height and appear rounded, owing largely to the principal septa being wide and pretty regularly rounded toward the summit, with nearly even denticulations, may be regarded as the typical variety.

The most marked variation from the typical form is that in which the collines appear sharper or narrower at the crests, or have a gothic form, due mainly to the narrowed upper portion of the septa, but in part to the greater height of the collines and thinness of the walls. This is the form figured under the name of *labyrinthica* by Ellis and Solander, 1887, and which has generally been known by that name in later works. It was admirably illustrated in the plates of Prof. L. Agassiz (see our fig. 73), under the name of *M. strigosa*, applied to it by Pourtalès, who considered it a distinct species.*

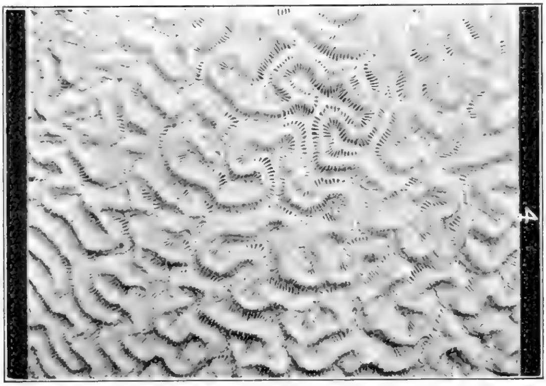


Figure 73.—*Mœandra cerebrum*, var. *strigosa*. Part of a large specimen, ⅓ nat. size. Phot. A. H. V.

It seems desirable to retain a special varietal name to designate this form, and none seems so available as *strigosa*, which seems to be the earliest, except *labyrinthica*, which cannot be used, because it was originally applied to another species (*meandrites* Linn.).

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* My own description of *M. cerebrum* in a former article (these Trans., vol. xi, pp. 74–76, was based more largely on this variety than on the variety now taken as the type form (var. *cerebrum*), but the figures there given mostly pertain to the latter. Intermediate forms often occur.

Variety **strigosa** Dana. Figures 73, 73*a*, 6–9.

Madrepora labyrinthica Ellis and Sol., p. 160, pl. 46, figs. 3, 4, 1787 (*non* Pallas.

Mæandrina labyrinthica Lamx., Expos. Meth., p. 54, pl. xlvi, figs. 3, 4, and of many later writers.

Mæandrina strigosa Dana, Zoöph. Expl. Exped., p. 257, pl. xiv, fig. 4*a*, 1846. Pourtalès, in L. Agassiz, Florida Reefs, pl. ix, figs. 6–9, 1880, (figures reproduced here).

Platygyra viridis Vaughan, Stony Corals, Porto Rico, 306, pl. ix–xiii, 1902 (*non* Lesueur).

Mæandra cerebrum (*pars*) Verrill, these Trans., xi, p. 74, 1901, (where detailed synonymy is given).

This common variety, as seen in collections, usually forms large evenly rounded hemispheres, often of large size and generally having the collines and calicles long and very sinuous or convoluted,

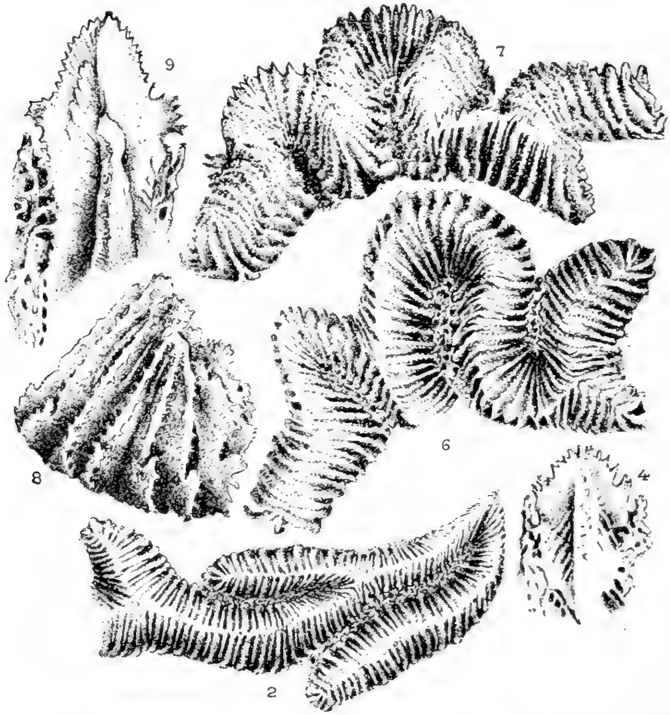
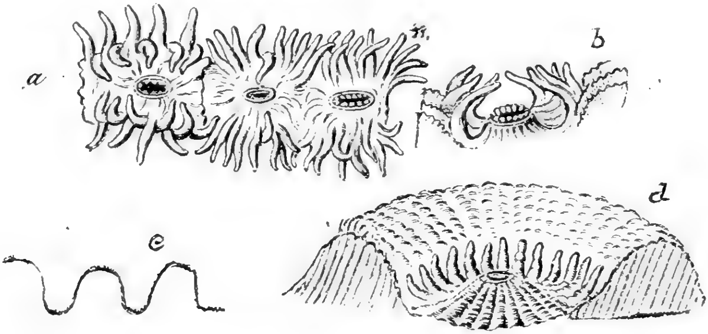


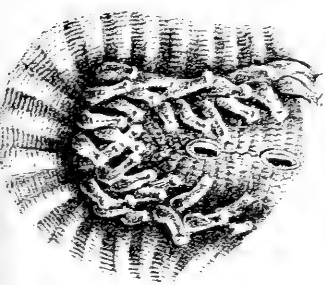
Figure 73*a*.—*Mæandra cerebrum* var. *strigosa* (Dana) ; 6, 7, calicles and collines somewhat enlarged ; 8, perspective view of septa and paliform lobes, more enlarged ; 9, section of colline and profiles of septa ; 2, *M. clivosa*, collines slightly enlarged ; 4, the same, section of colline and profiles of septa more enlarged. After L. Agassiz.

but sometimes long and parallel in some parts. In nature, however, it occurs of various irregular forms, often merely forming thick crusts when young, as in other related forms. When well grown it usually can be readily distinguished by the open or cellular appearing, rather deep and wide calicinal grooves, which have sloping sides and are therefore wider above, and by the gothic form of the larger septa and rather narrow acute collines, with thin, simple walls. The full grown calicinal grooves are usually 8 to 10^{mm} deep, and 9 to 13^{mm} wide, from crest to crest of the collines.

74



74b



74a

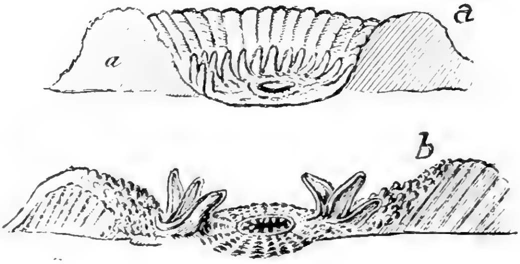


Figure 74.—*Mœandrina sinuosa* Lesueur, showing his varieties; *a*, *b*, var. *limosa*, polyps partly retracted; *c*, *d*, var. *viridis*; *c*, profile of collines, enlarged; *d*, polyp of terminal calicle, much enlarged. Photographed from Lesueur's figures.

Figure 74*a*.—The same; *a*, var. *rubra*; *b*, var. *vineola*, both much enlarged. Photographed from Lesueur's figures.

Figure 74*b*.—*Mœandra clivosa*, terminal part of a calicinal valley with the polyps partially expanded, much enlarged. Photographed from L. Agassiz.

The principal septa are thin at base with a distinct, roughly spinulose paliform lobe; they decrease in width distally, either regularly or in a gothic form, and are quite narrow at the apex, which projects a little above the wall and bears a few rough denticles; the inner edge is covered with rather irregular, rough, often spinulose or lacerate divergent or ascending denticles; their sides are sharply and roughly granulose or spinulose. Very narrow and thin secondary septa, disappearing below, usually alternate with the larger ones, but are often absent, which results in wide, open interseptal spaces. When they are present there are about 22 to 24 septa to a centimeter. Those on opposite sides of the collines usually alternate, and the thin crest of the wall is often a little zigzag. The wall becomes thicker below and solid.

Dr. Vaughan gave some excellent photographic illustrations of this variety, some of which are considerably enlarged (op. cit., 1902, pls. ix–xiii), but the name *viridis*, used by him, did not originally apply to this form, for it was given to a color variety of *M. sinuosa* Les. (see our fig. 74, *c*, *d*, copied from Lesueur), which is a very different coral, with much lower collines, rounded at the top, and very narrow calicinal grooves, which, according to Lesueur's natural-size figure, made to show their arrangement (his pl. 15, fig. 5*a*) measure only 4 to 5^{mm} from crest to crest of the walls and 4.5 to 5^{mm} from the polyp mouths of one series to those in the next. These dimensions are scarcely half as large as in the coral under discussion here. Indeed, the dimensions given and the low collines, as figured by Lesueur in his profile views, not only of the var. *viridis*, but of all his other varieties of *M. sinuosa*, can scarcely apply to any West Indian species except *M. clivosa*.* That is the only mæandriniform coral of this fauna that has such small collines and narrow grooves.

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* After a careful study of this matter I believe that his *sinuosa* and all its color varieties, figured by Lesueur, should be referred to *M. clivosa* (Ellis and Sol.), which is the only American species having such low and narrow collines as he figures.

Moreover, the figures of the polyps which he gives, and which I have reproduced here, of four of his varieties, agree best with those of *M. clivosa*, as figured by L. Agassiz (see our fig. 74*b*). *M. clivosa* is also one of the most abundant species at St. Thomas, in shallow water, where Lesueur obtained his specimens, gathering them by hand, as he stated, while wading on the reefs and without any special appliances. In fact, it would be far more likely to be obtained in that way than either of the other species, which are more massive and grow in deeper water. Moreover, so far as known to me, *M. clivosa* is the only species which has such various and bright colors as Lesueur described. His varieties are described as scarcely differing at all, except in colors.

At any rate, there can be no direct relation between var. *viridis* and our var. *strigosa* of *M. cerebrum*, for they stand almost at the opposite extremes of the various forms of the mæandriniform corals of this region.

I have reproduced here some of the figures of *M. clivosa*, given by L. Agassiz (fig. 73*a* (2, 4) and fig. 74*b*), for easy comparison with those given by Lesueur in 1820. The differences in the polyps are no more than constantly occur, due to different degrees and modes of contraction of the polyps and the individual variations in the colonies. Lesueur said nothing about the general form of his *sinuosa*, but though *M. clivosa* becomes nodular and irregular when large, it has an even and regular surface when young. Probably all of Lesueur's hand-gathered specimens were young and in the crust-like stage of growth, when they can be easily detached and carried ashore alive.

M. clivosa has not yet been found at Bermuda, though it might well be expected to occur on the outer reefs, for it is very common on the Florida and Bahama reefs.

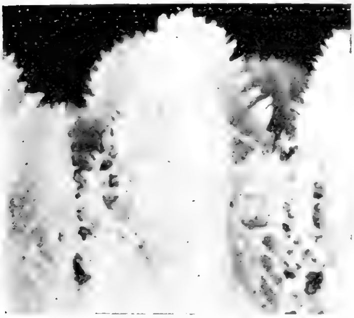
Favia fragum (Esper) Edw. and Haime. *Star Coral.* Figure 75.

Astræa (or *Favia*) *ananas* and *coarctata* of many modern writers.

Favia fragum Vaughan, op. cit., p. 303, pl. viii, figs. 1, 2, 1902. Verrill, these Trans., xi, pp. 90, 171, pl. xiii, figs. 1, 2, 1901. Duerden, Mem. Nat. Acad. Sci., viii, p. 569, pls. xiii–xv, figs. 92–116, anatomy, histology, and larvæ, 1902.

This forms small rounded or hemisphærical masses, seldom more than 2 or 3 inches across, usually solidly attached. It is generally pale yellowish or greenish yellow, sometimes dark yellowish brown, or tinged with green, often with white specks, especially on the

72*b*



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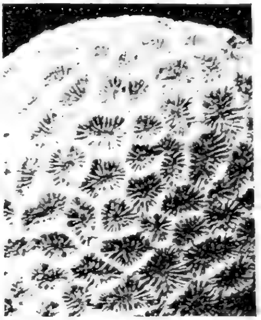


Figure 72*b*.—*Mæandra cerebrum*, typical variety, section of collines showing forms of septa and denticles, × about 2.

Figure 75.—*Favia fragum*. Part of the upper surface of a specimen with crowded calicles (var. *coarctata*), about natural size. Both phot. by A. H. V.

tentacles while living. It can live close to the surface and is often found in tide-pools of the shore ledges, as well as on the reefs. The star-like calicles are a little elevated, usually elliptical or oval, seldom circular, and quite variable in size, though usually not more than .25 to .30 inch in the longer diameter.

In expansion the polyps rise up somewhat above the rims of the calicles. The tentacles vary in number from about 30 to 50 or more, and form two or more crowded circles, the inner a little the larger; in full extension they are slender with a rounded or knobbed whitish tip, but more often they are short, tapered, and blunt. The disk, in contraction, is rugose in radial lines, and may fold inward so as to entirely conceal the tentacles. Often there are two or more mouths on one disk, due to incipient fission. The disk is often convex and the mouth elevated in full expansion.

Dr. Duerden (1902) has described and figured a series of the larvæ, both before and after attachment, According to his observations the polyps are hermaphrodite and viviparous. The larvæ fix themselves within a few days after extrusion.

It is not very abundant at Bermuda. Common on the Florida Keys and throughout the West Indies.

Mussa (Isophyllia) fragilis (Dana) Ver. *Rose Coral.* Figs. 76, 77, 78. Plate xxx, fig. 1, *i*, i; pl. xxi, fig. 1.

Isophyllia or *Symphyllia fragilis* of many writers.

Isophyllia dipsacea Pourtalès, in L. Agassiz, Florida Reefs, pl. vii, figs. 1–7, 1880 (*non* Dana).

Isophyllia fragilis Verrill, these Trans., xi, p. 121: plate xvi, figs. 1, 2; pl. xvii, figs. 1–7; pl. xviii, figs. 1, 6; pl. xix, figs. 1, 5, 1901.

Mussa fragilis Dana; Verrill, op. cit., p. 180, 1901.

Symphyllia anemone, S. conferta, S. strigosa, S. Aglæ, S. thomasiana, S. aspera, var., Duch. and Mich., Coral. Antilles, pp. 69–74, 1860. (Identifications by photographs of original types in Mus. Turin made for Dr. T. W. Vaughan.)

? *Lithophyllia argemone* Duch. and Mich., op. cit., p. 68, pl. x, fig. 15, 1860. (Young.)

?*Lithophyllia cubensis* (*non* Haime) and *L. lacera* (*non* Pallas) Quelch, op. cit., 1886. (Young.)

Isophyllia strigosa, I. fragilis, I. australis, Quelch, op. cit., pp. 82–84, 1886.

This handsome coral is very common at Bermuda, both on the reefs and close to the shores, where it may be attached to scattered rocks and ledges, even in very shallow water. It is also abundant in Harrington Sound. It lives best where exposed to strong light, in open waters.

When living, and with the polyps fully expanded, it is a beautiful object, for its colors are often brilliant and remarkably variegated.

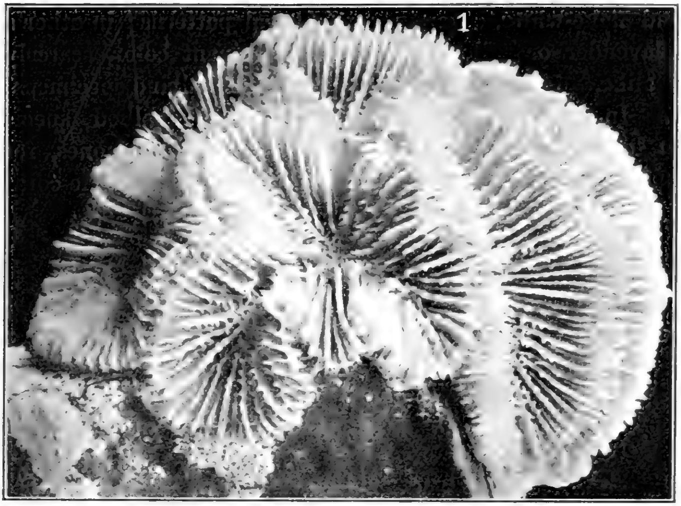


Figure 76.—*Mussa fragilis* Dana. Common Rose Coral. Original type of Dana, nat. size. Phot. by A. H. Verrill.

One of the most common shallow water varieties had the disk translucent lavender-gray, tinged in places with emerald-green, and flecked with unequal flake-white specks, most of which are in radial lines. Tentacles are often swollen at base and obtuse at tips, usually translucent gray, with a large patch of flake-white on the outer base, sometimes running up on the outer side, and sometimes another on the inner base; or the whole surface may be flecked with white;

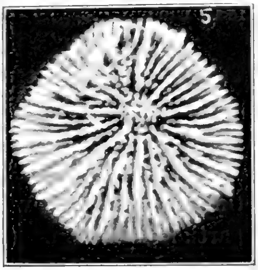
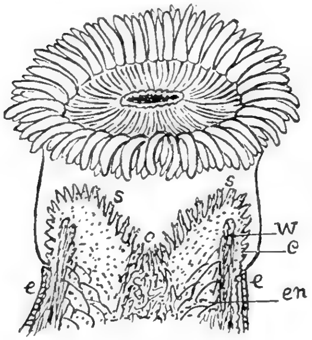


Figure 77.—*Mussa fragilis* in the simple young or *Lithophyllia*-stage. ×1½. Phot. A. H. V.

lips translucent gray with white lines. Cœnenchyma and column translucent olive-brown, usually tinged with emerald-green.

Sometimes emerald-green is the prevailing color, varied with lavender and flake-white, often in symmetrical patterns; in other specimens lavender or yellow may be the dominant color, scarcely two being alike. Some pale yellow and almost albino specimens were taken. In full expansion this coral and the allied species of *Mussa* look like clusters of bright colored sea-anemones, for the soft upper body can rise half an inch or more above the coral and expand a fine wreath of large tapering tentacles, 48 or more in number, often entirely concealing the coral beneath the fleshy membranes. (Fig. 78*a*.) When it contracts the soft upper-bodies, disk, and tentacles sink down into the calicles, below the bounding rims, and in full contraction the tentacles are withdrawn out of sight, though often visible in partial expansion. (Plate xxxi, fig. 1.) At such times the fleshy column walls, which cover the ridges and outer parts of the coral, are curiously wrinkled and verrucose over the denticles, and in that state the form of the coral can usually be seen through the translucent tissues.

78*a*



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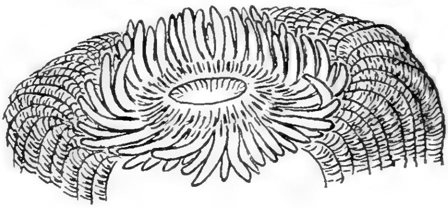

Figure 78.—*Mussa fragilis*, a calicle with a polyp partly expanded, slightly enlarged. Sketched from life by the author.

Figure 78*a*.—The same, one of the isolated polyps fully expanded, about nat. size, with a diagrammatic section of the coral to show the relations of the parts; *e*, epitheca; *c*, costæ; *en*, endotheca; *o*, columella; *s*, *s*, septa; *w*, wall. Drawn from life by the author.

Ordinary specimens are 3 to 4 inches in diameter, but in favorable localities it often forms hemispherical masses 6 inches or more in diameter and 4 to 5 inches thick.

Young specimens of this and the other species of *Mussa* are simple, circular, cup-shaped corals, usually up to half an inch or more in diameter (fig. 77), and have been described by many writers* as distinct species of another genus (*Lithophyllia* or *Scolymia*). But all stages of transition between these simple forms and the complex calicles of the adults can easily be found at Bermuda †

It is very variable in general form and in the size and form of the calicles and the intervening ridges, which may be simple or double, and in the form and breadth of the septa. The denticles of the larger septa are nearly always numerous and slender, often looking like sharp lacerations of the thin septa, but they vary considerably in form and number.

Duchassaing and Michelotti made several species out of ordinary variations of this one, and Quelch followed them in this respect, but as their species could not be identified by their brief and imperfect descriptions, his names were often erroneously applied. To Dr. Vaughan I am greatly indebted for an excellent series of photographs made for him from their original types, which are still preserved in the Museum of Turin.‡

Their *Symphyllia conferta* and *S. anemone* agree very closely with Dana's type of *fragilis.* Their type of *thomasiana* is nearly a typical *fragilis*, but many of the calicles had been badly injured before death. The types of *S. cylindrica* and *S. guadalupensis* are, without doubt, abnormal or diseased specimens of the same species or of *M. dipsacea.* In these the septa and their denticles have become unnaturally thickened by pathological deposits of calcium carbonate in nearly all the calicles. But some of the younger marginal calicles, which remain partially or wholly normal, show the ordinary characters of *dipsacea* rather than of *fragilis.*

Their *S. verrucosa* is the same as their *guadalupensis.* In the type

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* Quelch, Voy. Challenger, xvi, has recorded *Lithophyllia cubensis* and *L. lacera* from Bermuda; both are young of *Mussa.*

† See these Trans., xi, plates xvi–xix, 1901.

‡ Dr. T. Wayland Vaughan, when in Turin in 1897, was kindly permitted by Prof. Camerano to study the types of the species of *Symphylliæ* described by Duchassaing and Michelotti. Count M. G. Peracca, who has charge of the Herpetological Collections at the Turin Museum of Natural History, very courteously made a series of photographic negatives, illustrating each one of the species whose type had been preserved. The United States Geological Survey had a number of duplicate prints made and these were distributed by Dr. Vaughan to various museums. Dr. Vaughan has given me permission to use them in making the revisions of the species described in this paper.

of *guadalupensis* the unnatural thickening is so great that many of the denticles have become thick obtuse cones or tubercles, often in contact, while the septa are so thick that they are often in contact at the wall. Similar diseased specimens are common in Bermuda.

Var. *strigosa.* The photographs of the two types of their *S. strigosa*, one of which is the same that they figured (pl. x, fig. 16, but their figure is reversed,) and their type of *S. Aglæ** are all much alike in details, and in essential characters agree with those Bermuda specimens of *fragilis* in which the calicles become crowded, especially when they become older than usual. In this state, or variety, the calicles become rather smaller than usual, and many are circumscribed ; the intervening ridges are rather high and mostly simple, and the calicles rather deep and abrupt, owing to the septa being wider distally. Their teeth are slender, acute, numerous, usually 10 to 12, and the distal ones are mostly wider, especially on the summits of the exsert septa. The name is retained as a varietal term, simply for convenience in designating a form or condition due to age or conditions of growth.

The figures on pl. vii, figs. 1–7, of L. Agassiz, Florida Reefs, referred to *I. dipsacea* by Pourtalès, agree better with this variety of *fragilis* than with *dipsacea.*

Var. *asperula* nov. (the name of the type, *aspera* D. and M., was preoccupied in *Mussa* by Edw. and Haime, 1857).

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* The type of *S. Aglæ* is a large specimen with numerous crowded calicles, many of which are nearly circumscribed and separated by narrow and usually simple collines. The septa are thin, not very wide, rather openly arranged, with slender acute teeth, as in *fragilis.* The longer, sinuous, calicinal valleys of the type are sometimes 2 inches or more in length, and .40 to .50 broad ; the hemispherical mass is about 6 inches wide and 4 high. The specimen is very much like that figured on our plate xvii, fig. 5, these Trans., vol. xi, in form, number and character of calicles, septa, etc.

The type of *S. thomasiana* is very similar in details, but the calicles are larger and more flaring (the larger ones .80 to 1 inch broad), and many are circumscribed ; the ridges are very narrow and simple ; septa unequal, very thin with wide interspaces.

The type of *S. helianthus* is abnormal, for many of the calicles had been injured or killed and were being regenerated, while parasitic barnacles, serpulæ, algæ, etc., had interfered with the normal development of many calicles. However, a few are nearly normal and are very like those of *strigosa.* The only notable peculiarity is the rather unusual breadth of many of the larger septa, which are apt to be convex about mid-height ; their surfaces are sharply granulose ; the denticles are numerous, slender, irregular, roughly granulose or spinulose. It is probably an abnormal *fragilis*, of the var. *strigosa*, with dwarfed calicles, but it might be *dipsacea.*

The type of their *S. aspera* is also very similar to many specimens of *fragilis*, and in many respects like their *S. Aglæ* and *S. thomasiana.* I am disposed to consider it a variety of *fragilis*, for convenience.

The most tangible character is found in the rough septa, which are thin, rather narrow at the summit, and openly arranged, so that the calicles appear rather shallow and open, with narrow and usually simple walls between. The surfaces of the septa and their denticles are thickly covered with sharp, rough granules or spinules, but not much more so than in some specimens of true *fragilis.* The denticles are slender and rough, usually 10 to 12, the upper ones somewhat stouter and wider. The larger calicles are .70 to .80 of an inch (18–22^{mm}) broad ; mostly in long series in the type.

The *I. aspera* of Quelch is different and appears to be only a slight variation of *dipsacea.*

Mussa (Isophyllia) dipsacea (Dana) Ver. *Rose Coral. Cactus Coral.* Figures 79, 80, 81.

Isophyllia or *Symphyllia dipsacea* of many writers.

Isophyllia dipsacea Verrill, 1864 ; these Trans., xi, p. 118, plate xviii, figs. 2, 5 ; pl. xix, figs. 2, 3 ; pl. xx, fig. 2, 1901. Pourtalès, in Agassiz, Florida Reefs, pl. vii, fig. 8 (section). Duerden, Mem. Nat. Acad. Science, viii, pp. 574–576, pls. xvii, xviii, figs. 121–128, 1902, (anatomy, histology and larva).

Mussa dipsacea Verrill, op. cit., p. 180, 1901.

Symphyllia knoxi Duch. and Mich., op. cit., p. 71, 1860 ; *? S. cylindrica* and *? S. verrucosa* D. and M., loc. cit., pp. 71, 72, 1860. (Both abnormal.)

Isophyllia knoxi, I. dipsacea, I. cylindrica, I. aspera (*non* D. and M.), Quelch, Voyage Challenger, Zool., vol. xvi, pp. 84–87, 1886.

This species closely resembles the last in colors, form, and general appearance, as well as in its habits of growth and localities, for they are often found together.

The calicles are often complex and large, up to 1 to 1.5 inches, broad and frequently quite shallow. They are often circumscribed, partly or wholly, and frequently nearly circular. The intervening ridges or collines may be high or low, simple or double, often thick and solid.

Some writers have made half a dozen or more nominal species out of mere slight variations of this and the preceding species.* It is

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* This is particularly true of Duchassaing and Michelotti, Coral. Antilles, and their Supplement. Also of Quelch, Voy. Challenger, Zool., vol. xvi, pp. 10–12, 83–86. For more details see note on a previous page, and Verrill, these Trans., xi, pp. 115–121, plates xviii–xx : Zool. of Bermuda, article 11, the same plates.

even a question whether these two be really distinct species in the broader sense, for they nearly intergrade, or else hybridize more or less.

The chief differences are in the closer and thicker radial septa, their fewer, shorter and stouter, often triangular or saw-tooth shaped denticulations, and other details of structure.

The type of *Symphyllia knoxi* Duch. and Mich., of which Dr. Vaughan has sent me a photograph, is a young *dipsacea*, very much like my figure 2, pl. xix, these Trans., vol. xi. It consists of six broad, shallow, mature calicles grouped around a primary simple one; some of them are nearly circular and simple; others are becoming lobed. The septa are numerous, close together, not very unequal; the teeth are strong, triangular, and rather regular.

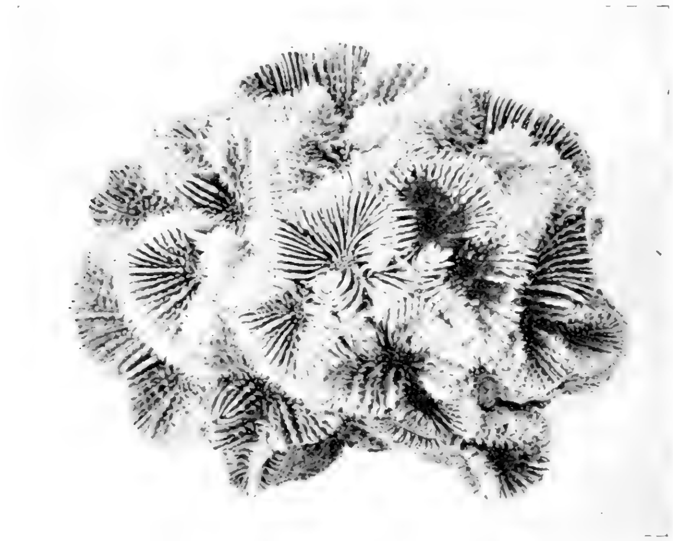

Figure 79.—*Mussa dipsacea.* About ⅔ nat. size. Phot. by A. H. V.

The remarkable and elaborate figures drawn and lithographed by Mr. A. Sonrel for Prof. Louis Agassiz, but eventually published by A. Agassiz, with explanations by Pourtalès (Florida Reefs, pl. vii, figs. 1–8), are perhaps as accurate as can be made by lithography. But such corals cannot be satisfactorily represented except by photography. Pourtalès referred them all to *dipsacea*, but he was at that time unacquainted with the type of *fragilis.* They all have slender crowded teeth and appear to me to belong mostly to *fragilis.* Fig.

6 has more crowded septa and is like var. *strigosa*. But the section shown in fig. 8 represents *dipsacea*, to judge by the stouter triangular teeth, though the calicle is deep. As long ago as 1861–1864, when I had charge of the collection of corals in the Mus. Comp. Zoology, I could not find the originals from which these figures were made. Therefore I presume that Pourtalès did not find them, and they must be judged as they appear on the plate. The septa are too thin and too crowded and their denticles too slender to belong to *M. dipsacea*, as now understood.

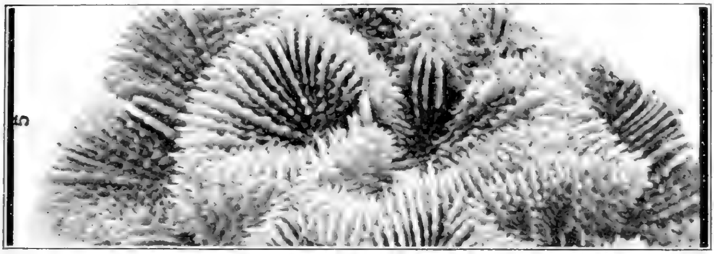

Figure 80.—*Mussa dipsacea*, a group of calicles from a normal specimen, about natural size. Phot. A. H. V.

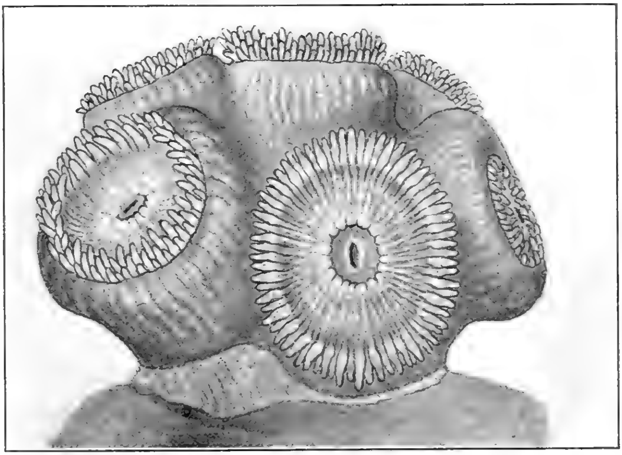

Figure 81.—*Mussa dipsacea*, var. *aster*. A young colony. Polyps partly expanded, one in full expansion, about nat. size. From a colored figure by A. H. V.

Dana's original type of *dipsacea*, which I have seen, was not mature. It had narrower calicles than the adult (mostly 12 to 18^{mm}), but the denticles are pretty regularly triangular, or saw-tooth shaped, and not very numerous. Dana's figure, also, represents them of this form. Specimens like the type are common at Bermuda.

Var. **aster**, nov. Figure 81.

See these Trans., xi, pl. xx, fig. 2, 1901, for type.

It seems desirable to retain a varietal name for those forms that have unusually large, often circumscribed, and generally shallow calicles, like those illustrated in the figure referred to. They may be called var. *aster*, alluding to the appearance of the expanded polyps, which resemble certain varieties of "China Aster" of the gardens, both in form and colors.

The septa are numerous and rather thick; the principal ones bear strong, rather regular, and mostly triangular teeth. The calicles may be 25 to 35^{mm} in diameter.

Mussa (Symphyllia) annectens Verrill. *Cactus Coral.* Figure 82.

These Trans., xi, p. 178, pl. xxxv, figs. 1, 2, 1901.

This is a comparatively rare species, probably best at home on the outer reefs, though originally found on the inner ones, off Hamilton Harbor, where it is rare. It is a much heavier and coarser species than the others, with much larger and longer teeth on the stout distal part of the exsert radial septa; the upper ones are generally the largest and longest.

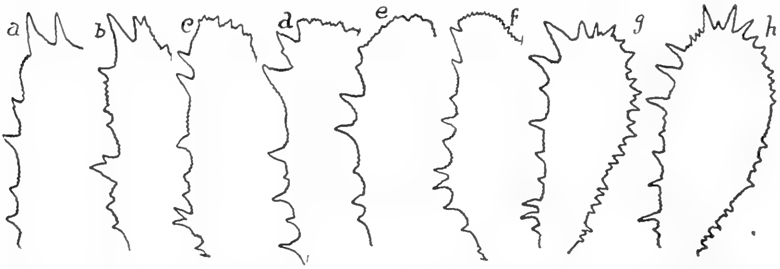

Figure 82.—*Mussa annectens;* forms of larger septa of type, enlarged; *a–b*, septa with typical *Mussa* denticles; *e, f*, septa with *Isophyllia* denticles; *c, d*, intermediate forms; *g, h*, marginal septa with costal spinules. Drawn by A. H. V.

The mature calicles are mostly 15 to 20^{mm} wide, rather deep, with the sides abrupt, owing to the width of the upper part of the septa. Some of them, in the larger specimens, may be distinctly and sometimes regularly 4- to 6-lobed, with a stellate effect; many are circumscribed, but most are lobed or sinuous. The collines are mostly simple, thick, and nearly solid below the surface, but usually appear double at the summit, with a median line or furrow, across which the septa do not often blend. It is a rare species; the type specimens were obtained from the reefs in Great Sound, off Hamilton, and off Ireland Island, by A. H. Verrill, 1901. The expanded polyps were not observed.

At present it is only known from Bermuda, with certainty.

Mussa (Isophyllia) multiflora Ver. *Small Rose Coral.* Figure 84.

Isophyllia multiflora Verrill, these Trans., xi, p. 125, pl. xx, fig. 1 (not pl. xxv, fig. 1), 1901.

Isophyllia multilamella Pourtalès, Florida Reef Corals, p. 70, 1871 (*non* Duch. and Mich. sp.).

? Isophyllia marginata Quelch, op. cit., p. 85, 1886 (*non* Duch. and Mich.).

This is also a rather uncommon species, at least on the inner reefs. It is distinguished mainly by the small shallow calicles, thin, narrow, crowded septa, with long and slender denticulations, which are roughly spinulose, about 10 to 12 on the larger septa; distal ones shorter and divergent at the slightly exsert convex summits of the septa. It most resembles *M. fragilis*, var. *strigosa*. The latter has larger and deeper calicles with wider septa, which are less crowded.

The polyps when expanded form beautiful crowded clusters, similar to those of *M. fragilis*, but smaller. The predominant colors are emerald-green, lavender, and flake-white. It occurred on the serpuline atolls, off Hungry Bay; also on the reefs off Great Sound, and in other places, but it is not common. Florida Reefs,—Pourtalès.

When I first described the species I erroneously referred to it a young specimen of *M. rosula*, which is quite distinct in structure.

Mussa rosula Verrill, sp. nov. *Little Rose Coral.* Figure 83.

Mussa multiflora (*pars*) Verrill, Trans. Conn. Acad., xi, p. 126 (No. 4009), pl. xxv, fig. 1, 1901. (Young.)

Isophyllia rigida (*pars*) Verrill, Bull. Mus. Comp. Zool., i, p. 50, 1864 (*non* Dana, *non* Pourtalès, *nec* Quelch).

This is a rare and but little known species of which I have only recently obtained a mature specimen, through the young have been known to me since 1864. It was a young specimen of this species that I recorded from Bermuda in 1864 (as *Isophyllia rigida*, coll. Mus. Comp. Zool.), but the subsequent discovery of Dana's type of *rigida* in the collection of Yale University proved long ago that it is a distinct species. (See these Trans., xi, p. 127, pl. xxv, figs. 2, 3, for the true *M. rigida*, which has not been found in Bermuda.)*

A careful examination of the photographs of all the types of the forms described by Duch. and Mich. shows that it cannot be referred to any of them. It appears, therefore, to still lack a name and a place in the system. It resembles *multiflora* only in the small size and rapid division of the calicles.

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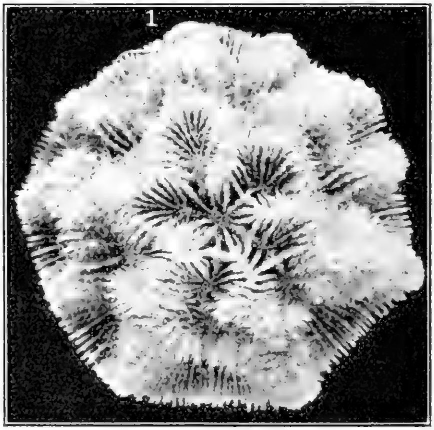

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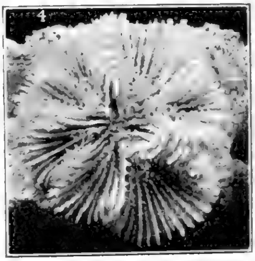

Figure 83.—*Mussa rosula*, sp. nov. Young; natural size.
Figure 84.—*M. multiflora* (?), a young specimen, about natural size. Both phot. by A. H. V.

This species, when mature, forms convex masses up to 4 to 5 inches in diameter. The calicles are unusually small for the genus, and many soon become isolated and nearly circular, especially the marginal ones; most of the calicles are only 10 to 12^{mm} in diameter before division, but some of the marginal ones may be 18 to 20^{mm}, in the largest specimen. They are usually rather deep with steep sides. The intervening collines may be simple and solid in the young (as in the example figured), but in the larger specimens they

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* Judging by a photograph of the type, sent to me by Dr. Vaughan, (see p. 223,) the *Acanthastræa dipsacea* Duch. and Mich., op. cit., p. 78, 1860, is identical with the true *M. rigida* of Dana.

are generally truncate and double at the surface, with a naked groove or furrow interrupting the costæ ; beneath the surface the wall, as seen in sections, is thick and nearly solid, with very few exothecal vesicles.

The principal septa in the younger specimens are rather thin and not very closely crowded, but in the largest one they become so thick distally that they appear crowded, the spaces between being less than their thickness; those of the last cycle are poorly developed. The larger septa are rather wide distally and evenly rounded at the somewhat exsert summits, where they bear three or four angular, rather strong, but not very long, divergent teeth ; the teeth or denticles of the inner margin are usually 8 to 12 on the larger septa, of moderate length, wider at base, subacute, mostly increasing in size and length distally. In the younger specimens the teeth are sharply granulose or spinulose, but only moderately so in the adult. Columella moderately developed, lamellose and spinulose. The epitheca covers the larger specimen almost to the margin, but one of the younger ones, which has very little of it, has wide and thin lamellar costæ, finely serrulate below, but thickened and covered with strong triangular teeth distally, toward the margin.

This species resembles *rigida* in the solidity of the walls, but that species has smaller, mostly astreiform calicles, and different septal teeth. It is nearest related to *M. annectens*, but the latter is a much larger, coarser, and heavier coral, with larger calicles, stouter and more exsert septa, and much larger and longer distal and terminal teeth, so that it appears much more spinose.

This species appears to be rare at Bermuda and unknown elsewhere. I have not seen more than half a dozen specimens among the hundreds of specimens of *Mussa* examined.

Additional notes on the species of Mussa recorded by Quelch.

Many species of *Mussa* (as *Isophyllia*) were recorded from Bermuda by Quelch.* Most of those that he enumerated are slight variations of *M. fragilis* and *M. dipsacea* (see above, pp. 223–225). In addition to those already discussed, he recorded *marginata* Duch. and Mich., *australis* Edw. and Haime, *multilamella* (D. and Mich., 1866, as *Lithophyllia*), and *I. spinosa* Edw. and Haime.

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* Of the 28 species of true corals recorded by Quelch, 13 are here regarded as synonyms. He enumerated 11 species of *Isophyllia* and *Lithophyllia*, all of which are here referred to the two common species of *Mussa* (*fragilis* and *dipsacea*) with one possible exception (his *marginata*).

The original *Lithophyllia multilamella* was a young *Mussa*, indeterminable from the description and figure. The Bermuda specimens are more likely to be *M. fragilis* than any other ; *I. spinosa* Edw. and Haime appears to be the young of *fragilis ; I. australis* was originally based on the young of an Australian species, but the *australis* of Quelch is apparently *fragilis.*

The *I. marginata* of Quelch was probably my *M. multiflora*, but the real *Symphyllia marginata* was quite different, as shown by a photograph of the type sent to me by Dr. Vaughan.* The latter is a large convex mass, with very numerous, mostly circumscribed, angular or irregular, flaring calicles, the larger ones 10 to 15^{mm} broad, of moderate depth, with unusually thin, narrow, and fragile septa, loosely arranged, so as to leave wide open spaces between them, those of the later cycles being extremely delicate ; the denticles are long and slender, but irregular, 12 to 15 or more on the larger septa, becoming smaller distally. The septa are thickened at the wall and the ends seem to have been narrow or falcate and considerably exsert, but they are mostly broken off. The walls are thin, separated by a narrow groove, and apparently by a vesicular exotheca. The columella is feebly developed. It is probably a valid species, distinct from all those recorded from Bermuda. It resembles some of the larger specimens of *fragilis* more than any other Bermuda species, but the latter rarely if ever has so many of the calicles circumscribed, nor so small, nor the septa so narrow and loosely

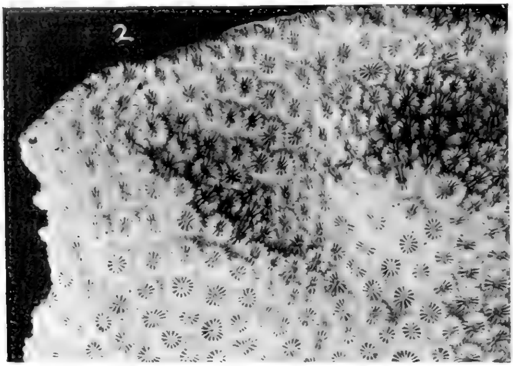

Figure 85.—*Orbicella annularis*, nat. size. Phot. by A. H. V.

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* For critical remarks on most of their other types, see pp. 223–226.

arranged. In general appearance it resembles *M. hispida* Dana.* (See Verrill, these Trans., xi, p. 127, pl. xxi, figs. 2–2*c*, 1901.) The type of the latter is in the Museum of Yale University.

Orbicella annularis (Dana) Ver. *Star Coral.* Figures 85, 86.

Astræa annularis and *Heliastræa annularis* of many writers.
Orbicella annularis Verrill, these Trans., xi, pp. 94, 171, pl. xv, figs. 1, 1*a*, 1901. Duerden, Mem. Nat. Acad. Sci., viii, pp. 564–566, pls. viii–x, figs. 64–73, anatomy, histology.
Orbicella acropora Vaughan, op. cit., p. 301, plates vi, vii, 1902.

This coral grows both in the form of thick crusts, 2 to 4 inches thick, and in hemispheres up to 3 feet or more in diameter. It is found mainly on the outer reefs, but has often been obtained from those not far off Ireland Island. In life it is usually pale yellow, yellowish brown, or greenish, due to zoöxanthellæ. It can be distinguished from most others by its slightly prominent, circular calicles, about ⅛ inch in diameter (fig. 85). The polyps, when fully expanded, rise considerably above the rims of the calicles, as shown in fig. 86, *b*. They have about 24 slender, short, unequal tentacles with a small white knob at the tip. The soft upper body and the tentacles in expansion are translucent, usually yellowish or greenish with white specks.

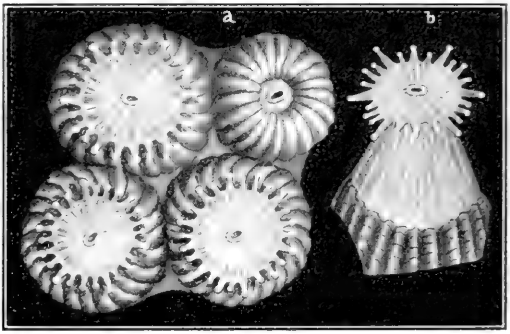

Figure 86.—*Orbicella annularis*; *a*, polyps partially expanded; *b*, in full expansion. From colored drawings by A. H. Verrill.

It is common on the Florida reefs and throughout the West Indies, where it often grows to great size, sometimes forming masses 3 to 5 feet in diameter.

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* *M. hispida* has wider and much more irregular and lacerate septal teeth, and the septa are more numerous and more spinulose laterally.

Orbicella cavernosa (Linn.) Ver. *Great Star Coral.* Fig. 87. Pl. xxxa, fig. 1.

Astrea cavernosa, *A. radiata*, and *A. argus* of many writers.
Orbicella cavernosa Verrill, 1864; these Trans., xi, pp. 102, 171, 189, 1901. Vaughan, Fossil Corals, p. 27, 1901.

This fine coral is much less common than the last. It grows chiefly on the outer and most exposed reefs, where it forms hemispherical masses. I have seen a few small specimens from the inner reefs, 2 to 3 inches thick. The largest Bermuda specimen that I have seen is a dome-shaped mass, rather more than a foot in diameter, but it is said to grow much larger there, as it certainly does in the West Indies and Florida, where it is much more common and reaches the diameter of 4 to 5 feet at least. According to Pourtalès it occurs in 10 to 15 fathoms, off Florida.

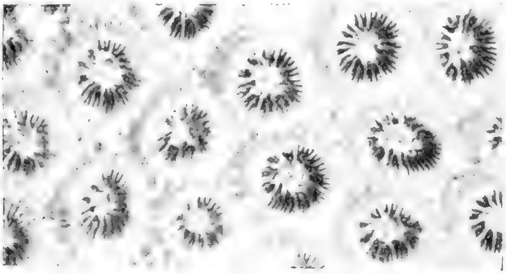


Figure 87.—*Orbicella cavernosa*, about natural size. Phot. by A. H. V.

It is also found as far south as Pernambuco, Brazil. It is one of the common fossil corals in the elevated reefs of many of the West Indian Islands. At Dominica Island it occurs in an elevated reef, near Rosseau, about 1,000 feet above the sea, from whence I have good specimens collected by A. H. Verrill, 1905. It has also been found fossil in the Devonshire formation of Bermuda (see p. 187).

It is easily distinguished from *O. annularis* by the much larger calicles, which are usually .25 to .30 of an inch (6 to 9^{mm}) or more in diameter, and by the more numerous septa (about 48). The columella is usually large.

Plesiastræa Goodei Verrill. *Star Coral.* Figure 88.

These Trans., xi, pp. 106, 172, fig. 1, pl. xxxi, figs. 1, 1*a*, 1901.

This is, apparently, a rare species. I have seen but two Bermuda specimens, one of which, now in the American Museum, New York, was taken by Mr. Whitfield on one of the small inner reefs, off

Bailey Bay. The other, collected by Mr. G. Brown Goode, may have been from the outer reefs, but had no special label. It forms thick, solid crusts and also hemispheres up to a foot or more in diameter. Its small stellate calicles are very regular in structure, but vary somewhat in form and size. They have a simple, solid columella in the center. The living polyps have not been described.

It occurs also in the Bahamas.

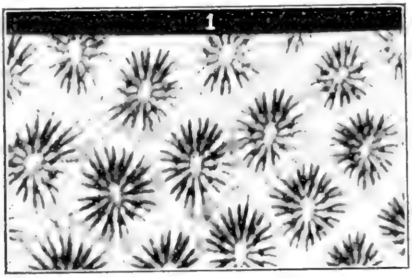


Figure 88.—*Plesiastræa Goodei*, × about 5. Phot. by A. H. V. Type.

Oculina diffusa Lam. *Bush Coral.* Figures 36*a*, 89. Plate xxviii, fig. 2.

Oculina diffusa Dana, Zoöph., p. 397, 1846. Edw. and Haime (*pars*), Corall., ii, p. 107, 1857. Pourtalès, Reef Corals, p. 65, 1877; Florida Reefs, pl. i, figs. 2, 3, 4 (polyps); pl. iii, figs. 10–13, 1880. Quelch, op. cit., p. 47, 1886, descr.

Oculina diffusa Vaughan, op. cit., p. 294, pl. i, figs. 5, 5*a*, 1902. Verrill, these Trans., xi, p. 175, 1901. Duerden, Mem. Nat. Acad. Sci., viii, pp. 585–588, pl. xxii, fig. 149.

This is the most common of the Bermuda Oculinas. It grows abundantly in Harrington Sound, Castle Harbor, etc., as well as in the outer waters, but it is not found, like the massive corals, exposed to the heavy surf of the outer reefs, in very shallow water. In the outer waters it is found in abundance at the depths of 5 to 10 fathoms or more, on the reefs and "broken ground." Wherever there are stones or ledges on the bottom for attachment, it is found in the sounds and channels, in 3 to 10 fathoms. I also saw a specimen at Bermuda, 7 inches high, taken from the bottom of a ship recently arrived from the West Indies. In Harrington Sound it grows in shallow water 3 to 4 feet deep, as well as in 5 to 8 fathoms.

When well grown this coral forms handsome densely branched clusters of very numerous branchlets, becoming quite slender at the tips. The clumps are often a foot or more high. The calicles are round and a little prominent, though varying in this respect. When not so well developed, the clusters of branches are irregular and often misshapen or straggling. The main branches are often an inch or more in diameter.

When living these corals are dull yellow or ocher-yellow to brownish yellow; the soft upper bodies of the expanded polyps are pale yellow, or translucent with whitish lines, and rise high above the calicles. The slender tentacles are specked and tipped with flake-white, due to raised clusters of cnidæ.

The figures 2–4, on pl. i, of L. Agassiz, Florida Reefs, which Pourtalès referred to *O. varicosa*, belong, without much doubt, to this species, and my fig. 89 is only slightly altered from his fig. 2. It agrees better with the polyps of *O. diffusa*, as seen by me at Bermuda, than with either of the other species, though the differences between them are only slight, when seen in the corresponding states of expansion. However, this figure was drawn by Mr. Burkhardt from a living specimen in Florida, while he was artist for Prof. L. Agassiz on his visit to Florida to study the reefs. *O. diffusa* is the only *Oculina* that is ordinarily found on the Florida reefs and Keys, where it is abundant, and therefore it would naturally have been the species figured while living. Pourtalès himself states (op. cit., p. 66) that *O. varicosa* has not been found on the Florida reefs to his knowledge. I can say the same. The specimens of the coral of *O. varicosa* on the same plates were all from Bermuda.

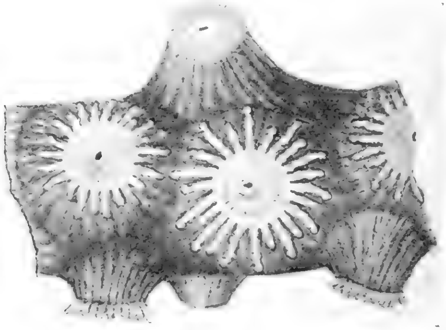


Figure 89.—*Oculina diffusa*, showing polyps in partial and full expansion. From colored figure by A. H. V., altered from L. Agassiz.

It is a common coral throughout the West Indies and Florida Keys, in sheltered places.

Oculina varicosa Lesueur. *Ivory Coral.* Figures 90, 91, *a*. Plate xxviii, fig. 1.

Oculina varicosa Les., Mem. Mus. Paris, vi, p. 291, pl. xvii, fig. 19, 1820. Young. Dana, Zoöph. Expl. Exp., p. 394, 1846. Pourtalès, Reef Corals, p. 66; Florida Reefs, pl. i, figs. 1–1*a*; pl. ii, figs. 3, 4; pl. iii, figs. 8, 9, 1880. Verrill, these Trans., xi, p. 173, pl. xxxii, figs. 2, 3, 4, 1901.

When well grown this is one of the most elegant corals of these waters. It grows taller, with a stouter trunk than the last, and branches more sparingly and in a more tree-like manner, with stouter and longer branches. The calicles are larger and more prominent and much swollen at base, or even mammiform, and on the large branches are often surrounded by a depression and ridge. The coral, when dried and bleached, becomes pure white, but in life it is usually light yellow. The polyps are translucent and rise much above the calicles in full expansion. The tentacles are slightly knobbed at the tip and specked with white.

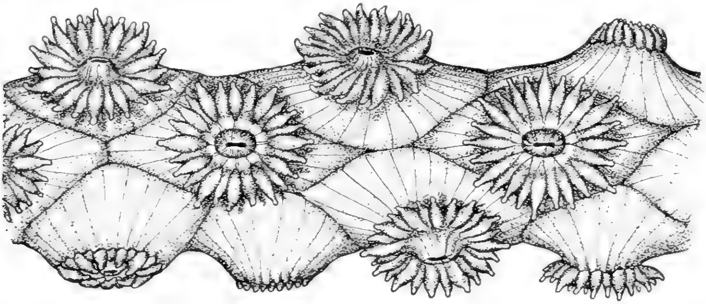


Figure 90.—*Oculina varicosa*, part of a branch with the polyps well expanded, × about 5. Drawing by A. H. V.

Variety **conigera** Verrill. Figure 91, *a*.

These Trans., xi, p. 175, pl. xxx, fig. 3, 1901.

This singular variety has the corallets much more elevated, swollen or mammiform at base, with the calicles smaller than usual. The surface is nearly smooth. It is rather rare. The best examples that I have seen were from deep water in Harrington Sound.

Oculina Valenciennesi Edw. and Haime. *Ivory Coral.* Figure 91, *b*.

Monog. Oculinidæ, p. 69, 1850; Hist. Corall., ii, p. 108, 1857.

?*Oculina bermudiana* Duch. and Mich., Supl. Corall. Antilles, p. 162 [68], pl. x, figs. 1, 2 (poor), 1866. Quelch, op. cit., p. 51 (as *bermudensis*).

Oculina Valenciennesi Verrill, these Trans., vol. xi, p. 176, pl. xxxii, fig. 5, 1901.

This coral branches rather loosely and irregularly, usually with pretty long and often crooked, tapered branches, forming open clumps often a foot or more high.

The calicles project but little and are usually surrounded by a shallow depression or fosse and outer circular ridge, sometimes as high as the calicles.

It is common at the depth of 2 to 10 fathoms or more, in the sounds and channels between the reefs, and also in Harrington Sound, etc.

Oculina pallens Ehrenberg. *Ivory Coral.* Figure 92. Plate xxxvi, fig. 2 (3).

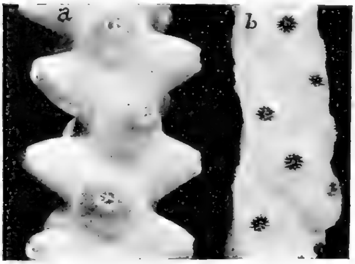
Corall. Rothen Meeres, p. 79, 1834. Dana, Zoöph., p. 67, fig. 29, p. 395, 1846. Pourtalès, Florida Reefs, pl. iii, figs. 14–17, 1888.

?*Oculina speciosa* Edw. and Haime, Monog., p. 67, pl. iv, fig. 1, 1850; Hist. Corall., ii, p. 106, 1857. Quelch, op. cit., p. 50 (descr. and notes on the original type, examined).

Oculina pallens Verrill, these Trans., xi, p. 175, 1901.

This, when well grown, is a handsome species, branching in an aborescent form. The branches are larger and less numerous than in *O. diffusa*, to which it is nearly allied. It has calicles less swollen and less prominent than those of *O. varicosa*. It occurs in the same places with the preceding.

91



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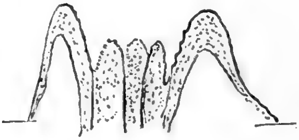

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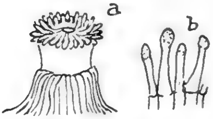


Figure 91.—*a*, *Oculina varicosa*, var. *conigera*; *b*, *O. Valenciennesi.* About natural size. Phot. by A. H. V.

Figure 92.—*Oculina pallens*; *a*, one of the polyps expanded, × about 2½; *b*, a group of tentacles more enlarged to show the alternation. By the author.

Figure 93.—*O. coronalis.* Section of a calicle much enlarged. After Quelch.

Oculina coronalis Quelch. *Ivory Coral.* Figure 93.

Voy. Challenger, xvi, p. 49, pl. i, figs. 6–6*c*. Verrill, these Trans., xi, p. 177, 1901.

This is a loosely branched coral distinguished mainly by the circle of 12 pali around the columella being rather more prominent than usual. But all the species vary in this respect. It may be merely a variety of the preceding, which it resembles in mode of growth, large size of calicles, and general appearance. I found no specimens agreeing perfectly with the type, though some from Harrington Sound seem to be the same.

Madracis decactis (Lyman) Ver. Figures 94, 95.

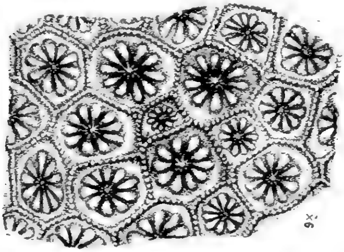
Astræa decactis Lyman, 1859.

Madracis decactis Verrill, 1864. Pourtalès, op. cit., pp. 28, 67, pl. vii, figs. 1–4, 1871. Verrill, these Trans., x, p. 554, pl. lxvii, figs. 8, 10, 1900; xi, p. 108, figs. 2, 2*a*, pl. xiv, fig. 6, 1901.

Axhelia decactis Vaughan, op. cit., p. 8, 1901.

This coral is not uncommon at Bermuda, even on the inner reefs and in Harrington Sound and Castle Harbor. When young it forms crusts, or small, irregular, nodular masses, but later usually grows up into blunt branches or irregular lobes, sometimes becoming round and forking into smaller branches, which are usually very brittle, though seldom less than ½ inch in diameter. The coral is rarely more than 4 to 6 inches high.

94



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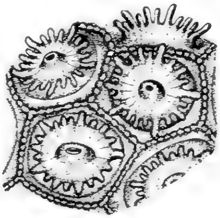


Figure 94.—*Madracis decactis*, × about 6.
Figure 95.—The same, with polyps expanded. Drawings by A. H. V.

It can easily be distinguished by the small, usually sunken calicles which have only ten septa (except sometimes a few calicles at the tips of the branches, which may have 20). This number 10 for the septa is rare in corals. The polyps, however, have 20 unequal tentacles, sometimes only 18, and rise above the calicles when they expand (fig. 95). The color in life is variable, usually light yellowish brown and rust-color, or purplish brown, varying to pink and light yellow. Disk dull yellow, russet-brown or lavender, with white radial lines, wider near the mouth; lips whitish; tentacles have white tips.

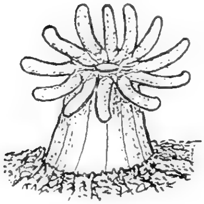
It occurs, also, in Florida and the West Indies. Gregory has reported it as fossil from the Bermuda beach-rocks.

Porites astreoides Lam. Figures 96, 96*a*. Plate xxix, fig. 1.

Madrepora porites (*pars*) Pallas, Elench. Zoöph., p. 324, 1766.
Porites astreoides Lam., Hist. Anim. sans Vert., ed. 1, ii, p. 269, 1816.
Porites astræoides Dana, Zoöph. U. S. Expl. Exp., p. 561, 1846. Verrill, Bull. Mus. Comp. Zoöl., i, p. 42, 1864. Pourtalès, Florida Reefs, pl. xvi. figs. 1–12, 1880. Duerden, Mem. Nat. Acad. Sci., viii, pp. 550–552, pl. iii–v, figs. 28–42, 1902, anatomy.
Porites astreoides Vaughan, op. cit., p. 317, plates xxxii–xxxiv, 1901. Verrill, these Trans., xi, pp. 160, 181, pl. xxxi, figs. 4, 4*a*, 1901.

This coral is one of the most important of the reef-building corals. It forms large hemispherical, subglobular, or dome shaped masses when well grown, on the outer reefs, but is often found in the form of thick crusts. Its surface is generally more or less uneven or nodular. It sometimes becomes 2 feet or more in diameter, but is more commonly not more than 6 to 10 inches in diameter.

97



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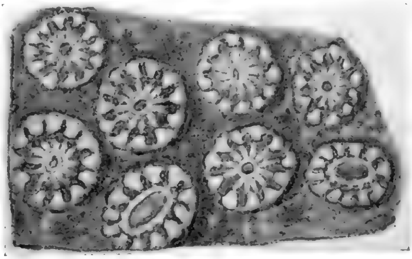


Figure 96.—*Porites astreoides.* Polyps in partial expansion, much enlarged. From colored drawing by A. H. V.

Figure 97.—*Porites porites*, var. *clavaria.* One of the polyps fully expanded. Much enlarged. From life by the author.

In life its color is usually greenish yellow, sometimes pale ocher-yellow, yellowish green or yellowish brown. Duerden describes it as sometimes blue.

The polyps, in contraction, are usually brighter yellow than the cœnenchyma ; when fully expanded they rise considerably above the coral and have twelve small blunt tentacles. The small mouth is bordered with white, and usually there are twelve thin white radial lines on the disk. The tentacles are sometimes whitish or very pale yellow, in other cases brownish yellow. Twelve small white specks often surround the base of each polyp. They usually stand so close together that when fully expanded the tentacles interlock and entirely conceal the surface of the coral. Occasionally there are more than 12 tentacles. Dr. Duerden has described its anatomy very fully.

When dried the coral becomes dark brown or black, unless cleaned with potash or bleached.

It is most abundant on the outer reefs, but is also common on the inner reefs and serpuline atolls off the southern shore. It is occasionally found, also, in Harrington Sound.

This is an abundant reef coral in the West Indies and Florida and has received many names not given above.

Porites porites (Pallas), var. **clavaria** Lam. Figure 97.

Madrepora porites (*pars*) Pallas, Elench. Zoöph., p. 324, 1766.

Porites polymorphus (*pars*) Link, Besch. Nat. Samml., Rostock, p. 162, 1807.

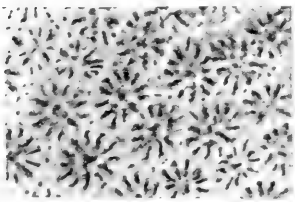
Porites clavaria Lam., Hist. Anim. sans Vert., ii, p. 270, 1816. Dana, Zoöph., p. 554, 1846. Pourtalès, Florida Reefs, pl. xii, figs. 4–6, 1880. Rathbun, Proc. U. S. Nat. Mus., x, pp. 356–361, pl. xvi, pl. xvii, fig. 2, pl. xix, fig. 1, 1887. Duerden, Mem. Nat. Acad. Sci., viii, p. 427.

Porites porites (*pars*=forma *clavaria*) Vaughan, op. cit., pp. 314–316, pl. xxix, pl. xxxi, fig. 2, 1902.

Porites polymorpha Verrill, these Trans., xi, pp. 158, 181, pl. xxxi, figs. 3, 3*a*, 1901.

This is a rather unattractive coral. As found in Bermuda it grows in irregular clumps or clusters of stout, uneven, often crooked, short, blunt branches, dead below, and covered with small, inconspicuous, shallow calicles. The color in life is dark brown to yellowish brown or gray. It occurs in shallow water near the shore attached to small masses of rocks, as well as on the reefs. It was not very abundant in any locality visited by us. It is variable in form, but the variety (or allied species) called *P. furcata*, abundant in Florida and the West Indies, has not been found in Bermuda, so far as I know.

97*a*



96*a*

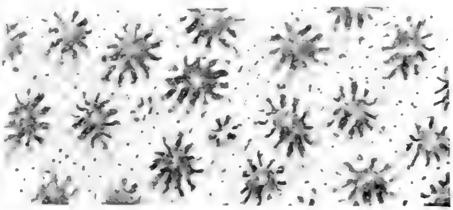


Figure 96*a*.—*Porites astreoides*, group of calicles.

Figure 97*a*.—*P. porites*, var. *clavaria*, group of calicles, × 4. Both phot. by A. H. V.

The polyps, when fully expanded, rise considerably above the calicles. The column and tentacles are translucent and usually nearly colorless, specked with white. There are generally 12 nearly equal tentacles; occasionally a large calicle occurs with 24 blunt tentacles and 24 septa. Such abnormally large calicles soon undergo fission. They are more frequent in *P. astreoides* and some other species.

Vaughan unites the *clavaria* and all the other branching West Indian forms in one species, under the name *Porites porites.* There may be good reasons for doubting the correctness of this, but there is no reason to doubt that *clavaria* was one of the forms included under *M. porites* by Pallas.

Siderastrea radians (Pallas) Ver. *Star Coral.* Figs. 98-99*b*. Pl. xxix, fig. 2.

Madrepora radians Pallas, Elench. Zoöph., p. 322, 1766.

Siderastræa radians Verrill, Bull. Mus. Comp. Zoöl., i, p. 55, 1864; these Trans., xi, p. 153, 181, pl. xxx, fig. 1. Vaughan, Corals Porto Rican Waters, p. 309, pl. xv, pl. xvi, fig. 2, 1901.

Duerden, Mem. Nat. Acad. Sci., viii, pp. 508, 520, 523. The Coral *Siderastrea radians* and its Postlarval Development. Carnegie Inst., Washington, Publ. No. 20, 130 pp., 11 pl., 1904.

Siderastræa galaxea of many writers. Pourtalès, Reef Corals, p. 81; Florida Reefs, pl. xi, figs. 14–21, series of young; pl. xv, figs. 1–12, figs. 1–7 show living polyps.

This is a very common coral, both on the reefs and on the flats in shallow water near the shore, and in Harrington Sound. We found

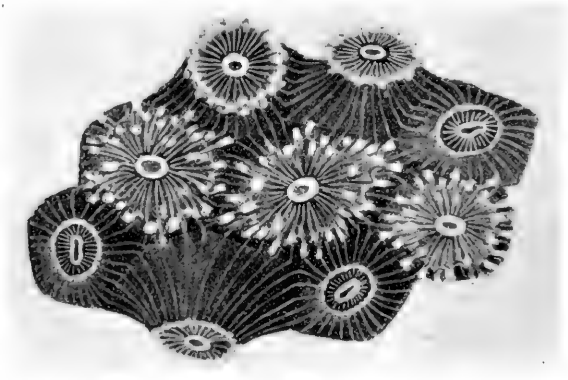
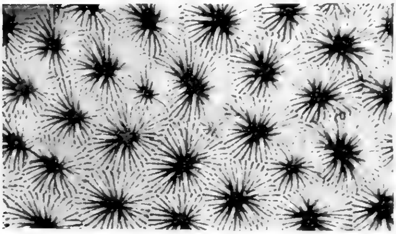


Figure 98.—*Siderastræa radians* with the polyps partially expanded, much enlarged. Altered from Agassiz. Phot. from a colored drawing, hence too dark.

it abundant on the shallow flats at Long Bird Island, even in places laid bare at low tide, and also at Walsingham Bay in one or two feet of water in a sheltered, muddy cove. In such places it often forms ovate or subglobular masses, 3 to 6 inches in diameter, wholly unattached, and with calicles on all sides. They were evidently attached, when very young, to small shells or loose bits of stone which have been entirely enclosed. On the reefs it forms thick crusts or more or less hemispherical masses, up to more than a foot in diameter.

In life the color is usually dull orange-brown, or brownish yellow, or sometimes clay-color, varying according to the situation. In full expansion the polyps rise only a little above the calicles. The tentacles, about 36 in number, are scattered over about one-half the disk, forming three or four irregular circles ; they are mostly small, slender, tapered, but the larger inner ones are bilobed. In 1898, I did not see that the tips were bilobed, as they were figured by L. Agassiz many years ago,* but his enlarged figure (5) does not show bilobing, but indicates that the appearance was due to their peculiar grouping, which the artist did not understand. The cœnenchyma is marked by lighter and darker radial lines of color, the disk is often dark orange-brown or yellowish brown, with paler radial lines ; lips lighter ; tentacles yellow or yellowish brown with whitish enlarged tips.

99



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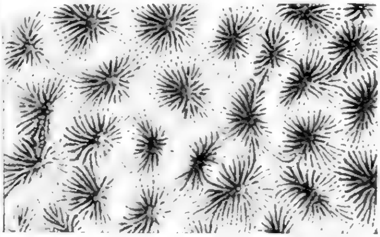

Figure 99.—*Siderastræa radians*, group of calicles, × 2¼.
Figure 100.—*S. siderea*. Calicles, × 2¼. Both phot. by A. H. V.

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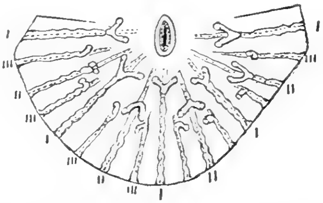
* Duerden has, however, recently described them as bilobed at the tip (op. cit., 1904, p. 10). They are small and may have been imperfectly expanded when observed by me, but it is possible that they vary in this respect. According to Dr. Duerden they are dimorphic, the inner ones, which are endocœlic, being bilobed, while the outer ones are ectocœlic and simple. (See figs. 99*a*, 99*b*.)

The description of this species given by Pallas, in 1766, is very good and applies perfectly well to this species and to no other. Therefore there is no reason why his name, *radians*, should not be universally adopted, instead of *galaxea* of much later date.

The development of this species has recently been the subject of an extended work by Dr. Duerden. It proves to be hardy in confinement and well adapted for such studies (Carnegie Inst., 1904, Publ. No. 20). Dr. Duerden there fully describes the adult and young polyps, as well as the gradual development of the corallum from its earliest appearance, with admirable illustrations.

99*a*



99*b*

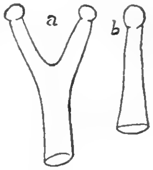


Figure 99*a*.—*Siderastrea radians;* diagrammatic view of disk and tentacles, much enlarged. The tentacles and septa are numbered according to their cycles.

Figure 99*b*.—The same; *a*, inner bilobed tentacle; *b*, outer simple one. Both after Duerden.

Siderastræa siderea (E. and Sol.) Blainv. *Star Coral.* Figures 100, 100*a*.

Madrepora siderea Ellis and Sol., op. cit., p. 168, pl. xlix, fig. 2, 1786.

Siderastræa siderea Blainv., op. cit., p. 335. 1830; Mán. Actin., p. 370, 1834. Edw. and Haime, Monog., p. 141, 1849. Verrill (*pars*), these Trans., x, p. 554, 1900; vol. xi, pp. 151, 181, pl. xxx, figs. 2, 3, 1901. Vaughan, op. cit., p. 309, pl. xiv, figs. 1, 2, pl. xvi, fig. 1, 1902. Duerden, Mem. Nat. Acad., viii, pp. 427, 488, 588–591, pls. xxiii, xxiv, figs. 150–160.

This coral grows in the same forms as the last, but appears to be much less common at Bermuda, at least in the places that we visited.

100*a*

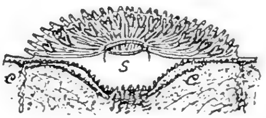


Figure 100*a*.—*Siderastræa siderea*, one-half of a calicle in section, but showing expanded polyp; from life; *c*, *c*, septa; *s*, mouth and stomodæum. Drawn by the author, × about 8.

It is more restricted to the outer reefs, where it may become large.

It differs from the preceding mainly in having a larger number of radial septa (about 48), which are less unequal in size and thickness, and in having somewhat larger calicles, which are commonly distinctly bounded by an intervening angular ridge, so that they often appear hexagonal or polygonal.

The living polyps of this, apparently in full expansion (fig. 100*a*), as seen by the writer, had small, tapered, blunt or knobbed tentacles, in four or five rows, the inner ones largest and bilobed, situated about midway between the mouth and margin of the disk. The colors were about as in the preceding species.*

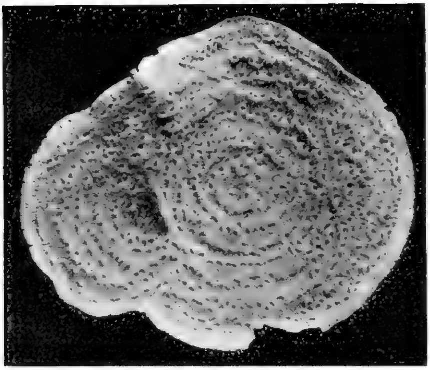
It is an abundant West Indian reef coral, where it often forms solid hemispheres 3 to 5 feet in diameter.

Agaricia fragilis Dana. *Hat Coral. Shade Coral.* Figs. 101, 101*a*.

Agaricia fragilis Verrill, these Trans., xi, pp. 142, 181, pl. xxvi, figs. 1*a*–1*d*, 1901; The Zoology of Bermuda, i, article 11, pp. 142, 181, same plate.

Mycedium fragile of many authors. Pourtalès, in L. Agassiz, Florida Reefs, pl. xi, figs. 1–10, young; pl. xiii, figs. 1–5; pl. xiv, figs. 1–9, details.

101



101*a*

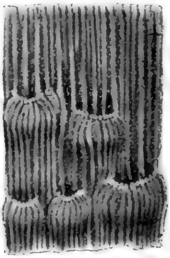


Figure 101.—*Agaricia fragilis*, a specimen with two primary calicles, probably due to two young specimens growing together; about ½ nat. size. Phot. A. H. V.

Figure 101*a*.—The same; living polyps at and near the margin, apparently fully expanded, and showing the minute tentacles. Drawn by A. H. V., from a sketch by the author. Enlarged.

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* The coral called *Astrea siderea* by Lesueur (op. cit., p. 286, pl. 16, figs. 14, *a*, *b*, *c*), and of which he figured the polyps, is not of this genus. It is an astræan coral with about 36 short tentacles, in two submarginal series. If I understand his description of the coral, which is rather ambiguous, it has a

This delicate coral is rare on the outer reefs, but is common in sheltered situations on the reefs and ledges, especially in Harrington Sound, where it occurs under shaded cavernous places in the shore ledges, in very shallow water, and also to the depths of 2 to 6 fathoms or more. It also occurs in Castle Harbor.

When full grown it may become a foot in diameter, but large specimens are nearly all irregular. The best formed are 2 to 5 inches in diameter. It is always attached by a narrow but strong pedicel, so that the thin edges of the cup are usually broken in detaching the coral, unless found in so shoal water that it can be taken by hand.

The color of the coral, in life, on the upper side is usually chocolate brown, yellowish brown, or purplish brown with pale radial lines; often dull yellowish brown below. The tentacles are whitish, very small and short in those that were best expanded ; disk not raised to level of calicle rims, but possibly we did not see them fully expanded; the mouth is relatively large, rounded or elliptical.

Spurious and Superfluous Species.

On the previous pages I have enumerated all the true corals that are known to occur at Bermuda in shallow water. Others may yet be found there. Several others have been found in deep water, near Bermuda, and on Challenger Bank, in 25 to 40 fathoms. (See list in these Trans., xi, p. 182.)

Certain species have been erroneously attributed to Bermuda, from various causes.

Gregory erroneously recorded *Colpophyllia gyrosa* from Bermuda because of his confounding it with *Mussa fragilis.* He also erroneously recorded *Agaricia agaricites* because he confounded *A. fragilis* with it in his synonymy. Neither of these two common West Indian species has hitherto been found in Bermuda.

Nor have any of the varieties of *Acropora* (or *Madrepora*) *muricata*, though they are often sold in the curiosity shops to travelers, as if of Bermuda origin. They are all imported from the West Indians "for the trade," especially variety *prolifera.*

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more or less solid columella, or else a circle of close pali, which he speaks of as a central "cylinder" united to the "lamellæ." The calicles were described as prominent and the septa free at the summit, rounded, and crenulate. It may have been a variety of *Favia fragum*, though the latter has no solid columella.

Quelch (Voyage Challenger, xvi), recorded about a dozen species too many because he followed other authors in regarding trivial variations in growth, etc. as true species. Most of his errors of this kind have been corrected in the previous pages, especially those in the genus *Mussa* (his *Isophyllia* and *Lithophyllia*), and in *Mæandra* (his *Mæandrina*). However, it may be useful to add in this place a list of the species recognized by him, with their present equivalents, so far as they can be determined without reëxamination of types. Thirteen out of the 28 listed by him I regard as synonyms.

Species listed by Quelch.	*Present names.*
Oculina diffusa, p. 47.	No change.
O. pallens, p. 48.	No change.
O. varicosa, p. 48.	No change.
O. coronalis, sp. nov., p. 49.	No change.
O. speciosa, p. 50.	*O. pallens*, var.
O. bermudensis, p. 51.	*O. Valenciennesi*, var.
O. Valenciennesi, p. 11.	No change.
Madracis decactis, p. 53.	No change.
Isophyllia strigosa, p. 82.	*Mussa fragilis*.
I. fragilis, p. 84.	*M. fragilis*.
I. australis, p. 84.	*M. fragilis*, young.
I. dipsacea, p. 84.	*M. dipsacea*.
I. marginata, p. 85.	*M. multiflora*.
I. cylindrica, p. 86.	*M. dipsacea* (abnormal).
I. Knoxi, p. 86.	*M. dipsacea*, young.
I. multilamella, p. 11.	*M. multiflora* ?, young.
I. spinosa, p. 11.	*M. fragilis*.
Lithophyllia cubensis, p. 11.	*M. fragilis*, young.
L. lacera (*non* Pallas, sp.), p. 11.	*M. dipsacea*, young.
Diploria cerebriformis, p. 90.	*Mæandra labyrinthiformis*.
Mæandrina labyrinthica, p. 91.	*M. cerebrum*, var. *strigosa*.
M. sinuosissima, p. 91.	*M. cerebrum*.
M. strigosa, p. 92,	*M. cerebrum*, var. *strigosa*.
Astræa ananas, p. 98.	*Favia fragum*.
A. coarctata, p. 98.	*F. fragum*, var.
Siderastræa galaxea, p. 113.	*S. radians*.
Agaricia fragilis, p. 117.	No change.
Porites clavaria, p. 179.	*P. porites*, var. *clavaria*.

Actinaria*; **Sea Anemones,** etc.

Actinacea.

Several large and handsomely colored sea anemones occur commonly, both on the outer and inner reefs, and some are often very conspicuous when expanded, especially *Condylactis gigantea*, which is one of the largest and most abundant. It has very long and large flexible tentacles, usually with pink or purple tips, which are not retractile when disturbed.

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* The more important recent special works relating to the Bermuda Actinaria are as follows:

Andres, A.—Le Attinie. Fauna u. Flora d. Golfes von Neapel. Monog. ix, 1883.

An admirable work on the Mediterranean species. Enumerates most of the Actinians then known from other seas.

Carlgren, O.—Ost-Afrikanische Actinien. Mith. Naturhist. Mus. Hamburg, 1900.

Contains some results of an examination of the types of Duchassaing and Michelotti.

Duerden, J. E.—Jamaican Actinaria. Part i, Zoanthæ. Royal Dublin Soc. Trans., ser. 2, vol. vi, pp. 329–376, plates xvii*a*–xx (with anatomy), 1898; Part ii, op. cit., vol. vii, pp. 133–208, pl. x–xv, 1900.

——— Actinaria around Jamaica. Journ. Inst. Jamaica, vol. ii, No. 5, pp. 449–465, 1898.

——— The *Edwardsia*-stage of *Lebrunia.* Journ. Linn. Soc. London, Zoöl., vol. xxvii, pp. 269–316, pl. 18, 1899.

——— Report on the Actinians of Porto Rico. Bull. U. S. Fish Com. for 1900, vol. xx, part 2, pp. 321–374, 12 plates, 1902.

——— West Indian Sponge-incrusting Actinians. Bull. Amer. Mus. Nat. Hist., xix, pp. 495–503, 4 plates, 1903.

——— On the Actinian *Bunodiopsis globulifera* Verrill. Trans. Linnean Soc. London, vol. viii, part 9, pp. 297–317, plates xxv, xxvi, 1902.

Contains full anatomical and histological details of this Bermuda species.

Erdmann, A.—Ueber einige neue Zoantheen. Jena Zeitsch. für Naturwissenschaft., vol. xix, pp. 430–488, 2 plates, 1886.

Describes two unnamed species from Bermuda with anatomy.

Gray, J. E.—Spic. Zool., viii, 1825. Notes on Zoanthinæ. Proc. Zool. Soc. London, pp. 233–240, 1867.

Enumerates the West Indian genera and species.

Haddon, A. C.—Revision of the British Actiniæ. Part i. Sci. Trans. Royal Dublin Soc., iv, pp. 297–361, pl. xxxi–xxxvii, 1889.

Some of the social actinians (*Zoanthacea*) form broad encrusting colonies, several feet across. One of the most common (*Palythoa mammillosa*) is light ocher-yellow and is often very conspicuous on the reefs.

Aiptasia annulata (Les.) Andres. *Ringed Anemone.* Figs. 102, 103. Plate xxxi, fig. 2.

Actinia annulata Les., Journ. Philad. Acad. Sci., i, p. 172, 1817.

Aiptasia annulata Andres. McMurrich, Actin. Bahama Is., p. 7, pl. i, fig. 1; pl. iii, fig. 1, 1889. Duerden, Actinaria around Jamaica, p. 457, 1898.

Verrill, these Trans., x, p. 556, pl. lxviii, fig. 3, 1900. Duerden, Actinaria of Porto Rico, pp. 355–358, pl. iii, xi, xii, figs. 11, 41, 44, 1902, anatomy.

This, when full grown, is a large and elegant species, with very numerous (often over 200) long, slender, tentacles, covered with

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Haddon, A. C. and *Shackleton, Miss Alice M.*—Revision of the British Actiniæ. Part ii; the Zoantheæ. Sci. Trans. Royal Dublin Soc., vol. iv, ser. 2, pp. 609–672, 3 plates, 1891.

Contains a synopsis of the described genera and species with anatomical details of the English species. Enumerates species from Bermuda and West Indies.

Hertwig, R.—Report on the Actinaria. Challenger Exped. Zoöl., vol. vi, 1882: vol. xxvi, 1888.

McMurrich, J. P.—Contribution to Actinology of Bermuda. Proc. Acad. Nat. Sci. Philad., xli, 1889, pp. 102–126, pl. vi, vii; reprinted in Heilprin's The Bermuda Islands.

——— Actinaria of the Bahama Islands, W. I. Journ. of Morphology, vol. iii, pp. 1–74, pl. i–iv, 1889.

——— Notes on some Actinians from the Bahama Is. Annals N. York Acad. Sci., vol. ix, 1896.

——— On some Irregularities in the number of the Directive Mesenteries in the Hexactiniæ. Zoolog. Bulletin, vol. i, pp. 115–122, 1897.

Discusses (p. 120) the directives of *Actinotryx*, which has but one pair.

——— Report on the Actinaria of the Bahama Expedition of 1893. Bulletin Laboratory State Univ. of Iowa, iv, pp. 225–249, 3 plates, 1898.

——— The Mesenterial Filaments in *Zoanthus sociatus.* Zoölogical Bulletin, vol. ii, No. 6, 1899.

Verrill, Addison E.—Descriptions of imperfectly known and new Actinians. Parts 1–5 (36 cuts). Amer. Journ. Science, 1898–99.

Contains descriptions and figures of several Bermuda species.

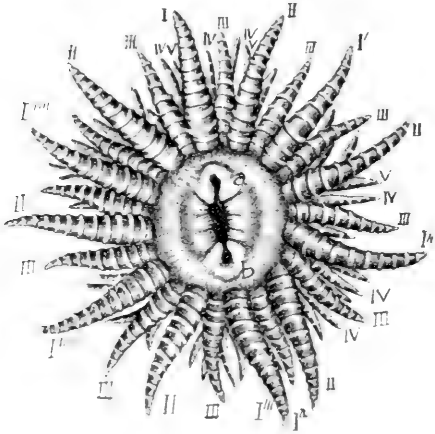
——— Additions to the Fauna of Bermuda. These Trans., vol. x, pp. 555–567, 1900, 3 plates; vol. xi, pp. 47–52, pl. vi, vii, ix, 1901.

——— Zoology of Bermuda, vol. i. Contains the two preceding papers as articles 5 and 10.

Many other works are quoted below in the synonymy.

broken spiral bands or rings of white, often a little raised or thickened. Its body or column is sometimes 2 inches or more in diameter and 4 to 6 inches or more high, while the disk in full expansion may be 3 or 4 inches broad and the longer tentacles 4 to 5 inches long. Thus its total expanse may be nearly a foot, but such large examples are rare, while those of half that size are common. In full expansion the column is often tall and narrow. When large it is frequently so firmly attached in some deep hole or crevice of the reefs that it cannot be extracted entire without cutting away the stone.

102



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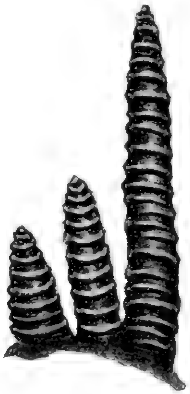

Figure 102.—*Aiptasia annulata.* Disk and tentacles of a young specimen, preserved in formalin, enlarged; *a*, *b*, gonidial grooves; I–I′′′′′, six primary tentacles; I, I^{a}, directive tentacles; II, second cycle; III, third cycle; IV, fourth cycle; V, fifth cycle of tentacles.

Figure 103.—Tentacles of a larger specimen in formalin, more enlarged. Both drawn by A. H. V.

The color is somewhat variable. Very often the column is olive-green, the disk paler green, with the lips whitish, especially at the gonidial grooves, and with pale radial streaks at the bases of the tentacles; the tentacles may be pale green annulated with narrow, raised, flake-white rings or short interrupted spirals (in var. *solifera*), or they may be pale translucent with separated narrow bands of olive-green or brownish,* so as to give a beaded appearance (var. *monilifera*, nov.). Frequently the column is pale yellowish or light

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* Probably due to clusters of zoöxanthellæ (see Duerden, op. cit., p. 356, 1902.)

flesh-color, specked with olive and flake white. Yellowish brown specimens also occur.

The tentacles can be contracted in length, but are not retractile, so that it can be easily preserved partially expanded. The raised annuli of the tentacles are usually distinct in alcoholic specimens.

In some small specimens, preserved in formalin (var. *monilifera*), the thickened bands are longer than thick, thus becoming truly bead-like, and separated only by narrow constrictions. Possibly this may be a distinct species.

Many specimens of this species do not have the tentacles and mesenteries arranged in regular hexamerous cycles. Octamerous specimens have been described by McMurrich from the Bahamas.

Hermaphrodite specimens have been observed by Duerden (1902).* Gonads are borne on mesenteries of the 2d and 3d cycles and sometimes on those of the 1st cycle, except the directives. There is no distinctly defined sphincter muscle, though the general musculature may appear a little stronger at a certain level than elsewhere, perhaps due to a stronger local contraction.

Var. **solifera** (Lesueur).

Actinia solifera Les., op. cit., p. 173, 1817.

The large specimen figured on our plate xxxi, fig. 2, belongs to this form, described by Lesueur, but his specimens were much smaller. Its distinctive character is the presence of interrupted flake-white spirals, usually not distinctly thickened in life, on the tentacles. Intermediate states between the spirals and the raised rings frequently occur, and hence the two forms have been united.

This species and the varieties are also common in the West Indies.

Aiptasia tagetes (Duch. and M.) Andres. *White-specked Anemone.* Figs. 104, 105, 106.

? *Aiptasia*, sp. McMurrich, Proc. Acad. Nat. Sci. Philad., 1889, p. 102, pl. vi, figs. 1, 2 (anatomy); Heilprin's Bermuda Is., p. 106, pl. 10, figs. 1, 2. (May be a distinct species of *Paranthea*.)

Aiptasia tagetes McMurrich, Actinaria of the Bahama Is., pp. 12–17, pl. i, fig. 2 (anatomy, varieties, etc.), 1889.

Aiptasia tagetes Duerden, Actinaria around Jamaica, p. 457, 1898.

Verrill, Trans. Conn. Acad., x, p. 557, pl. lxvii, fig. 2, 1900; vol. xi, p. 49, pl. vi, fig. 6, 1901. (Var. *bicolor*.)

This is one of the most common species, but does not grow nearly so large as the last. It occurs in the crevices and under rocks and

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* Dr. J. E. Duerden has given a very full account of the anatomy and histology of this species in Actinians of Porto Rico, pp. 355–358. His specimens, however, were not full grown, though sexually mature.

dead corals on the reefs and ledges, but is more abundant in sheltered places along the shores. It was also found attached within the oscules of sponges, like the var. *spongicola* of McMurrich.

Var. **bicolor**, nov. Figures 105.

The more common colors of the column are smoky brown, pale green, olive-green, greenish or yellowish brown, usually darker distally, and often flecked with white spots. Flesh-colored specimens are not rare.

104

105

Figure 104.—*Aiptasia tagetes*, fully expanded, dark-olive green variety, showing two long directive tentacles; about natural size; *ac*, acontia extruded; *b*, var. *bicolor*, one of the tentacles more enlarged.

Figure 105.—The same, light flesh-colored specimen of variety *bicolor*, somewhat enlarged. Both from colored drawings by A. H. V.

The tentacles generally correspond with the body in color, but are usually paler.

The larger mesenteries often show through the sides as pale longitudinal lines, and small specks of brown or green are usually present. Acontia are long, slender, white.

It occurred in abundance attached to floating leaves and twigs in the edges of the mangrove swamp at "Fairy Lands." It varies considerably in color at this place, but most had the body pale olive-green, the disk darker olive-green, with white loops around the bases of the tentacles, white radial spots, and a white bar across the disk in line with the longer diameter of the mouth and very long directive tentacles. Other tentacles were pale grayish green with alternating half rings or angular spots of white, interrupted along the median line by a narrow dark line. The tentacles are nearly always spotted on the inside with angular or crescent-shaped spots or half-bands of flake-white, alternating on opposite sides, and generally there are two odd directive tentacles, longer and larger than the rest, and in line with the angles of the mouth; these may be nearly all white, or at least have a long stripe of flake-white or rows of white spots on the inner surface for about half their length, or only one may be thus marked. A white stripe usually crosses the disk between their bases.

Acontia, in the form of slender white threads, are often emitted from pores arranged in two or three transverse rows a short distance below the tentacles. The slender tentacles form several (3–5) rows, the inner longest; they are contractile but not retractile.

The column of the larger specimens is often 2 to 3 inches high and up to 1 inch in diameter, with tentacles about 1 to 1.5 inches long, but most of those seen were less than half that size.

One nearly albino specimen was found, with the body pale flesh-color, finely specked with flake-white, but the pale yellowish tentacles still showed 8–12 crescent-shaped spots of flake-white and the dark median line.

According to McMurrich, this species, as studied by him at the Bahamas (1889), has no sphincter muscle. Duerden found a very feeble lower one in his Jamaica specimens (1898). But McMurrich described, 1889 (as *Aiptasia*, sp.), an actinian from Bermuda very much like this species in other respects, in which he found two sphincter muscles quite distinctly developed, which is contrary to the normal conditions in this genus, but has been found, also by him, in *A. pallida* of the American coast—a species for which I proposed to establish a genus (*Paranthea*) in 1869.*

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* It is possible that the Bermuda species described (from preserved specimens) by McMurrich was really *P. pallida*, or a similar small species, though it has not since been recognized there by others. Otherwise we must suppose that *A. tagetes* varies to a remarkable extent in the development of the sphincter muscles,—from none at all to two distinct ones. However my figure 106 represents a specimen that has a strong constriction at some distance below the margin, about in the position where the lower sphincter described by McMurrich was situated, clearly indicating the presence of a somewhat muscular band

This species was originally described from the Antilles. It has been recognized as common at the Bahamas and Jamaica.

It resembles closely, in form and colors, the Mediterranean species, *A. diaphana* (Rapp.), as figured by Andres (Attinie, pl. ii, figs. 13–19).

Phellia rufa Verrill. Figures 107, 107*a*, 108, 108*a*, p. 266.

Trans. Conn. Acad., x, p. 557, pl. lxviii, fig. 4, 1900; vol. xi, p. 49, pl. vi, fig. 4, 1901 (not fig. 5, as there erroneously quoted.) Mark, Proc. Amer. Assoc. Adv. Science, p. [31], pl. 14, fig. 25, 1905, (not fig. 26, as there quoted).

? *Phellia clavata* Duerden, Actin. around Jamaica, p. 459, 1889, (*non* Duch. and Mich. *nec* Stimp.).

When well grown and fully expanded this is a handsome species. The column is nearly always salmon-red, brownish red, or terra cotta, largely covered with a tough dirty brown epidermis. The light reddish or salmon tentacles are elegantly marked with flake-white rings and bands, with M- or W-shaped patches of dark red or purple near base; the disk is radially marked with the same colors.

The tentacles may be flesh-color, brick-red, or dark red, and the white markings vary in form.

One curious variety (fig. 107) had the disk and tentacles slate-gray, with almost black radial spots and tentacle bands, while the body was brownish red. Var. *nigropicta*, nov.

The external cuticle usually ends distally in an abrupt often flaring edge, above which the column is brighter colored and often partially translucent, flesh-color or light red.

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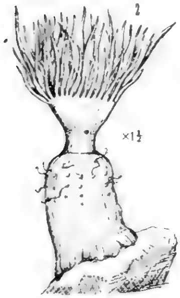
at that place. This may belong to the same variety or species described by McMurrich. I have seen others with the same constriction, but have not examined them with reference to the existence of the two sphincter muscles mentioned by him. His species also had reproductive organs on part of the six primary or complete mesenteries.

However, it seems to me desirable to keep apart, as a separate genus, those species which have, like *pallida*, two sphincters, and for such forms the generic name *Paranthea*, given by me in 1869 (Com. Essex Inst., v, p. 322 [8]), should be retained, with *pallida* as the type, as then given.

To combine in one genus species with and others without sphincters seems inconsistent, considering the perhaps exaggerated importance attached to this anatomical feature by Hertwig, Carlgren, McMurrich, and many others, in recent years, unless it can be proved that one and the same species can vary to this extent, which is not impossible, in view of the extensive variations now known to occur in the mesenteries, siphonoglyphs, gonads, etc. in many species of Actinians. But this is not yet proved for species of *Aiptasia*.

Large specimens, in full extension, are often 3 to 4 inches long and .75 to 1 inch in diameter of body, but most are not half that

106



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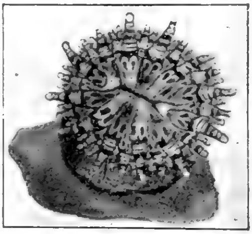

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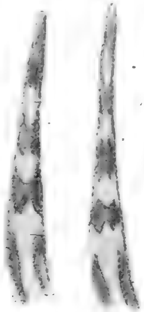

Figure 106.—*Aiptasia tagetes* (?), young, from a preserved specimen, somewhat enlarged.

Figure 107.—*Phellia rufa,* var. *nigropicta,* nov., not fully extended, nat. size from colored figures, by A. H. V.

Figure 107*a*.—The same, var. *rufa*, tentacles enlarged.

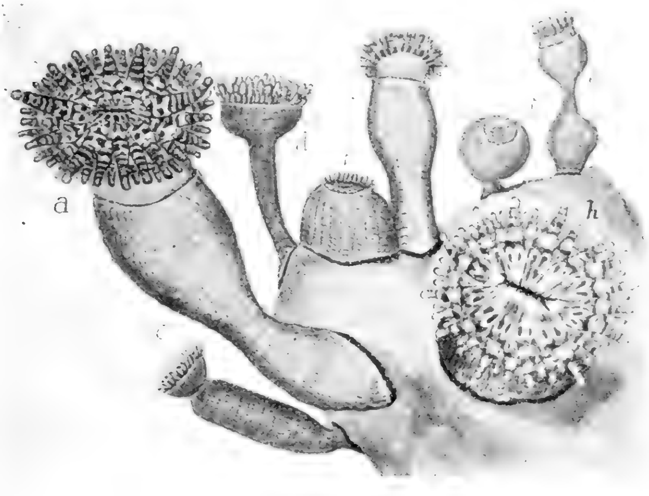

Figure 108.—*Phellia rufa.* Group of polyps in different states of expansion to show variations in form ; *a–g,* var. *rufa ; h,* var. *nigropicta.* About ⅔ nat. size. From colored drawing by A. H. V.

size. The column can take a great variety of forms ; sometimes it is elongated hour-glass shape, club-shaped, or salver-shape, or some portion may swell out into a globular form on a narrow pedicel.

It was abundant under the stones on the shores of Castle Harbor, where there are out-flowing streams of salt water, and in other similar places. Also in crevices and under dead corals on the reefs.

Actinia bermudensis Verrill. *Red Anemone.* Figs. 109, 110, 111.

Amer. Journ. Science, vi, p. 495, 1898; Trans. Conn. Acad., x, part 2, p. 558, pl. lxvii, fig. 7, 1900.

Diplactis bermudensis McMurrich, Proc. Philad. Acad., 1889, p. 111, pl. vi, figs. 4. 6; vii, figs. 1, 2; reprint in Heilprin's Bermuda Is., p. 116, pl. 10, figs. 4–6, pl. 11, figs. 1, 2; Annals. N. York Acad. Science, 1896, p. 186, pl. xvii, fig. 3.

This is one of the most common of the actinians,* especially on the ledges and shores. It prefers the under sides of large loose stones and the roofs of cavernous places where it can hang mouth downward. It is often found in such places between tides.

Figure 109.—*Actinia bermudensis*, ⅔ nat. size. Phot. from life by A. H. V. The white specks are due to loosely adhering sand and mucus.

The body is usually cherry-red, varying to crimson, brownish red, and terra cotta red, rarely yellowish, or yellowish brown. The circle of large, globular, bright blue acrorhagi below the tentacles is conspicuous only in full expansion, for they are often concealed

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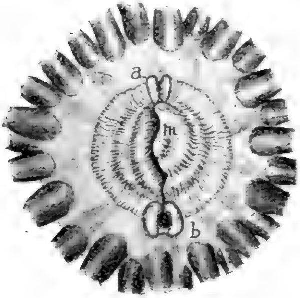
* The first specimens of this species and of *C. gigantea* seen by me were brought from Bermuda alive in 1860, and exhibited at "The Aquarial Gardens" in Boston, for some time. It was also collected by Mr. G. Brown Goode, in 1872. McMurrich, in a recent paper (op. cit., 1905), has definitely decided that it is the same as his *Diplactis bermudensis*, which was described from badly preserved specimens. Therefore his genus *Diplactis* must be cancelled. The colored figure by Northrop, from a Bahama specimen, referred to it by McMurrich, 1896, does not agree with the common Bermuda form, especially in its darker color and lacking the conspicuous blue acrorhagi. It may be the form here called *var. prunicolor*.

by the color. The tentacles are brighter or paler red than the body and usually plain in color; lips bright red or carmine.

This species is viviparous. The young when born have well formed tentacles and basal disk, and are red; some have 24 or 36 tentacles and are up to 5^{mm} or more in diameter.

110



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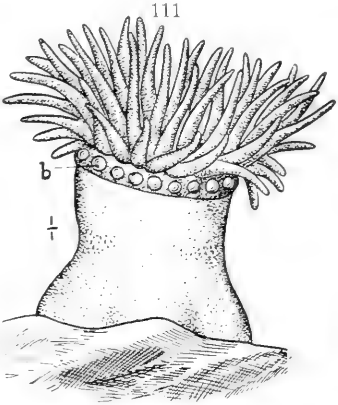


Figure 110.—*Actinia bermudensis*, disk; *m*, mouth with portion of stomodæum everted; *a*, *b*, gonidial grooves.

Figure 111.—*Actinia bermudensis*, about nat. size; *b*, blue acrorhagi. By A. H. V.

Var. **prunicolor**, nov. *Prune-colored Anemone.*

A peculiar color-variety, or possibly a distinct species, was found at Castle Harbor and Elbow Bay, March, 1901, by A. H. Verrill, who made very good colored drawings of it. The body was uniform dark purple, prune-color or plum-color. The tentacles, which were longer than the diameter of the disk, were a paler tint of the same, or pale carmine with lighter tips, and with a small white stripe on each side of the base; lips vermillion.

Tentacles do not differ much in length and form about three marginal rows. No acrorhagi were observed in life; they were probably inconspicuous in size or color. Height of column, 1.25 inches; diameter, 1 inch; length of tentacles, 1 inch.

This agrees pretty closely with the colored figure of *Diplactis bermudensis* McMur. from the Bahamas (op. cit., 1896, pl. xvii, p. 3).

Actinia melanaster Verrill. *Dark-star Anemone.* Figure 112.

Trans. Conn. Acad., xi, p. 51, pl. vi, figs. 2, 3, 1901.

This is a rather rare species, usually found sheltered in deep crevices of the reefs and ledges. It expands to about two inches across the tentacles, with the body about an inch in diameter and two inches high. Tentacles about 96, in the larger ones. The body is dark brown tinged with red. The disk has a conspicuous, central, stellate area of rich brown, with about 24 tapering rays, running out between the bases of the 24 inner tentacles, with paler radial lines, and bordered with light yellow; tentacles reddish brown with a median paler stripe; mouth red; lips whitish.

In formalin the tentacles are longitudinally fluted and the column is covered with longitudinal rows of small elevated rugæ, due to wrinklings; the acrorhagi are conspicuous.

This may prove to be only a strongly marked color-variety of the last, when a larger series can be obtained, but all those found were very uniform in color and habit.

It was found in crevices of a ledge near Flatts Inlet.

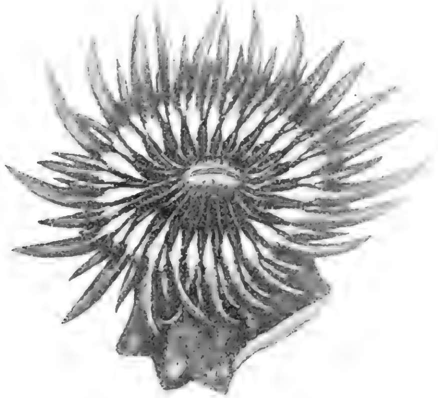


Figure 112.—*Actinia melanaster* (type), about natural size. From a colored drawing by A. H. V., therefore too dark.

Condylactis gigantea Weinland. *Pink-tipped Anemone.* Figures 113, 114, pl. xxx, fig. 1, *e*; pl. xxxvi, fig. 1, 13.

Anthea gigantea Weinland, Jahreshefte des Vereins f. Vaterländische Naturkunde, Wurttemburg, 1860, pp. 38, 44, pl. 1, fig. 4 (young).

Condylactis passiflora Duch. and Michelotti, supl. p. 31, pl. v, fig. 7, 1866.

McMurrich, Actinaria Bahama Is., p. 18, pl. i, fig. 3; pl. iii, figs. 4–6, 1889; McMurrich, Proc. Acad. Nat. Sci., Philad., 1889, p. 104, pl. vi, fig. 3 (anatomy); reprint in Heilprin, Bermuda Is., p. 108, pl. x, fig. 3.

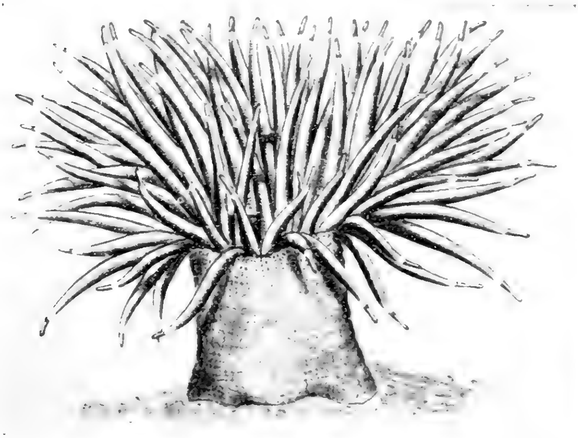
Duerden, Actinaria around Jamaica, Journ. Inst. Jam., ii, p. 453, 1898.

Verrill, Trans. Conn. Acad., x, p. 555, 1900; xi, p. 52, 1901.

Cereactis Bahamensis McMurrich, Johns Hopkins Univ. Circular, viii, No. 70, p. 30, 1889. Wilson, loc. cit., p. 38 (abnormal stomodæum).

This is the most abundant and conspicuous of the larger actinians found on the reefs. It generally occupies some hole or crevice in or between the rocks, in which the body is entirely concealed, but the large and long, soft, waving tentacles may project 4 to 8 inches or more beyond the disk. When several individuals stand side by side in a continuous wide crack, the long row of crowded tentacles presents a very peculiar appearance, for in length, thickness, general color, and soft appearance they look much like some slender-branched sponges. The tentacles are usually swollen at base and often as large as one's fingers, or larger, and usually taper more or less regularly to the tip, but at times they may be swollen and thickest in the middle or at the tips. Their color is usually pale fawn, dull brown, or grayish, finely transversely lined with paler or white interrupted wavy or zigzag rings or vermiculate lines and spots, sometimes specked with white, and nearly always broadly tipped with bright pink, magenta, crimson, or bright purple, below which there is usually a pale or white band, usually not definitely limited proximally. But the terminal pink and white colors are wanting in some examples, when the white band extends to the tip, and sometimes the tentacles are nearly plain yellowish, greenish, or pale flesh-color, with lines of reddish specks and spots. The body is

113



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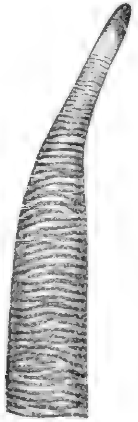

Figure 113.—*Condylactis gigantea*, variety with pink tips to tentacles, about ⅓ nat. size.

Figure 114.—A small tentacle enlarged. Both from colored drawings by A. H. V.

generally bright red, varying from pale red to carmine and dark red and brick-red in different specimens. Color-varieties occur with the body orange, ocher-yellow, salmon, pale yellow, gray, or even white; and with corresponding variations in the color of the tentacles, which are rarely entirely purple, pink, or salmon. Sometimes the tentacles are iridescent. They can contract much in size, but are incapable of retraction. The basal disk is generally dark red. The surface of the column toward the summit has rows of more or less numerous small, inconspicuous, adhesive suckers, capable of contracting so as to be invisible. They are often deeper red than the ground color and surrounded by a whitish ring, or white specks. The upper part of the column is often fluted, due to the swelling of the intermesenterial spaces; in such cases the swellings are often translucent with red pigment specks.

The disk is similar to the tentacles, but often has white or red radial lines or streaks; or it may be entirely red. Lips usually red or pink; gonidial grooves pink with white borders.

A very strongly marked color variety was found by A. H. Verrill, in 1901, living between the rocks of the abutment at Mangrove Creek. The body was light pink, spotted with crimson, but the tentacles, which were 10 inches long and .75 of an inch in diameter when fully distended, were bright pea-green, with sky-blue tips, which were often swollen.

A variety was found at Bailey Bay, in shallow water, in which the column was lemon-color or light orange; margin and tentacles grayish, the latter vermiculated with darker brown lines; tips whitish, no purple.

In life, there are short rows of small and rather inconspicuous suckers or verrucæ on the upper part of the column, but they are usually indistinct on preserved specimens.

The anatomy was described to some extent by McMurrich, 1889. The sphincter muscle is diffuse and feebly developed. All the mesenteries, except the directives, are fertile, but those of the last cycle were incomplete in his specimens, which were not full grown.

This species is also found in the Bahamas and throughout the West Indies.

There can be no reasonable doubt that this is the species named *gigantea* by Dr. Weinland in 1860. Although his note (op. cit., p. 38) and his figure of the young have been known to me for many years, and have been considered by me as pertaining to this species, I had, in view of that scanty description, hesitated to definitely change the name. However, I had, until recently, overlooked the more definite description on p. 44, which makes it certain that this was the species in view. The following is a translation of his description :

"The polyp is beautiful dark red, with brown tentacles having red tips. Later I found a specimen with blue tentacular tips, and finally still another with dark green tentacles and light green tips. The diameter of the crown of this anemone amounts to two feet. I obtained this specimen at Corail in three fathoms (18 feet) of sea depth."

Anemonia elegans Verrill. Figure 115.

Trans. Conn. Acad., xi, p. 50, pl. vi, fig. 5 (not fig. 4, as there quoted), 1901
Mark, Proc. Amer. Assoc. Adv. Science for 1905, p. [31], pl. 14, fig. 26 (not fig. 25, as there quoted).

This is a small graceful species, apt to be mistaken for the young of the preceding. Its column is about half an inch in diameter, smooth, without suckers, usually fawn-color or yellowish, tinged with brown or orange ; tentacles pale yellow to light orange yellow, usually with pink tips, and a red line behind and at the sides of the base, often with a white spot on front of base; disk yellowish with reddish or brown radii; lips scarlet red or pink. Tentacles changeable in length, but not retractile. It occurs in sheltered spots and under masses of dead coral.

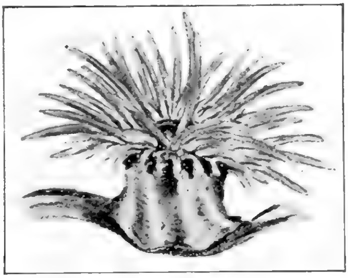

Figure 115.—*Anemonia elegans*, × 1½. From colored fig. by A. H. V.

Bunodactis stelloides (McMur.) Ver. *Small Stellate Anemone.* Figures 116, 116*a*.

Aulactinia stelloides McMur., Actinaria of Bahama Is., p. 28, pl. i, figs. 5, 6, pl. iii, figs. 8–10, 1889.
Aulactinia stella Duerden, Journ. Ins. Jamaica, ii, p. 454, 1898.

Bunodella stelloides Verrill, Amer. J. Sci., vii, p. 43, 1898.

Bunodactis stelloides Verrill, op. cit., vii, p. 146, note, 1898; Trans. Conn. Acad., x, p. 556, 1900.

Actinoides pallida Verrill, op. cit., x, p. 558, pl. lxviii, fig. 4 (*non* Duerden).

This small species is common, both upon the reefs and ledges, but prefers sheltered spots or the under surfaces of large stones and dead corals, occurring in such places even above low tide. Often, also, found buried in the sand up to the tentacles and with many bits of broken shells, etc., attached to the suckers of the column, and in such cases having the body much elongated and slender. The upper part of the column is covered by 12 or more vertical rows of distinct suckers, often bright red in color, decreasing in size downward, about 6 to 8 in each row; the upper one in each row is larger, verruciform, and marginal. The column may be long and slender, or contracted to a short form, broader than high; the basal disk may be expanded much beyond the breadth of the column. Tentacles slender, usually about 36, in three or more rows, longer than diameter of disk.

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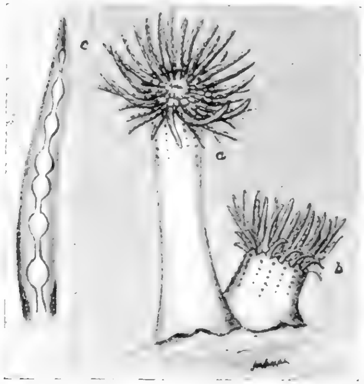

116*a*

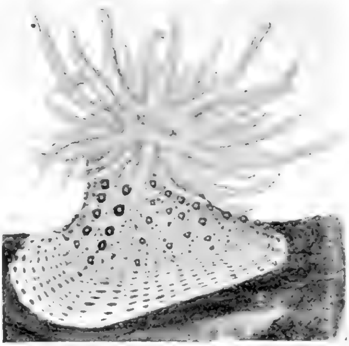

Figure 116.—*Bunodactis stelloides*, var. *catenulata*; *a*, elongated state; *b*, contracted to short form; nat. size; *c*, a tentacle enlarged. From sketches by the author.

Figure 116*a*.—The same, var. *carneola*, nov. From a colored drawing by A. H. Verrill.

The column may be flesh-color, grayish, greenish, yellowish, or milk white, often darker above; the verrucæ may be pink, red, or white; there may be rows of red spots or specks below the lines of verrucæ, partly continuous with them. The tentacles may be of the same various colors as the column, but paler; they are most often pale grayish, greenish, or light brown, sometimes light pink or flesh-color. They usually have a yellow or white spot on each side of the base. The inner surface is often (var. *catenulata*) characteristically marked by a median row or chain of rounded or elliptical flake-white spots, often connected together by a median narrow stripe, and clearly defined laterally by a continuous narrow dark line of green or brown, on each side, which usually persist in preserved specimens after all other colors have faded. The spots may be transversely elliptical when the tentacles are partly contracted and sometimes they are nearly or quite in contact. In some specimens these spots are more irregular or not so clearly defined, and in some pale varieties the tentacles appear to be unspotted (var. *carneola*).

The disk is somewhat like the column in its ground colors, but paler. The mouth is usually surrounded by a green or light brown zone; next there is a zone of white radial spots, bars, or lines, bordered outwardly in many cases by angular or V-shaped brown or green markings, which often unite into a stellate zone, but in other cases are separated by white radial lines. The white radial lines or bars opposite the 12 inner tentacles are wider than the others, and are often defined by dark lines continuous with those on the tentacles (var. *catenulata*). It is viviparous.

Found also in the Bahamas and Jamaica.

Var. **catenulata,** nov. Figure 116.

Actinoides pallida Verrill, op. cit., p. 558, p. lxviii, fig. 4 (*non* Duerden).

This name is here given to the color variety, described above, having a chain of connected, well defined white spots bordered by narrow dark lines, on the inner surface of the tentacles. It is the most common variety at Bermuda and may eventually prove to be a species distinct from the true *stelloides* of the Bahamas, which was not described as having markings of this character.

Var. **carneola,** nov. Figure 116*a*.

This name is proposed for a rather peculiar color variety, obtained in 1901, and of which I have an excellent colored drawing by A. H. Verrill (see fig. 116*a*).

The column is light red or flesh-color, with longitudinal rows of bright or light red spots, larger below, and with rows of conspicuous darker red suckers on the upper part; the tentacles are pale pink, usually without distinct lines of spots, but with streaks of white, light orange or yellow at their bases, forming a nearly continuous discal zone; inside of this is a zone of white radii, while the mouth is usually surrounded with light green. In some specimens there are inconspicuous ovate or roundish spots on the tentacles. The V-shaped dark markings of the disk are nearly or quite lacking.

Bunodactis versus Cribrina.

I do not agree with McMurrich* in adopting *Cribrina* (Ehr.) as a substitute for *Bunodes* or *Bunodactis.*

Cribrina as established by Ehrenberg (1834) was a composite group, practically synonymous with *Cereus* Oken, 1815, and therefore should be dropped from the system. Moreover, the fundamental generic character, as given by Ehrenberg, was the perforation of the walls, as the vernacular name given by him also implied, "sieve anemones." He included in it *polypus* Forsk., evidently the only species that he had personally studied, and added such other sagartians, like *Metridium*, *Adamsia*, etc., as were known to him to have perforated walls, and such, beyond doubt, should be considered his idea of the type.†

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* Report on the Hexactiniæ of the Columbia Univ. Exped. to Puget Sound during the summer of 1896. Annals N. Y. Acad. Science, xiv, No. 1, p. 14, May, 1901.

† Ehrenberg's first species and two others belong to the *Bunodes*-group, it is true, but he had already established the genus *Urticina*, on a previous page, to include such forms, and his placing them in his *Cribrina* was an error due to misinterpretation of figures, mistaking verrucæ for pores. If *Cribrina* were to be adopted at all, it should be applied to a Sagartian genus—in place of *Adamsia* (1840) for instance, which would be a typical group, for three species of that genus were included by him (*effœta*, *polypus*, *palliata*). There is a rule of nomenclature generally adopted which forbids the restricting of a genus to a type that *contradicts* the original generic diagnosis. This has been done by McMurrich, in this instance, as I understand it, and without any necessity, so far as priority is concerned. Moreover, another valid rule of nomenclature requires that the *earliest restriction* of the name of such a composite group (if not done contrary to obvious rules) shall hold good, as having priority. Now *Cribrina* had been thus restricted long before McMurrich took it up (e. g. by Grubé, 1840), with *bellis* as a type, which was one of the species named by Ehrenberg and conforming to his definition.

Professor Haddon (Revis. Brit. Actiniæ, i, p. 323, 1889), also definitely restricted *Cribrina* to the Sagartian group, taking *polypus* Forsk. (=? *effœta*

Grubé,* who first restricted the genus, placed under *Cribrina* three species: *C. bellis*, *C. effœta* and *C. carciniapodos* (=*palliata*). All these were included in *Cribrina* by Ehrenberg, and all conform to his definition of the genus, in being perforate. *Adamsia* was established for the last of these in 1840, and *effœta* is included in the same genus by many, thus leaving *bellis* as the sole type, which had already been the type of *Cereus* (1815). *C. effœta*, however, belongs to the genus *Calliactis*, proposed by me in 1864, but not deemed sufficiently distinct from *Adamsia* by many writers.

Neither can I agree with him in uniting *Evactis* and *Bunodosoma* to *Bunodactis*. If that should be done, however, *Evactis* must be adopted as the name of the larger genus. But its type, *E. artemisia*, is peculiar in having distinctly ectacmæous tentacles,—a remarkable character for this family, and as good as most generic characters. There is also good reason to believe that it has numerous definite perforations in the upper part of its column, as stated in Dana's Report, 1846, through which streams of water can be ejected in life, though McMurrich did not find them in his strongly contracted specimens. Pores known to exist in other species cannot be discovered in similar material by sections hardened out of all natural conditions.

As for *Bunodosoma*, the non-adhesive verrucæ, which differ histologically from those of *Bunodactis*, afford a sufficient generic character.

Linn.) as the type, which would be perfectly logical if the previous application or restriction of the name by Grubé could be ignored. Both these restrictions of the name not only had priority over that of McMurrich, but they, unlike his, were in accordance with the ordinary rules of nomenclature, providing, of course, that the name is to be retained at all.

My own view of it, many years ago (1864), when I first definitely restricted *Cereus* (Oken, 1815) to *bellis*, as its unquestionable type (which Haddon and most others now admit was correct), was that *Cribrina*, after having been restricted to the same group by Grubé, as he had the right to do, should be regarded as a synonym of *Cereus* and therefore should be dropped from the system. I still believe that this is the best and most logical course to take, and it is in accordance with the usual rules of nomenclature.

The only other thing to do, so far as I can see, is to adopt the genus with *polypus* as the type, as Haddon has done, in place of *Adamsia* and *Calliactis* of previous writers. At any rate, McMurrich's recent action, in ignoring Haddon's more explicit restriction, and applying the name in a totally different sense, cannot be sustained, for it violates rules of nomenclature universally approved.

* Grubé, A. E. Actinien, Echinodermen und Würmer des Adriatischen und Mittelmeers, p. 12, Konigsberg, 1840.

Asteractis flosculifera (Les.) Verrill. *Ruffled Anemone.* Figure 117.

Actinia flosculifera Les., Journ. Acad. Sci. Philad., i, p. 174, 1817 (not *Oulactis flosculifera* Duch. and Mich.)

Oulactis fasciculata McMurrich, Proc. Philad. Acad. Sci., 1889, p. 108; also in Heilprin's "The Bermuda Islands," p. 112, pl. x, fig. 5 (section), 1889.

Oulactis flosculifera McMurrich, Actinaria Bahama Is., pp. 56–58, pl. ii, fig. 2 (general); pl. iv, figs. 12–14 (anatomy), 1889.

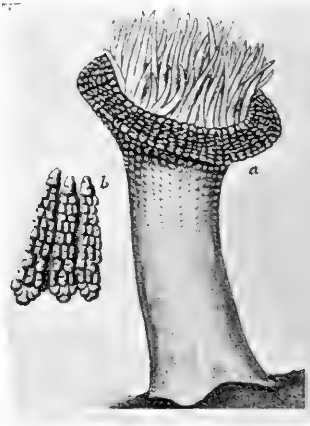
Asteractis flosculifera Verrill. Amer. Journ. Sci., vol. vii, p. 47, 1899; Trans. Conn. Acad. Sci., x, p. 572, pl. lxviii, fig. 1 (*Actinactis* by error), 1900.

Cradactis fasciculata McMurrich, Report on Actiniæ coll. by U. S. F. C. Steamer Albatross, Proc. U. S. Nat. Mus., xvi, p, 197, 1893.

Actinostella flosculifera McMur., Boll. Mus. Turin., xx, p. 7, 1905.

This species is common on the sand-flats in shallow water, where it lives buried in the sand up to its broad, expanded collar, but it is also found occasionally on the reefs, where sand collects in sheltered depressions under large stones. We found it in numerous localities.*

117



108*a*

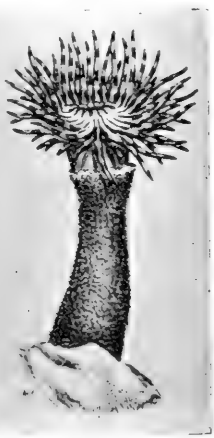


Figure 108*a*.—*Phellia rufa*, about ⅔ nat. size.

Figure 117.—*Acteractis flosculifera*, about ½ nat. size; *b*, three of the pseudofronds, enlarged. Both from colored figures by A. H. V.

It is easily distinguished by the wide collar, external to the tentacles, made up, in large specimens, of about 48 pseudofronds, appearing slightly free at their outer ends, where there are two or three prominent tubercles; the upper surface of each is covered with

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* Several large specimens are in the collections made at Bermuda by Mr. G. Brown Goode in 1876.

irregular simple and lobulated tubercles or verrucæ, arranged in three or four crowded rows; the innermost tubercle of each, situated close to the base of a tentacle, is usually simple and a little larger than the rest, like a special acrorhagus, especially in young specimens, in which it is often conspicuous.

The tentacles are moderately long, rather slender, about 48 in the adult specimens. The upper part of the column bears rows of distinct suckers, which do not reach the basal portion, but disappear about mid-height. Ordinary specimens are about 2 inches high and the column is about 1 inch in diameter, but the column can extend to a much longer form when in its burrow. The width across the expanded disk and collar may be 2 inches or more. The color is variable, but most commonly the lower part of the column is translucent flesh-color or whitish, with the white mesenteries showing through as pale lines; distally the color grows darker, the upper part often becoming orange-brown or burnt-umber, specked with flake-white and darker brown. The verrucæ of the pseudofronds are usually similar to the column in color, but paler and with more white spots. One specimen had twelve radii of reddish brown on the collar surface. Tentacles usually translucent grayish, greenish, or whitish, with obscure streaks of brown, and with transverse blotches and many specks of flake-white.

This species is viviparous. One specimen, taken in April, 1901, when put into formalin, gave birth to about a dozen well developed young ones, from 2 to 6^{mm} in diameter of column, as contracted. The larger ones had the essential characters of the adult, with 12 to 24 tentacles, and with corresponding distinct prominent acrorhagi, representing the pseudofronds of the adults, but simple, bilobed, or with very few minute lobules; suckers of the column were present.

It is found, also, in the West Indies.

The colored figure of the Bahama form published by McMurrich (1889, pl. ii, fig. 2) does not agree well with our specimens in respect to the pseudofronds, which appear too wide and too finely divided, perhaps due to inaccurate drawing. But McMurrich, in his last paper, 1905, identifies the specimen with this species, after a reëxamination.

McMurrich there adopts *Actinostella* Duch., 1850, for this genus. The type of Duch. was *A. formosa*, sp. nov. But the genus and species were then so imperfectly described as not to be recognizable by subsequent writers. Indeed, in Duchassaing's later work (Duch. and Mich., 1860), neither the genus nor the species is referred to.

In the latter work *Oulactis formosa* is described *as a new species*, and there is no evidence that it was considered the same as "*Actinostella formosa*" of 1850. Indeed, there is good reason for believing that they were totally different things. Therefore there is no good reason why that obscure generic name should be adopted, for it had no definite diagnosis and no tangible type.*

If *Phyllactis*, *Oulactis*, and *Asteractis* are all congeneric, as McMurrich maintains, then it would be most correct to adopt the first for the whole group, for it has precedence, as to the pages, and has the characters of the family in the most specialized form. In that case the present species should be called *Phyllactis flosculifera*, and the closely allied West Indian species would be *P. conchilega*.

But so far as I can judge, there is no sufficient reason for uniting these three genera, at least not until their internal organization has been fully studied comparatively, for their external differences are greater than those of the majority of actinian allied genera. *Asteractis* is especially characterized by the comparative simplicity of its pseudofronds, which are only slightly differentiated portions of the upper column or collar, and the tubercles that cover them are simple or only lobulated, while the slightly free border is due only to the projection of the outer tubercles; by the adhesive verrucæ of the column, confined to the upper part; and the narrow naked true disk, with the true tentacles crowded around its margin.†

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* In fact, Edward and Haime even referred it to their genus *Cereus*, with a mark of doubt.

† The type of *Phyllactis* E. and H. (*Metridium prætextum* Dana) has a wide collar consisting of large fronds that are free for about one-third of their length; the free portion is stalked, digitately branched distally, and covered with lobes or tubercles, forming true fronds. They are thus quite unlike the far more simple pseudofronds of *Asteractis*. The verrucæ are confined to the under surface of the fronds, which are separated from the smooth column by a groove.

The type of *Oulactis* (*M. mucosum*) Dana has a very broad undulated disk, with the tentacles considerably scattered, in 5 or 6 rows. The column is entirely covered with verrucæ, which are represented as adhesive. The fronds are united nearly or quite to their ends, much as in *Asteractis*, but with complex lobules on the upper side.

The character of the disk, arrangement of tentacles, and entirely verrucose body seem to be characters of generic value, and indicate the existence of internal differential characters of greater importance.

The third species (*M. concinnatum*) of Peru is similar to the last, as to the verrucæ of the column and tubercles of the pseudofronds; the pseudofronds have the tips or terminal tubercles free, but apparently not branched; probably

Lebrunia Danæ (Duch. and Mich.). *Gill-bearing Anemone.* Figures 118, 119. Plate xxxii A, fig. 2.

Oulactis Danæ Duch. and Mich., Coral. Antil., p. 47, pl. vii. fig. 10, 1860.

Rhodactis Danæ Duch. and Mich., Supl., p. 37, 1866.

Lebrunia Danæ Verrill, Amer. Journ. Sci., vii, p. 48, fig. 15, 1899; Trans. Conn. Acad., x, p. 555, pl. lxvii, fig. 3 (gill), pl. lxix, fig. 1, general, 1900; vol. xi, p. 48, pl. vi, fig. 1, general, 1901.

Lebrunia neglecta (as *Lebrunea*) McMurrich, Actinaria of the Bahama Is., p. 33, pl. i, fig. 7 (general), pl. iii, figs. 11–14 (anatomy), 1889.

Lebrunia neglecta Duerden, Actinaria around Jamaica, p. 456, 1898; McMurrich (*pars*), Bolletino Mus. Zool. ed Anat. Comp. Univ. Torino, xx, p. 8, 1905 (described from original type of *L. Danæ*).

This is a large and very curious species, often 6 to 8 inches in diameter in expansion, not uncommon on the ledges and reefs, where it is always firmly attached to the bottom of some deep hole or crevice, showing only the disk, tentacles and gills when expanded. It can seldom be obtained entire without cutting away the rock.

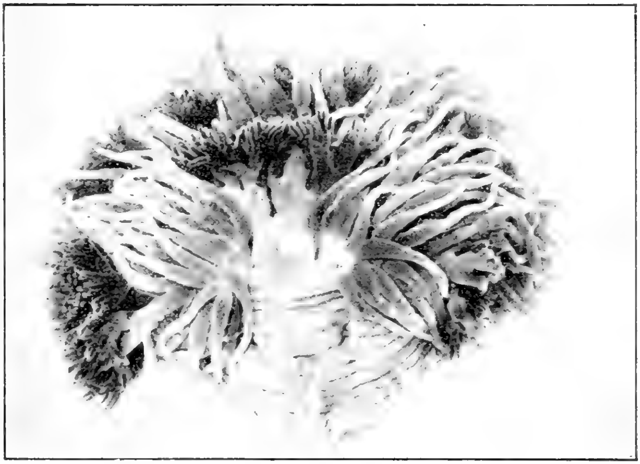

Figure 118.—*Lebrunia Danæ*, ⅜ natural size. Phot. from life by A. H. V.

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they are much like those of *Asteractis*. It appears to be nearer *Asteractis* than either of the others, but differs in the wide naked disk and verrucæ extending to the base of the column.

As for *Lophactis* Verrill, 1867, also made a synonym of *Actinostella* by McMurrich, it was discovered by myself, many years ago, that it was based upon a mutilated specimen of an unknown organism; certainly not an actinian, nor even an Anthozoan. That name, therefore, should be cancelled. Yet its disk, tentacles, and "fronds" were remarkably like *Phyllactis*, superficially.

Its most remarkable feature is the presence of large, handsome, arborescently much branched gills (*actinobranchiæ*) or "pseudotentacles" outside the true tentacles and usually much exceeding them in length. There are normally six of these, but frequently only four or five are present. In some cases this is probably due to injury, but some specimens appear to be normally pentamerous. Duerden records specimens with eight.* These branched organs usually bear numerous conspicuous, semi-globular bodies (acrorhagi) commonly pale blue in color, but sometimes there are but few of them. The tentacles are very numerous, long, rather slender, tapered, often flexuous.

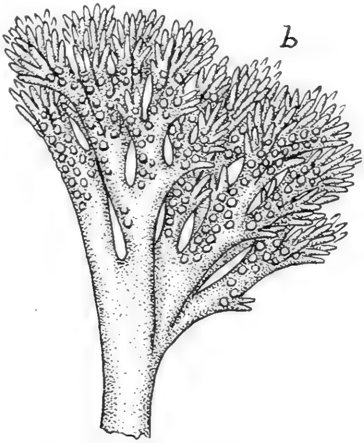

Figure 119.—*Lebrunia Danæ*; gill, contracted in formalin, natural size. From drawing by A. H. V.

Some of the larger specimens were 8 to 10 inches across in full expansion; the column may be 1 to 2 inches or more in diameter and 2 to 6 inches in length, according to the state of expansion.

The color is somewhat variable. Perhaps most frequently, the column is light brownish or fawn-color, but it is often dull greenish or olive. The tentacles and gills are similar in color to the body, but usually lighter yellowish brown or greenish brown, often flecked

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* This may indicate an octamerous arrangement of mesenteries and tentacles in the adult, especially since Duerden has shown that the very young larvæ of *Lebrunia* are truly tetramerous or octamerous for a brief period. Some may retain that condition through life, as in some other Actinians (see Duerden, The Edwardsia stage of the Actinian, *Lebrunia*, etc., Journ. Linn. Soc. London, Zoölogy, xxvii, pp. 269–316, pl. 18, 19, 1899, where the early stages are fully discussed).

with white and paler toward the tips; the acrorhagi are often blue, but sometimes pale brownish or yellowish; sometimes they are inconspicuous; disk similar to the tentacles, but often with paler radii, or flecked with whitish.

This species has nematocysts capable of stinging the hands of some persons quite severely. The tentacles and gills are not retractile.

One individual was found in 1901, with a young one budding from the side of the column. It is hermaphrodite and viviparous, according to Duerden. The young are born in much earlier stages of growth than in the preceding species. (See Journ. Linn. Soc. London, xxvii, pp. 269–316, pl. 18, 19, 1889.)

We found it at numerous localities. It is in the collections made at Bermuda by Mr. G. Brown Goode in 1876, together with *Epicystis crucifera*, *Aiptasia annulata*, *Condylactis gigantea*, etc., but without notes or special stations.

McMurrich has adopted the name *L. neglecta* (D. and Mich., 1860) for this species, or rather he has united the two forms under the former name, in his article of 1905, after studying and redescribing the original type of *L. Danæ*, preserved in the Turin Museum.* But as the type of *L. neglecta* was not found, his argument for uniting them is not very convincing. Certainly I have never found any Bermuda specimens agreeing with the one described and figured by McMurrich from the Bahamas (1898, pl. 1, fig. 7).

But Duerden's Jamaica specimens, described as *L. neglecta*, agree well with those from Bermuda. The matter needs further study. Possibly McMurrich's Bahama specimen was one that had lost its gills and was regenerating new ones, so that they were not normally developed. They not only lack evident acrorhagi, but are not more than one-fourth as large as those of similar sized Bermuda specimens, and have far less numerous divisions. It is not improbable that there are two West Indian species of the genus. Therefore it seems to me better not to unite them at present. Until more

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* The synonymy of *L. neglecta* is as follows:

Lebrunia neglecta Duch. and Mich.

Lebrunia neglecta Duch. and Mich., op. cit., p. 48, pl. vii, fig. 8, 1860 (young). Andres, op. cit., p. 362 (*non* Duerden).

?*Actinodactylus neglectus* Duch. and Mich., op. cit., p. 44, 1860 (very young).

?*Stauractis incerta* Andres, op. cit., p. 225, 1884 (new name for last).

Lebrunea neglecta McMurrich, Actin. Bahama Is., p. 33, pl. i, fig. 7 (general), pl. iii, fig. 11–14 (anatomy). Verrill, Amer. Journ. Sci., viii, p. 48, 1899.

specimens of the Bahama form can be studied its relations must remain uncertain.

McMurrich (op. cit., 1905) preferred to adopt *neglecta* as the name for the group of united forms, on the ground of priority. But the two names have the same date, *Danæ* occurring on the earlier page (47). Moreover, McMurrich has shown (1905) that the type of the latter is alone preserved in Turin, which is an additional reason for retaining the latter name. Further, *Danæ* was originally described from a more adult specimen, while *neglecta* was a younger form (about half an inch high). For all these reasons *Danæ* should be preferred for the name, if the two forms be united.

If it can be proved that *Actinodactylus Boscii* D. and M., 1850, is the young of *Lebrunia*, which is very doubtful, *Actinodactylus* (1850) has priority for the generic name, with *A. Boscii* as the type.*

Epicystis crucifera (Les.) Ehr. *Cross-barred Anemone.* Plate xxxii, fig. 1; Plate xxxiiA, fig. 1.

Actinia crucifera Lesueur, Journ. Acad. Nat. Sci. Philad., i, pl. i, p. 174, 1817.
Epicystis crucifera Ehrenberg, Corall. Roth. Meer., p. 44, 1834.
Phymanthus cruciferus Andres, Le Attinie, p. 501, 1883.

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* *Actinodactylus* was defined by Duch. and Mich. as having the (5) branched gills alternating with the (15) simple tentacles in a *simple marginal row*. The figure reminds one of the terminal portion of a siphon-tube of some bivalve mollusca, or of the tentacles of a holothurian, rather than of an actinian. If an actinian, the branched gills are probably not in the same row with the tentacles. In the second named species, *A. neglectus*, 1860, there were 30 simple tentacles, so that both were probably pentamerous. Both were probably very young forms, and the descriptions are very imperfect and may be erroneous. A more careful search for the young forms of West Indian actinians would easily settle this and many other similar doubtful points. Neither of these forms is preserved in the Turin Museum. The very young forms of *L. neglecta* described by Duerden, and considered by him the same as *Hoplophoria coralligens* Wilson, differ much from the type of *Actinodactylus.*

The *Hoplophoria* had 48 hexamerous tentacles, with four large, prominent, *simple*, but not stalked acrorhagi, much as in the young of *Asteractis.* Although having much more numerous tentacles than either form of *Actinodactylus*, the acrorhagi show no signs of branching, while in the latter, with but 15 tentacles, they are already divided into numerous branches at the end of a slender stalk, longer than the tentacles. Evidently the latter is in no way connected with *Hoplophoria*, whatever its relations to *Lebrunia* may be. *Hoplophoria*, although evidently young, had small ovaries on some of the primary septa.

The young of *Asteractis flosculifera* also resemble Wilson's species, for it has simple, or bilobed, elongated acrorhagi or actinobranchs, somewhat as in the latter, but much smaller. (See page 267.)

Phymanthus crucifer McMurrich. Actinaria Bahama Is., p. 51, pl. ii, fig. 1, pl. iv, figs. 6–11 (anatomy), 1889. Duerden, Actinaria around Jamaica, p. 452, 1898; Jamaican Actinaria, pt. ii, p. 139, pl. x, figs. 1, 2, pl. xi. figs. 1, 2 (anatomy), 1900; Actinaria of Porto Rico, p. 368, pl. iii, fig. 13, 1902.

Epicystis crucifera Verrill, Amer. Journ. Sci., vi, p. 496, 1898. McMurrich, Bolletino Mus. Zool. Anat. Comp., Turino, vol. xx, p. 12, 1905.

This is also a large and very handsome species, not uncommon on the reefs and ledges, where the water is apt to be much agitated. It buries itself nearly up to the tentacles in holes and crevices of the rocks, into which it can withdraw when disturbed. It adds to its ability to conceal itself, by fastening bits of broken shells, etc., to the conspicuous suckers on the upper part of the column.

It is also frequently found on the sand flats in shallow water, attached to a stone several inches below the sand and expanding its broad undulated or frilled disk on the surface of the sand, where it often presents a very elegant appearance.

When fully extended the body of the larger specimens may be 6 to 8 inches or more long and 2 to 3 inches in diameter, while the disk and tentacles may expand to the breadth of 6 to 8 inches, but specimens of about half these dimensions are much more common. In full expansion the edge of the disk is usually curved into six to twelve wavy undulations, or they may become deep sinuous frills; sometimes they disappear and the broad disk is then usually concave, but changeable. Occasionally there are only four great undulations of the disk. The tentacles, which are very numerous, and form three or four crowded rows, are of moderate length, stout and tapered, but not very different in form or length. They are generally crossed by several raised, flake-white, transverse ridges or bars, usually bilobed or dilated at the ends, and containing large batteries of nematocysts.* Sometimes these are interrupted along the median line, and frequently they are reduced in number, but I have never

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* Mr. Duerden, in his recent work (Actinians of Porto Rico, 1902, p. 368) adopts *Phymanthus* Edw., 1857, for the generic name, and quotes Carlgren's opinion that this species is congeneric with *P. loligo*, of the Red Sea, the type of that genus. Whether that be the case or not (for the difference is considerable), *Epicystis* must be adopted for the American genus, on the ground of *priority*. The genus *Epicystis* Ehrenberg was established, with a brief diagnosis, for *E. crucifera* in 1834. It was the first of the three species mentioned by Ehrenberg, and the only one that can be considered typical, for the other two belong to genera previously established. *Phymanthus* was not named till 1857, and therefore, if they are to be united, the Red Sea species must take the name *Epicystis loligo* (Ehr.). But the latter has clusters of papillæ on the tentacles, so conspicuous that Ehrenberg referred it to *Actinodendron* Bv.

seen specimens without them, unless referable to the next species or subspecies by other characters.

The disk is covered with numerous unequal radial rows of small, simple papillæ or tubercles of various sizes, the rows corresponding to the tentacles of all but the outer cycles. The smaller are rounded and wart-like; the larger, conical or papilliform. The column is smooth below, but has short rows of suckers, usually bright red in color, to which foreign objects adhere, on the upper part. Each row usually has 6 to 10 suckers in large specimens, decreasing in size below. The margin bears a circle of rounded acrorhagi, each one in line with a row of suckers.

The ground color of the column is usually pale flesh-color, cream-color, or whitish, irregularly striped, streaked, on flammulated with carmine, rose-red, light red, or crimson, not unlike some varieties of striped apples; near the upper margin it usually changes to gray; verrucæ bright red. The disk is elegantly variegated with several colors; the central part is often bright iridescent green, beyond which it may be variegated with lavender, russet-brown, green, yellow, and flake-white, in various patterns. Frequently the ground-color of the disk is whitish, grayish, or yellowish green; while the tubercles may be darker yellow, green, olive, or brown. The basal disk is usually light red. The lips may be lavender, with white gonidial grooves; inside of mouth often pink. The tentacles also vary in colors, but usually correspond in color more or less with the disk; most commonly they are greenish or olive-brown, with the cross bars flake-white; the white cross-bars are often most numerous and most distinct on the outer tentacles.

The lips have about 24 grooves on each side, besides the gonidial grooves, which are strongly developed.

When expanded in their burrows, the disk spreads out into a broad frilled form, but it can contract very quickly when disturbed and retreat entirely within the burrow, though the tentacles are not retracted.

It is found throughout the West Indies.

Subspecies **formosa**, nov. *White-striped Anemone.* Fig. 120. Pl. xxxii, fig. 2.

Epicystis osculifera Verrill, Trans. Conn. Acad., x, p. 556, 1900 (perhaps not Les., sp.).

This beautiful actinian grows as large as the preceding and has the same undulated and frilled form of the disk, and usually the same red-streaked colors of the column. But the tentacles, which are in four rows, are entirely destitute of the raised transverse white ridges or bars, so characteristic of *crucifera*. Moreover, the smooth tapered tentacles are usually fawn-color or orange brown with a conspicuous stripe of flake-white on each side, becoming wider at base and running inward on the disk as white radial lines or streaks; on the outer tentacles the white patches often meet around the outer base and extend about half way to the tips. The disk is colored like the tentacles, often with an iridescent green tint, variegated with brown and lavender and specks of white, and with many white radial lines.

The tubercles of the disk are small and very numerous in each of the larger radial rows ; they are mostly small and verruciform, but some are conical, papilliform, or even slender and clavate. They are usually darker than the ground color of the disk, but vary in color.

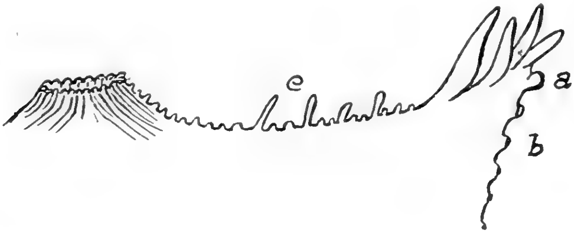

Figure 120.—*Epicystis formosa*. Diagrammatic profile of disk and tentacles, natural size ; *e*, tubercles of disk ; *a*, acrorhagus or larger upper verruca ; *b*, adhesive suckers of the wall. Sketched from life by the author.

The large verrucæ or suckers of the upper part of the column are bright red. They remain conspicuous in preserved specimens.

Although in a former article I described this as a distinct species, I have here reduced it to a subspecies or variety, mainly out of deference to the opinion of Mr. Duerden, who claims to have found intermediate forms at Jamaica, though it would seem that the two characteristic forms are also abundant there, as in Bermuda.

It is quite possible that though really distinct, they may often hybridize, and thus produce intermediate forms, as in the case of our two New England starfishes of the genus *Asterias*, which are well known to hybridize where their ranges overlap, as in Vineyard Sound.

In many respects this agrees with the description of *Actinia osculifera* Les., 1817, with which I formerly identified it. The latter had similar colors, radial rows of tubercles on the disk, and verrucæ on the upper part of the column from which water could be ejected, as in *crucifera*, with which Lesueur himself compared it.

However, McMurrich justly remarks that Lesueur described the disk tubercles as lobed or branched, which has not been observed in this species. But his attempt to explain away the verrucæ of the column as due to an error of observation on Lesueur's part, he being supposed to have mistaken accidental wrinkles of the smooth-walled *Actinotryx* for verrucæ, seems to me very improbable. They must have been conspicuous, for they not only ejected water, but suggested the name of the species.

Moreover Lesueur was an able and careful observer, well-trained in zoology for that period, and an excellent zoological artist, as his published figures show. In fact, he exceeded most zoologists of his time in the attention to all minor details of the objects he described, as is shown, for instance, in his figures of the anatomy of *Zoanthus*, giving correctly the unusual arrangement of the mesenteries.

Hence I think we must allow that the species described by Lesueur had distinct suckers or verrucæ on the column, of which some were perforated, and that the disk tubercles were lobed or branched. Moreover, he speaks of the marginal tentacles as large.

Hence it seems to me quite unreasonable to assume, as McMurrich does, that he had before him *Actinotryx Sancti-thomæ*, which has a remarkably smooth and lubricous column, and only very small marginal tentacles. It also has a very different style of coloration. Moreover its peculiar form surely would have attracted Lesueur's attention, as being quite unlike any species he had previously described.

However, if we eliminate these two species, I do not know any other West Indian species, described by modern writers, to which his description could apply. Perhaps it was a species not yet rediscovered. We are certainly not yet acquainted with all the West Indian actinians.

Actinotryx sancti-thomæ (Duch. and Mich.) Figures 121, 122, 123.

Actinotryx Sancti-Thomæ Duch. and Mich., Corall. Antill., p. 45, pl. vii, fig. 2, 1860; Andres, p. 509, 1860; Duerden, Jamaican Actinaria, part ii, pp. 148–154, pl. x, figs. 3–6 (general), pl. xi, figs. 3, 4 (anatomy), pl. xii, fig. 3 (anatomy), 1900.

Verrill, Trans. Conn. Acad., x, p. 555, pl. lxviii, fig. 5, 1900.

Rhodactis Sancti-Thomæ McMurrich, Actinaria Bahamas, p. 42, pl. i, fig. 9, pl. iv, figs. 2, 3 (anatomy), 1889. Duerden, Actinaria around Jamaica, p. 451, 1898.

Rhodactis osculifera McMurrich, Revision, Bull. Mus. Turin, xx, p. 13, 1905 (*non* Les. sp.).

This curious species is common on the reefs, often living exposed to the surf, as well as in sheltered spots. It often grows in large groups or colonies, nearly covering the rock for a considerable area, those in each colony being of nearly one pattern of color, due, without doubt, to the fact that this actinian can produce young asexually, both by direct fission and by fragmentation of the edges of the lobulated basal disk. Therefore a concolorous group indicates that all in such a group are of one parentage. But there is great diversity in the members of different groups.

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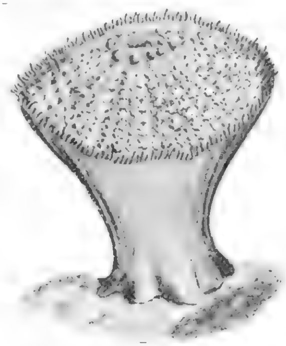

Figure 121.—*Actinotryx sancti-thomæ.* A small specimen fully expanded. Phot. from life, nat. size. The irregular patches on the column are due to loosely adherent mucus. Phot. A. H. V.

Figure 122.—The same, a larger specimen, not so fully expanded, ¾ nat. size. From colored drawing by A. H. V.

Figure 123.—*Actinotryx sancti-thomæ*; *a*, diagram of mouth and disk-tubercles, ×2; *b*, group of marginal tentacles, more enlarged. Sketches from life by the author.

The base, which is often expanded and lobulated, adheres very closely to the rocks, and is very liable to be injured in removal. It sometimes secretes an epidermal basal cuticle. The body, in full expansion, is narrow below, but spreads out toward the disk into a cup-like or vase-like form, or even into a broad salver-shape, with the thin rim of the broadly distended disk often horizontal, or even reflexed, and frequently undulated. The exterior is very smooth and lubricous, and when irritated it secretes a great amount of tenacious mucus, but in partial contractions the wall is often longitudinally lined or grooved, corresponding to the mesenteries, and sometimes transversely wrinkled, but never has verrucæ or suckers. The broad disk may be concave or convex, according to state of expansion, and is often flexuous; the mouth is generally raised on a broad conical elevation; the lips have numerous (48–60) small lobes and grooves, but no distinct gonidial grooves. Several short, rounded or wart-like tubercles surround the mouth.

Then there is a nearly naked smooth area, beyond which numerous radial rows of disk-tubercles run out toward the bases of the marginal tentacles, but leave a naked zone in front of them. The disk-tubercles vary in form and size. Twelve primary rows can usually be distinguished by their larger size, greater complexity, and often by their white or lighter color. The proximal and distal tubercles of the larger rows, and all of those in the smaller rows are simple, rounded, mammiform, or verruciform, and in specimens of less than an inch in diameter all are usually simple. But in the larger specimens, 5 to 8 or more of those in the middle part of the larger rows are lobulated, each bearing 3 to 6, or even 8, irregular, short, blunt, divergent digitations or lobules, while those more distal become gradually smaller and simple. There may be 12 to 20 or more in a radial row.

The margin is thin and bears a single row of short simple, unequal tentacles, in which groups of one to three larger ones alternate with groups of three or four smaller ones, somewhat irregularly.

The body is but little contractile, and the disk cannot be enrolled, but may be incurved. The internal structure is peculiar in several respects.

The color of the column varies greatly. It is often greenish brown below, becoming chocolate-brown or umber-brown above, and usually finely lined with paler, and frequently flecked with whitish or pale spots; specimens that are olive-green, purplish, or fawn-color are also common; they are usually paler near the base.

The disk is variously colored and variegated. Common colors are emerald-green, lavender, chocolate-brown, gray, and flake-white, often with an iridescent luster when green. Frequently the colors are in radial lines or stripes. The primary rows of tubercles are often flake-white or light green on a green ground-color, or gray with white specks, alternating with other rows of lavender-color. Toward the margin there are often alternating radii of light brown and whitish. Inside of mouth often light green, sometimes greenish brown.

The largest specimens observed were 3.5 inches across the expanded disk and about 2 inches high; specimens of 1.5 to 2 inches in diameter are not uncommon. The larger ones sometimes have 2 or 3 mouths on the disk, indicating incipient fission.

It is also common in the West Indies.

Duerden in his work of 1900 (Jamaican Actinaria, pt. II) has given an excellent account of its anatomy and histology, which are peculiar. There is no definite sphincter muscle, and therefore the margin of the disk and column cannot be completely retracted. The mesenteries are irregular. Only one pair of directive mesenteries is usually developed, and there is no distinct gonidial groove. Nematocysts are lacking in the column wall and disk tentacles, but occur at the tips of the marginal tentacles. The mesenterial filaments are unusually simple and lack the ciliated streaks.

It is viviparous, but extrudes the young in early stages of development. Duerden found it breeding in September.

In addition to the preceding species, which are mostly common and well known,* the following species was described from a preserved specimen obtained by the Challenger expedition from the "Reef of Bermuda." It has not been observed since that time, so far as I know. There may, perhaps, be an error as to the locality, but it should be carefully looked for on the outer reefs.

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* Several species of Bermuda actinians have not been described above, because they are not ordinarily found on the reefs. They are as follows:

Cerianthus natans Verrill, Trans. Conn. Acad., xi, p. 47, pl. ix, fig. 6, 1901.
Phellia simplex Verrill, op. cit., p. 48.
Bunodopsis globulifera Verrill, op. cit., x, p. 559, pl. lxvii, fig. 4, 1900; Amer. Jour. Sci., vii, p. 146, fig. 20, 1899. Duerden, Trans. Linn. Soc. London, viii, pp. 297–317, plates 25, 26, anatomy, 1902.

Ilyanthopsis longifilis Hertwig.

Voyage Challenger, Zoölogy, vol. xxvi [p. 13], pl. ii, fig. 2 (gen. and sp. nov.).

It is a turbinate form, as contracted, with a small pedal disk. It had about 160 long, slender, perforated tentacles, in about four rows. Wall of column and collar smooth. No acontia; mesenteries 160, all fertile and perfect; no sphincter. Height of column, 35^{mm}; diameter of disk, 70^{mm}; of base, 40^{mm}; length of larger tentacles, 40^{mm}.

It probably belongs to the *Actinidæ*, but in its anatomy it is unlike any West Indian species known to me.

It seems to most resemble *Condylactis gigantea.*

Zoanthacea.

Several species of these social or colonial actinians occur at Bermuda in great abundance, not only on the reefs, but in shallow water along the shores, in small bays, and even in tide pools. The bottom of Hungry Bay, in the spring of 1900, seemed to be completely carpeted with two or three species, over large areas. One of the species abundant there was a bright green *Zoanthus,* another was the larger yellow or orange-colored *Protopalythoa grandis.* Two species of *Palythoa* occur commonly on the reefs, forming more or less extensive pale yellow coriaceous crusts, often several feet across. The most abundant is *P. mammillosa,* in which the polyps, when fully contracted, sink entirely into the cœnenchyma, so as to show little or no prominences. In this the encrustation of white sand is so dense that the colonies can be preserved in the dry state so as to retain much of their natural form and size.

The species of this group are variable in form, color,* number of tentacles, etc., and therefore they are difficult to identify, especially when preserved. Several recent writers have endeavored to find good specific characters in their internal anatomy and histology, but so far with little success, for the internal structure seems to vary quite as much as the external. The mode of growth, crowding, and even the state of contraction give rise to apparent structural differences, even in a single colony. The mesenteries and tentacles

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* The green, yellow, brown, and olive colors, so common in the Zoanthacea, as well as in the coral polyps, are mostly due to microscopic unicellular plants (Zoöxanthellæ) living symbiotically in the tissues, especially in the cells of the endoderm, and varying in relative numbers as well as in color, thus causing corresponding variations in the polyps. But they also have, in many cases, special pigment granules of different kinds in the ectoderm cells of the disk and tentacles. (See p. 210.)

increase by pairs, to the right and left of the directives, so that they vary in number up to full maturity. The number of tentacles and mesenteries in the full-grown polyps seems to be fairly constant within rather narrow limits.

The Bermuda reef species all have short tentacles. The species with long tentacles mostly belong to *Epizoanthus* and *Parazoanthus*, and are found chiefly in deeper or colder waters.

Protopalythoa grandis Verrill. Figures 124–128. Plate xxx, fig. 2.

Protopalythoa grandis Verrill, Trans. Conn. Acad., x, p. 563, pl. lxvii, fig. 6, 1898.

This common species is one of the largest American zoanthids. It usually occurs in large groups, coated with white sand, and united together at base by broad membranous expansions, but when the clusters are small the polyps may be united by narrow stolons (figs. 124, 125).

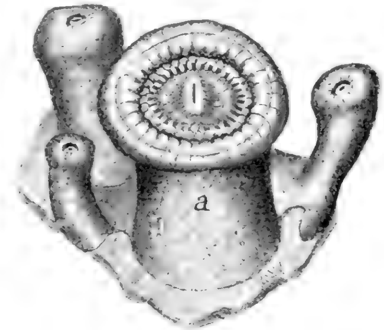

Figure 126.—*Protopalythoa grandis*. A group of adult and young, yellow variety, ×1½; *a*, an adult polyp with 64 tentacles, partially expanded. From a colored drawing by A. H. V., from life.

The column may be of almost any form, according to the place of growth and state of expansion. In many cases it is short and cylindrical, but spreading distally in expansion (figs. 126, 127). Very often it is clavate or trumpet-shaped, narrow at base and regularly enlarging distally, as in figs. 125, 128. In expansion the disk may be flat or concave, but when very fully expanded it becomes convex and reflexed, as in figs. 124, 125. The length of the column varies, in adult polyps, from 1 inch or less to 2 inches (20–50^{mm}); diameter of contracted summits, 8 to 13^{mm}; of expanded disks, 12 to 18^{mm}. The tentacles are numerous, usually 60 to 68; sometimes 80 in the largest polyps, rather short and blunt, arranged in two alternating rows. Surrounding the disk, outside the tentacles, there is a circle of angular pointed lobes, usually white in color, corresponding to the inner

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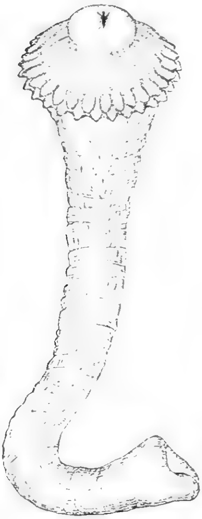

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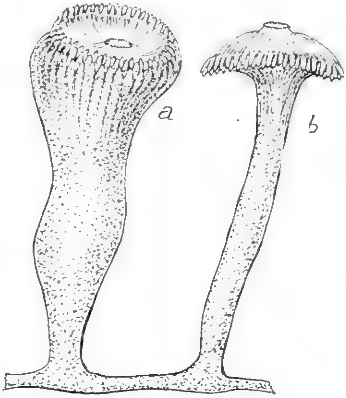

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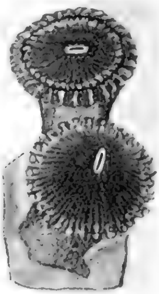

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Figure 124.—*Protopalythoa grandis*, two polyps in different states of expansion, about nat. size. Drawn by the author from life.

Figure 125.—The same, a detached polyp with elongated column, slightly enlarged. Drawn by A. H. V.

Figure 127.—The same. Two polyps of the short form, with white marginal lobes and ocher-yellow disk, expanded, somewhat reduced. Drawn by A. H. V.

Figure 128.—The same. Group of polyps, contracted, ⅞ natural size.

circle of tentacles, and of the same number. These show as white convergent points when the polyps are contracted and enable us to ascertain the number of tentacles, even in contraction. In some cases one of the directive tentacles was longer and lighter colored than the rest, and the corresponding marginal papilla was whiter.

The disk and tentacles are most frequently ocher-yellow, orange-yellow, or buff, usually darker near the tentacles, and mostly marked with brown or green radial lines; the whole disk may be tinged with green or olive; lips whitish or pale yellow. The column, under the sand, is usually buff, salmon, or ocher-yellow.

Common on the reefs and in sheltered bays and sounds; low-water to 8 fathoms.

Protopalythoa Heilprini Verrill.

Verrill, these Trans., x, p. 560, 1900 (as *Parapalythoa* by error).

Gemmaria Riisei (*Russi* by error) McMurrich, Proc. Acad. Nat. Sci. Philad., 1889, p. 124, pl. vii, figs. 7–9 (*non* Duch. and Mich.).

This is a much smaller species found in small groups attached to stones at North Rocks. Height of column about 25^{mm}; diameter, in contraction, 5 to 7^{mm}. The column is usually clavate and transversely wrinkled. Thirty-one pairs of mesenteries were found by McMurrich. The tentacles should, therefore, be about 62. It appears to be rare.

Palythoa mammillosa (Ellis and Sol.), Lamx. Figs. 129, 129*a*, 130. Pl. xxx, fig. 1, *a*.

Alcyonium mammillosum Ellis and Solander, Hist. Zoöph., p. 179, pl. 1, figs. 4, 5, 1786.

Palythoa mammillosa Lamx., Polyp. Flex., p. 369, pl. xiv, fig. 2, 1816; Edw. and H., iii, p. 304; Dana, Zooph. Expl. Exp.

Corticifera flava Lesueur, op. cit., p. 179, 1817.

Palythoa flava Duch. and Mich., Corall. Ant., 1860, p. 53. McMurrich, Actinaria Bahama Is., p. 66.

? *Palythoa caribæorum* Duch. and Mich., Corall. Ant., p. 53, 1860.

Palythoa cinerea Duch. and Mich., Supl. Coral., p. 47, pl. vi, fig. 8, 1866.

Corticifera lutea Hertwig, Voyage Chall., Zool., xxvi, p. 44, pl. i, fig. 6, 1888 (*non* Quoy and G., sp.).

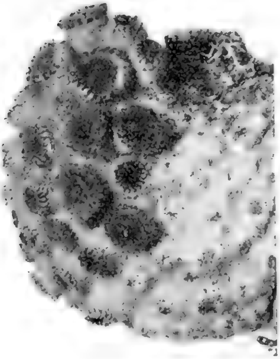
Corticifera flava McMurrich, Actinaria Bahama Is., p. 66, 1889.

Corticifera glareola McMurrich, Proc. Acad. Nat. Sci. Philad., 1889, p. 122; also reprint in Heilprin's Bermuda Is. (*non* Les. sp.).

Palythoa mammillosa Duerden, Actinaria of Jamaica, p. 359, pl. xviiA, figs. 7, 8, pl. xix, figs. 1–4, anatomy, 1889. Verrill, Trans. Conn. Acad., vol. x, p. 564, pl. lxviii, fig. 7, 1900.

This is the most common species at Bermuda as well as in the West Indies. It forms broad, coriaceous, pale yellow crusts, due to the thick coat of calcareous sand, on the ledges and reefs, both at low tide and in deeper water. These colonies are often two to four feet across and from one-third to one-half an inch (8–12^{mm}) or more in thickness when living, and with a nearly smooth surface when the polyps are entirely retracted. But when they expand they can rise considerably above the cœnenchyma, the projecting portion being 3 to 5^{mm} high, cylindrical, or expanding toward the disk, conical, or hemispherical according to the degree of expansion (figs. 129, 130).

129



129*a*

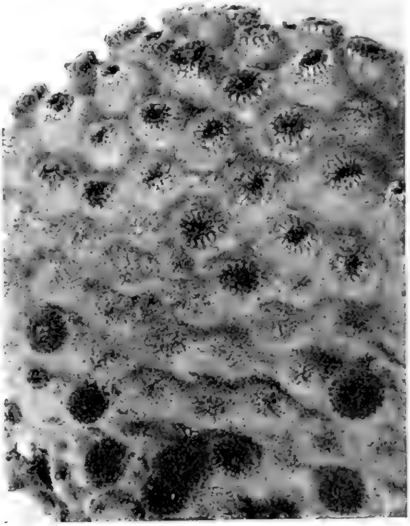


Figure 129.—*Palythoa mammillosa*, part of a colony, with some of the polyps expanded ; nat. size.

Figure 129*a*.—The same. Another part of the same colony, nat. size. Both phot. while living, under water, by A. H. V.

When dried, therefore, these crusts sometimes show slight mammilliform elevations over the polyps, and sometimes depressions, or even round openings (as in *ocellata* of Ellis and Sol.).

The tentacles are small and short, about .05^{mm} long, varying from 34 to 40, but usually 36 to 38 in full grown polyps. They form two alternating rows, with an outer circle of whitish, angular, columnal lobes, opposite the inner circle of tentacles and of the same number.

The disk is ocher-yellow or light orange-yellow, with the central part darker or more brownish, with radial white lines or rows of spots, and usually a circle of small flake-white spots around the mouth. Tentacles similar to the disk, but usually paler, often specked with white at the tips, and frequently with white specks between their bases. But the color may vary in the same colony, some of the polyps being without white lips and radii on the disk and spots on the tentacles, while others will have them.

The anatomy has been described by McMurrich, Duerden, and others. The internal structure seems to vary considerably in various features.

It is common throughout the West Indies.

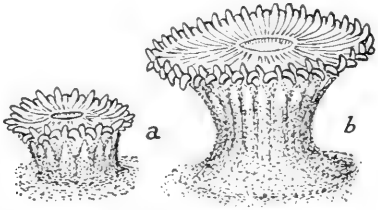


Figure 130.—*a*, *Palythoa mammillosa*, expanded polyp; *b*, *P. grandiflora*, expanded polyp. Both about 1¼ natural size, by the author.

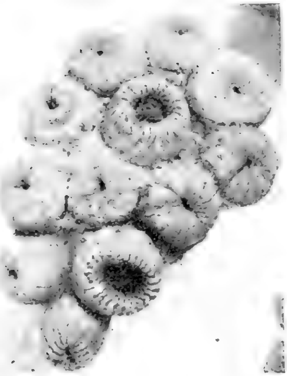
Palythoa grandiflora Verrill. Figures 130, *b*, 131, 132. Plate xxx, fig. 1, *b*.

Palythoa grandiflora Ver., Trans. Conn. Acad. Sci., x, p. 564, pl. lxviii, fig. 6, 1900; op. cit., vol. xi, p. 52, pl. vii, fig. 2, 1901.

Corticifera ocellata McMurrich, Proc. Acad. Nat. Sci., Philad., 1889, p. 120; reprint in Heilprin's The Bermuda Is. (*non* Ellis and Solander sp.).

This is one of the largest known species of Zoanthidæ. When full grown it forms broad but not very thick crusts, several feet broad, but more frequently it is found in smaller colonies, a foot or less in breadth. In contraction the large polyps cannot contract entirely to the level of the cœnenchyma, but their summits remain as prominent rounded tubercles or mammillæ, 10 to 14^{mm} broad, on its surface (fig. 131). In this state the summits of the contracted polyps are sulcated with about 26 to 30 grooves, terminating in white, angular points around the disk. In expansion the polyps rise considerably above the cœnenchyma (about 15 to 20^{mm}), and swell out at the summit into broad cup-shaped or flower-like forms, often with the disk flat or even convex, and so broad that their margins often overlap each other in the clusters, entirely concealing their bodies and the cœnenchyma. The disk is 14 to 18^{mm} broad in expansion. The tentacles vary from 52 to 60 in the full grown polyps; they are short, subequal, in two regularly alternating rows, usually dark yellow or dull orange with white tips. The disk is also generally some shade of brownish orange, with specks and radial lines of whitish, lips usually white. The angular columnal lobes, opposite the inner tentacles, are tipped with flake-white, and one in line with the directive tentacles is often larger and whiter than the rest. Column and cœnenchyma, under the coating of sand, is ocher-yellow, pale orange, or orange-brown.

131



132

Figure 131.—*Palythoa grandiflora*, a small colony partly contracted, about nat. size.

Figure 132.—The same, part of a larger colony, slightly reduced. Phot. by A. H. V.

It was most abundant in the course of streams of salt water flowing out from caverns, etc., through the rocky shores, especially on the west side of Castle Harbor. It occurred also on the reefs and in 5 to 8 fathoms. It does not appear to be known from the West Indies.

The polyps of this species agree so well in size, color, and number of tentacles with those of *Protopalythoa grandis*, that it may naturally be suspected that they are the same species with different forms of growth, the latter having no cœnenchyma above the basal stolons. But I found no truly intermediate forms. Should they ultimately prove to be identical, it would probably be necessary to unite the genus *Protopalythoa* (= *Gemmaria* of many authors) to *Palythoa*.* The type of the latter (1816) was *P. mammillosa*. The only tangible difference between the two genera is the presence in the latter of a thick crust-like cœnenchyma, uniting the polyps together laterally. But in this species they are often united for less than half their height.

Zoanthus proteus Verrill. Figures 133, 134, 135. Plate xxx, fig. 1, *c*.

Zoanthus, sp. 1. Erdmann, op. cit., p. 438, pl. iv, figs. 1, 2, general, pl. v, figs. 1–5, anatomy.

Zoanthus Danæ Hertwig, Voy. Chall., Zool., xxvi, p. 36, pl. i, fig. 1, 1888 (*non* Verrill, 1867).

? *Zoanthus flos-marinus* McMurrich, op. cit., 1889, p. 113, pl. vii, figs. 3, 4; Heilprin's The Bermuda Is., p. 119, pl. xi, figs. 3, 4, 1889 (*non* Duch. and Mich.).

? *Zoanthus pulchellus* (*pars*) Duerden, Act. of Porto Rico, 1902, p. 332, pl. ii, figs. 2, 3, general, pl. iv, fig. 14, sphincter (*non* Duch. and Mich.).

Zoanthus proteus Verrill, these Trans., x, p. 561, pl. lxvii, figs. 5–5*b*, 1900.

This is the most common Bermuda species of *Zoanthus*. The polyps are extremely variable in form and height; the column may be short or long cylindrical; bottle-shaped; jug-shaped; club-shaped; or tall, slender, trumpet-shaped; all these forms often occurring in one cluster (see fig. 134). The wall is soft, but often has dirt, diatoms, etc., adhering slightly to the surface, except on

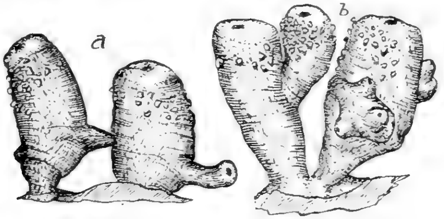


Figure 133.—*Zoanthus proteus*, from same colony as 134; *a*, two polyps with lateral stolons and buds; *b*, polyps with lateral buds. × about 2. Drawn from preserved specimens by A. H. V.

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* Or else the latter would need to be restricted to species in which the polyps can be entirely withdrawn into calicles immersed in the cœnenchyma.

the upper third or fourth part, which is smoother and naked, so that the surface is usually divisible into two regions, usually with a constriction between, and with a secondary sphincter muscle corresponding to it; but this difference is not always evident externally.

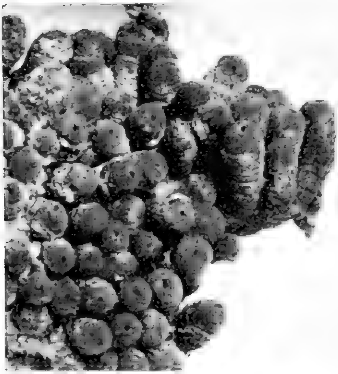
In many contracted specimens small irregular verrucæ and transverse rugæ occur about the middle of the column, where the wall appears to be thickest. The mesenteries sometimes show through the column, where thin distally, as longitudinal lines.

The two sphincter muscles agree well in sections with the figure of Erdmann (op. cit., pl. v, fig. 2).

The polyps are united into more or less extensive clusters either by slender narrow stolons, or by flat expansions of cœnenchyma, or directly, the buds often springing from the basal regions of the column, or even from higher up on the sides; sometimes stolons also arise from above the base (fig. 133). These variations may all occur in one colony.

The polyps may be crowded or openly grouped, but seldom if ever wide apart, as in *sociatus.* According to Hertwig and Erdmann their Bermuda specimens were hermaphrodite.

134



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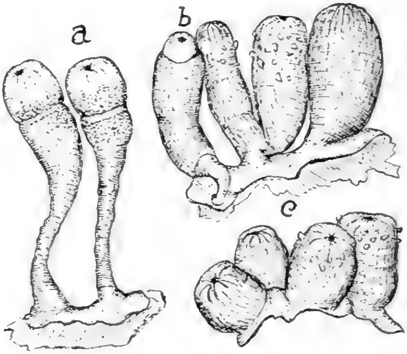

Figure 134.—*Zoanthus proteus;* part of a large colony in contraction, about ⅞ nat. size.

Figure 135.—*Zoanthus proteus*; *a*, pedunculate form; *b*, ordinary forms; *c*, short forms, all from one colony. × 1¼. Drawn by A. H. V.

Tentacles numerous, slender, usually 48 to 52, green or yellow.

Color of column distally is olive-green, sometimes bluish or turquoise-blue; disk pale ochre-yellow, with white specks, sometimes green, with paler radial lines.

Height of longest polyps, in contraction, 18 to 24^{mm}; usual diameter, 3.5 to 5^{mm}; height of short forms, 6 to 10^{mm}; diameter, 4 to 6^{mm}; height of average polyps, about 10 to 15^{mm}; breadth of expanded disk, 5–8^{mm}.

At and considerably below low-tide mark, on the reefs, adhering to stones and dead corals; also in the sheltered bays and sounds; abundant in Hungry Bay in shallow water.

This is the species described by Erdmann, op. cit., 1886, p. 438, pls. iv, v, with some anatomical details, and afterwards referred erroneously to *Z. Danæ* by Hertwig. It also resembles a species described by Duerden under the name of *Z. pulchellus* (*non* Duch. and Mich.) from Porto Rico, in 1902, but not so much the one described by him under that name from Jamaica, in 1898. The figure of the sphincter muscle given by Duerden is very much like that of this species, as figured by Erdmann, more like it in fact than like that of the Jamaica *pulchellus* figured by Duerden in 1898, pl. 18*a*, fig. 3. In Erdmann's figure the two sphincter muscles are both well developed, much as in Duerden's Porto Rico specimens, which is not the case in the smaller Jamaica form.

Zoanthus sociatus (Ellis and Sol.?) Cuvier. Figure 136 (*Solandri*).

Actinia sociata Ellis (?) 1767, p. 428, pl. xiii, figs. 1, 2; Ellis and Sol., 1786, p. 5, pl. 1, figs. 1, 2. (Figs. reproduced by Lamouroux, Expos. Meth.)

? *Zoanthus sociata* Lesueur, Journ. Acad. Nat. Sci., Philad., i, p. 176, 1817.

? *Zoanthus Solandri* (color-variety) Les., op. cit., pp. 177, 183, pl. viii, fig. 1 1817* (not of Duerden, 1898).

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* Lesueur's general figure of *Z. Solandri* (fig. 136), if natural size, as most of the general figures in his plates were, represents a much larger species than the one here discussed, for the expanded disk in his figure is 12^{mm} in diameter; contracted columns, 9–10^{mm}; height of column, 45^{mm}. He gives, as a measurement, "length about two inches" which agrees with the figure. As the above species agrees so well with his type in other respects, and no large West Indian species having similar characters is now known, it seems most logical to conclude that his figure was enlarged to nearly double the natural size (at least $1\frac{2}{3}$). Allowing for this, the agreement would be very close. He stated that it had 60 tentacles. Probably it was a mere color-variety of his *Z. sociata* (op. cit., p. 176), which also had 60 tentacles and the same form of column and stolons, and lived in the same place. No measurements were given of the latter. Both lived buried to the tentacles in sand, but were attached by slender stolons in crevices of rocks below the surface. The figure of *Solandri* by Duch. and Mich., 1860, is much like that of Lesueur, and similar in size; height 40–50^{mm}; diameter of expanded disk 13^{mm}, and it is stated to be natural size; the tentacles are short.

If both figures of *Solandri* are natural size, it certainly is a distinct species, *Zoanthus sociatus* McMurrich, Actin. Bahama Is., p. 62, pl. ii, fig. 3; pl. iv, figs. 15–18, 1889 (anatomy). Bull. Labr. Nat. Hist. Univ. Iowa, iv, p. 242, pl. iii, fig. 1, 1898 (anatomy); Zoölog. Bulletin, vol. ii, No. 6, mesenterial filaments, 1899.

Zoanthus flos-marinus Duerden, Jamaican Actin., part i, p. 339, pl. xviiA, fig. 2, pl. xviiiA, fig. 2, 1898 (*non* Duch. and Mich.).*

Zoanthus sociatus Verrill, these Trans., x, p. 561, 1900. Duerden, Actinians of Porto Rico, p. 334, pl. ii, fig. 4, pl. iv, figs. 15, 16; pl. v, figs. 17–22, 1902 (anatomy).

The polyps in this species are pedunculated; they arise from slender stolons and form open colonies. The column is clavate or enlarges upward to the disk, in expansion, and at the widest part is about 4 to 5^{mm} in diameter; expanded disk, 5 to 8^{mm}; height usually about 20 to 25^{mm}.

The tentacles are about 56 to 60 in adult polyps; they are small and rather slender, bluish green, olive, or brown.

The disk is usually green, more or less varied with blue, yellow, or brown. There is sometimes a brown triangular spot at one or both angles of the mouth (t. McMurrich and Duerden). The column is bluish, greenish, or dark violet above, yellowish below.

The original figure of *Z. sociatus* in Ellis and in Ellis and Solander, if natural size, represents it as a larger species than the one now so-called. Moreover, one of the polyps is represented as expanded, and as having numerous long, slender tentacles, like an *Epizoanthus.* No measurements were given, and therefore it is doubtful whether the figure is natural size. If the drawing of the tentacles was cor-

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characterized by its large size, pedunculate form, and about 60 short, conical tentacles. But the early writers often measured and described their species of such animals from the drawings, not from specimens, and it may well be doubted whether either figure is natural size, for it is difficult to represent the small tentacles, etc. of these forms without enlargement. If such a common large species exists in the West Indies, it is remarkable that modern collectors have not found it.

The species very fully described, 1898, with anatomical details by Duerden, under the name of *Solandri*, is a shorter and stouter species with cylindrical bodies and short stolons, similar to *Z. proteus.*

* The *Z. flos-marinus* of Duerden, 1898, had much smaller polyps than the original type of Duch. and Mich., and differed in form, and in the size, color, and number of tentacles; the latter was described as having 36 tentacles (the figure shows 40). The *flos-marinus* of McMurrich, 1889, from Bermuda, seems to be my *Z. proteus.* No recent writer has noticed a large species 1.5 inches high, with 36 tentacles, corresponding with the original *flos-marinus.*

rect it cannot represent this species, which has much shorter tentacles.*

The only West Indian species of similar size, described by later writers as having long slender tentacles, like those represented in the plate of Ellis, is *Z. nobilis* of Duch. and Mich. (Corall., pl. viii, fig. 7), which has about 60 long tentacles, their length, as figured, exceeding the breadth of the disk, as in the figure of Ellis. The polyps are clavate, slender at base, with narrow stolons. If the figure is natural size, it is much larger than the species now commonly called *sociatus*, and it may be identical with the original *sociatus* of Ellis. But the statement that it is natural size may be erroneous; no measurements were given. However, as no recent writer has seen a species like *Z. nobilis*, and the original description is too brief and indefinite to be of much value, I have thought it best to leave the nomenclature of the present species undisturbed, awaiting the rediscovery of *Z. nobilis.*

Zoanthus dubius Les. Figures 137, 138.

Zoanthus dubius Les., op. cit., p. 176, 1817 (*non* D. and M.).

Verrill, these Trans., x, p. 562, pl. lxviii, fig. 3, 1900.

Zoanthus pulchellus Duerden, op. cit., 1898, p. 460; Jamaican Actinaria, i, p. 341, pl. xvii*a*, fig. 3, pl. xviii*a*, figs. 3, 4 (anatomy), 1898. Not that in Actinians of Porto Rico, p. 332, pl. ii, figs. 2, 3 (general), pl. iv, fig. 14 (anatomy), (*non* Duch. and Mich. sp.).

The specimens referred to this species have smaller and shorter polyps than the two preceding species,† seldom exceeding 8 to 12^{mm} in height and 4^{mm} in diameter of the contracted column. The column is usually more or less cylindrical, rarely clavate; it is com-

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* The source of this drawing and of those of several West Indian gorgonians with expanded polyps, published by Ellis, is not known. Although they appear to have been made from living specimens, it is not absolutely certain that they were not drawn from preserved specimens, for some of them have non-retractile polyps. However, I will venture to suggest that several of those excellent drawings, reproduced in the plates of Ellis, were made from life by Catesby, while he was in the Bahamas, where he spent some time drawing the fishes. A large part of his collection is known to have gone into the museum of Sloane, who was one of his patrons, and the drawings may have gone to him also. Ellis is said to have made use of Sloane's collections, and he may have used his drawings also.

† Lesueur stated that the polyps of his *dubia* were one-third smaller than those of *Z. sociata*, which it otherwise closely resembled, though it lived "in bunches" entirely exposed "in all its parts" to the water; tentacles "very numerous"; "body cylindric, pedunculated, reddish."

monly divided into two regions by a slight constriction above the middle; the lower part usually increases in size downward to the base; its substance is firm; the surface is longitudinally sulcated in contraction, somewhat rough, and usually covered more or less with foreign growths (diatoms, small sponges, etc.). The distal portion has a thinner wall, with a smooth, soft surface, and usually increases in size upward to the rounded summit; which is sulcated in contraction. The expanded disk is broad, often convex, 7–9^{mm} in diameter.

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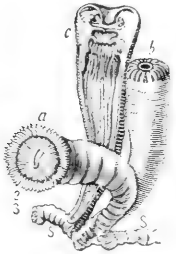

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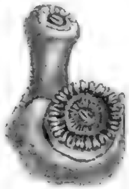

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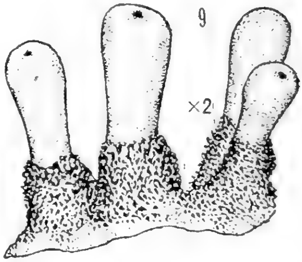

Figure 136.—*Zoanthus Solandri* Les., copied from Lesueur's figure, ⅜ original size of figure.

Figure 137.—*Zoanthus dubius* Les. Two polyps of the blue variety, expanded; × about 1⅓.

Figure 138.—The same. Group of contracted polyps, enlarged about 2½. The basal part of column is encrusted with living diatoms, etc.

It forms somewhat open clusters; the polyps are united together by a thin membranous basal expansion, or by wide thin stolons. Sometimes the colonies are of considerable extent.

The tentacles are short and vary from about 40 to 52.

According to Duerden the lower part of the column is usually pale buff, while the upper part is olive-blue; disk bright green with lighter radial lines, sometimes pale green or yellow; lips often pink, sometimes red or yellow; sometimes a dark triangular spot at each angle of the mouth.

Some of our specimens (as the one represented by fig. 137) were bright turquoise-blue all over the column; disk bluish green, or pale blue with green radii; lips reddish; tentacles 40–44, outer row green, inner ones bright blue. The cluster represented in fig. 138 had the column olive-green distally; disk pale ocher-yellow. Lesueur's type had the disk green; mouth and tentacles yellow; body reddish.

This species, very fully described anatomically by Duerden, seems to me to agree better with the original *dubia* than any other known,* and should, I believe, take that name. The *dubius* of Duch. and Mich., 1860, appears from the figure to be a larger and stouter species, more like *Z. proteus*, but they gave no description, not even of the colors or number of tentacles, nor any measurements. Their *pulchellus* is probably *Z. nymphæa* Les. The *Z. pulchellus* described from Porto Rico, 1902, by Dr. Duerden appears to be my *Z. proteus*, (see above, p. 289), but that of his previous papers is probably *Z. dubius*.

Isaurus tuberculatus Gray. Figures 139, 140.

Isaurus tuberculatus Gray, Spicil. Zoolog., p. 8, pl. 6, fig. 3, 1828; op. cit. 1867, p. 234.

Zoanthus tuberculatus Duch., Anim. Rad., p. 11, 1850. Duch. and Mich., Corall. Ant., p. 327, pl. viii, fig. 5, 1860.

Antinedia tuberculata Duch. and Mich., Supl., p. 136, pl. vi, figs. 2, 3, 1866.

Antinedia Duchassaingi Andres, p. 330, 1873.

Mammillifera tuberculata McMurrich, Proc. Acad. Nat. Sci., Philad., p. 117, 1889, pl. vii, figs. 5, 6; reprint in Heilprin's Bermuda Is.

Isaurus Duchassaingi McMurrich, Notes on Actinians, p. 190, pl. xvii, figs. 6–8. Duerden, Jamaican Actinaria, p. 346, pl. xvii*a*, fig. 4 (general), pl. xviii*a*, figs. 5, 6 (anatomy), 1898; Actinians of Porto Rico, p. 336, pl. ii, fig. 5, pl. vi, figs. 23–25, pl. vii, fig. 26, 1902 (anatomy).

This species is usually found growing solitary or in small groups on the reefs, or united by basal stolons into small colonies of 3 to 5 individuals. The column is usually curved to one side or crooked. It is easily recognized by its firm consistency, translucency, and by the more or less prominent tubercles which cover the upper part of

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* Probably other species of *Zoanthus* occur at Bermuda which I have not met with, but all my species seem referable to the three species given above. But I did not make any special search for small forms. I have given a provisional analytical table of the West Indian and Bermuda forms usually recognized as distinct species in a former article (these Trans., vol. x, p. 566, 1900). I should remark that I have now reduced the species there given, by the union of *Solandri* to *sociata*; and *pulchella* to *dubia*. Also that the measurements there given for *Solandri* were taken from the figure, which was probably considerably enlarged. All the species need a thorough study, with numerous living colonies, in order to determine the limits of their variation, as well as a very much more extended study of their anatomy by sections, than they have yet received. Large series of sections should be made from polyps known to be certainly of one species, in order to know how much the internal structure may vary. Too often writers have depended on sections of actinians made from only one or two specimens, and have been much misled. We now know that the internal structure often varies widely.

the column, especially on the convex side, but these are sometimes nearly obsolete in small specimens. A circle of about 10 to 12 tubercles surrounds the infolded portion of the summit in contraction; the summit is covered by numerous convergent sulcations. The greater part of the column is covered with longitudinal and transverse sulcations, most conspicuous in strongly contracted alcoholic specimens; the tubercles are lacking on the concave side and toward the base. The column is translucent, so that the mesenteries show through the wall. The tentacles are about 40 to 46. Perfect mesenteries about 20. Height 20 to 40^{mm}; diameter of column usually 8 to 10^{mm} in contraction. Our best specimen is 40^{mm} high and 9^{mm} in diameter as contracted; it is much smoother than some of those figured. It differs generically from *Zoanthus* chiefly in having but one sphincter muscle instead of two. The color of the column, disk, and tentacles in life is buff or ocher-yellow. It is not uncommon on the Bermuda reefs and is also found throughout the West Indies.

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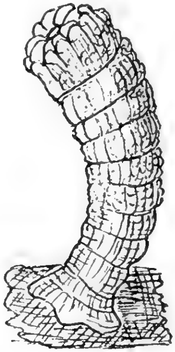

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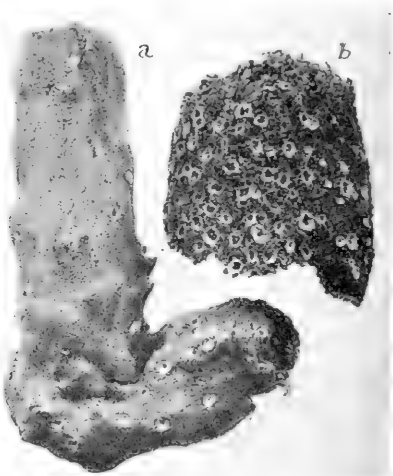

Figure 139.—*Isaurus tuberculatus*, smoother var., contracted. × 1½.

Figure 140.—The same, rougher var., strongly contracted. × 1½. Drawn by the author from preserved specimens.

Figure 141.—*Parazoanthus parasiticus*, ⅔ nat. size: *a*, parasitic on "tube-sponge"; *b*, parasitic on *Hircina ?* Phot. A. H. V.

McMurrich considered the Bermuda form (as *tuberculatus*) a species distinct from that of the Bahamas. To me the differences noted seem to be individual variations.

Parazoanthus parasiticus (D. and M.). Verrill. Figure 141.

Zoanthus parasiticus Duch. and Mich., Corall. Antill., p. 50, pl. viii, figs. 3, 4, 1860.

Parazoanthus parasiticus Verrill, Trans. Conn. Acad., x, p. 560, 1900. Duerden, Amer. Mus. Nat. Hist., xix, p. 500, pl. xlv, 1903.

Parazoanthus separatus Duerden, Jamaican Actinaria, pt. ii, Trans. Royal Dublin Soc., vii, p. 197, pl. x, figs. 12, 13, pl. xiii, fig. 8, pl. xiv, fig. 4, 1900, anatomy.

This minute species is frequently found parasitic on the tubular sponge (*Tuba* or *Spinosella sororia*). The disks show at the surface of the sponge, when dried, as small, circular, about 12-rayed, stellate, and mostly separated spots, 1.5 to 2^{mm} in diameter, more or less scattered over the surface. It also occurs on a species of *Hircina*, and probably on various other species.

In life it rises above the sponge in expansion about 4^{mm}; diameter of disk about 3^{mm}; its column is then quite translucent. It has about 24 to 26 small alternating tentacles, which, like the disk, are pale brownish in life; column in contraction whitish, from enclosed white sand, etc. Dr. Duerden (1900) has published a very full account of the anatomy and histology of this species.* It appears to be the species very poorly described by Duch. and Mich., 1860.

Undetermined species of Zoanthacea.

No doubt several other species of this and allied genera will be found at Bermuda. My notes indicate some of which I did not obtain sufficient material.

One of these is a form found entirely free, and somewhat resembling an *Edwardsia* externally. It was 16^{mm} long in contraction; diameter 3^{mm}. The wall was thin, but tough, brownish, with 20 to 24 slight sulcations, the ridges having minute papillæ distally. Tentacles minute, about 24 counted, but they were difficult to observe,

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* Dr. Duerden in his later paper (1903) also describes the anatomy of *Bergia catenularis* Duch. and Mich., which has the same parasitic habits and mode of growth. He places it in *Parazoanthus*, but if it be congeneric it will be necessary to adopt *Bergia* as the generic name for the whole group, on the ground of priority, for although the original diagnosis was nearly worthless, the type species is easily recognizable. However, Dr. Duerden points out important structural differences, quite sufficient, in my opinion, to require generic separation. He states that the type species of *Bergia* lacks a distinct sphincter muscle and also lacks the ciliated band of the mesenterial filaments, both of which are present in genuine species of *Parazoanthus*. These certainly seem sufficient for generic characters.

and judging by the mesenteries were more likely about 48. About 24 perfect mesenteries, alternating with very small ones; two small ones in each of two pairs adjacent to directives; 8 (or perhaps 10) are fertile. There is no evidence of attachment, the base being smooth and evenly rounded.

It is probably a true *Zoanthus*, but my study of it was too incomplete to place it accurately, and the specimen seems to have been lost.

Alcyonaria.

Gorgonacea; Sea-fans, Sea-plumes, etc.*

Several large species of gorgonians, called sea-fans, sea-rods, etc. by the fishermen, are very common on the inner as well as on the outer reefs. Some are found in Castle Harbor, but nearly all are absent from Harrington Sound.

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* Among the more recent works relating to Bermuda Gorgonacea are the following:

Cook, Frank C.—The Chemical Composition of some Gorgonian Corals. Amer. Journ. Physiology, vol. xii, pp. 95–98.

Six of the species analyzed were from Bermuda.

Dana, James D.—Corals and Coral Islands. Three editions. Ed. 3, 1890, has the list of Bermuda corals and gorgonians on p. 114.

Hargitt, C. W. and *Rogers, Chas. G.*—The Alcyonaria of Porto Rico. Bull. U. S. Fish Com., for 1900, pp. 265-287, 4 plates and cuts in text, Dec., 1901.

Contains a useful analytical table of the families and genera of the Alcyonaria. Also figures and descriptions of several Bermuda species.

Heilprin, Angelo.—The Bermuda Islands, pp. 103-105, 1889.

Gives a list of 8 species of gorgonians, mostly without descriptive notes. Two are doubtful.

Jones, J. Matthew.—Contributions to the Nat. History of the Bermudas; Coralliaria. Nova Scotian Institute Nat. Sci., vol. ii, pt. 2, pp. 7–16, 1869.

A list of 4 species (determined by A. E. Verrill), with some notes.

Kölliker, Albert.—Icones Histiologicæ, ii, Die Bindesubstanz der Cœlenteraten, 13 cuts, x plates. Leipzig, 1865.

The first work demonstrating the systematic importance of the spicules of Alcyonaria. It includes a revision of the genera and species. His figures of the spicules, etc., in many cases, represent preparations from the type-specimens of Esper, Ehrenberg, Lamarck, and Duch. and Michelotti. A set of mounted slides of the same species was sent to me by Dr. Kölliker.

Mendel, L. B.—On the occurrence of Iodine in Corals. Amer. Jour. Physiology. iv, No. 5, pp. 243–246, 1900.

The three species of gorgonians analyzed, *Gorgonia flabellum*, *G. acerosa*, and *Plexaura flexuosa* were from Bermuda, furnished by the writer. (See Cook, F. C.)

They are, however, much more abundant and luxuriant on the outer reefs, and especially at a few fathoms below the surface, all around the islands. The most common are *Gorgonia flabellum*, the "sea-fan"; *Plexaura flexuosa;* and *Pseudoplexaura crassa*, known as "sea-rods." These all grow to great size on the outer reefs, at moderate depths, becoming in some cases 4 to 6 feet high.

Gorgonia flabellum Linn. *Sea Fan.* Figure 142. Plate xxxiiic, fig. 1 (2, 3). Pl. xxxvi, fig. 1 (19).

Gorgonia flabellum Esper, Pflanz., ii, plates ii, iiiA, 1794. Dana, Zoöph., 1846, and nearly all other writers up to 1857.

Rhipidogorgia flabellum Edw. and Haime, Coral., iii, p. 173, pl. B2, fig. 4, 1857, and many later writers. Pourtalès, in L. Agassiz, Florida Reefs, pl. xxi, figs. 1–7. Nutting, Bull. Univ. Iowa, i, p. 151, pl. x, 1889.

Gorgonia flabellum Kölliker, Icones Histiol., ii, 1865, and most later writers. Verrill, Critical Remarks on Halcyonoid Polyps, No. 4, Amer. Jour. Sci., xlviii, p. 424, 1869, there made the type of the most restricted genus *Gorgonia;* these Trans., x, p. 568. Hargitt and Rogers, Bull. U. S. Fish Com., 1902, p. 287, pl. iii, fig. 3.

This species always grows in fan-like forms with the branchlets closely reticulated, except close to the tips. The fans vary much in shape, some being round, others broad, and some tall and narrow, the shape depending much upon the place of growth and amount of space. Sometimes two or more fans arise from the same base, and

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Nutting, C. C.—Contributions to the Anatomy of Gorgonidæ. Bull. Labr. Nat. Hist. State Univ. Iowa, pp. 97–160, 1889.

Rogers, Chas. G.—See Hargitt, C. W.

Verrill, Addison E.—Bull. Mus. Comp. Zool., i, pp. 29–60, 1864.

Records a number of gorgonians and corals from Bermuda.

——— Critical Remarks on Halcyonoid Polyps, Nos. 1–4. Amer. Journ. Science, No. 1, vol. xlv, p. 411; No. 3, vol. xlvii, p. 281, 1869; No. 4, vol. xlviii, p. 419, 1869.

Includes revisions of many genera and species, some of which are West Indian and Bermudian.

——— Additions to the Anthozoa and Hydrozoa of Bermuda. These Trans., vol. x, pp. 551–572, 3 plates, 1900.

——— Additions to the Fauna of the Bermudas from the Yale Expedition of 1901. Trans. Conn. Acad., xi, pp. 15–62, plates i–ix; 6 cuts in text, 1901.

——— Zoölogy of the Bermudas, vol. i, 427 pp., 45 pl., 1903. Includes the two preceding papers as articles 5 and 10.

Wright, E. P. and *Studer, Th.*—Report on Alcyonaria. Voyage Challenger, Zoöl., vol. xxxi, part 64, 1889.

Includes a few reef forms from Bermuda and some from deep water adjacent.

sometimes small ones branch out from one or both sides of large ones, at various angles. Off the outer reefs, in 10 to 20 feet of water, it often grows to great size, the height sometimes being 5 to 6 feet and the breadth 4 to 5 feet. Such specimens are very firmly attached and are difficult to obtain entire.

On the inner reefs and in Castle Harbor it is usually only one or two feet high, partly, perhaps, because so many are constantly gathered by the fishermen for sale to travellers as curiosities.

In life this species is usually dark purple, becoming lighter purple on drying. But many specimens are more or less tinged with yellow, especially on the trunk and main branches. Entirely yellow specimens are not so common at Bermuda as in the West Indies. These colors are due to the fact that the microscopic spicules of the cœnenchyma are partly bright purple and partly bright yellow, the proportion of each color varying in different specimens and in different parts of the same specimen.

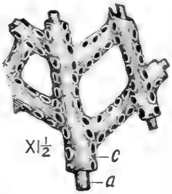

Figure 142.—*Gorgonia flabellum;* small portion to show arrangement of calicles; *a*, axis; *c*, cœnenchyma, × 1½. After L. Agassiz.

The polyps, when expanded, are very small, pale, and translucent; they project strongly from the calicles and resemble those of *G. citrina* in form.

This is one of the species of which the axis has been analyzed by Professor Mendel and Mr. Cook for the iodine contents.* The large specimens used were furnished by me and came from the outer reefs of Bermuda. It was also analyzed by Mr. Cook for its other constituents.

Gorgonia acerosa Pallas. *Sea Plume.* Plate xxxiiic, fig. 1(1); pl. xxxvi, fig. 1 (18).

Gorgonia acerosa Pallas, Elench. Zoophy., p. 172, 1766 (*non* Esper).
Gorgonia setosa Linn., Syst. Nat., ed. xii, 1767, p. 1292.
Esper, Pflanz., ii, Gorg., p. 66, pl. xvii, figs. 1–3, 1794 (*non* Linn.).

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* Mendel, L. B., Amer. Journ. Phys., iv, pp. 243–246, 1900. Cook, F. C., Chem. Composition of Gorgonian Corals, op. cit., xii, pp. 95–98.

Gorgonia pinnata (*pars*) Lamk., Hist., ii, p. 316.
Pterogorgia pinnata (*non* Linn. sp.) and *P. Sloanei* Edw. and Haime, iii, p. 168, 1857.
Pterogorgia setosa Ehrenberg, 1834 (purple var.). Dana, Zooph., p. 650. Edw. and Haime, iii, p. 168, and many later writers.
Pterogorgia acerosa Ehr., 1834 (yellow var.). Dana, Zoöph., p. 649, 1846. Kölliker, op. cit., p. 139, pl. xviii, figs. 34, 35.
Verrill, 1864, and many later writers.
Gorgonia acerosa Verrill, Crit. Rem., No. 4, p. 424, 1869, and most later writers. Hargitt and Rogers, op. cit., p. 287, pl. iii, fig. 2, 1902.

This beautiful gorgonian, when well grown on the outer reefs, is sometimes four or five feet high, with a strong, elastic stem, and very numerous long, slender, and very flexible pinnate branchlets, which are usually more or less pendulous in the form of a loose plume.

Large specimens often consist of several such plumes arising from one base or from one large main trunk near the base. The axis in the main trunk and larger branches is large, black, tough, horn-like, and often much flattened; in the terminal branchlets it becomes capillary or setiform, translucent, yellow or amber color.

The color is usually light purple or purplish red in Bermuda waters, but not rarely light yellow or pale straw-color, or in dry specimens long exposed to light it may be almost white.

Many writers, like Ehrenberg and Edw. and Haime, have made two or three species out of what seem to me merely slight variations in form and color of this species.

After examinations of large numbers of specimens from Florida, West Indies, and Bermuda, I cannot find any reliable characters for separating *setosa* or *Sloanei* from this species. Very young specimens have undoubtedly been described under other names. The original *G. pinnata* of Linn. and Pallas appears to be a distinct South African species, *Lophogorgia* or *Leptogorgia flammea* Ellis and Sol., though many early writers have confused it with the present one. Probably Linnè himself confounded the two, as Pallas stated.*

The axis of this species was also analyzed by Prof. Mendel and Mr. Cook. It was found to contain about 2 per cent. of iodine.

It is not often found on the inner reefs and is not very common in shallow water, even on the outer ones. It prefers water 3 to 6

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* Lamouroux, Exped. Method., pp. 51, 52, 1821, added greatly to the confusion by uniting under *G. pinnata*: *G. americana*, *G. setosa*, *G. acerosa*, and *G. sanguinolenta*, while he confounded the true *pinnata*=*flammea* Ellis and Sol. with the *palma* of Pallas, which is *Eunicella palma*.

fathoms deep. It appears to be less common than in the West Indies, where it is more often yellow.

Gorgonia americana Gmelin.

Gorgonia americana Gmel., Syst. Nat., ed. 13, based on pl. xiv, fig. 3, of Ellis and Sol., 1787.

Gorgonia pinnata (*pars*) Lamx., Expos. Method., p. 32, pl. 14, fig. 3, after Ellis and Sol. (*non* Linn.).

Pterogorgia turgida Ehr., Corall., p. 146, 1834.

Pterogorgia pinnata Dana, Zooph., p. 649, 1846 (*non* Pallas, sp.).

Pterogorgia Ellisiana Edw. and H., Corall., iii, p. 168, 1857.

Pterogorgia americana Verrill, Bull. M. C. Z., i, p. 31, 1864.

Gorgonia americana and *G. turgida* Verrill, Crit. Rem., No. 4, p. 424, 1869.

This is a much less common species than the last, which it somewhat resembles. The branchlets are not so long, slender and flexible, and scarcely droop. The branchlets are thicker and more terete ; the polyps along the edges of the branchlets are much larger than in the last and do not readily retract, so that most of the dried specimens are disfigured by the dead extended polyps adhering to the outer surface. When the soft parts are entirely removed the calicles are relatively large and open, forming two or three rows on the edges of the branchlets. Its color is usually pale yellow, sometimes light purple. It is seldom more than 1.5 to 2 feet high. The branchlets are 3 to 4^{mm} thick.

This is the species recorded by me from Bermuda in 1864, under the name of *P. turgida* Ehrenberg, which I now consider a synonym.

It is also found on the West Indian and Florida reefs, but not abundantly.

Gorgonia citrina Esper. Figure 143.

Gorgonia citrina Esper, Pflanz., ii, Gorg., p. 129, pl. xxxviii, figs. 1, 2, 1794. Edw. and H., iii, p. 171, 1857.

Gorgonia (*Pterogorgia*) *citrina* Dana, Zooph., p. 648, 1846.

Pterogorgia fasciolaris Ehr., Corall. Roth. M., p. 145, 1834. Dana, op. cit., p. 648.

Pterogorgia sancti-thomæ Ehr., op. cit., p. 145 (purple var.).

Xiphigorgia citrina Verrill, Bull. M. C. Z., i, p. 33, 1864.

? *Xiphigorgia americana* Duch. and Mich., Supl., p. 113, pl. ii, fig. 6, 1866 (*non* Gmel. sp.)=*Gorgonia pumila* Ver., 1869.

Gorgonia citrina Kölliker, Icones Histiol., ii, p. 139, 1865. Verrill, Crit. Rem., No. 4, p. 42, 1869, and of most later writers.

This is a small and rather inconspicuous species, seldom more than 6 inches high. It forms small clusters of rather stiff, flattened, forked branches, with a row of polyps along their thin edges. It is usually bright or light yellow, with purple edges and calicles, but is not uncommonly all purple or entirely yellow.

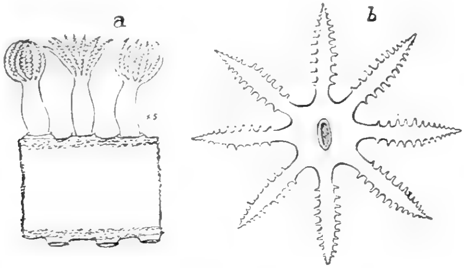

Figure 143.—*Gorgonia citrina; a*, portion of branch with polyps of one edge expanded, × about 5; *b*, tentacles and disk, more enlarged. Drawn from life by the author.

It occurs sparingly on the reefs. It was also found in Harrington Sound, where most other gorgonians do not occur. At Dominica it grows much larger, with numerous branches.

Muricea muricata (Pallas) Blainv. Figs. 144, 145. Plate xxxiiiB, fig. 2, *a*, (polyps expanded); plate xxxiiic, fig. 2, *d*; plate xxxvi, fig. 2 (?).

Gorgonia muricata Pallas, Elenchus Zoöph., p. 198, 1766. Ellis and Sol., Zooph., p. 182, 1787. Esper (*pars*), Pflanz., ii, Gorg., pl. xxxix.

Eunicea muricata Lamx., Polyp. Flex., p. 439, 1816.

Muricea spicifera Lamx., Exposit. Method., p. 36, pl. 71, figs. 1, 2, 1821, (after Ellis and Sol. ?). Ehr., 1834, p. 134.

Muricea muricata Blainville, Man. Actin., p. 509, pl. 88, fig. 1.

Muricea spicifera Dana, Zooph., p. 673, 1846. Edw. and Haime, iii, p. 142, 1857. Kölliker, Icones Histiol., ii, p. 135.

Muricea muricata Verrill, Crit. Rem., No. 1, p. 411, 1868; these Trans., x, p. 569, fig. 1, 1900. Cook, op. cit., p. 98, 1904, from Bermuda (analysis).

This is easily distinguished from all the other Bermuda gorgonians by the prominent calicles, covered externally with acute imbricated spicules, having projecting points easily visible to the naked eye. It forms rather closely branched, flattened clusters, seldom more than a foot high. Its color is pale straw-yellow to ocher-yellow, sometimes with a rusty or brownish yellow tint; old dried specimens often fade to white.

It occurs on the reefs in Castle Harbor, but we found it most abundant on the ledges in Bailey Bay, one of which it occupied to the almost complete exclusion of other species. It is also found on the outer reefs.

The polyps, when expanded (fig. 145 and pl. xxxiiiB, fig. 2, *a*) are very elegant; they are slender, whitish, and translucent; they stand so close together that they nearly conceal the coral. The tentacles have about ten slender pinnæ on each side.

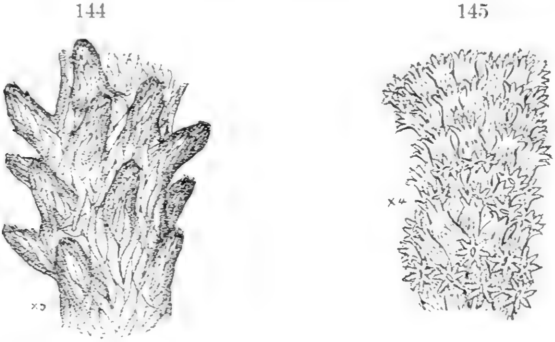

Figure 144.—*Muricea muricata*, portion of a branch, ×4.
Figure 145.—The same, with the polyps expanded, ×3. Drawn by A. H. V.

Plexaura flexuosa Lamx. Figure 146; plate xxxiiiB, fig. 2, *b*, *c*; plate xxxiiic, fig. 2, *a*, *b*, *c*. Plate xxxvi, fig. 2 (6). Plate xxxviB, fig. 4, spicules.

Plexaura flexuosa Lamx., Polyp. Flex., p. 424, 1816; Expos. Method., p. 54, pl. 70, fig. 1, 2, 1821. Edw. and H., iii, p. 154. Verrill, Bull. Mus. Comp. Zool., i, p. 34, 1864; these Trans., x, p. 568. Kölliker, Icones, p. 138.

Gorgonia anguiculus Dana, Zoöph. Ex. Exped., p. 668, 1846.

?*Plexaura salicornoides* Edw. and Haime, Corall., iii, p. 153, pl. B^2, 1857.

Plexaura flexuosa Hargitt and Rogers, Bull. U. S. Fish Com., 1902, p. 284, pl. iv, figs. 13-16, spicules.

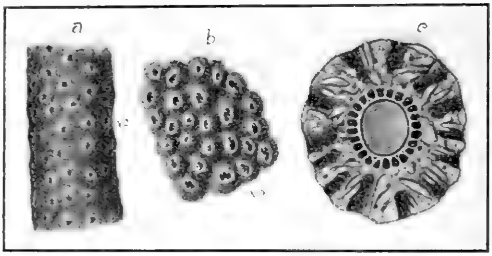

Figure 146.—*Plexaura flexuosa*; *a*, portion of a small branchlet, × about 2; *b*, part of same, more enlarged; *c*, section of branchlet, more enlarged. Drawn by A. H. V.

This is the most common of the stout-branched gorgonians on the Bermuda reefs. It forms upright, bushy colonies consisting of numerous forking branches arising from a stout basal trunk. The branchlets have a tendency to stand somewhat in one plane, so that the group is flattened ; they curve outward at base and then become rather rigidly erect, with blunt tips. They are usually more or less crooked or wavy, and vary in length up to 6 to 8 inches or more, and when well grown have a diameter of about 5 to 7^{mm}. The calicles are small, often almost punctiform, pretty evenly scattered over the whole surface, about 1^{mm} apart. They are usually slightly 8-rayed, and when fully contracted are level with the cœnenchyma or may even be a little sunken, but frequently, in less strongly contracted specimens, they are slightly raised on low mammilliform elevations, and then the pores are larger, up to about $.5^{mm}$, as in fig. 147, *b*.

The color, in life, is almost always dark purple or purplish brown, but when dried, under identical conditions, part of them will remain purple, others become reddish brown, and many become brownish yellow, russet, or fawn-color, but no other differences could be found.

The polyps are small, but quite prominent (see pl. xxxiiiB, fig. 2, *b*, *c*), nearly translucent, with rather long, delicately pinnate tentacles.

The axis of this was also analyzed by Prof. Mendel and Mr. Cook, for iodine, etc. It contained a larger percentage of iodine than any other species tested: 4.95 per cent. of the water-free substance in one case.

It is doubtful if this be the true *flexuosa* of Lamouroux, which was described as a yellow species, like *P. mutica* D. and M. I have personally seen no bright yellow variety of this species, and think it possible that *flexuosa* may be a distinct species. But this is the *P. flexuosa* of most recent writers, and therefore it seems best to retain that name until the yellow form can be reexamined microscopically. This is the true *P. anguiculus* of Dana, and that name should be used if *flexuosa* proves to be distinct.

It is a common species on the Florida Reefs and is found throughout the West Indies, south to Dominica.

Plexaura Valenciennesi Wright and Stud., Voy. Chall., Zoöl., vol. xxxi, p. 137, pl. xxxiii, fig. 1 (spicules).

Plexaura flexuosa Val., MSS., Edw. and H., Corall., iii, p. 154 (*non* Lamx., t. Wr. and Studer).

This species was described from a single specimen dredged in shallow water. It was about 10 inches high, dichotomous, with the terminal branchlets 3–5^{mm} in diameter. The calicles are "thickly set in irregular spirals," circular or oval, with the margin slightly raised. Cœnenchyma "massive and formed of several layers of spicules." The outer layer is composed of purple spindles and foliated clubs; the middle layer of large tuberculate spindles; the innermost layer of small radiate, tripartite, and fusiform spicules, purple or colorless.

Polyps wholly retractile, tentacles with double rows of minute spindles on the outer side. Closely related to the preceding species.

This appears to be one of the forms that have been included under *P. flexuosa* by several writers. The typical form of *flexuosa* (Lx.) was yellow and is not well known. The spicules have not been described. *P. mutica* D. and M., op. cit., p. 28, pl. iii, figs. 9, 10, is a similar yellow species, probably identical with *flexuosa.* Color alone is, however, of little specific value in this group.

Plexaura homomalla (Esper) Lamx. Figure 147. Plate XXXVA, fig. 3, spicules.

Plexaura homomalla Lamx., Polyp. Flex., p. 430, 1816. Blainv. Man. Actin., p. 509. Edw. and Haime, iii, p. 155. Hargitt and Rogers, 1902, p. 285, fig. H (spicules).

Gorgonia homomalla Esper, Pflanz., ii, p. 104, Gorg., pl. 29, figs. 1, 2, 1794. Lam. Hist., ii, p. 319. Dana, Zooph., p. 667.

This is closely related to the preceding and has similar but smaller calicles and polyps. The branches and branchlets are more slender and flexible, with a softer axis, so that when dried they nearly always droop over to one side, but they are upright in life. It is usually only about a foot high (250 to 350^{mm}) and often about as broad, forming rather closely branched or bushy clumps.

Branchlets about 4 to 6^{mm} in diameter.

Color usually dark brown, becoming umber-brown or blackish when dried. The surface is granular under a lens.

The cœnenchyma is apt to be rather friable when dried and like the axis very hygroscopic, so that it easily becomes detached from the axis by unequal contraction.

The axis is round and black in the larger branches.

Common on the outer reefs. A common species on the Florida reefs and through the West Indies.

Plexaura flavida (Lam.) Val. Figure 148. Plate xxxvA, fig. 4, spicules.

Gorgonia flavida Lam., Hist., ii, p. 318; 2d ed., p. 496. Lamx., Plyp. Flex., p. 402. Dana, Zoöph., p. 664, 1846.

Plexaura flavida Edw. and Haime, Corall., i, p. 153. Kölliker, Icones, p. 138, pl. xiii, fig. 6, 1865 (spicule from type).

? *Eunicea ramulosa* Ehr., op. cit., p. 139, Dana, Zoöph., p. 665. Verrill, these Trans., vol. ix, p. 569.

Gorgonia spicifera Dana, Zooph., p. 665 (*non* Lamk.).

Of this species, which is rather rare in collections, I have seen a few specimens from Bermuda, but did not find it myself.

It has one or two main stalks from which numerous slender, terete, divergent branches arise on all sides, so as to produce a somewhat plume-like form, when full-grown. The main stems may be 6 inches to a foot or more high; the side branches or branchlets vary from 2 to 5 inches in length, but are mostly 3 to 4 inches (75 to 100^{mm}) and about 2 to 3^{mm} in diameter. The calicles are very small, with the borders slightly raised, especially on the lower side; they are about equally distributed on all sides of the branchlets, and not very close together, though numerous. The color is usually yellow, varying from pale yellow to light olive-yellow.

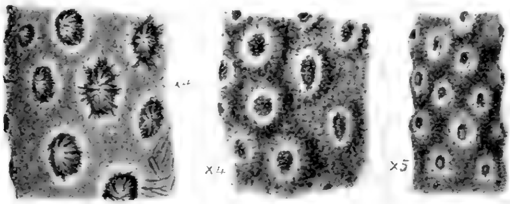

Figure 147.—*Plexaura homomalla*, surface with polyps contracted; 148.—*P. flavida*, × 4; 149.—*P. bicolor*, × 4. All from dry specimens by A. H. V.

It appears to be rather uncommon in the West Indies. My son, A. H. Verrill, has recently sent several well grown specimens from Dominica Island. There are specimens from other West Indian localities and from Colon, in the Yale Museum.

Plexaura Esperi, nom. nov. Figures 153–155. Plate xxxviA, fig. 4, spicules.

Plexaura antipathes Kölliker, op. cit., p. 138, pl. xviii, figs. 21, 22 (*non* Linn. sp.).

Gorgonia antipathes (*pars*) Esper, Pflanz., Gorg., pl. xxiii, only (*non* Linn. *nec* Pallas). Determined by comparison of spicula from Esper's original specimen.

A small specimen, collected in 1901, agrees closely in size, mode of branching, and character of calicles with Esper's figure (pl. xxiii), and it has the peculiar forms of spicules characteristic of the latter, as shown by a slide of spicules from Esper's type, sent to me by Professor Kölliker. But Esper included several other species under the name *G. antipathes*, as did Linné and most of the other early writers. Pallas definitely restricted that name to a large, much branched East Indian form, with short and slender terminal branchlets, a stout trunk, with a very black, spirally striated axis, and with large, pore-like calicles, quite unlike the present species. Therefore it is necessary to adopt another name for this. I am unable to identify it with any other of the more recently named West Indian species, many of which have been described very imperfectly without figures.*

This species branches dichotomously, nearly in one plane, with elongated, upright terminal branchlets, from 4 to 8^{mm} in diameter. The cœnenchyma is rather thick, not very friable when dry, nearly smooth, with a thin cortical layer of very minute, foliated clubs, and short, rough, irregular white spicules, which give the surface, under a pocket-lens, a very finely granulated appearance. This superficial layer is pale or yellowish white, often with a purple tint where the underlying larger spicules show through. The latter are rather large, symmetrical, warty spindles, warty heads or spheres, and other short thick forms, partly deep purple and partly white in color. Surrounding the axis is a close layer of much smaller, short, double-whorled, dark purple spindles.

The calicles are rather small (about $.5^{mm}$), round, pit-like or pore-like, not crowded, the intervals between them exceeding their diameters, and with their borders slightly sunken, without any fringe of larger spicules. The polyps are wholly contractile and apparently without any spicules.† The axis is black, compressed at the axils.

The short, thick, elliptical and subsphærical spicules, abundant in the cœnenchyma, are very characteristic of this species.

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* The descriptions of West Indian Gorgonians by Duch. and Michelotti are mostly nearly worthless, but some of their general figures are fairly good.

A set of slides of spicules from a number of their types, sent to me by Professor Kölliker, have been of great assistance to me in determining some of their species. The descriptions by Lamarck, Ehrenberg, Dana, and Edwards and Haime are also very brief and indefinite, without any account of the spicules. The *Plexaura antipathes* of Ehrenberg is a West Indian species different from *Esperi*, and named *P. Ehrenbergii* by Kölliker. It may be a form of *P. crassa*.

† If this should prove to be the case, the species should be referred to *Plexauropsis;* the polyps are badly decayed in my specimens.

Pseudoplexaura crassa (Ellis and Sol.) Wright and Stud. *Sea Rod.* Figures 150, 151, 152. Plate xxxiii. Plate xxxviA, fig. 3, spicules.

Gorgonia crassa Ellis and Sol., p. 91, pl. xviii, fig. 3, 1787. (*non Plexaurella crassa* Köll.), *non* Dana.

? Gorgonia porosa Müller. Esper (*pars*), Pflanz., ii, Gorg., p. 49, pl. x, 1794.

Plexaura friabilis (the figure, not the descr.) Lamx., Exp. Method., p. 35, pl. xviii, fig. 3, 1821 (fig. from Ellis and Sol.), *non* Lamarck.

Plexaura macrocythara Lamx., Polyp. Flex., p. 429, 1816.

Plexaura porosa (*pars*) Dana, Zooph., p. 670. Edw. and Haime, iii, p. 156, 1857.

Plexaura crassa Verrill, Bull. M. C. Zoöl., i, p. 34, 1864; Crit. Rem., No. i, p. 413, 1868. Hargitt and Rogers, op. cit., 1902, p. 285, pl. iv, figs. 1–12 (general and spicules).

? Gorgonia (Plexaura) multicauda Heilprin, Bermuda Is., p. 104 (not of Lam. which belongs to *Eunicea*, t. Edw. and H.).

Pseudoplexaura crassa Wright and Studer, Voy. Challenger, xxxi, p. 142, pl. xxxiii, fig. 3 (spicules).

This, when well grown, is sometimes four to five feet high, with a basal trunk 1.5 to 2 inches in diameter; it is repeatedly forked and has slightly tapered, long, round terminal branchlets, up to two feet (300 to 600^{mm}) or more in length, and 6 to 12^{mm} in diameter, near origin. The calicles are unequal, rather large, up to 1^{mm} in diameter, round or ovate, and generally more or less widely open in dried specimens, with the borders slightly or not at all raised. When entirely expanded, they are large and unusually close together

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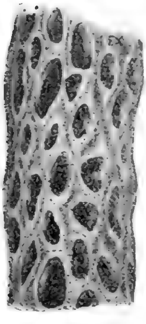

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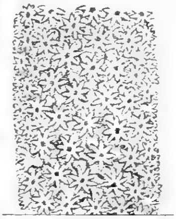

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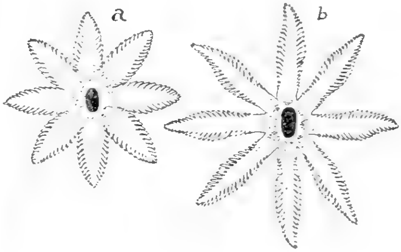


Figure 150.—*Pseudoplexaura crassa*, portion of a small branch, with wide open calicles, +2½.

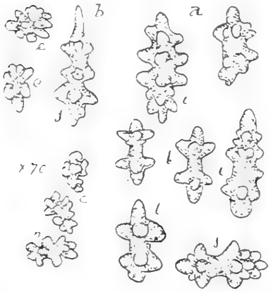
Figure 151.—The same, portion of branch with the polyps expanded, × about 1¼. Both drawn by A. H. V.

Figure 152.—The same, disk and tentacles, much enlarged; *a*, partly contracted; *b*, fully expanded (too many pinnæ are shown). Drawn by A. H. Verrill.

(fig. 148), the intervals between them being generally less than their diameters, and often much less on the distal part of the branchlets, but sometimes, when partly contracted, on the large branches, they are not very close in external appearance.

The polyps in expansion are very prominent and much larger than in *P. flexuosa*, and so close together that their tentacles overlap and entirely conceal the cœnenchyma. They are translucent and dull yellowish or brownish, disk and tentacles yellowish brown. The tentacles are long and tapered, with 10–12 short pinnæ on each side (fig. 148). They have but little activity in contracting, and generally remain expanded when preserved, but they are able to contract slowly and completely. They contain no spicules in the soft body nor in the tentacles.

153



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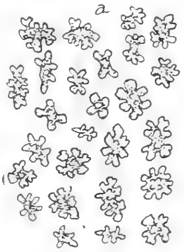

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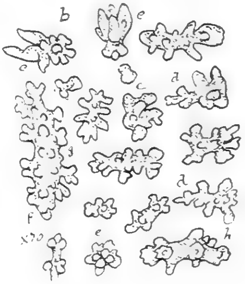

Figure 153.—*Plexaura Esperi*: *a*, small purple spindles and double spindles of inner layer; *b*, small purple spicules of middle layer. Fig. 154.—The same: small purple spicules of middle layer. Fig. 155.—The same: white spicules of surface; *c*, *c*, foliated clubs; *d*, *d*, irregular forms; *g*, *h*, double spindles, ×70. Drawn by A. H. V.

The axis is hard and rigid at base, but in the branches it is black and flexible. It is the one usually made into riding whips by the fishermen.*

The cœnenchyma is thick and apt to be friable, unless dried with care. It should be previously soaked in alcohol or formalin, for the exsert polyps are so numerous and large that they often cover up and disfigure the surface as well as prevent it from drying rapidly.

In life the cœnenchyma is usually light yellow or brownish, but when dried the surface often becomes pale straw-yellow or purplish gray, or nearly white, due to large white fusiform spicules, but the

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* These generally consist of two or three long terminal branches twisted together and polished.

interior of the cœnenchyma, near the axis, is usually purple, due to the internal fusiform purple spicules.

This is most common on the outer reefs in 10 to 20 feet of water, where it grows to great size, but it is also common on the inner reefs and ledges, where specimens 2 to 3 feet high are often found. It is a common species in the West Indies and on the Florida Reefs.

Plexauropsis, gen. nov.

Axis and spicula similar to those of *Plexaura.* Polyps wholly retractile, nearly destitute of spicula both in the column and tentacles. Cœnenchyma rather thick, with a cortical layer of small spinose or foliated clubs, and sometimes with one-sided, irregular, spinose forms, giving a finely granular appearance to the surface under a lens. Calicles wholly immersed or with the borders only slightly raised and unarmed.

Plexauropsis bicolor, sp. nov. Figure 149. Plate xxxiiiB, figs. 2, *b*, *c*, spicules. Plate xxxviA, figs. 1, 2, spicules.

Colony dichotomously branched, a foot or more high (300^{mm}), with the terminal twigs 4 to 6^{mm} in diameter and 75 to 125^{mm} long, terete, little tapered, obtuse at tips. Calicles nearly round, about .5^{mm} in diameter, arranged somewhat in quincunx, rather close together, the intervals often about equal to their diameters, often more crowded distally, and more separated on the larger branches.

Polyps much exsert (see plate), translucent, pale brownish yellow; tentacles lanceolate, a little obtuse, with about seven or eight close obtuse pinnæ on each side. The polyps contract only very slowly and seldom completely when disturbed, so that they are easily preserved fully extended in formol.

The cœnenchyma is relatively thick, dark purple within, but with a thin cortical layer of pale yellow or whitish spicules (hence the name). The cortical spicules are mostly rough, subfoliated and spinose minute clubs, of various sizes and forms, but mixed with many irregular and one-sided spindles and oblong forms, with the outer edge roughly spinose or thorny, much as on the distal end of the clubs. The purple spicules of the cœnenchyma are mostly elongated, rather slender, acute spindles of various small sizes, with the verrucæ small and not much crowded; a few are branched and there are a few shorter and thicker acute spindles, enlarged in the middle.

Taken in shallow water in 1901.

Plexaurella dichotoma (Esper) Köll. Figs. 156, 157. Pl. xxxiiiB, fig. 1, *b*. Plate xxxviA, figs. 1, 2, spicules.

Gorgonia dichotoma (*pars*) Esper, Pflanz., Gorg., pl. xiv (right hand figure), 1788.

Gorgonia (*Plexaura*) *dichotoma* Dana, Zoöph., p. 667, 1846.

Plexaura dichotoma Verrill, Bull. M. C. Z., i, p. 34, 1864. Synonymy only in part.

Plexaurella dichotoma Kölliker, Icones, p. 138, pl. xiii, fig. 7, pl. xiv, fig. 10, pl. xviii, fig. 1, 1865. Nutting, op. cit., 1889, pp. 113–123, pl. ii, figs. 1–17.

Gorgonia heteropora Lamk., Hist., 1816.

Plexaura heteropora Lamx., Polyp. Flex., p. 429, 1816. Dana, Zooph., p. 670.

Gorgonia vermiculata (*pars*) Lamk., Hist., ii, p. 319, 1816 ; p. 497, 2d ed.

Plexaura vermiculata Edw. and H., Corall., i, p. 156.

? *Plexaurella vermiculata* Kölliker, Icones, p. 138, pl. xviii, fig. 13 (spicule from type).

Eunicea anceps Duch. and Mich., Corall., p. 25, pl. iii, figs. 1, 2 (young).

Plexaurella anceps Köll., op. cit., p. 138, pl. xviii, fig. 14 (spicule from type).*

This species is easily recognized by its stout, rigid, upright, blunt branches covered with large irregular calicles, varying in shape when dried from round to oval and slit-like forms, with the margins slightly or not at all raised (fig. 156). In life the calicles are round, or with 8 slight lobes. The cœnenchyma is dense and very thick in proportion to the diameter of the axis, especially in the branchlets (fig. 157), and contains a great number of crowded spicula, all much smaller than in the two preceding species, many of them elegantly cruciform and strongly verrucose, while those in the outer layer are partly club-shaped. There are no large, fusiform internal spicules ; those of the innermost layer are slender, acute, small, purple spindles. The longitudinal ducts surround the axis uniformly on all sides and are rather large (fig. 157).

The color in life is dull yellowish brown, or russet-brown. When dried it usually becomes dull grayish yellow, straw-color, or whitish, with a finely granular surface. The polyps are without spicules and contract completely.

The axis at the base and in the main trunk is hard, rigid, and partly calcareous, in layers, but in the terminal branches it is rather

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* Dr. Kölliker regarded *P. dichotoma*, *P. vermiculata* and *P. anceps* as distinct species and figured a single cross-shaped spicule of each, from specimens believed to be the types. But on the slides of the same, which he sent to me, the corresponding spicules vary to an extent more than sufficient to include his figures of the three forms. See pl. 36A. But *P. nutans* Duch. and Mich., 1860, of which he also sent spicules from the type, is quite distinct, having the crosses much more slender, with longer, more acute, and less verrucose branches.

soft and brittle. It is grayish or dull wood-color. The branches curve strongly outward at base, and then become rigidly erect. The trunk is often an inch or more (20 to 30^{mm}) in diameter; the branchlets, when full grown, are about 6 to 10 inches (150 to 250^{mm}) long, and 10 to 14^{mm} in diameter; larger calicles 1 to 1.5^{mm} in diameter.

Dwarfed specimens are sometimes found with much smaller and shorter branchlets and smaller calicles.

It occurs both on the outer reefs and on those in Castle Harbor, Great Sound, etc. It is also found on the Florida reefs and in the West Indies generally, south to Dominica.

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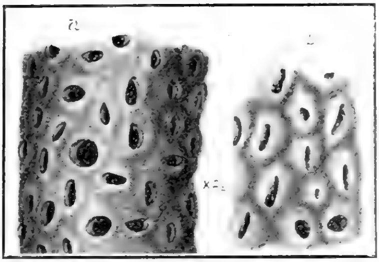

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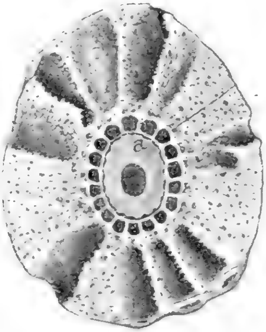

Figure 156.—*Plexaurella dichotoma; a, b,* portions of the surface of two specimens to show variations in form of calicles due to contraction, × about 2.

Figure 157.—*Plexaurella dichotoma,* cross-section of branch, × about 3½; *a,* axis, with circle of longitudinal ducts around it.

Euniceopsis, gen. nov. Type *E. Tourneforti.*

I propose to separate, as a genus, those species usually referred to *Eunicea*, in which the column and tentacles contain double rows of spicula, which are absent in typical species of *Eunicea*[*] (restr.). The presence of these spicules renders the tentacles somewhat rigid and slow to contract, and in incomplete contraction they serve as a sort of opercular covering for the calicles.

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[*] I propose to consider *E. mammosa* Lx. and *E. limiformis* Lx. the typical forms of *Eunicea.* The former was the only species figured by Lamouroux when he established the genus (1816). His first species (*G. antipathes* of early authors) is indeterminable, being a heterogeneous assemblage of several genera and species. His second species (*E. microthela*) is not certainly known, but probably belongs to *Eunicella.* Other species of true *Eunicea* are *E. muricata* Lam. (t. Edw. and H.), *E. madrepora* Dana, etc.

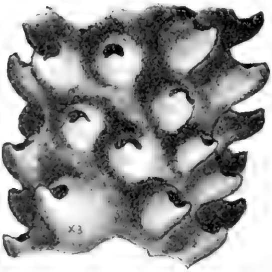
The spicula of the cœnenchyma consist of larger and smaller warty spindles, some often very large, and of a dense superficial layer of smaller rough, warty or spinulated, club-shaped or irregular spicules of various forms, giving the surface a roughly granular appearance under a lens. The calicles may be low or high, 8-lobed or bilabiate. Axis horny. Besides the species here described, several other West Indian species (or varieties) belong to *Euniceopsis;* among them are: *E. crassa* (Edw. and H.); *E. Rousseaui* (E. and H.); *E. multicauda* (Lam.); *E. aspera* Duch. and M.; *E. hirta* D. and M.; *E. laciniata* D. and M., and *E. lugubris* D. and M.

Euniceopsis Tourneforti (Edw. and Haime) Ver. Figures 158–160. Plate xxxviB, figs. 1, 2, spicules.

Eunicea Tourneforti Edw. and Haime, Corall., i, p. 150, 1857. Verrill, these Trans., x, p. 570, 1900. Nutting, op. cit., pp. 142–151, pls. viii, ix, 1889.

? *Gorgonia* (*Eunicea*) *pseudo-antipathes* Dana, Zoöph., p. 671, 1846 (not of Lam., which was a *Muricea*, t. Edw. and H., i, p. 148). Heilprin, Bermuda Is., p. 104 (no description).

158



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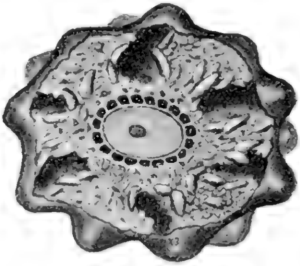

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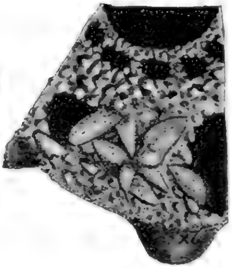

Figure 158.—*Euniceopsis Tourneforti.* Portion of a terminal branch, × about 3½ times.

Figure 159.—The same, section of a branchlet, × about 3 times.

Figure 160.—The same, portion more enlarged. Drawn by A. H. Verrill.

This is a large, stout, stiff species, with thick, forking, upright, blunt branches, dark brown or nearly black in color. It is easily distinguished from most of the allied species by the large prominent, somewhat conical calicles with the bilabiate aperture on the upper side and the lower lip prolonged and curved upward and inward (fig. 158).

The cœnenchyma is thick and hard, filled with rather large, very stout, and mostly fusiform spicules (fig. 160), but with a smoothish or subgranular surface. The axis in the terminal branches is relatively small and soft, shrinking much and becoming brittle when dry, but black, hard, and rather rigid in the large branches and trunk, and flattened at the axils.

The polyps are brown and relatively large, and so filled with spicules that they cannot readily contract. Even the tentacles are thus stiffened and are often seen incurved in the form of a ball over the apertures of the calicles.

Well grown specimens are often 2 feet or more high. The terminal branches are usually over half an inch in diameter (12 to 16^{mm}) and 4 to 8 inches long.

It is found in Castle Harbor; The Reach; and other inner waters, where there are strong currents, but is more common and larger on the outer reefs.

It is found, also, in the West Indies.

Euniceopsis grandis Ver. Figures 161–163. Plate xxxiiiA. Plate xxxiiiB, fig. 1, *a*. Plate xxxviB, fig. 3, spicules.

Eunicea grandis Verrill, Trans. Conn. Acad., vol. x, p. 570, pl. lxix, figs. 3, 3*a*, 1900.

? *Eunicea crassa* Edw. and Haime, Corall., i, p. 148 (*non* Ellis sp.).

161 162

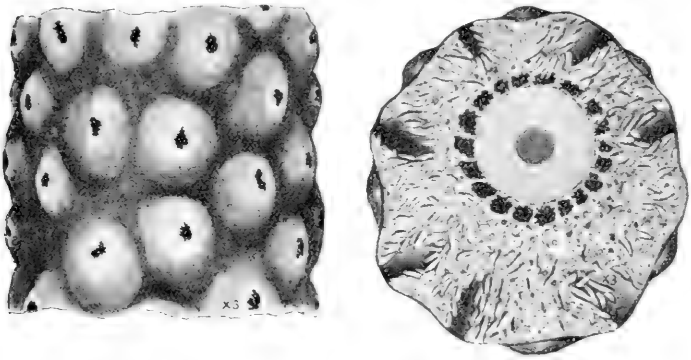

Figure 161.—*Euniceopsis grandis*, portion of a branch, × 3.
Figure 162.—The same, section of a branch, showing the axis surrounded by numerous longitudinal ducts, × 3. Both drawn by A. H. Verrill.

This large robust species is similar in size and form to the preceding, and like it is dark umber-brown or sepia-brown in color while living, becoming russet brown, dark brown, or black when dried; the inner part of the cœnenchyma around the axis is usually purple, due to the large, fusiform, purple spicules.

It can be readily distinguished by its large, slightly mammiform, or verruciform calicles, with the aperture terminal and usually slightly eight-lobed when dried, but much more prominent and distinctly eight-lobed in life.

The cœnenchyma is very thick (fig. 162), but the spicules are much smaller than in the preceding species. The longitudinal canals around the axis are numerous and large. The axis is black and hard in the larger branches, but soft, shrinking much in drying, and brittle in the smaller branches.

The branches are forked, very stout, blunt, and large, and form somewhat flattened colonies, the terminal branches upright and nearly straight. They are up to .65 of an inch or more (10 to 16^{mm}) in diameter and 6 to 12 inches or more in length, in large specimens. The main stalk may be 1 to 2 inches in diameter near the base, and the total height of the colony 2 to 3 feet; breadth 1.5 to 2 feet.

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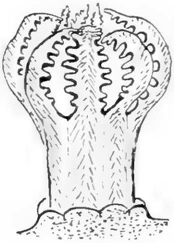

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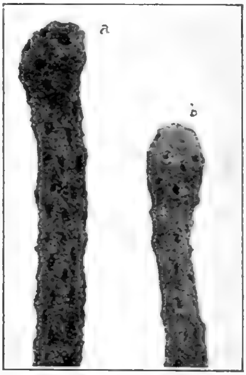

Figure 163.—*Euniceopsis grandis.* One of the polyps, nearly expanded, much enlarged. From life, by the writer.

Figure 164.—*Euniceopsis atra*; *a*, one of the larger, and *b*, one of the smaller terminal branchlets, nat. size. Phot. by A. H. V.

The polyps are large, brownish yellow, and so filled with whitish spicules that they appear rather stiff, and contract slowly when disturbed; the tentacles roll their tips inward, forming a sort of ball, which often seems too large to be drawn into the calicles, but can be entirely retracted, though slowly. The median part of the tentacles has two rows of conspicuous slender fusiform spicules arranged en chevron (fig. 163), continuous with similar lines on the column; lines of similar but much smaller white spicules extend along the pinnæ.

It is found, like the last, in strong currents of water, both on the outer reefs and on the inner ledges; most commonly in 6 to 20 feet or more of water.

This species is allied to *E. multicauda* (Lam.); *E. crassa* Edw. and Haime; and *E. turgida* Ehr., in having low verruciform calicles with the borders 8-lobed. Possibly they may all belong to but one or two species.

Euniceopsis atra Verrill. Figures 164, 165.

Eunicea atra Verrill, Trans. Conn. Acad. Sci., vol. xi, p. 52, pl. ix, figs. 4, 5, 1901.

This species forms flattened groups of rather rigid, black branches, which subdivide dichotomously. The branches and branchlets are distinctly smaller than in the three preceding species.

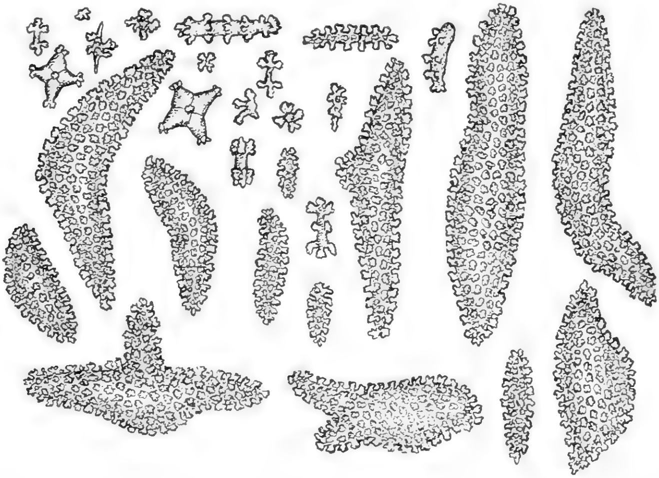

Figure 165.—*Euniceopsis atra*, group of the spicules, × 17. Drawn by A. H. V.

The branches mostly spring from near the base; the terminal ones are long, about 100 to 150^{mm} and 6 to 10^{mm} in diameter, where largest; they are often crooked or slightly sinuous, and frequently clavate at the tip.

The calicles are rather large and usually open when dry, up to 1^{mm} or more in diameter, and not very close together; aperture round or elliptical, with the borders only slightly raised, and usually not distinctly 8-lobed in the dry specimens; lower lip usually very slightly developed, as an angular point, often entirely lacking.

The polyps in expansion are large and prominent, yellowish brown, and so stiffened with chevrons of white spicules that they contract very slowly, though completely. The color of the cœnenchyma is inky black in life, and when taken from the water it exudes a large amount of a black mucus that stains one's hands and clothes like ink. It also discolors a large quantity of alcohol or formol solution. When dried it is usually dark umber-brown or black.

It was taken in "The Reach," in 8 to 10 feet of water, where there was a strong tidal current, and also on the reefs. It is not yet known from other waters with certainty.

It resembles *E. lugubris* Duch. and Mich. more than any other described species, but the latter has the calicles distinctly 8-rayed. I have compared the spicules with those of the type of the latter, mounted by Dr. Kölliker.

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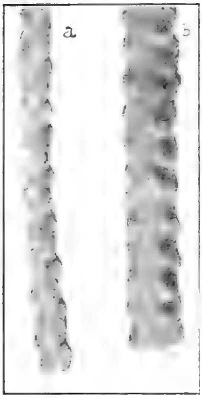

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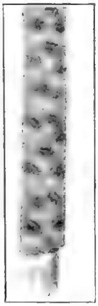

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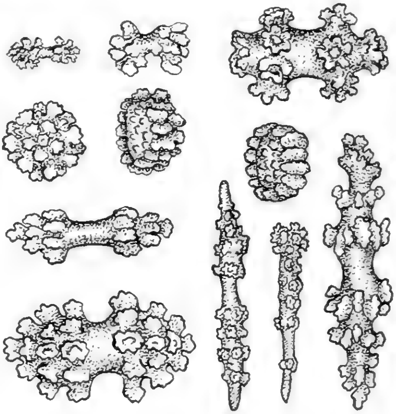

Figure 166.—*Verrucella grandis; a*, portion of terminal branchlet; *b*, portion of a larger branch, both natural size. Phot. A. H. V.

Figure 167.—The same. Side-view of portion of a branch.

Figure 168.—The same. Spicules, × 170. Drawn by A. H. V.

Verrucella grandis Verrill. Figures 166, 167, 168.

Trans. Conn. Acad. Sci., vol. xi, p. 53, pl. xi, figs. 1, 2, 3, 1901.

This is a large and handsome species, growing in a tree-like form, with long and rather slender, sparingly forked, flattened branches, having the small verruciform calicles in two or more rows on each of the edges, with the sides naked. The axis is nearly rigid, brittle, stony or calcareous, and pale dull yellow.

The cœnenchyma is hard and rather thin, with very small orange-colored spicules of various forms (fig. 168). Its color when dried is dark ocher-yellow, inclining to orange.

The only specimen yet known is about 5 feet high; the longer terminal branches are 12 to 18 inches (300 to 450^{mm}) long and about 2 to 4^{mm} in diameter.

It was taken outside the reefs, near North Rocks, in about 100 feet of water.

Doubtful species of Gorgoniæ.

Several species have been recorded, without descriptions, from Bermuda, which cannot be determined without examination of the specimens. Probably most, if not all, are synonyms of the species listed above.

Among them are the following:

Gorgonia (*Plexaura*) *purpurea* (Pallas). Recorded by Heilprin, op. cit., p. 104.

The genuine *purpurea* (Pallas) is a slender species of *Leptogorgia*, ranging from Brazil to Chili. Heilprin's species may have been the purple var. of *P. flexuosa* or *P. anguiculus*.

Gorgonia (*Plexaura*) *multicauda* (Lam.). Recorded by Heilprin, loc. cit., p. 104.

The original species of Lam. belongs to *Euniceopsis*, but Heilprin gives, as synonyms of his species, *G. crassa* Ellis and Sol. and *G. vermiculata* Lam. The latter is a *Plexaurella*; the former is a *Pseudoplexaura*.

Gorgonia (*Eunicea*) *pseudoantipathes* Lam. Recorded by Heilprin, loc. cit., p. 104.

The original type was a *Muricea* (t. Edw. and H.), but the name has been variously misapplied by authors.

HYDROZOA.

Millepora alcicornis Linn. *Sea Ginger. Finger Coral.* Figures 36, 169. Plate XXXA, fig. 2; plate XXXVI, fig. 1 (20).

Dana, Zoöph., p. 543, 1846. M. Edw. and Haime, Corall., iii, p. 228, 1860. Pourtalès, Florida Reefs, pl. xx, figs. 1–6, 1880, excellent. Quelch, Voy. Challenger. Vaughan, Corals Porto Rican Waters, p. 318, plates xxxv–xxxviii. Verrill, these Trans., xi, p. 182.

This is the most abundant coral, both on the outer reefs and on the inner rocks and ledges. It grows in very shallow water as well as at the depth of 5 to 8 fathoms. It forms, when well grown, large rosette-like clusters of lobed and digitate flat fronds, diverging in all directions, the groups often being 4 to 6 feet or more across, while the fronds are from 1 to 2 feet high, and terminate in very slender, tapering, fragile branches of various sizes and shapes. Its color in life is usually dark russet brown, but sometimes is light yellowish brown or orange-brown, or even umber-brown.

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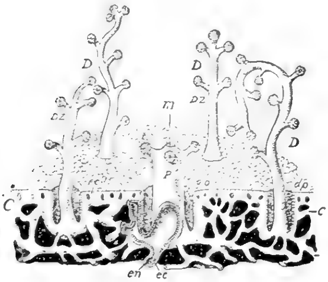

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Figure 169.—Zoöids of living *Millepora;* P, Anthozoid or feeding polyp, *m*, its mouth; D, DZ, defensive zoöids; C, cœnenchyma; *ec*, ectoderm; *en*, endoderm. Much enlarged, after Moseley.

Figure 170.—*Sertularia Gayi*, much enlarged. Drawn by A. H. Verrill.

When young it forms more or less thick encrustations on dead corals, shells, etc. Sometimes it completely encrusts the dead axis of a gorgonian, and then by the unequal shrinking and swelling of the gorgonian when dried, the crust of white coral usually breaks up into short, often bead-like fragments (var. *moniliformis*). A form (var. *ramosa*) with unusually well rounded and forked branches has been separated by many former writers as a distinct species, but intermediate forms are common. Quelch (Voy. Chall.) recorded it from Bermuda. We did not find at Bermuda the variety, or distinct species (*M. plicata*), with broad, flat, unbranched fronds, which is common in some parts of the West Indies. Quelch also recorded var. *carthageniensis* D. and M. from Bermuda. The hydroid nature of the zoöids of this coral was first ascertained by Professor Louis Agassiz, in 1858,* and his discovery has since been confirmed by many others, who have observed the zoöids of Millepores in

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* Amer. Journ. Science, ii, xxvi, p. 140, 1858. Proc. Boston Soc. Nat. Hist., vol. vi, p. 364, 1858.

various parts of the world. Prof. Wm. N. Rice observed the zoöids of *Millepora* at Bermuda in 1876–7 and published sketches of the defensive zoöids in various states of expansion, showing considerable variety of forms.*

The zoöids, so far as now known, are very similar to, if not practically identical with those of the East Indian species, which have been most carefully studied by Moseley and others.

The Bermuda varieties agree exactly in form and structure with those of Florida and the West Indies, and essentially the same form occurs on the coast of Brazil, at the Abrolhos Reefs, but is there associated with a species (*M. nitida* V.) not known in the West Indies.

The nettling cells (cnidæ) of *Millepora* are unusually powerful, and are capable of stinging the hands of some persons with delicate skin. When a freshly taken specimen is touched with the tongue or lips the stinging power is sufficiently obvious to warrant its vernacular name of "Sea Ginger." Very few other hydroids were met with by my parties, on the reefs, though probably a considerable number occur there later in the season.

Sertularella Gayi. Figure 170.

This is the only Sertularian hydroid that we found common. It grows on loose stones and dead corals, but all of our specimens were small and immature.

30. *Echinoderms; Sponges; Mollusks; Annelids; Crustaceans, etc.*

ECHINODERMATA: ECHINODERMS.†

This group is fairly well represented on the coral reefs, though most of the species conceal themselves so well in cavities and crevices that they must be carefully sought for. Only one species of starfish (*Asterias* (or *Stolasterias*) *tenuispina*) is common. The sea urchins are, however, represented by several large species, and the serpent-stars or ophiurans by a still larger number. Of crinoids only one specimen was found, and that was quite young (*Antedon*).

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* Amer. Journ. Science, vol. xvi, pp. 180–182, figs. 1–20, 1878.

† Bibliography.—The echinoderms of the reefs are nearly all well known West Indian species, described in the general treatises on this group. The following are the most essential works:

Agassiz, A.—Revision of the Echini. Parts i–iv. Illustrated Catalogue of Museum Comparative Zoölogy, No. II. 4to. 49 plates, 1872. Contains figures and descriptions of all the Bermuda species.

HOLOTHURIOIDEA: HOLOTHURIANS.

Although a large species of this group (*Stichopus Möbii*, see p. 143, fig. 37) is one of the most common and conspicuous creatures on the bottom of the lagoons, the few species living on the reefs are small and live well concealed under stones or in cavities of dead

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Agassiz, A.—North American Starfishes. Memoirs Mus. Comp. Zoölogy, vol. v, No. 1, 1877.

Clark, Hubert Seymour.—Notes on the Echinoderms of Bermuda. Ann. New York Acad. Sci., vol. xi, pp. 407–413, 1898.

— Further Notes on the Echinoderms of Bermuda, op. cit., vol. xii, pp. 117–138, 1899.

— Bermudian Echinoderms. A Report on Observations and Collections made in 1899. Proc. Boston Soc. Nat. History, vol. xxix, No. 16, pp. 339–344.

Heilprin, Angelo.—The Bermuda Islands, pp. 136–145, pl. xii, xiii, 1887.

Lütken, Chr. Fr.—Oversigt over de Vestindiske Ophiurer. Naturhist. Foren. Vidensk. Meddelelser, 1856.

— Additamenta ad Historiam Ophiuridarum. Pt. ii, 92 pp., 5 plates. Kgl. Danske Videnskab. Selskabs Skrifter, 5te Række, Naturvidensk. og mathem. Afdeling, v, 1859.

— Additamenta ad Historiam Ophiuridarum. Part iii. Kgl. Danske Videnskab. Selskabs Skrifter, 8, Bd. ii, pp. 24–101, 1869.

— Synopsis generum Ophiuridarum verarum. (Forms part of the preceding work, pp. 87–100.) 1869.

Lyman, Theodore.—Ophiuridæ and Astrophytidæ. Illustr. Catalogue Museum Comp. Zoölogy, I, 1865.

Müller J., and *Troschel, F. H.*—System der Asteriden, 1842.

Sladen, Walter P.—Reports Voy. Challenger, Zoöl., vol. xxx; Report on the Asteroidea. 1 vol. text, 1 vol. plates, 1888.

Theel, Hjalmar.—Report on the Holothurioidea. Voyage Challenger, Zoölogy, vol. xiv, part 39, 1886.

Verrill, Addison E.—Notice of the Corals and Echinoderms collected by Prof, C. F. Hartt at the Abrolhos Reefs, Province of Bahia, Brazil, 1867. Trans. Conn. Acad. Sciences, i, pp. 351–371, 1 pl., 1868.

— Revision of certain Genera and Species of Starfishes, with descriptions of New Forms, op. cit., vol. x, part 1, pp. 145–234, (a.) 8 pl. + 1899.

— North American Ophiuroidea. Part i. Revision of certain Families and Genera of West Indian Ophiurans. Trans. Conn. Acad., vol. x, pt. 2, pp. 301–371, 1899. (b.)

— The same. Part ii. A Faunal Catalogue of the known Species of West Indian Ophiurans, op. cit., pp. 372–377, pl. xlii, xliii, includes Bibliography, 1899. (c.)

— Additions to the Echinoderms of Bermuda. Trans. Conn. Acad., x, part 2, p. 583, 1900.

— Additions to the Fauna of the Bermudas from the Yale Expedition of 1901, with Notes on other Species, op. cit., vol. i, pt. 2, pp. 35–37, 1901.

corals, etc. The larger number live buried in sand or mud on the flats and shores.*

Cuccumaria punctata Ludwig. *Sea Cucumber.* Figure 171.

Clark, H. L., op. cit., 1901, pp. 342, 344.
Semperia bermudensis Heilprin, The Bermuda Is., p. 138, pl. xii, figs. 2, 2*a*, 3, 1889.

This is, perhaps, the most common reef species. It lives firmly attached by its sucker-feet under loose stones. In expansion it is fusiform and becomes 4 to 6 inches long, and when its ten dendritically branched tentacles are well expanded it presents an elegant appearance. Its color varies from yellowish brown to dark olive-green ; often with darker brown blotches or longitudinal stripes; sucker-feet lighter, yellowish or sometimes reddish.

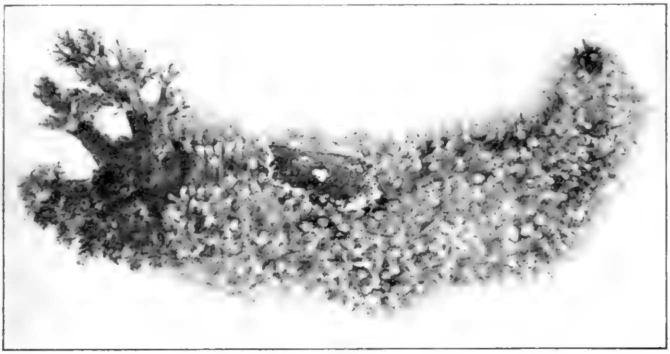

Figure 171.—*Cucumaria punctata*, about nat. size. Phot. from life by A. H. V.

Holothuria captiva Ludw. *Sea Cucumber.*

Clark, op. cit., 1899, p. 124 ; p. 342, 1901.
Holothuria abbreviata and *H. captiva* Heilprin, The Bermuda Is., p. 137, pl. xii, figs. 4, 5, 8, 8*a*, 1889.

This is of about the same size as the last, but is usually more elongated in form when fully expanded. It has about 18 to 20 short

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* Among those found burrowing in the calcareous sands of the flats are *Holothuria Rathbuni* (see p. 145, fig. 38), *Chirodota rotifera*, and several species of *Synaptæ*. (See p. 145.) One small species of *Synapta* or *Chondroclœa* (*C. vivipara*, fig. 173) has the habit of living exposed, clinging firmly to algæ, corals, hydroids, etc. by means of its dermal anchors. In life it is often green, blotched with white, but sometimes dull red, mottled with green or brownish red. Usually there is a pair of dark brown spots at the base of each tentacle.

shield-like tentacles and its sucker-feet are in three definite rows underneath. Its color is usually deep olive green. It lives under stones, like the last.

Holothuria surinamensis Ludw. *Sea Cucumber.* Figure 172.

Clark, op. cit., 1899, p. 121; 1901, p. 344.

Holothuria floridana Heilprin, op. cit., p. 136, pl. xii, figs. 6, 6*a*, 7, 7*a*, 1889 (*non* Pourtalès).

Common under stones and corals, both on the reefs and on the islands at low water mark. Similar to the last in appearance, but longer. Color dull pale yellowish brown to dark olive-brown. The tentacles vary in number, but 20 is the most common number.

Figure 172.—*Holothuria surinamensis*, about natural size. Phot. from life by A. H. V.

ECHINOIDEA: SEA URCHINS.*

The most abundant sea urchin is the dark purple or sometimes greenish species (*Toxopneustes variegatus*, see p. 146, fig. 40), which is to be seen almost everywhere on the white bottom of the lagoons in shallow water. It is sometimes found, also, on the reefs, though it is not a true reef species. It often covers itself with broken shells and other debris.

Cidaris tribuloides (Lam.).

Plate XXXIVa, fig. 1. Plate XXXIVb, fig. 2. Plate XXXVI, fig. 1 (11).

This species is easily recognized by its stout cylindrical spines. It is not uncommon on the outer reefs, as in the vicinity of the

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* Three additional echini occur only in the bays on sandy or muddy bottoms. These are *Melitta hexapora* (see above, p. 146); *Echinoneus semilunaris* (under stones in sand near Hungry Bay); *Brissus unicolor*.

North Rocks. It adheres firmly to the rocks, in crevices and cavities, by means of its sucker-feet.

Diadema setosum Gray. *Long-spined*, or *black Sea Urchin.* Figure 174.

PLATE XXXIV, FIGURE 1. PLATE XXXVI, FIGURE 1 (12).

This is one of the largest and most interesting forms. When full grown the shell may be 3 inches in diameter and the slender, barbed, and very sharp spines may be more than 6 inches long. In life the color of the adults is purplish black, but when young the slender spines are annulated with purple and white. The spines are effective organs of defence, and are notorious for the painful wounds that they inflict when an inexperienced person attempts to capture the creature. When touched large numbers of spines are almost instantly converged toward the point of contact. The very sharp tips are brittle and break off in the wounds. They are hard to remove on account of their barbed structure. They also seem to convey some poisonous secretion, very irritating to most persons, causing much pain and swelling, but the purple discoloration of the flesh around the wounds, often very alarming in appearance, is due to the absorption of the purple coloring matter of the spines and soon passes away. This creature is very active for a sea-urchin, and when disturbed usually quickly glides away and conceals itself in some nearby cavity beneath the rocks. It is common on the outer

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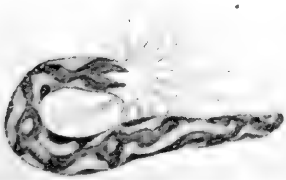

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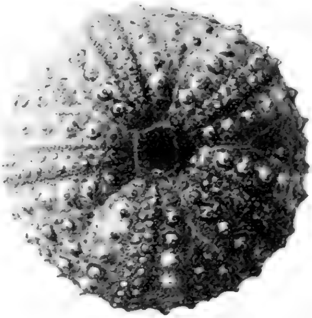

Figure 173.—*Chondroclœa* (or *Synapta*) *vivipara*, ×2. From colored figure.
Figure 174.—*Diadema setosum*, with spines removed, about ½ nat. size. Phot. and drawn by A. H. V.

reefs and is also to be found on the rough rocky shores of the outer islands, as at Cooper's Island, Castle Island, etc., in shallow water.

It can be easily taken by means of a barbed wire, or straightened fish-hook attached to a long slender stick and used as a spear.

Echinometra subangularis (Leske). Plate xxxivA, fig. 2.

The stout, sharp spines and somewhat oblong form of the shell are characteristic of this species. Its spines, in life, are generally dull purple or greenish.

It is found on the reefs and outer islands among rough rocks in shallow water, like the last. It has the singular habit of excavating holes for itself in the limestone rocks, the holes being just large enough to hold the creature, whatever its size. How it bores the rock is not certainly known.

Hipponoë esculenta (Leske). *Edible Sea Urchin.* Plate xxxivB, fig. 2.

This large round species is found in the same situations as the last two. It is not common in most localities. It becomes 4 to 5 inches in diameter. Its spines are numerous, rather short, and usually pale green or whitish in color. In some of the West Indian islands it is an important article of food. The principal edible portions are the large clusters of roe.

ASTERIOIDEA: STARFISHES.*

Asterias (Stolasterias) tenuispina (Lam.) *Common Starfish.* Plate xxxiv, fig. 2. Plate xxxivC, fig. 2. Plate xxxvi, fig. 1 (7).

No other starfish is commonly found on the reefs without diligent search under stones, etc. This species, however, is very common and usually lives exposed. Its rays are slender and easily detached. It is usually irregular in form, with part of its rays much shorter than the rest, due to the partial restoration of lost rays. The number of rays varies from 5 to 9 or more, but is most frequently 6 to 8. It rarely becomes more than 7 to 8 inches in extent. In life its colors are variable and often attractive, commonly some shade of purple, or purple varied with orange.

It is found also in the Bahamas and in the Mediterranean Sea.

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* The only Bermuda shallow water starfish not found on the reefs is *Luidia clathrata*, which lives in sheltered sandy bays. (For habits, see above, p. 146.)

Asterina folium (Lütken) Agassiz. Plate xxxivc, figs. 3, *a*, *b*.

Asteriscus folium Lütken, Vidensk. Medd. nat. Foren., Kjobenhavn, p. 60, 1859.

Asterina folium A. Agassiz, Mem. Mus. Comp. Zool., v, pt. 1, p. 106. Sladen, Voy. Challenger, xxx, p. 393.

This small starfish is peculiar in being distinctly blue while living, a color very unusual among echinoderms. It is seldom more than about .75 inch in diameter (15 to 20^{mm}). It is not uncommon adhering to the under surfaces of large loose blocks of stone and in crevices.

Linckia Guildingii Gray. Plate xxxivc, fig. 1.

Gray, Ann. and Mag. Nat. Hist., vi, p. 285, 1840. A. Agassiz, North American Starfishes, p. 105, pl. xiv, figs. 1–6. Verrill, these Trans., vol. xi, p. 36, 1901. Sladen, op. cit., p. 410.

Ophidiaster ornithopus Müll. and Trosch., Syst., p. 31, 1842.

This is easily recognized by its round, slender, finely granulated rays, either five or six in number, and very often in process of restoration after injuries. One ray is even capable of regenerating a new body and the other arms. It may become 6 inches or more in breadth. It is found under blocks of stone or in crevices, but is not common. It is found also in the West Indies and Cape Verde Islands.

OPHIUROIDEA: OPHIURANS.

The Ophiurans are well represented on the reefs, though most of the species hide themselves very effectively in crevices, under stones and corals, or in the cavities of sponges.*

Ophiura cinerea (Müll. and Tr.) Lyman.

Ophioderma cinereum Müll. and Troschel, Syst. Aster., p. 87, 1842.

Ophioderma antillarum Lütk., Vid. Meddel., p. 9, 1856; Add. ad Hist. Ophiur., pt. ii, p. 88, pl. i, figs. 1*a*–1*e*, 1859.

Ophiura cinerea Lyman, Illust. Catal. Mus. Comp. Zool., i, p. 27, 1865. Verrill, these Trans., x, p. 585, 1900.

A large species, variable in color; usually brown or grayish, often specked with darker brown; arms often banded. The radial shields are naked and conspicuous at the base of the arms; the lower arm-

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* In addition to the reef Ophiurans, enumerated below, the following species are found in more sheltered situations in the bays and sounds: *Ophionereis reticulata*, (pl. xxxivE, fig. 2, *a*), common under stones in sand at low tide mark (see above, p. 146); *Ophiolepis paucispina; Amphipholis squamata; A. Goesi; Ophiostigma isacanthum.*

spines are the longest ; oral shields broad heart-shaped ; arms long, terete, regularly tapered.

It conceals itself in rock crevices. Ranges through the West Indies to Bahia, Brazil.

Ophiura appressa Say.

Ophiura appressa Say, Journ. Phil. Acad., v, p. 151, 1825. Lyman, Ill. Cat. Mus. Comp. Zool., i, p. 34, 1865. Verrill, op. cit., 1899.

Ophioderma virescens Lütken, Vid. Meddel., Jan., 1856, p. 9 ; Add. ad Hist. Ophiur., pt. ii, p. 92, pl. i, fig. 4.

Agrees with the last in having the lower arm-spines longest, but the radial shields are covered by the granulations of the disk ; arm-spines about nine, short and flat. The color is very variable; usually greenish or grayish green, mottled or specked with darker green and whitish ; sometimes pale.

It lives in rock-crevices ; ranges southward to Brazil.

Ophiura brevicauda (Lütk.) Lyman.

Ophioderma brevicauda Lütken, Vidensk. Meddel., Jan., 1856, p. 8 ; Addit. ad Hist. Ophiur., pt. ii, p. 94, pl. 1, figs. 3–3*e*, 1859.

Ophiura brevicauda Lyman, Illust. Catal. Mus. Comp. Zoöl., i, p. 16, 1865. Verrill, these Trans., x, p. 584, 1900.

The arm-spines are equal, short, stoutish. Disk coarsely granulated ; arms short, about 3½ times diameter of disk ; lateral oral plates granulated. Colors various ; often green, red, or brown, irregularly mottled.

Crevices in the reefs ; not common. Florida and West Indies to South America.

Ophiura brevispina Say. Plate xxxive, fig. 2, *b*.

Ophiura brevispina Say, Jour. Phil. Acad. Nat. Sci., v, p. 149, 1825. Lyman, Proc. Bost. Soc. Nat. Hist., vii, p. 258, 1860 ; Ill. Cat. Mus. Comp. Zool., i, p. 18. Verrill, Bull. Univ. Iowa, v, p. 4, 1899.

Ophioderma olivaceum Ayers, Proc. Bost. Soc. Nat. Hist., iv, p. 134, 1852.

Ophioderma serpens Lütken, Vid. Meddel., Jan., 1856, p. 7 ; Add. ad Hist. Ophiur., pt. ii, p. 96.

Ophiura olivacea Lyman, Ill. Cat. Mus. Comp. Zool., i, p. 23, 1865.

This species has 6 to 8 arm-spines, about equal and flattened. Radial shields usually covered ; lateral oral shields naked. Color variable, usually green or greenish gray, mottled with lighter green or yellowish ; the arms often banded above with pale green or whitish ; sometimes plain olive-green (var. *olivacea*).

Ranges from southern New England (var. *olivacea*) to Brazil.

Ophiothrix angulata (Say) Ayres. Plate xxxivD, fig. 1.

Ophiura angulata Say, Jour. Phil. Acad. Nat. Sci., v, p. 145, 1825.
Ophiothrix violacea Müll. and Trosch., Syst. Aster., p. 115, 1842. Lyman, Ill. Cat. Mus. Comp. Zool., i, p. 164. Lütken, Add. ad Hist. Oph., pt. ii, p. 150, pl. iv, figs. 1–1*d*, 1859.
Ophiothrix angulata Ayers, Proc. Bost. Soc. N. Hist., iv, p. 249, 1852. Lyman, Illust. Cat. Mus. Comp. Zool., i, p. 162, pl. i, figs. 1–3, 1865. Verrill, Bull. Labor. Nat. Hist. Univ. Iowa, v, p. 19, 1899 (descr.); these Trans., x, p. 585, 1900.

Easily distinguished by its long, slender, glassy spines and violet or purple, rarely brown color, often with a white median line on the arms or with whitish blotches or bands, bordered by dark brown.

Not common here. It often lives gregariously among and in sponges. Cape Hatteras to Rio Janeiro, Brazil.

Ophiothrix Suensonii Lütken.

Ophiothrix Suensonii Lütken, Vid. Meddel., p. 15, 1856 ; Add. ad Hist. Oph., pt. ii, p. 148, pl. iv, fig. 2. Lyman, Illust. Catal., p. 157, 1865 ; Bull. Mus. Comp. Zool., v, 9, p. 232 ; Verrill, Bull. Labor. Nat. Hist., Univ. Iowa, v, p. 21, 1899 (descr. colors, etc.) ; these Trans., x, p. 585, 1900.

Similar to the last in form, but with more slender arms and spines. Its colors are paler, often lavender, with a purple line along the middle of the back of each arm, bordered by white, and with radial lines of purple on the disk. It lives among sponges, etc. ; not common. More common in Florida and the West Indies.

Ophiocoma echinata (Lam.) Agassiz. Plate xxxivD, fig. 2 (1, 2).

Ophiura echinata Lamarck, Hist. Anim. sans. Vert., ii, p. 543, 1816.
Ophiocoma echinata L. Agassiz, Mem. Soc. Sci. Nat. Neuchatel, i, p. 192, 1835. Lyman, Ill. Cat. Mus. Comp. Zool., i, p. 81, fig. 5, 1865. Lyman, Report Voy. Challenger, Zool., v, p. 171, pl. xlii, fig. 12, 13, 1882, anatomy. Verrill, Bull. Univ. Iowa, v, p. 22, 1900.
Ophiocoma crassispina Say, Jour. Phil. Acad. Nat. Sci., v, p. 147, 1825.
Ophiocoma crassispina Lütken, Add. ad Hist. Oph., pt. ii, p. 142, pl. iv, fig. 7, 1859.

A large dark brown or grayish black species with large stout upper arm-spines. Lives among corals and in crevices of the reefs. Common from Florida to Colon, and Cumana and throughout the West Indies to Brazil in shallow water.

Ophiocoma Riisei Lütken. Plate XXXIVD, fig. 2 (3).

Ophiocoma Riisei Lütken, Vid. Meddel., p. 14, 1856; Add. ad Hist. Oph., pt. ii, p. 143, pl. iv, fig. 6. Lyman, Ill. Cat. Mus. Comp. Zool., i, p. 76. Verrill, Bull. State Univer. Iowa, 1899, p. 22; these Trans., x, p. 586, 1900.

Similar in size to last, but has the upper arm-spines slender. Usually jet-black or nearly so.

Common on the reefs. Has the same range and habits as the last.

Ophiocoma pumila Lütken. Plate XXXIVE, fig. 1.

Ophiocoma pumila Lütken, Vid. Meddel., p. 13, 1856; Add. ad Hist. Oph., pt. ii, p. 146, pl. iv, fig. 5, 1859. Lyman, Ill. Cat. Mus. Comp. Zool., i, p. 71, 1865.

Much smaller than the two preceding. Often has six arms. Colors light brown varied with darker. Same range as the last two.

Ophiopsila Riisei Lütken.

Ophiopsila Riisei Lütken, Add. ad Hist. Oph., pt. ii, p. 136, pl. v, fig. 2, 1859. Lyman, Illus. Catal. Mus. Comp. Zool., i, p. 150, figs. 16, 17, 1865; Report Voy. Challenger, Zool., v, p. 160, pl. xl, figs. 1–3, 1882 (anatomy). Verrill, these Trans., vol. x, p. 586, 1900.

Not common; lives under corals and stones and in crevices.

Ophiactis Krebsii Lütken.

Ophiactis Krebsii Lütken, Vid. Meddel., p. 12, 1856; Addit. ad Hist. Oph., pt. ii, p. 126. Lyman, Ill. Cat., i, p. 111, figs. 10, 11. Verrill, Bull. Univ. Iowa, v, p. 34, 1899.
Ophiactis Savignyi (*pars*) Lyman, Report Voy. Challenger, Zool., v, p. 115.

A small, rough, green and gray species, usually with six or seven unequal arms; four oral-papillæ; upper arm-plates lobed medially. It spontaneously divides when young. Lives in cavities of large sponges, etc.; common. Ranges from South Carolina to Brazil.

Ophiactis Mulleri Lütken.

Ophiactis Mulleri Lütken, Add. ad Hist. Oph., ii, p. 127, 1859. Lyman, Illus. Cat., p. 109, 1865.

Similar to the last in appearance and habits. It has but two oral papillæ, four rough, short and blunt arm-spines, next to the upper largest; upper arm-plates oval, not lobed. Color usually green.

Ophiomyxa flaccida (Say) Lütken.

Ophiura flaccida Say, Jour. Phil. Acad. Nat. Sci., v, p. 151, 1825.

Ophiomyxa flaccida Lütken, Add. ad Hist. Ophiur., pt. ii, p. 138, pl. v, fig. 1, 1859. Lyman, Ill. Cat. Mus. Comp. Zool., i, p. 178, pl. ii, figs. 18, 19; Voy. Chall., v, p. 246, pl. xliii, figs. 1–3 (anatomy), 1882. Verrill, Bull. Univ. Iowa, v, p. 66, 1899 (colors, etc.).

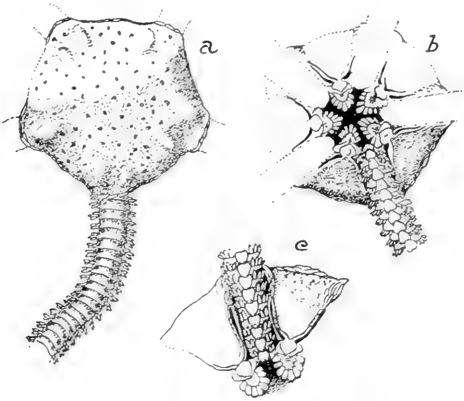

Figure 175.—*Ophiomyxa flaccida*; *a*, dorsal side of disk; *b*, oral side, nat. size; *c*, mouth-organs and lower side of arm, enlarged. After Lütken.

This rather large species has the disk covered with a soft, smooth skin, without plates. Its colors are usually bright or dark yellow, orange, or greenish varied with yellow. It may become 6 to 8 inches across. Conceals itself in crevices of the reefs and under dead corals. Ranges from Florida to Brazil.

Astroporpa affinis Lütken.

Addit. ad Hist. Ophiur., ii, p. 154, pl. v, figs. 5*a*, 5*b*, 1859. Verrill, these Trans., xi, pt. 1, p. 36, 1901.

This singular species has only occurred clinging to the large stony gorgonian, *Verrucella grandis*, taken in about 100 feet of water on the outer reefs. It is rough and so annulated with lighter and darker brown that it closely resembles the gorgonian branches.

CRINOIDEA.

Antedon, sp. Young.

A single specimen, too young for accurate identification, was obtained in 1901.

PORIFERA: SPONGES.*

Numerous species of sponges, some of them of large size and conspicuous on account of their colors, grow on and about the reefs in shallow water, as well as in the sounds. The larger of these mostly

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* The following are the principal modern descriptive works relating to the reef sponges found in Bermuda, the West Indies, and Florida:

Carter, H. J.—Some Sponges from the West Indies and Acapulco. Ann. and Mag. Nat. Hist., ser. 5, vol. ix, 1882, pp. 266–301, 346–368, pl. xi, xii.

Describes many silicious sponges.

Duchassaing and *Michelotti.*—Spongiaires de la Mer Caraibe. Natuurk. Verh. Holl. Maats. Wetensch. Haarlem, vol. xxi, 1864. 25 plates (many errors in references to plates).

Dendy, A.—Observations on West Indian Chalinine Sponges, etc. Trans. Zool. Soc. London, xii, part 10, pp. 349–368, pls. 58–63, 1890.

Describes and figures several species.

Higgin, Thomas.—Descriptions of some sponges obtained during a cruise of the steam yacht Argo, in the Caribbean and neighboring seas. Annals and Mag. Nat. Hist., ser. 4, vol. xix, p. 291, pl. xiv, 1877.

Hyatt, Alpheus.—Revision of the North American Poriferæ, with remarks upon foreign Species, Part I. Mem. Boston Soc. Nat. Hist., vol. ii, 10 pp., 1 pl., 1875; Part II, op. cit., vol. ii, part 4, pp. 441–554, pl. xv–xvii, 1876.

Lendenfeld, R. von.—Monograph of the Horny Sponges. 955 pp. 4to, 50 plates. Royal Society, London, 1889.

Contains full descriptions of all known species, with anatomy, distribution, etc. Also a complete bibliography of sponge literature, and a general system of classification of sponges.

Maynard, C. J.—No. 2. Sponges. West Newton, Mass., 133 pp., 42 cuts, 4 plates, 1898, publ. by the author.

A popular work; contains descriptions and figures of numerous Florida and Bahama sponges.

Poléjaeff, N.—Report on the Calcarea. Voy. Challenger, Zoöl., vol. viii, 1883.

Nine Bermuda species are described, mostly from 32 fathoms, off Bermuda.

——— Report on the Keratosa, op. cit., vol. xi, 1884.

One species (*Verongia hirsuta*) is recorded and figured from Bermuda.

Ridley, S. O. and *Dendy, A.*—Report on the Monaxonida. Rep. Voy. Challenger, Zoöl., vol. xx, part 59.

Contains only a very few Bermuda species.

Solas, Wm. J.—Report on the Tetractinellida. Rep. Voy. Challenger, Zoöl., vol. xxv, part 63.

Three species are described from off Bermuda, in deep water.

Schmidt, O.—Die Spongien Fauna des Atlantischen Gebietes, 1870.

belong to the group of horny sponges (*Keratosa*), which includes the commercial sponges (genus *Spongia*), but there are very few species in Bermuda waters that are sufficiently fine and elastic to be of any value, though two or three species are used by the fishermen for boat-sponges and similar rough uses.

It is quite probable that some of the more valuable Bahama and Florida sponges would flourish at Bermuda, if once introduced there by artificial means, which could easily be done by vessels having live wells.

Most of the horny sponges while living are dark umber-brown, purplish brown, or glossy black, though a few are distinctly yellow, purple, or red. The tube-sponges (*Tuba* or *Spinosella*), which are common and attractive silicious species, are dark yellowish gray to grayish brown in life. The most conspicuous of all the sponges is a very common, large, soft, bright red species (*Tedania ignis*) which grows in various forms, either encrusting or massive and lobate, or even branching. It varies in color from scarlet to bright red and dark red, and is often two to three feet across. It belongs to the group of monaxid silicious sponges.

The Bermuda sponges have hitherto been but little studied, although large collections have been made.*

——— Die Spongien des Meerbusens von Mexico und des Caraibischen Meeres, Jena, 1879, 1880, 2 parts.

Topsent, E.—Une Réforme dans la Classification des Halichondrina. Mémoirs Soc. Zoologique de France, vol. vii, pp. 1–36, 1894. Diagnoses of all the genera.

——— Introduction a l'Etude Monog. des Monaxonides de France. Classification des Hadromerina. Archives de Zoologie expérimentale et générale, ser. 3, vol. vi, 1898, pp. 91–113. Diagnoses of all the known genera.

——— The Same, Part III, op. cit., vol. viii, 1900, pp. 1–331, plates i–viii. (Descriptions of Hadromerina, bibliography, etc.)

Whitfield, R. P.—Notice of a New Sponge from Bermuda and of some other Forms from the Bahamas. Bull. Amer. Mus. Nat. History, New York, vol. xiv, pp. 47–50, 1901.

Wilson, H. V.—The Sponges collected in Porto Rico, in 1899, by the U. S. Fish Com. Steamer Fish Hawk. Bull. U. S. Fish Com. for 1900, vol. xx, part 2, pp. 377–411, 1902.

* Mr. G. Brown Goode and Professor W. N. Rice, in 1876 and 1877, made large collections, especially of the horny sponges, some of which were examined by Professor A. Hyatt, while preparing his memoirs on that group of Porifera, but the bulk of Mr. Goode's large collection was not received until after Hyatt's second memoir was completed. Part of this collection is now in the Museum of

Most of the keratose sponges have been recorded in the memoirs of Prof. Hyatt. Those found on the reefs by my parties will be discussed in the latter part of this chapter.*

SILICIOUS SPONGES.

The Bermuda silicious sponges are represented in our collections by about 38 species, but many of them have not yet been carefully studied and are not now enumerated. The reef species belong mostly to the Monaxonida, in which the skeletal spicules are unbranched; but there are also several representatives of the Tetraxonida, in which part of the skeletal spicules have four branches, often in the form of anchors or grapples with three flukes and a long shank. Several species of this group, forming more or less spheroidal masses, with a radiate interior structure, belong to the

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Wesleyan University, and part in the U. S. Nat. Museum and Boston Soc. Nat. History, with Hyatt's identifications, mostly made after his works were published. My own parties, 1898 and 1901, also made large collections. I have compared most of our specimens of Keratosa with those labelled by Professor Hyatt.

Many of the calcareous sponges (9 species, mostly dredged) were described by Poléjaeff in the Reports of the Voy. of the Challenger (vol. viii, part 24), but several others, found on the reefs, are in our collections.

* The following are the principal ones hitherto recognized by me:

Spongia lapidescens. Common: var. *turrita* Hyatt, very common: var. *conifera* Ver. (with finer texture and smaller and more regular cones).
Spongia lignea, var. *crassa* Hyatt.
Spongia anomala Hyatt.
Spongia punctata, var. *bermudensis* Hyatt MSS.
Spongia corlosia, var. *elongata* Hyatt.
Spongia gossypina D. and M. (t. Hyatt).
Spongia cerebriformis, var. *obscura* Hyatt.
Hircina armata (D. & M., *sens. ext.*) Very common: var. *fistularis* V., var. nov., very common; it has hollow branches, with large terminal vents. Also varieties *marginalis, cylindrica, columnaris*, etc.
Hircina acuta (D. & M.).
Spongelia fragilis (Mont.)=*Dysidea fragilis* H.
Dendrospongia crassa Hyatt. Common.
Aplysina fistularis (Esper), Yellow tube-sponge.
Aplysina hirsuta (Hyatt, as *Verongia*).
Verongula prætexta (Hyatt, as *Aplysina*). This new generic name is proposed as a substitute for *Aplysina* Hyatt, for those species having regular, divergent, angular radial canals, with thin latticed walls, producing a honeycomb-like structure. It includes also: *V., gigantea* H.; *V. rigida* (D. & M.); *V. cellulosa* (H.); *V. aurea* (H.), etc.

genus *Stelletta;* some of them occur under large flat stones, others in sand. A large species, growing in hard, thick, lobate crusts on the reefs, is *Geodia gibberosa;* its hard cortex is filled with spheroidal spicules (sterrasters), fig. 176. Also one of the fleshy sponges.

Oligosilicina. Fleshy or cartilaginous sponges, without a skeleton, but usually with abundant, minute, star-shaped flesh-spicules, with many rays (euasters). Family, *Chondrillidæ.*

MONAXONIDA.

Some of these are conspicuous on account of their large size or brilliant colors, like the very common scarlet sponge (*Tedania*); or have characteristic forms, like the tube-sponges (*Spinosella*), but many are inconspicuous and have irregular or incrusting forms.

This order is represented here by several groups, mostly distinguishable by their spicules:

1. *Chalinoidea*, or *Homorhaphida*, in which the spicules are nearly all of one kind, usually fusiform, acute at both ends (*oxea*), and enclosed in or held together by reticulated horny fibers; no flesh-spicules (microscleres). Families, *Chalinidæ* and *Renieridæ.*

2. *Heterorhaphida*, in which the skeletal spicules may be of two or more forms, usually oxeotes (oxea), combined with needle-shaped forms (styles), pin-shaped forms (tylostyles); with a head at both ends (tylotes); or with both ends blunt (strongyles). With these there are usually minute flesh-spicules, generally either C-shaped (sigmas or sigmata); bow shaped (toxa); or slender hair-like forms (rhaphides); but never anchor-like (chelæ). Families, *Tedanidæ*, *Desmacellidæ*, *Gelliodidæ.*

3. *Desmacidontoidea.* In this family the skeletal spicules may be of various forms: styles, tylostyles, oxea, etc., but the flesh-spicules are minute anchor-like forms (chelæ) with hooks or flukes at both ends; sometimes these are combined with sigmata, etc. The skeletal spicules are usually enclosed in horny fibers. Family, *Esperellidæ.*

4. *Echinonemata.* In these, spicules project as special spines from the surfaces of the fibers: they are usually styles or tylostyles, often spinulated. Families, *Agelasidæ* (= *Ectyonidæ*), *Clathriadæ.*

5. *Axinelloidea.* Usually branched sponges with distinct axial fibers, which are plumosely branched and filled with styles, strongyles, or oxea. Flesh-spicules seldom present, sometimes spirasters or asters; never chelæ. Family, *Axinellidæ.*

6. *Clavata* or *Suberitoidea.* Massive, lobate, or boring sponges; skeletal spicules mostly tylostyles or styles; often no flesh-spicules;

when present, spirulas, spirastes, or asters; little or no spongin; no horny fibers; usually a compact cortex. Families, *Suberitidæ, Polymastidæ, Clionidæ, Spirastrellidæ.*

Family, *Chondrillidæ.*

Chondrilla nucula O. Schm. Figure 177.

A soft, smooth sponge, with a tough cortex and a lubricous surface, forming small hemispherical masses, or thick convex, often irregular, incrusting forms, usually 1 to 3 inches in diameter, on rocks, dead corals, etc. Color various; most frequently dark olive green, varying to smoky brown or blackish, and to light green and yellowish green. Its texture is somewhat cartilaginous and elastic, without skeletal fibers. Minute, spinulated, spherical flesh-spicules (spherasters) are thickly scattered through the interior and more abundantly and partly of larger size in the cortex.

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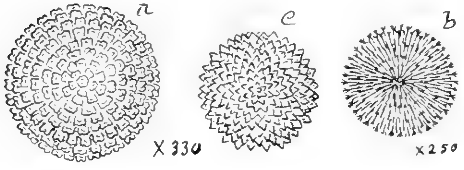

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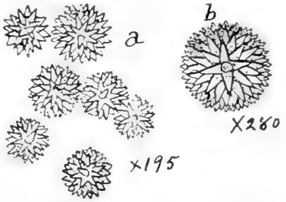

Figure 176.—*Geodia gibberosa; a, b, c,* sterrasters in different stages of growth.
Figure 177.—*Chondrilla nucula;* euasters of different sizes. Drawn by A. H. V.

Very common at low tide; occurs, also, throughout the West Indies.

Family, *Chalinidæ.* (See p. 333.)

Spinosella sororia (D. and M.) Dendy. *Tube Sponge.* Figures 141*a*, 179; Plate xxxvi, fig. 1 (21).

Tuba sororia Duch. and Mich., Spong. mer. Caraibe, p. 46, pl. viii, fig. 1, 1864. (The name *Tuba* was preoccupied.)

Spinosella sororia Dendy, Trans. Zool. Soc. London, vol. xii, p. 360, pl. lviii, fig. 7, pl. lix, fig. 1, 1890.

Siphonochalina papyracea* Schmidt, Spong. atlant. Gebiet., p. 33, 1870, and var. *Bermudensis.*

This species is common at moderate depths, especially in partially sheltered places. It generally forms a group of several upright tubes, 1.5 to 2 inches in diameter, more or less united at the base, with the

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* The name *Siphonochalina* has been restricted by recent writers to the tube-sponges having a smooth, even surface. It seems doubtful if this be a good generic character. One species of that group occurs in Bermuda.

free portion often a foot or more high. The opening at the summit of the tubes has a thin edge, usually fringed with little plumose projections. Outer surface usually ornamented with more or less numerous spiniform processes. Oscules on the inner surface of the tubes.

There are numerous varieties, based mainly on the character of the outer surface, which may be quite smooth or it may have various forms of conules. Sometimes the same tube will be smooth distally, for half its length, and covered with aculeate or conical prominences below. The color in life is usually dark yellowish-gray or tawny yellow; when well dried it is usually yellow, yellowish-gray, or yellowish-brown.

Spinosella stolonifera (Whitf.).

Siphonochalina stolonifera Whitfield, Bull. Amer. Mus. Nat. Hist., vol. xiv, p. 47, plates i–iii, 1901.

? *Callyspongia Eschrichtii* Duch. and Mich., op. cit., p. 56. Pl. xii, fig. 1.*

This singular and rare species has smaller tubes than the preceding, with one or two circles of spinose elevations near the top, while an intricate mass of stolon-like processes, mostly not tubular, is given off from the base. The spicules are simple oxeote forms, nearly as in the last.

Pachychalina cellulosa, sp. nov. Plate XXXVD, figs. 8, 9, spicules.

Sponge irregularly dichotomously branched, the branches rounded, unequal, about .75 inch (15–25^{mm}) in diameter, and 4 to 6 inches long, often repent, elastic when wet, subrigid and light when dry. Oscules scattered, very little raised, 3–4^{mm} in diameter. Internal reticulations rather coarse, with rather strong fibers containing much spongin. Beneath the surface layer the canals or areolæ are relatively large (2–3^{mm}), angular, honeycomb-like, separated by thin reticulated walls, and often form linear series. The dermal layer, when intact and dry, is thin, openly but finely reticulated, with the angular pores mostly arranged in groups or double circles around a central pore over the areolæ, and with a small projecting point at each angle. The skeleton fibers are .05 to .12^{mm} in diameter and contain very numerous multiserial, slender, sharp, oxeote spicules, usually .10 to .15^{mm}, rarely .18^{mm} long, mostly shorter than the sides of the meshes, and mostly entirely enclosed in the spongin fibers. Color, when dried, dark reddish brown; lighter red in life.

Our specimens are much infested with the Zoanthid, *Parazoanthus parasiticus*. (See p. 295.)

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* In the text the reference is erroneously to pl. vii, fig. 3. Many similar errors occur in referring to the plates in the same work.

Pachychalina elastica, sp. nov.

Sponge tough and elastic when wet, elastic even when dry, digitate and somewhat dichotomous, the branches springing from a short, stout, compressed stem. Branches 10 to 25^{mm} in diameter, and 50 to 75^{mm} long, nearly round, often swollen distally, sometimes coalescent. Oscules large, scattered on the sides. Surface, when dry, conspicuously areolated when the external net-work is lost. The areolæ are 2–3^{mm} in diameter, deep, subangular, and separated by rather stout partitions, often 1–2^{mm} thick, composed of strong and elastic, rather coarsely reticulated fibers, many of those next the surface free at the tips, giving the surface a tufted and spongy appearance. Outer layer easily detached; when present, it consists of a rather open and regular network of slender fibers, allowing the areolæ to be easily seen through it, with the meshes about .2^{mm} wide.

The spicules are slender oxeotes, very acute, often bent, .15 to .20^{mm} long. They are multiserial and crowded in the fibers, but well covered by spongin. Color, when dried, yellowish brown. Not very common on the reefs.

Pachychalina millepora, sp. nov. Plate XXXVC, fig. 8.

A delicate irregularly branched sponge, fragile when dry; surface nearly smooth, very finely reticulated; branches irregular in size and form, varying from 12 to 25^{mm} or more in diameter at different places. Oscules irregularly scattered on the branches, 2–4^{mm} in diameter, with the edges slightly fringed and little raised; sometimes funnel-shaped. Dermal layer very finely and pretty regularly reticulated. The meshes angular or rounded, with minute points at the angles. Areolæ, under the cortex, not crowded, separated by walls equal in thickness to the diameter of the areolæ. Fibers about .03 to .04^{mm} thick, filled with abundant multiserial spicules, which are rather slender oxeotes, mostly .2 to .22^{mm} long, often about equal in length to the sides of the meshes.

Pachychalina monticulosa, sp. nov. Plate XXXVD, figs. 6, 7.

Sponge encrusting, or massive and irregularly lobulate, bearing subconical on mammiform elevations, each having at the summit a rather large oscule, 3–5^{mm} in diameter. Internal texture not very fine; dermal reticulation formed by small polygonal meshes, visible to the naked eye. Subdermal areolæ rounded, very unequal in size, the larger about 1^{mm} broad, separated by walls usually about as wide, made up of irregular and somewhat coarse reticulations, tympanized by films of sarcode. Fibers rather coarse, uneven, with numerous slender, acute, oxeote spicules, mostly entirely enclosed in the reddish spongin, but many are partly free in the meshes.

The spicules are mostly about .22–.26^{mm} long. Very common.

Color red in life; reddish brown when dry.

Pachychalina micropora, sp. nov. Fig. 178. Plate xxxvc, fig. 7, spicules.

A delicate sponge, friable when dry, encrusting, or forming small convex or lobate masses. Surface smooth; dermal layer thin, distinct, very finely reticulated, the pores microscopic, oscules few, 4–5^{mm} in diameter, mostly on summits of low conules. Subdermal areolæ small, about .5–1^{mm} in diameter, with rounded angles, and separated by walls often 2–3^{mm} thick and finely reticulated. Fibers slender, multispiculose, with small amount of spongin. Spicules very small and mostly decidedly short, mostly bent oxeotes (see figures) about .01–.015^{mm} in length, by .00066 to .00094^{mm} in diameter.

A few long slender oxeotes, about .45^{mm} long (fig. 7, *b* of plate), were also observed; they may be of extraneous origin.

Color yellowish white when dry.

Figure 178.—*Pachychalina micropora;* one of the conules, with oscule, × 2; by A. H. V.

Cribrochalina Bartholmei (D. & M.).

Spongia Bartholmei Duch. and Mich., op. cit., p. 42, pl. vi, figs. 3, 4, 1864.

When well grown this has the form of a large regular funnel, or of a broad cup, with a short narrow stem. It may become 10 inches high and 6 to 8 broad. The sides are 8 to 12^{mm} or more thick, not thinning much at the edges, which are rounded. The surface of both sides is smooth and very finely reticulated, the meshes .1 to .2^{mm} in diameter.

The oscules are mostly on the inside of the cup, numerous but inconspicuous and very small, mostly .2 to .3^{mm} in diameter.

In one large specimen from Bermuda there were two stout fistular side-lobes at the base, with a terminal oscule about 6–8^{mm} wide.

The skeletal fibers are densely spiculose, stout, and reticulated, much as in *Pachychalina*, the radial ones plumose, but the sponge is harder and firmer when dry, though soft when wet.

The spicules are polyserial, very slender oxeote forms, variable in size; some are nearly styliform, being blunt at one end and acute at the other. Much fine calcareous sand is imbedded in the outer layers.

Bermuda, on a reef in Bailey Bay, one large specimen in Amer. Mus. Nat. Hist., coll. Whitfield; Bahamas, Whitfield.

Family, *Desmacellidæ.* (P. 333.)

Desmacella jania, sp. nov. Plate xxxvc, figs. 5, 6.

? *Terpios jania* Duch. and Mich., Spong., p. 101, pl. xxii, fig. 8.

Our examples of this curious species are massive and irregularly lobulate, 2 to 3 inches high; the lobes are more or less conical, with a terminal osculum, 3 to 5^{mm} in diameter. The whole surface and often most of the thickness of the walls are composed largely of a small slender-branched coralline (*Jania*), white when dry. Toward the base of the sponge this often nearly disappears, as if absorbed. The spicules are mostly long, slender tylostyles, .22 to .25^{mm} long, mostly with small round heads, and mixed with styles of about the same length. The microscleres are minute, strongly curved, *c*-shaped sigmas, about .037 to .040^{mm} long.

Other sponges, associated with *Jania* in the same way, have been described as the *Reniera fibulata* of Carter (1882). The *Terpios jania* D. and M. may not be this species, though it had the same form, for its spicules were not described. When treated with acids the form of the sponge is still preserved, with the translucent organic basis of the *Jania* imbedded in its structure, even close to the edges of the oscules.

Family, *Esperellidæ.* (P. 333.)

Esperiopsis fragilis V., sp. nov. Plate xxxvc, figs. 1–3.

A very porous, fragile sponge, forming crusts or irregular masses 15–20^{mm} or more thick, soft while living, friable when dry. Surface, as dried, irregularly pitted or vermiculate; subdermal channels irregular, deep, often labyrinthiform, .5 to .7^{mm} wide, separated by walls made up of fine irregular meshes, hispid at the surface.

Dermal layer thin, mostly destroyed, easily detached; pores microscopic, numerous; oscules scattered, small. Skeletal fibers delicate, composed mostly of numerous, closely packed, slender spicules. These are mostly slender tylostyles and styles, about .27 to .32^{mm} long, with smaller tylotes .16 to .21 long, with well-rounded ends. Microscleres numerous, very small sigmas (fig. 2, *d*, *d'*), and isochelæ (*c*, *c'*); the latter with the flukes minutely three-toothed. A few very long acute oxeotes, much larger than the other spicules (fig. 3, *b*, *b*), were scattered through the sponge; perhaps they were extraneous. Numerous minute circular disks (fig. 2, *z*) were present, but disappeared when treated with acids; they are probably symbiotic algæ.

Family, *Tedanidæ*. (P. 333.)

Sub-family, *Tedaninæ* Ridley and Dendy ; Topsent, etc.

Tedania ignis (D. and M.) *Scarlet Sponge.* Fig. 180. Plate xxxvc, fig. 4, spicules.

Thalisias ignis Duch. and Mich., op. cit., p. 83, pl. xviii, fig. 1, 1865.*
? *Arcesias hostilis* D. and M., op. cit., p. 97 (encrusting form).
? *Tedania digitata*, var. *bermudensis* Ridley and Dendy, Voy. Chall., xx, p. 51.
Amphimidon variabilis Maynard, Sponges, p. 31, fig. 19, pl. iv (colored), *non* Duch. and Mich.

This is one of the most abundant Bermuda sponges and is very conspicuous in shallow water on account of its brilliant colors, which vary from bright scarlet to blood-red. In life it is very soft and brittle. When young it forms broad thin incrustations on rocks, dead corals, shells, and other sponges. Later it grows up into large irregular lobulate or convex massive forms, often with large conical or fistular elevations, each bearing a large terminal osculum. Sometimes it is branched, or encrusts the branches of dead gorgonians, etc. It often penetrates into the cavities of dead corals and forms a red film over the surface, but there is no proof that it forms excavations for itself. When dry the surface is usually covered with rather deep, irregular, angular pits or areolations, 2–3^{mm} in diameter, with a small central pore, the ridges between being thin and sharp ; in some cases a thin dermal film remains over the areolæ. The interior is made up of small irregular angular and rounded reticulations of slender spiculose fibers, with irregular channels and lacunæ, some often of large size. The spicules are of several forms : 1. the spicules in the fibers are mostly long, slender styles and subtylostyles; 2. oxeotes, acute at both ends ; 3. smaller, slender, often bent, tylote spicules, with both ends slightly enlarged, which are abundant in the external layer, mixed with oxeotes ; 4. very slender, long, acute, capillary forms (rhaphides) abundant, both singly and in fascicles. The larger spicules are .23 to .30^{mm} long.

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* This sponge has the several forms of spicules characteristic of *Tedania* (1867). But though *Thalisias* D. and M. antedated the latter, it was a heterogenous group, not intelligibly defined, and if adopted at all some other species may be taken as its type.

Owing to its softness it is not easy to dry the larger specimens in good condition without previously hardening in alcohol; even then the specimens often collapse. When dry the color is usually pale green or yellowish white. It may form masses 6 to 8 inches thick and 12 to 20 broad.

It is reputed to be poisonous if handled. It certainly irritates the skin of many persons and causes eruptions and intense itching. This is probably due to the very fine and sharp spicules entering the skin, as in the case of other similar sponges. Also common in Florida and the West Indies. It is closely related to Mediterranean and Pacific Ocean forms of the genus (*T. digitata*, etc.).

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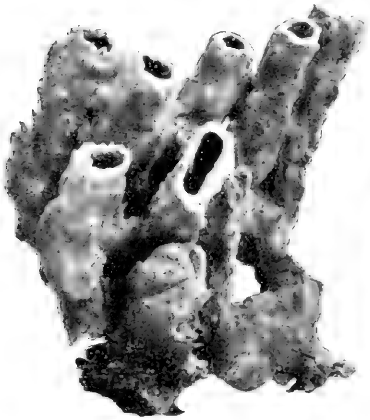

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Figure 179.—Tube-sponge, *Spinosella sororia*, var., ¼ nat. size.
Figure 180.—Scarlet Sponge, *Tedania ignis*, from a dry specimen of the massive form. ¼ nat. size. Both phot. by A. H. V.

Family, *Axinellidæ*. (P. 333.)

Axinella appressa, sp. nov. Plate XXXVD, figs. 10, 11.

Sponge divided into numerous, upright, slender, angular branches, 6 to 8^{mm} thick, covered with small, irregular, conical and compressed elevations, mostly directed upward, and slightly hispid; subdermal areolæ tubular, roundish, very unequal. The larger, 1^{mm} wide, rather close together. Dermal layer seldom preserved, thin, with small pores often arranged in small circular groups over the areolæ. Fibers rather strong, closely filled with rather long, mostly curved, stylote spicules, the longer ones .32 to $.40^{mm}$; the shorter ones .20 to 25^{mm} long. The primary fibers are not very distinct from the others, but form evident loose axial lines, ascending and divergent, plumosely branched in the branchlets and conules.

Color red in life, buff when dry. Found also in the Bahamas and Florida.

Axinella rudis, sp. nov. Plate XXXVD, fig. 13.

Sponge upright, with tall, rather stout irregular branches, 15–20^{mm} in diameter. Sides of branches covered with irregular, very unequal, rough tubercles and lobules, mostly blunt and ascending, 2–5^{mm} high; 1–4^{mm} broad; on the lower parts of branches and stem they become much smaller and more verruciform. Surface rough or subhispid, everywhere irregularly reticulated with rather coarse stiff fibers. Oscules abundant in the depressions, .5 to 1^{mm} in diameter, surrounded by more numerous smaller pores. Color, in life, bright red; when dried it often retains a rose-red color, gradually changing to reddish or orange-brown.

The fibers have a good amount of light yellow spongin. The spicules in the fibers are mostly rather large and stout, often curved, acute stylotes; with these are some slender, and a few almost capillary styles, or rhaphides, nearly as long as the others; very few regular, slender, tricurved toxa were also noticed in the thin dermal layer.

It occurs also on the Florida reefs.* It belongs to the group named *Pandaros* by Duch. and Mich. It is related to *A. Walpersii* D. & M., but that has flat or flabellate branches; also to *A. angulosa* and *A. pennata* of D. and M. (as *Pandaros*).

Family, *Polymastidæ.* (P. 334.)

Polymastia varia, sp. nov. Plate XXXVD, figs. 1, 1*a*.

Sponge compact, thick, encrusting and also massive, sometimes with a nearly even surface, often tuberculate, or when large rising into long finger-like elevations 1 to 1.5 inches high and .3 to .5 inch in diameter, often concave at top but not fistular. Some of the masses are 3 to 5 inches thick and broad. Surface, when dry, hard and compact, often appearing granulated or subareolate, and minutely hispid with the projecting points of small tylostylote spic-

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* *Axinella rosacea*, sp. nov. Plate 35D, fig. 12. A similar species occurs at Florida and Bahamas. It has stunter branches densely covered with groups of short capitate and tuberculate branchlets, often forming rosette-like forms. Color light red or pink when dried. Stylote spicules much stouter than in *A. angulata*, the larger ones .28 to .34^{mm} long; with these are much more slender oxeates .37 to .40^{mm} long.

ules, perpendicular to the surface. Internal texture rather compact, with irregular canals; thick supporting lines of densely crowded spicules run in various directions in the interior. Color, in life, orange-red; dull orange-brown when dry.

Spicules are tylostyles of various sizes, mostly .36 to .48^{mm} long and .008 to .014 in diameter, rarely styles by reduction of the heads; the heads are mostly regularly oval, sometimes slightly three-lobed.

After a long search only a single microsclere was found; it was a minute spinispirula of about 1½ turns.

Common on the reefs; perhaps a boring sponge when young.

Family, *Clionidæ.* (P. 334.)

Heterocliona, gen. nov. Type, *Papillina cribraria* Sch.

Sponge massive or goblet-shaped when large, perhaps boring when young; interior very cavernous when dry, supported by irregular columns of crowded tylostyles. Cortex thick, tough, smooth, and lubricous in life; filled with tylostyles tangentially arranged. Microscleres few, spirulas or spirasters. Oscules usually grouped in large clusters.

Heterocliona cribraria (Schm.). Plate XXXVD, figs. 2, 3.

? *Papillina cribraria* Schm., Spong. Atl. Gieb.

This massive, cavernous sponge often grows to great size, sometimes becoming 2 feet or more in diameter, and over a foot high. The upper surface, when large, usually has a large central cup or one or more cones, each with a large terminal oscule, 15 to 25^{mm} in diameter; other smaller oscules occur close together, in clusters, over the top and border of the sponge. When young (1–2 inches across) the form may be cylindrical, capitate, or mushroom-like, with few, 3–10, oscules, .5–10^{mm} in diameter, above. The surface is smooth, in life, with a tough blackish cortex.

The interior, when dried, is very cavernous, with large irregular cavities partly intercepted by irregular, often curved, broad bands and columns of densely packed bundles of spicules. In drying much of the soft sarcode often decays and runs out of these cavities.

The spicules are mostly long, slender, curved tylostyles, with a slightly enlarged mostly ovate head; they are about .23 to .34^{mm} long; others of the same size are subtylostyles and styles. In the dermal layer they mostly lie tangentially and in radiate groups, without much order.

Microscleres are mostly wanting; after a long search only two or three were found; they were minute, slender, spined spirasters or spinispirulæ, with about $1\frac{1}{2}$ turns, and very minute, nearly straight rhabdi.

Irregular and ovoid dark brown pigment bodies are abundant.

Color in life, dark smoky brown or black, common; the largest seen were in Harrington Sound; also occurs on Florida reefs (Yale Mus.).

Cliona caribbæa Carter. *Boring Sponge.* Fig. 181. Plate XXXVD, fig. 4.

Cliona caribbœa Carter, Ann. and Mag. Nat. Hist., ser. 5, vol. ix, p. 346, pl. xii, fig. 26, 1882.

Cliona viridis (pars.) Topsent, Archives Zool. Exper. et General, vol. viii, p. 84, pl. iii, fig. 3*d*, 1900.

While young this common species excavates extensive and irregular cavities in shells and corals, especially in *Porites.* Later in life it may grow up into thick, massive, dull yellow, convex forms, 6 inches to a foot or more in diameter, with large oscules and a coarsely verrucose surface.* Interior coarsely cavernous,† as dried, and supported by irregular bands and columns of compacted tylostylote spicules. The soft sarcode quickly decays and runs out, in drying, with a very offensive odor Cortical layer compact. It usually includes numerous fragments of shells and corals.

Figure 181. *Cliona caribbœa; a,* one of the tylostyles from the boring sponge, × 165; *b,* a microsclere (spinispirula) much more enlarged (after Carter).

The spicules of this massive form (see pl. 35*d*, fig. 4) are mostly essentially like the one figured by Carter (fig. 181). They are variable in size and form, mostly .28 to .40^{mm} long; many are rather stout with a fusiform shaft; most are more slender with the shaft less fusiform; few are styles. The head is generally ovate, not very large. No microscleres were found after long searching.

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* In this form it corresponds to the genus *Oscarella.* Topsent (1900) referred this species and many other forms to *Cliona viridis* of Europe, in which he included, as massive states, *Osculina,* and *Papillina=Papillella* Vos.

† The massive form here described may not be the adult of the Carter's species; therefore I propose for it the provisional name *Cliona sordida.* See plate.

Spirastrella mollis, sp. nov. Plate XXXVD, fig. 5.

An encrusting species forming soft films .5 to 3^{mm} or more thick on dead, cavernous corals, and also penetrating into the cavernous spaces,—perhaps a boring sponge when young. Surface smooth; no oscules nor pores visible to the naked eye in alcoholic specimens; interior without visible canals. Skeletal spicules, long slender tylostyles, scattered and in groups (fig. 5, *a*), mostly with regular well-rounded heads, but some have ovate or elongate heads; in some the heads are much reduced. Microscleres (*b*,*b′*) are relatively large, spined spirasters, abundant in the cortical layer; they mostly have three or four whorls of sharp conical spinules; some are strongly curved (b′).

(To be continued.)

SOURCES OF ILLUSTRATIONS IN THE TEXT.

The following cuts are from photographs and drawings by Mr. A. Hyatt Verrill:—1, 20, 30, 34*a*, 34*b*, 36*b*, 36*c*, 37, 38, 39, 40, 41, 43, 43*b*, 45, 59, 59*a*, *b*, *c*, 60, 61, 62, 63, 66, 67, 70, 71*a*, *b*, 72, 72*a*, *b*, 73, 75, 77, 79, 80, 81, 82, 83, 84, 85, 90, 91, 94, 95, 96, 96*a*, 97*a*, 99, 100, 101, 101*a*, 102, 103–114, 116*a*–119, 121, 122, 125–128, 129, 129*a*, 131–135, 137, 138, 141, 144–162, 164, 176–180.

The following were by Mr. M. C. Cooke:—6, 16, 18

The following are from photographs bought in Bermuda:—8, 9, 10, 14, 15, 17, 21, 22, 25, 33*a*, 33*b*.

The following were loaned by the publishers of Webster's International Dictionary:—36, 36*a*, 43*a*, 142.

The sources of others are given under the cuts.

EXPLANATION OF PLATES.

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Plate XXVI. Fossil land snails; 1, 2. *Pœcilozonites bermudensis*, var. *zonatus*, nat. size; 3. *P. Reinianus*, var. *antiquus*, ×2½: 4. *P. Nelsoni*, var. *conoides;* 5, 6. var. *callosus;* 7, 8. var. *Nelsoni;* nat. size. See pp. 161–165.

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PLATE XXX. Figure 1. Group of living zoanthids, corals, etc.; reduced to ⅔; *a*, *Palythoa mammillosa*; *b*, *P. grandiflora*; *c*, *Zoanthus proteus*; *d*, *Actinia bermudensis*; *e*, *Condylactis gigantea*, young; *i*, *Mussa fragilis*, about ⅔ nat. size. Figure 2. Large dark brown zoanthid (*Protopalythoa grandis*) from life, partially expanded; all about ⅔ natural size. See p. 281.

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PLATE XXXII. Figure 1. *Epicystis crucifera*, side view; *b*, a tentacle enlarged; drawn from life, about ⅔ nat. size; p. 272. Figure 2. *Lebrunia Danæ*; photo from life, nat. size; p. 269.

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PLATE XXXIIIB. Figure 1. *a*, *Euniceopsis grandis*; *b*, *Plexaurella dichotoma*; dry, about 3⁄7 nat. size, p. 310, 313. Figure 2. *a*, *Muricea muricata*, with expanded polyps; *b*, *c*, *Plexauropsis bicolor* V.; nearly nat. size, photo from life; pp. 301, 310.

PLATE XXXIIIC. Figure 1. *Gorgonia acerosa*; *a*, *b*. purple var.; *c*. brown var. 2, 3. *G. flabellum*, ⅕ nat. size; 4. *a–c*. *Plexaura flexuosa*; *d*. *Muricea muricata*; ⅓ nat. size; pp. 301, 302.

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PLATE XXXIVA. Figure 1. *Cidaris tribuloides*, p. 322. Fig. 2. *Echinometra subangularis*, p. 324. Both nat. size.

PLATE XXXIVB. Figure 1. *Hipponoë esculenta*, with spines removed, ¾ nat. size. Figure 2. *Cidaris tribuloides*, with spines removed, about nat. size; *a*, anal pore; *o*, one of ocular plates; *c*, one of the genital plates, abnormal, with two pores; *m*, madreporite; *am*, ambulacra; *in*, interambulacra, × 1½, p. 322.

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Plate XXXVa. Figure 1, 2. Spicules of *Plexauropsis bicolor* V., type; *a, a*, white foliated clubs of surface; *a′, a′*, irregularly white and purple stellate forms; *b, b*, purple spheroidal or biscuit-shaped forms; *c, c*, small purple spindles of the cœnenchyma; *d, d*, light purple spicules; *e, e*, small and medium white spindles of the cœnenchyma; *e′*, larger irregular white spicule; *f, f*, small purple spindles of inner layer; × 44. Figure 3. *Plexaura homomalla;* Florida specimen; *a, a*, foliated clubs from surface; *a′, a′*, irregular stellate forms from surface; *b, b*, small crosses from surface; *b′*, double spindle; *c, c*, smaller spindles from cœnenchyma; *c′*, one of the larger spindles; *d′, d′*, tentacle-spicules; × 44. Figure 4. *Plexaura flavida*, olive-yellow variety from Dominica; *a, a*, larger spindles mostly light yellow, some purple; *b, b*, smaller spindles of same colors; × 92.

Plate XXXVb. Figure 1. Sea-cat, *Tethys dactylomela*, photo from life, $\frac{1}{2}$ nat. size. Fig. 2. Common bivalves; 1, 1*a*, *Spondylus americanus;* 2, 2*a*, Pearl Oyster, *Pteria* (or *Margaritophora*) *radiata;* 3. Scallop, *Pecten ziczac;* 4, 4*a*, "Rock Cockle, *Chama macrophylla;* 5. True mussel, *Modiola tulipa;* 6, 6*a*. "Mussel." *Arca noœ, occidentalis;* 7. *A. secticostata.* All reduced to $\frac{2}{3}$.

Plate XXXVc. Figure 1. *Esperiopsis fragilis*, sp. nov.; spiculose fibers, × 84. Fig. 2. The same; spicules; *a, a*, tylostyles; *b, b*, styles; *e*, trichites; *f*, tylotes; *z*, unicellular alga (*z*), × 132; *c, c*, isochelæ; *d*, sigmas, more enlarged; *c′, d′*, the same still more enlarged. Fig. 3. The same; *a, a*, tylostyles, × 225; *b, b*, large oxeotes, perhaps extraneous, × 225. Camera drawings by A. H. V. Fig. 4. *Tedania ignis;* spicules; *a, a*, tylostyles; *b, b*, tylotes; *c, c*, slender oxeotes; *d*, trichites; *f*, minute oxeotes, all × 132; *b′*, ends of a tylote, × 225. Fig. 5. *Desmacella jania*, spiculose fibers, × 84. Fig. 6. The same, spicules; *a, a*, tylostyles; *b, b*, styles; *c*, minute spicules; *d*, oxeote, × 132; *e*, sigmas more enlarged; *f*, sigmas still more enlarged. Fig. 7. *Pachychalina micropora*, sp. nov.; spicules; *a, a*, ordinary oxeotes of fibers; *b*, a more slender oxeote, × 170. Fig. 8. *P. millepora*, sp. nov.; *a, a, a′*, oxeotes; *b*, a substylote form, × 132.

Plate XXXVd. Figure 1. *Polymastia varia*, sp. nov.; *a, b*, tylostyles, × 120; 1*a*, heads of same to show variations, × 206; *c*, spiraster, more enlarged. Fig. 2. *Heterocliona cribraria*, grouped spicules, natural order. Fig. 3. The same, spicules, × 120; *a, a*, tylostyles; *b*, styles; *d*, spinispira more enlarged. Fig. 4. *Cliona sordida*, massive form; *a, a*, tylostyles, × 120; *a′*, one more enlarged. Fig. 5. *Spirastrella mollis;* *a*, tylostyles; *b, b′*, spirasters. Fig. 6. *Pachychalina monticulosa*, sp. nov.; spiculose fibers, × 76. Fig. 7. The same, spicules, × 150. Fig. 8. *P. cellulosa*, sp. nov., spiculose skeletal fibers, × 76. Fig. 9. The same; spicules; *a, a′*, oxeotes; *b, b*, styliform spicules; × 150. Fig. 10. *Axinella appressa*, sp. nov., spiculose skeletal fibers, × 76. Fig. 11. The same, spicules, × 120; *a*, longer styles; *b*, shorter do. Fig. 12. *Axinella rosacea*, sp. nov., spicules; *a, a′*, styles; *b*, oxeotes, × 120. Fig. 13. *Axinella rudis*, sp. nov., × about 120; *a*, styles; *b*, capillary oxeote or trichite; *c*, toxa, much more enlarged.

Plate XXXVI. Figure 1. Group of fishes, etc., under cavernous reef (ideal). Fishes about $\frac{1}{10}$ nat. size: 1, Pilot fish (*Seriola zonata*); 2, Parrot-fish (*Scarus vetula*); 3, Hog fish (*Lachnolaimus maximus*); 4, Trunk-fish (*Lactophrys triqueter*); 5, Cow-fish (*L. tricornis*); 6, Angel-fish (*Chætodon striatus*); 7, Starfish (*Asterias tenuispina*); 8, 9, 10, Serpent-stars (Ophiuroids); 11, *Cidaris tribuloides*; 12, *Diadema setosum*; 13, Pink-tipped Actinia (*Condylactis gigantea*); 14, Red Actinia (*A. bermudensis*); 15, Brain Coral; 16, Star Coral (*Siderastræa*); 17, Rose Coral (*Mussa fragilis*); 18, Sea-plume (*Gorgonia acerosa*); 19, Sea-fan (*G. flabellum*); 20, Sea-ginger (*Millepora alcicornis*); 21, 24, Tube-sponge (*Spinosella sororia*); 22, Scarlet sponge (*Tedania ignis*); 23, *Spongia turrita*; 25, Cup-coral (*Agaricia fragilis*). Fig. 2. 1 Green Moray (*Lycodontis funebris*); 2, 2, Spotted Moray (*L. moringa*), with a group of gorgonians, etc.; 3, Ivory Coral (*Oculina varicosa*); 4, Brain Coral; 5, Gorgonian (*Euniceopsis grandis*); 6, 6, *Plexaura flexuosa*; 7, 7, *Muricea muricata*; 8, *Euniceopsis atra*; 9, *Porites clavaria*; 10, 10, *Spongia turrita*; 12, Tube-sponge (*Spinosella sororia*); 14, Reef-rock; 18, Pink Conch (*Strombus gigas*); 19, Cowrie (*Cypræa exanthema*). About $\frac{1}{8}$ nat. size.

Plate XXXVIa. Figure 1. Spicules of *Plexaurella dichotoma* from the type of *P. anceps* (Duch. and Mich.); *a*, *a*, larger crosses; *a'*, *a'*, irregular or one-sided crosses; *b*, double spindle; *c*, *c*, smaller spindles; *d*, double whorled spicule, × 85. Fig. 2. *P. dichotoma*, spicules from the original type of Esper; *a*, *a*, Larger crosses; *a'*, *a'*, irregularly branched crosses; *a''*, *a''*, double spindles or imperfect crosses; *b*, *b*, spindles and double spindles, × 85. Fig. 3. *Pseudoplexaura crassa*, from Bermuda; *a*, *a*, small, irregular, purple spicules from the surface; *b*, *b*, large spindles from the middle of cœnenchyma; *b'*, *b'*, smaller spindles; *c*. *c*, small white spindles; *c'*, *c'*, small purple spindles, × 40. Fig. 4. *Plexaura Esperi*, sp. nov. Type; *a*, *a*, purple double whorled spicules; *a'*, cluster of the same forms in place, less enlarged; *b*, *b*, four-whorled purple double spindles; *c*, *c*, two-whorled purple double spindles; *d*, *d*, large purple spindles; *d'*, smaller purple spindle, × 85.

Plate XXXVIb. Figure 1. *Euniceopsis Tournefort*; *a*, *a*, large spindles; *b*, *b*, smaller spindles; *c*, double spindle; *d*, tentacle-spicule, × 40. Fig. 2. The same; *e*, *e*, small rough spindles; *e'*, branched variety; *f*, *f*, irregular rosettes of surface; *g*, *g*, foliated clubs of surface layer; *h*, *h*, slender spindles mostly from tentacles, × 85. Fig. 3. *Euniceopsis grandis* V., type; *a*. *a*, larger spindles; *b*, *b*, medium spindles; *c*, *c*, small spindles; *d*, *d*, tentacle-spindles, × 20. Fig. 4. *Plexaura flexuosa*; *a*, *a*, larger spindles; *a'*, large purple spindle; *b*, *b*, smaller purple and brown spindles; *b'*, small white spindles; *c*, *c*, brown biscuit-shaped or spheroidal forms; *e*, *e*, purple foliated clubs of surface; *e'*, *e'*, the same, white; *f*, *f*, small purple spindles, × 40.

Plate XXXVII. Map II. The Bermudas and outer reefs. Altered from Stevenson and Sir C. Wyville Thomson.

Plate XXXVIII. Map III. The Bermudas; southwestern section.

Plate XXXIX. Map IV. The Bermudas; middle section.

Plate XL. Map V. The Bermudas; northeastern section. This and the two preceding plates were loaned by Prof. E. L. Mark.

III.—STUDIES ON THE CALIFORNIA LIMBLESS LIZARD, ANNIELLA.

BY W. R. COE AND B. W. KUNKEL.

With Plates XLI–XLVIII and 15 figures in the text.

THE four papers of this series are intended to include the results of a general study of some of the principal organ systems of a rather common but yet little known lizard, *Anniella pulchra*, found on the barren sand dunes of California, Arizona, and southward. This form presents a number of anatomical features which deviate more or less widely from those usually thought to be characteristic of the lizards. In some respects these structures are quite different from those which have thus far been described for any other form.

The reproductive organs exhibit a feature apparently quite unique among lizards in that but a single oviduct is functional, the other being aborted and quite incapable of carrying an embryo. The copulatory organs likewise show a number of interesting deviations from the ordinary lacertilian type. An abstract of a paper dealing with the peculiarities of the urogenital and copulatory organs has been published in the American Naturalist (Coe and Kunkel, :**04**). A second paper on the female urogenital organs of this form has appeared in the Anatomischer Anzeiger (Coe and Kunkel, :**05**). A detailed and more fully illustrated account of these structures constitutes the third paper of this series.

A general account of the habits and mode of life both in the natural habitat and when in captivity, together with a brief discussion of the visceral anatomy, is included in the first of the four papers of this series.

The external anatomy and skeleton have already been briefly described in the papers by Cope (**'92** and :**00**) and by Baur (**'94**) and the systematic position of the genus discussed. Further details, however, both in regard to the arrangement of scales and the osteological peculiarities, are described in the second paper of this series.

The central nervous system and particularly the parts of the brain associated with the pineal apparatus have been carefully investigated and constitute the subject of the last paper of the series.

These structures by no means include all the anatomical peculiarities of the genus, for as yet no studies have been made on the circulatory system, the musculature, or the peripheral nerves. It is hoped, however, that the present series of studies may prove of interest because of their bearing on the evolution of this retrograde type of lizard and be of use in determining its systematic position.

The genus *Anniella* is apparently represented by a single known species (*A. pulchra*) described by Gray in 1852, although Boulenger ('87) briefly described a form said to have been collected in Texas (*A. texana*) which may possibly prove to be a distinct species. *A. nigra*, described by Fischer ('85) as a distinct species, is, as stated by Cope (:00, p. 675), merely a color variety of the common species. About two thirds of the individuals collected belong to this variety, the peculiarities of which are described below.

The systematic position of the genus is to some extent a matter of discussion. Gray ('52) placed it among the Scincidæ; Cope ('64) established for it a new family, Anniellidæ, placing it in the tribe Typhlophthalmi; Boulenger ('85) and Gill ('86) place the family Anniellidæ between the Anguidæ and the Helodermatidæ; and Baur ('94) from a detailed study of the skeleton confirms Boulenger's view that the family is closely related to the Anguidæ, of which the common European limbless lizard, *Anguis*, is the type.

As will be seen from the account of the anatomical peculiarities given on the following pages, the evidence afforded by these investigations emphasizes the close relationship of the Anniellidæ and the Anguidæ.

I.—HABITS AND VISCERAL ANATOMY. W. R. COE.

Text-figs. 1–8.

The natural history of *Anniella* is so imperfectly known that it seems desirable to give here such observations as we have been able to make on the habits of the animal. The brief observations in the field were supplemented by a study of some thirty animals which were kept alive for several months in the laboratory.

The adult lizard is long, slender, and snake-like, averaging about 170^{mm} in length when sexually mature, although there is great variation in the length as compared to the diameter of the body because a considerable proportion of the individuals encountered have previously lost a portion of the tail. After an injury of this sort the posterior extremity remains, at least for a long time, short, blunt, and rounded, while those animals which have not suffered such an injury have long and slender tails.

The length of the body of the adult from snout to cloacal opening varies commonly from 105^{mm} to 152^{mm}. It is of nearly uniform size, with an average diameter of about 6.3^{mm}. The length from cloacal opening to posterior end of these same animals, however, varies from 16 to 75^{mm}. Therefore in extreme cases the length of the tail may vary from one ninth to more than one third the total length of the body.

At the time of birth the young lizards are usually from 70 to 80^{mm} in length.

Anniella pulchra is widely distributed in central and southern California, where it prefers dry, barren localities and deserts. At Pacific Grove, California, it is common on the sand dunes of the seashore. Here it lives buried in the sand beneath small clusters of low bushes and under driftwood scattered about over the more sunny sand patches. A number of individuals are often found collected together beneath a small shrub or piece of driftwood on the sunny side of a sand dune, particularly where not exposed to the winds from the sea. Professor Heath of Stanford University writes that he has found them plentiful in just such situations. Van Denburgh ('97), on the other hand, states that they occur in the sand of pine forests in the same locality, and that they travel rapidly in the loose soil.

They naturally lie buried in the sand with only the anterior portion of the head exposed, so that it is usually quite impossible to see them unless they are more fully exposed by a rake or a hoe. Early in the morning and on a cloudy day they appear to lie more deeply buried in the sand; when exposed to view they very quickly bury themselves in the loose soil, especially if the weather is not too chilly. They are naturally much more active on a warm day, but even then they are not so agile as the ordinary running lizards.

At San Diego the species is said to be very common, and it is also reported from the central and eastern portions of the state, Fresno, Kern, and San Bernadino counties (Cope :00). We have also heard of its being seen, but not collected, at Yuma and in western Arizona.

The lizards live well in captivity. Some thirty individuals which were collected at Pacific Grove, California, were kept in our laboratory at New Haven, Connecticut, for several months. They were fed on the larvæ of the chestnut beetle (*Balanius*) and on small larvæ of Elater beetles. The method by which these insects were devoured is curious and interesting.

The lizard lies buried in the sand with only the anterior portion of the head projecting. In this position it may apparently lie for days without moving unless it is disturbed or its attention attracted by some noise or the sight of some moving object. When the temperature falls to 60° F. or below, the head is drawn into the sand, unless the sun is shining brightly, and in the laboratory nearly all the lizards collect together, as if for mutual warmth, as far from the surface of the sand as possible.

As soon as the room becomes warmer, however, the animals separate and as a rule bring their heads again to the surface of the sand so that their nostrils, eyes, and pineal organ are fully exposed. Sometimes an inch or two of the body is exposed, and at other times one or several of the lizards are seen crawling about on the surface of the sand.

The sight of a small moving object quickly attracts their attention, although usually no effort is made to approach it. The lizard simply waits until the insect larva or other small object reaches its immediate vicinity, when it raises its head an inch or more above the sand and crawls out of its burrow until its head is directly above the object. It then arches its neck sharply and with its jaws widely opened thrusts its head down quickly into the sand, thus holding its prey firmly pressed against the surface of the sand.

The struggles of the prey to escape force it farther into the mouth of the lizard and in the course of a minute or two it is completely engulfed. It is held for some time in the lizard's mouth before being swallowed. More or less sand is swallowed at the same time, and this accounts for its presence in both the stomach and the rectum of many of the lizards examined.

An examination of the stomach contents of a number of individuals killed soon after collecting at Pacific Grove revealed the presence of remains of both adult and larvæ of small beetles, larvæ and pupæ of other insects, and spiders. Van Denburgh (**'97**) likewise records the stomach contents as consisting of insect larvæ up to more than an inch in length, as well as small ground beetles (*Helops* and *Platydema*).

In many cases the lizards, although their eyes were fully exposed, apparently failed to detect the presence of an insect capable of being used as food until the insect actually touched the body. The eyes are very small, so that it seems probable that the animal relies quite as much on the sense of smell and other faculties as on the eyes in the detection of its prey. Furthermore, the presence in the stomach of inactive pupæ of insects demonstrates the ability of the lizard to recognize its food without relying upon the movements of its prey.

The lizards seem to require a considerable amount of water, and were often seen with their snouts thrust into the dish of water in the cage in which they were kept. In drinking, the neck is arched very much as in the process of capturing an insect.

Visceral Anatomy.

The structure and disposition of most of the organ systems of the body cavity agree closely with the descriptions published many years ago for *Anguis.* The urogenital organs, however, are so peculiarly modified that they form the subject of the second paper of this series. The peculiarities of the aborted left lung, the shape and position of the liver, the situation of the gall bladder, and the general form of the different portions of the alimentary canal are mentioned by Cope (:**00**, p. 670).

Alimentary canal.—The head of this lizard is very small as compared with the other regions of the body, and the mouth is in consequence much less extensive than in most other lizards. In an individual 20^{cm} in length, the mouth opening extends only about 6^{mm} behind the tip of the snout, and the greatest width across the posterior ends of the mouth opening is but 5 or 6^{mm}. The nature of the food and the method of its capture are described on the preceding page.

The teeth are small, conical, slightly recurved, and rather acutely pointed. They are disposed in a single row on each jaw as described below, and figured on pl. XLI, figs. 5–8. The number on the upper jaw is usually about 16 or 18 and on the lower jaw about 14. The secondary buds at the bases of the developing teeth in the embryo indicate that, as in most other reptiles, new teeth develop to replace such as are accidentally lost. Small and incompletely developed teeth are often interspersed with the larger ones. Each tooth exhibits a very shallow oval groove along the basal half of its median face.

The tongue, as in *Anguis*, is much shorter than in most other lizards, although it is highly muscular and rather distensible in life. In individuals kept in captivity it does not appear to be extruded from the mouth either when the animal is capturing its prey or at other times. The organ is nearly twice as long as broad and is bilobed both in front and behind. In a large individual the length of the body of the tongue, not considering the anterior lobes, is 8^{mm}, the anterior end being situated about 5^{mm} behind the tip of the lower jaw. The body of the tongue has its exposed surface covered with minute papillæ except at the anterior end where it passes into the two highly muscular lobes or forks. The forks, on the other hand, appear under the lens to be perfectly smooth or provided with slight longitudinal wrinkles. The anterior forks are slender and acutely pointed and may lie side by side or become widely separated, according to the muscular contractions of the parts. Their basal portions are deeply pigmented, the dark pigment commonly extending for a little distance on the body of the tongue and sometimes well toward the tip of the fork, very much as in *Anguis*. The posterior lobes are rounded and provided with papillæ directly continuous with those on the body of the tongue. The histological structure of the glands of the tongue of *Anguis* is described by v. Seiller (**'91,** p. 181).

The body of the tongue is attached to the floor of the mouth along its whole length, the lateral borders and anterior forks alone being free.

The glottis is represented by an oval opening situated on a short elevation in the angle between the two posterior lobes of the tongue.

The mouth leads into the long, narrow esophagus, which passes gradually into the straight stomach. A sharp bend and narrow opening through a highly developed valve lie between stomach

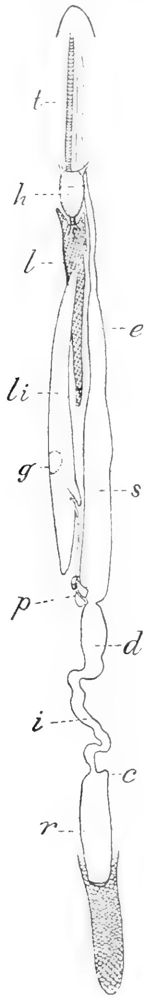


Figure 1. Diagram of digestive and respiratory organs, in their natural positions; *e*, esophagus; *s*, stomach; *d*, duodenum; *i*, ileum; *c*, rudimentary cæcum; *r*, rectum; *t*, trachea; *l*, lung, with large right, and rudimentary left lobes; *h*, heart; *li*, liver; *g*, gall bladder; *p*, the lobes of pancreas and spleen. × ¾.

and duodenum, the latter passing gradually into the more slender ileum, which is slightly convoluted and narrows gradually toward its posterior opening into the large intestine (text-fig. 1). The total length of the small intestine when straightened out and extended is about twice as great as in its natural position. The large intestine is sharply demarcated from the ileum and exhibits, especially when well distended, an indication of a cæcum. A fluted circular valve somewhat similar to that between the stomach and duodenum lies between the rectum and cloaca.

The whole alimentary canal thus consists of an almost perfectly straight tube (text-fig. 1) except for the slight convolution of the duodenum and ileum. As in *Anguis*, the conditions here conform to the requirements of a slender, elongated body, and are markedly different from those found in most lizards, where the intestine is greatly convoluted. Comparative lengths of different portions of this tube are as follows in a lizard about 22^{cm} long:

Tip of snout to opening of esophagus, .	8^{mm}
Length of esophagus, (about) . . .	70^{mm}
" " stomach, ...	20^{mm}
" " duodenum and ileum, . . .	40^{mm}
" " rectum, ...	20^{mm}
" " cloaca, ...	6^{mm}
Tail behind cloacal opening, . . .	75^{mm}

The esophagus is remarkably long and slender and is provided with highly distensible muscular walls. It passes into the stomach without any sharp line of demarcation (text-fig. 1). The stomach is usually straight and is directly continuous with the esophagus as in snakes. When much food is taken, a portion of it remains in the posterior part of the esophagus after the stomach has been moderately filled. In a few cases noted the stomach was distinctly curved, with the pylorus on the right side of the body. In histological structure the walls of the stomach comprise the usual muscular and connective tissue layers, while the mucous membrane is remarkably thin, and the glands short and much twisted (text-fig. 2). The lining, of simple columnar epithelium, continues directly into the shallow pits, from

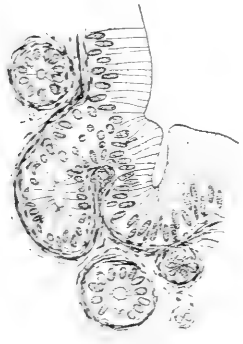


Figure 2. Portion of transverse section of mucosa of stomach, showing the simple short tubular gastric glands beneath the superficial epithelium. × 250.

the bottom of each of which one, two, or several short tubular glands extend to the rather thick muscularis mucosæ. In their basal portions the glands twist about considerably.

The pyloric valve is remarkably highly developed, as described by Leydig (**'72**, p. 120) for *Anguis*. It consists of a muscular, circular fold, fluted longitudinally and projecting into the lumen of the duodenum.

The duodenum has a diameter nearly as great as that of the stomach, and except for the sharp bend at its anterior end is almost straight. Its mucous membrane is thrown up into very conspicuous tongue-shaped villi (text-fig. 6), which are oval in section and placed with their long axes transversely to the length of the canal, as is common in many varieties of reptiles. The epithelium of the villus is, like that of the lining of the intervening intestinal surface, composed of simple columnar epithelium with thickly placed goblet cells (text-fig. 3). No other glands occur. The epithelial cells exhibit the peculiarly striated free border so characteristic of the small intestine of the higher vertebrates. Conspicuous blood and lymphatic vessels occupy the central portions of the villi.

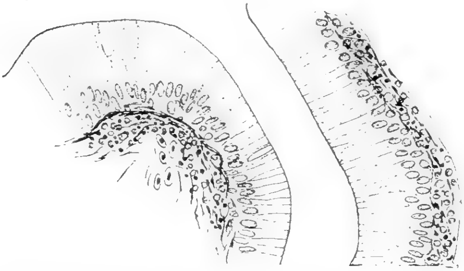


Figure 3. Section of epithelium of duodenum, showing absence of glands. ×250.

The duodenum passes imperceptibly into the ileum, there being no distinct line of demarcation either anatomically or histologically. The villi of the duodenum become gradually shorter and closer together, and eventually give place to irregular wavy folds which extend lengthwise throughout the ileum. The posterior end of the ileum, however, has a nearly smooth lining. Its posterior end is much narrower than the more anterior portions, and the change from ileum to large intestine is very marked; there is here a distinct annular constriction separating the two chambers (pl. XLIII, figs. 25, 26, text-fig. 1). This valve is marked by strong circular muscles, and the mucosa is thrown up into marked longitudinal folds. There is no free fold of the mucosa, however, such as occurs between stomach and duodenum or between rectum and cloaca.

The small intestine opens into the large intestine on one side of its central axis, so that an indication of a rudimentary cæcum is formed on the side farthest from this opening, as in most lizards. The large intestine is cylindrical and without convolutions. It lies in the middle line of the body and remains of about the same diameter throughout its length. Posteriorly it opens into the much narrower ventral cloacal chamber as described below. Instead of passing gradually into the cloaca, however, the posterior end of the large intestine is saclike and in ordinary states of contraction continues slightly farther back than the comparatively narrow opening into the cloaca. A pair of very shallow blind pockets are thus formed on the right and left sides of the anterior end of the ventral cloacal chamber. The epithelium of these blind pockets is sharply distinguishable from that of the other portions of the large intestine because of the presence of masses of lymphoid cells forming well-marked lymphatic nodules. In other states of contraction, however, the pockets entirely disappear, the large intestine passing gradually into the cloaca. The masses of lymphoid cells thus lie at the posterior end of the large intestine. The cloacal chambers and their relation to the ducts opening therein are described in detail in the chapter on the urogenital organs. The posterior opening of the cloaca is in ordinary states of contraction a transverse, crescent-shaped slit, guarded by a definite series of scales, as described in the following chapter.

Liver.—As is the case with the alimentary canal, the liver conforms in shape to the slenderness of the body, consisting of a single very slender mass with only a very small secondary lobe (text-fig. 1). The main body of the organ is apparently made up of the portion which constitutes the right lobe in most lizards, the small secondary lobe referred to being the left lobe, which is either rudimentary or has its anterior portions completely fused with the right lobe. The right lobe extends from a short distance behind the heart nearly as far as the posterior end of the stomach. It is somewhat crescentic in cross section, the concavity lying closely appressed to the esophagus, which it covers ventrally and on the right side in its normal position. Sometimes both esophagus and posterior portion of lung are almost completely surrounded thereby. The average length of the right lobe is about 50^{mm} in adult specimens, being very nearly one third as long as the distance from tip of snout to anal aperture. Both anterior and posterior extremities are very narrow. The epigastric vein enters the posterior end, while the vena cava inferior leaves the opposite extremity, and the portal vein enters the angle formed at the junction with the rudimentary left lobe.

The left lobe is represented by a very small projection situated a short distance behind the gall bladder and at about four fifths the distance toward the posterior end of the right lobe (text-fig. 1).

The gall bladder is conspicuous as a dark, oval body imbedded in the substance of the liver at about three fourths the distance toward the posterior end of that organ. In some cases it is largely covered by the liver tissue, but usually lies freely exposed ventrally. Several bile ducts (text-fig. 4) accompany the portal vein to the anterior end of the duodenum. One of these is larger than the four or five other ducts and probably leads directly from the gall bladder. They pass through the walls of the duodenum in company with the pancreatic ducts.

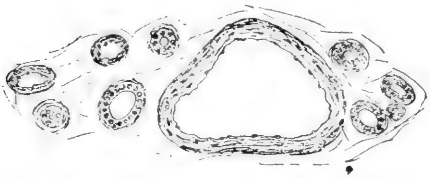


Figure 4. Section of portal vein with its accompanying bile ducts, of which three are seen on each side. × 62.

Pancreas.—Situated in the angle between the pylorus and anterior end of the duodenum, that is, on the ventral and right sides of the pylorus, are three small bodies of whitish color (text-fig. 1); two of these are flattened, irregularly triangular in outline and appressed rather closely to the stomach, while the third is ovoid, with a deeply pigmented posterior portion (text-figs. 5, 6). The two flattened bodies prove to be lobes of the pancreas; the paler portion of the ovoid body is likewise pancreas, while its pigmented posterior portion constitutes the spleen. In most cases at least two of these

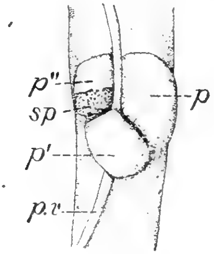


Figure 5. Ventral side of stomach and duodenum, showing position of lobes of pancreas and spleen; *p*, *p'*, left and middle lobes of pancreas respectively; *p''*, right lobe of pancreas, continuing posteriorly into spleen (*sp*); *p. v*, portal vein. × 3.

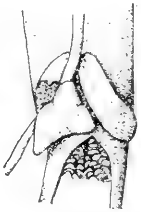


Figure 6. Ventral side of stomach and anterior portion of duodenum, the latter opened to show the tongue-shaped villi. The three lobes of the pancreas and the spleen are as in fig. 5. × 3.

bodies are more or less intimately fused together, and in some individuals all three are connected by a continuous mass of pancreatic tissue, the three bodies then being represented as distinct lobes of a single gland.

Of the pancreas lobes, one lies on the ventral and left side of the portal vein, close beside the pylorus. The second (text-figs. 5, 6) is situated somewhat posteriorly to this left lobe, and on the ventral side of the portal vein, and may be called the median lobe; it is sometimes slightly bilobed, and occasionally connected directly to the left lobe. The third lobe, which is intimately fused with the spleen (text-figs. 5–7), is usually situated a little anterior to the median lobe and to the right of the portal vein (text-figs. 5, 6); it may consequently be considered as the right lobe. It is usually connected with the left lobe by a mass of pancreatic tissue between the portal vein and the pylorus. Both the splenic and pancreatic tissues are so closely fused into a single mass that the spleen must be looked upon as an appendage to the right lobe of the pancreas.

Spleen.—As described above, the ovoid right lobe of the pancreas exhibits a marked differentiation posteriorly, in that the anterior part is pale and whitish in color, while the posterior portion is deeply pigmented (text-figs. 5–7). A longitudinal section shows that the pale portion is composed of true pancreatic tissue and the pigmented part has the histological structure of the spleen. The boundary between the two kinds of tissue is clearly marked by a thin layer of connective tissue.

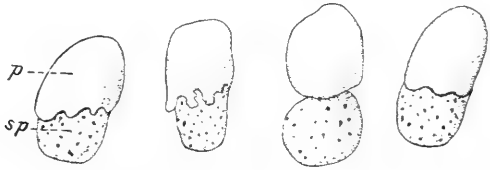


Figure 7. Outlines of right lobe of pancreas (*p*) in four individuals, showing its more or less intimate connection with the spleen (*sp*). × 6.

The spleen retains its natural ovoid shape and is imbedded anteriorly in the pancreatic mass, the convexity of the spleen fitting into a corresponding concavity in the pancreas. The extent to which the anterior portion of the spleen is buried in the pancreas varies in different individuals, as illustrated in text-fig. 7. The pancreas appears to grow back over the spleen by an outgrowth of its small lobules, so that the posterior border of the gland is irregular and wavy in outline. In a few cases the spleen was attached to the pancreatic lobe only by a narrow mass of connective tissue.

Lungs.—As stated above, the right lung is much elongated and well developed, while the left is small and rudimentary, although remaining functional. Both lungs are provided with a similar anterior lobe.

The larger, right lung is long and tubular, being largest in its middle portion and tapering gradually to the slender, pointed posterior end (text-fig. 8). The trachea enters the median border of this lung a short distance behind the anterior end, which is thus extended forward as a short anterior lobe. The lumen of this lobe is directly continuous posteriorly with that of the main portion of the lung, although there is often a slight constriction in this region. If the constriction becomes conspicuous, the opening into the posterior end of the anterior lobe is comparatively narrow.

The left lung is usually less than one fourth as long as the right, the cavities of the two being in all the individuals examined connected only by a narrow opening (text-fig. 8). Cope's statement (:**00,** p. 670) that the two lungs are fused proximally, "so that there is but a single lumen," is therefore erroneous or founded on an abnormal or artificial condition. The actual opening is small, oval in outline, and situated at the extreme posterior end of the trachea, which passes for a short distance along the median border of this as well as of the right lung. In this way the left lung is provided with an anterior lobe, projecting forward in front of the tracheal opening just as in the case of the right lung. The anterior end of this lobe is rounded and often fully as large as the corresponding lobe of the other lung. A slight constriction or lateral indentation usually occurs to demarcate the anterior lobe more definitely.

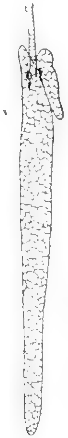


Figure 8.—Outline of lungs, showing large right lobe and rudimentary left lobe. × 1½.

Although the cavities of the two lungs are so well separated, yet the left lung is closely bound to the right by a strong sheet of connective tissue. The left lung is thus held closely appressed to the right except at its anterior and posterior extremities.

Although there exists such great discrepancy in size between the two lungs, yet both are functional in all parts. The walls of both are thin and membranous, the reticulate bars or laminæ, which carry the blood vessels, forming only shallow alveoli. There is in each lung, therefore, when well distended, a central air chamber nearly as large as the lung itself.

The anterior ends of both lungs are placed symmetrically close behind and beside the ventricle, the anterior lobe of each projecting forward to about the same extent (text-fig. 8). The large lung occupies the right side of the body cavity behind the heart and extends posteriorly on the dorsal side of the liver, while the esophagus is situated in a corresponding position on the left side of the body cavity. Nevertheless, when the lung is well distended and the esophagus empty, the lung actually fills the whole ventral portion of the body cavity for some distance behind the heart and thus lies ventral to the esophagus. This condition will, perhaps, justify Cope's statement (**: 00**, pp. 670, 671) that the lung lies ventral to the alimentary canal.

The average length of the right lobe in adult individuals is about 35^{mm}, and that of the left lobe about 8^{mm}, the comparative size in preserved specimens naturally depending largely on the state of contraction. In one instance noted the left was but 5^{mm} long and the right 30^{mm}. There is, however, great variation in size in life, particularly as regards the rudimentary lung. The length of the trachea is about 30^{mm}.

Cope states (**: 00**, p. 670) that the fusion of the lungs indicates a step nearer obliteration of one than occurs in any of the serpentiform genera of Teiidæ, Scincidæ, or Anguidæ, where, although reduced in size, the left is distinct from the right except at its anterior end.

II.—EXTERNAL ANATOMY AND SKELETON. B. W. KUNKEL.

Pl. XLI, figs. 4–8: Pl. XLII, figs. 9–24; Text-figs. 9–13.

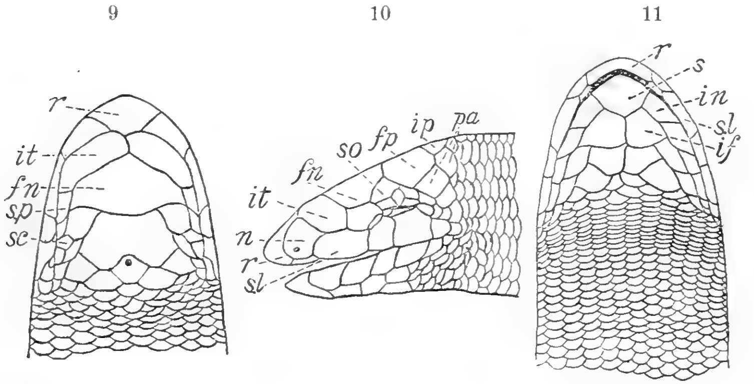
The external appearance of the limbless, snake-like lizard, *Anniella pulchra*, of California may be described as follows: Body cylindrical or flattened slightly dorso-ventrally. Head very much depressed, slightly broader posteriorly than rest of body and tapering gradually to a moderately sharp snout, which has the form of a truncated cone, and projects beyond the lower jaw. Body only slightly differentiated into head and neck. Externally there is no trace of limbs. Tail variable in length, being from one tenth to one half the length of body from snout to anus, due apparently to injury to this member. In every instance in which the tail was relatively short, it was rounded at the posterior end, but in several blunt-tailed individuals the tail was one half the length of the body proper, showing that when broken the tail always becomes rounded regardless of the position of the injury. Of some 50 adult specimens measured, the maximum length of the body from snout to cloacal opening was 153^{mm}, the average being 128.5^{mm}; the length of the tail of the same specimens averaged 41.1^{mm}; and the total length, 169.6^{mm}. The greatest diameter of these specimens varied from 5 to 7^{mm}.

There are apparently two distinct varieties of coloring, corresponding to the varieties *nigra* and *pulchra*. In the more common variety, *nigra*, which made up about two thirds of the total number of specimens examined, the dorsal side is of a dark purplish brown; and in the less common *pulchra*, it is of a pale steel blue. In both varieties the color is uniform and extends on the dorsal surface for about one third the circumference of the body; that is, ten or eleven longitudinal rows of scales on the dorsal side are deeply pigmented. Adjacent to the pigmented scales on each side is a row of scales slightly paler than the dorsal ones. In some of the more deeply colored specimens, the row next but one to the unpigmented is slightly darker than any of the dorsal ones, thus giving rise to a lateral line of darker color. The ventral side is always very faintly colored; the individuals of the variety *pulchra* are slightly more of a cream color on the ventral side than those of the darker colored variety, which tend more to a decidedly yellow color. There is comparatively little difference, however, in the coloring of the ventral side. In the variety *nigra* the scales on the ventral side show very slight and delicate pigmentation on their lateral borders, but this is entirely wanting in the paler individuals. The ventral side of the head and neck is pigmented like the dorsal side but is not quite so dark. This pigmentation extends back in the median line for nearly twice the length of the mouth, but not so far laterally, and gradually passes over to the general color of the ventral side of the body. A small number of scales immediately anterior to the cloacal opening are likewise pigmented in some individuals. The scales on the ventral side of the tail are pigmented on their lateral borders, giving the effect of slightly irregular zigzag lines equal in number to the longitudinal rows of scales on the ventral side. The pigment of the dorsal side extends around the tip of the tail for a distance of a millimeter or two on the ventral side.

There is no trace of an external ear, but the position of the auditory capsule in the skull is posterior to the specialized plates of the head. The eye is rather elongated and may be closed by a lower lid which is covered by three scales, the middle one of which is the largest.

Scales.

The scales covering the head are larger than those of the body and have a very definite position upon the underlying bones of the skull. The following are the most important peculiarities of the cephalic plates. The rostral plate (text-figs. 9–11, *r*) is more or less pentagonal, and is in contact with the nasals by a long suture, and with the low anterior end of the first superior labial and the internasoloreals, which have a short common suture. The nasals (text-fig. 10, *n*) are roughly rhomboidal with their apices directed posteriorly; they rest upon the first superior labials and are situated anterior to the second superior labials and internasoloreals.



Figures 9–11. Dorsal, lateral, and ventral views of head, showing arrangement of scales; *fn*, frontonasal; *fp*, fused frontal and frontoparietals; *if*, first infralabial; *in*, first inferior labial; *it*, internasoloreal; *ip*, interparietal; *n*, nasal; *pa*, parietals; *r*, rostral; *s*, symphysial; *sc*, second superciliary; *s.l*, second superior labial; *so*, supraocular; *s.p*, superior preocular. × 4.

The nostril is small and elongated with its long axis oblique; it is situated in the ventral and anterior portion of the nasal plate.

The internasoloreals are large and rectangular and meet in the middle line by a short suture which is slightly oblique. They are bounded posteriorly by the superior preocular and frontonasal (*fn*), which is a large median plate, subtriangular in form and somewhat wider than long. The superior preocular (*s.p*) is pentagonal, with its apex reaching the eye posteriorly; it is in contact ventrally with the second superior labial (*s.l*) and the very small elongated inferior preocular, and dorsally with the frontonasal, the supraocular by a very short suture, and with the most anterior of the three small superciliaries. Posterior to the frontonasal is a single large hexagonal scale, according to Cope (:00) probably the fused frontal and frontoparietals (*fp*), provided with a notch on its posterior margin to accommodate the small interparietal. The inferior preocular is situated ventrally with respect to the superior preocular. It is very small, linear or subtriangular in form with its base directed dorsally; it is in contact on the ventral side principally with the third superior labial and sometimes also by a very short suture with the second superior labial. Out of more than 30 specimens examined, four were found in which the inferior preocular was absent and in two cases it was present on the right side only.

The first supraocular (text-fig. 10, *so*) is triangular and situated posteriorly to the frontonasal and laterally to the large fronto-frontoparietal. It is in contact also with the second supraocular posteriorly, also with the superior preocular by a very short suture, and the first and second superciliaries. The second supraocular is rather small and elongated; situated dorsally to it are the fronto-frontoparietal and the outer one of the parietals; ventral to it are the second and third superciliaries; anterior to it are the first supraocular and second superciliary, and posterior to it are the parietal and one of the postoculars.

The three superciliaries form a series dorsal to the eye: the middle one (*sc*) is lozenge-shaped and higher than broad and separates the first and third, which are subequal; the first superciliary is elongated with parallel sides and is in contact with the superior preocular anteriorly and ventrally; the third is slightly lower than the first and is bounded dorsally by the second supraocular and by the superior postocular posteriorly.

Two squamiform subequal postoculars lie side by side in transverse series; the inferior one is in contact ventrally with the fourth superior labial; the superior postocular is bounded anteriorly by the second supraocular and the third superciliary, and dorsally by the parietal. Posterior to these the regular squamation of the body proper begins.

There are six superior labials which form a series bounding the mouth dorsally: of these the first is very low and situated ventral to the rostral and nasal plates; the second (*s.l*) is the largest, about twice as long as high, subrectangular in shape and in contact with the internasoloreals and superior and inferior preoculars dorsally;

the third is higher than broad and is bounded dorsally by the inferior eyelid, the anterior preocular and the fourth superior labial; the fourth is subrectangular, smaller but somewhat higher than the second and reaches the inferior eyelid; it is in contact also with the postocular dorsally and posteriorly. The fifth and sixth are somewhat smaller than the others; they are both squamiform and scarcely to be distinguished from the regular scales on the body in the same region.

Lying in the notch of the fronto-frontoparietal is the rhomboidal interparietal (text-fig. 10, *ip*), which bears somewhat anterior to its centre the browspot, a pigmentless area of circular shape and indistinct outlines, whose diameter is equal to about one fourth the greatest width of the scale. It is bounded posteriorly by the occipital plate in the median line and the parietals. The occipital is rhomboidal in shape and smaller than the interparietal and parietals. Two subequal, rhomboidal parietals (*pa*) are arranged on each side in a transverse row posterior to the fronto-frontoparietal and the interparietal. Several rows of scales posterior to these are slightly larger than the body scales.

On the lower jaw is a large symphysial plate (text-fig. 11, *s*) subhexagonal and equilateral. It is flanked by the first inferior labial (*in*), which is trapezoidal in form. Six inferior labials of gradually diminishing height form a series bounding the lower jaw medially. The second inferior labial is rhomboidal and of about the same size as the first. The fifth and sixth are considerably smaller than the others. Situated medially with respect to the inferior labials is a series of four infralabials. The first infralabials (*if*) are large and trapezoidal in form. They meet in the middle line and are bounded laterally by the first and second inferior labials; the second and third infralabials are oblong, about twice as long as broad; the third is somewhat smaller; and the fourth considerably smaller than the third. There is a second series of infralabials situated medially with respect to the first. The first scale of this series is broad and meets its fellow in the middle line by a long suture; the second is somewhat smaller and trapezoidal. Two squamiform scales somewhat larger than the regular scales of the body are situated posterior to the first infralabials of the second series medially. Posterior to these the regular squamation of the body begins.

The scales of the body in the region of the neck are considerably narrower in an antero-posterior direction than those of the body proper. There are also several more longitudinal rows in this region to allow for the slightly larger diameter of the base of the head. The scales of the body (text-fig. 13) are very regular in size and shape, subhexagonal or cycloidal and strongly imbricate and arranged in from 26 to 32 longitudinal rows, 30 being the usual number; the margins are entire and the surface smooth.

There are five preanal scales (text-fig. 12), of which the median one is the longest and more or less wedge-shaped with its apex posterior. The lateral scales are subequal and lozenge-shaped.

Some embryos just previous to the time of birth showed several interesting variations from the adult type. The interparietal plate of the embryo is much broader relatively than in the adult and the posterior margin of the fronto-frontoparietal is more rounded in its contour than in the adult (pl. XLII, fig. 11). The interparietal also showed considerable variation in size, for in some cases it was not only relatively but also actually larger than in the adult. In a single embryo the parietal in contact with the interparietal on the right was replaced by three small cycloidal scales which occupied approximately the same space that the single parietal on the left did. Of these three the anterior was the largest and the posterior one was the smallest and overlapped the occipital more than did the parietal on the left.

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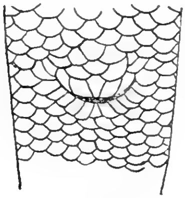

Figure 12. Arrangement of scales about cloacal aperture of adult. ×4.

13

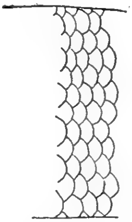

Figure 13. Arrangement of scales of body, seen from left side. ×4.

The position of the pineal eye with reference to the interparietal plate shows much variation in these embryos; usually it is in the anterior portion, but it may lie centrally or even posteriorly. In the adult, on the other hand, the pineal eye always lies entirely in the anterior portion. The eye can be seen clearly beneath this plate, for there is a circular unpigmented area directly above it with a diameter about twice that of the underlying structure (fig. 10), so that the eye appears as a perfectly black spot surrounded by a pigmentless area which blends off into the general color of the dorsal side.

Dermal Ossifications.—Dermal ossifications are strongly developed, underlying each scale. They are usually palmate in form with four or more rays and usually exhibit one or more foramina. Their outlines are irregular. The rays arise from a more or less stout base and extend posteriorly (pl. XLII, figs. 15–19).

Skeleton.

Skull.—The skull of *Anniella* is, in a general way, conical, corresponding for the most part to the external form of the head; posteriorly it extends beyond the differentiated cephalic plates. The cranium is broadest at the posterior portion of the fused parietals and supraoccipital which encloses the internal ear. Posterior to the broadest point the skull is more nearly hemispherical in form. The cranium is fairly well developed in comparison with the facial part of the skull.

The premaxilla (pl. XLI, figs. 4, 5, and 6, *pm*) is single and bears four or five teeth, and has a large median process which extends posteriorly and dorsally and separates the two nasals; the palatal portion bears posteriorly a slender median spine and two triangular processes. The latter are embraced externally by the maxillæ. Each maxilla (*mx*) bears usually six teeth, which are situated on a ledge on the inner side; the facial portion is large; the maxilla is in contact with the premaxilla and nasal anteriorly; the frontal, prefrontal, nasal, and jugal dorsally; with the supraorbital and ectopterygoid posteriorly, and with the palatine, ectopterygoid and vomer medially. The nasals (*n*) are rather large and separated anteriorly by the median process of the premaxilla. The facial portion of the maxilla and a slender process of the frontal lie externally.

The frontals (*fr*) form a wide entrant angle between the nasals posteriorly and, by a very small process, separate the nasals from the prefrontals. There is a small foramen on the external margin near the posterior end of the suture with the maxilla. Each prefrontal (*p*) is bounded medially by the frontal and to a slight extent by the maxilla, ventrally and posteriorly by the orbit of the eye and supraorbital, anteriorly and ventrally by the maxilla. The posterior end reaches the postfrontal; the descending process is well developed.

Posterior to the prefrontal is the small postfrontal, which is crescentic in shape and is situated laterally to the frontal and parietal, the concave border fitting over the angle formed by the frontal and parietal at the coronal suture. The postorbital is very small and scale-like, attached to the outer and posterior aspect of the postfrontal. The frontals (*fr*) are large and separate. They are slightly separated posteriorly by an entrant angle of the fused parietals. Laterally are situated the prefrontal and postfrontal. The descending processes meet ventrally, enclosing the olfactory lobes. The parietals (*pa*) are fused and very large. There is no pineal foramen, but near the anterior margin is a cavity on the under side in which lies the pineal eye as has been described for *Anguis*. The parietal broadens posteriorly, although just behind the coronal suture it is constricted sharply so that the lateral angles overhang. Posteriorly the two lateral portions are prolonged considerably to fit externally to the supraoccipital; in the median portion of the posterior edge of the parietal are several slender teeth for gomphosis with the supraoccipital (*so*). In one specimen there were four, as figured, but in others the lateral teeth had disappeared. Near the middle of the suture with the supraoccipital are two oval depressions. A short process of the outer and posterior end of the parietal rests on the petrosal and supports the anterior end of the squamosal. The parietal is in contact with the frontals, postfrontals, petrosals, squamosals, and supraoccipital.

The supraoccipital (*so*) is large and is fused with the exoccipitals. There is a deep notch at the posterior margin dorsal to the foramen magnum. This bone is expanded considerably to accommodate the anterior semicircular canal. In each internal ear there is a single large lenticular mass of very white carbonate of lime, the otolith. The horizontal semicircular canal extends around the otolith medially and very nearly meets its fellow in the middle line.

The vomers (fig. 5, *vo*) are separated anteriorly by the median process of the premaxilla. They are in contact with each other for about one half of their length but are separated posteriorly. The maxillæ and palatines lie externally to the vomers, immediately behind which the posterior nares open. There is a strongly developed longitudinal keel on each vomer which becomes more prominent posteriorly, and a foramen in the middle of each.

The palatines (*pl*) are separated widely from each other by the vomers and are in contact also with the maxillæ, ectopterygoids, pterygoids, and prefrontals; they are short and, with the ectopterygoids, enclose the anterior halves of the palatine foramina. Each pterygoid (*pt*) is long and Y-shaped and encloses the palatine foramen posteriorly. The outer limb of the Y is united with the ectopterygoid (*ec*) by a transverse suture; the posterior limb is the longest and extends medially to the quadrate. The median limb of the pterygoid articulates with the palatine. A short distance posterior to the union of the three limbs of the bone there is an articulation with a triangular process of the basisphenoid, called by Cope the basipterygoid process (*b*). The ectopterygoid forms a continuation of the outer limb of the pterygoid, fits into a notch of the posterior portion of the maxilla, and also sends a slender process, which comes in contact with the palatine, medially along the posterior margin of the maxilla.

The basisphenoid (*bs*) is more or less triangular in shape with two lateral processes, the basipterygoids, articulating with the pterygoids. The lateral, posterior processes of the basisphenoid unite with the basioccipital. The basioccipital (*bo*) is large and bears a single, simple occipital condyle; in one of Baur's ('94) specimens the sutures between the exoccipitals and basioccipital, which enter into the formation of the condyle, could be distinguished. The basioccipital and basisphenoid are not co-ossified. The quadrate (*q*) is more or less tri-radiate in form; it lies external to the stapes (*st*), the columellar portion of which fits into a slight concavity on its posterior aspect. The ventral arm lies external to the pterygoid. The stapes is large, the tympanic portion thick and circular, the columellar portion short and stout. The petrosal, according to Cope, lies lateral and posterior to the parietal; the anterior border is notched to receive the lateral borders of the parietal; the supraforaminal portion of the petrosal is produced to an acute angle, terminating at the parietal border much in advance of the anterior semicircular canal. The body of the petrosal is perforated by a large foramen just in front of the superior part of the quadrate.

The jugal (*j*) is slender and somewhat curved, free at its distal end and united with the maxilla at the posterior facial portion. It bounds the orbit of the eye ventrally and posteriorly. The squamosal (pl. XLI, fig. 6, *sq*) is small and of irregular shape, flat and splint-like. It lies dorsal to the quadrate and stapes and external to the parietal, petrosal, and supraoccipital. The exoccipitals are fused with the basi- and supraoccipitals. The lachrymal is very small and in connection with the maxilla on the outside, and the prefrontal on the inside. The supraorbital (*s*) is large and placed above the orbit anteriorly. The epipterygoid, mentioned by Cope, is very delicate and somewhat L-shaped. I could not determine its position, but found it in a thoroughly macerated skull.

The mandible is made up of the articular (fig. 7, *a*), angular, coronary (*cor*), dentary (fig. 7, *dn* and fig. 8), and splenial (*sp*). The articular is co-ossified with the supraangular. The angular is flat and splintlike, situated on the external aspect of the mandible, external to the articular and dentary. Eight teeth are usually borne on the dentary. They are acutely conical, grooved on the inner surface and directed slightly backwards.

The hyoid apparatus is, according to Cope, the simplest among the lizards: it consists of a continuous glosso-hyal rod, which is bifurcate posteriorly, and a simple branchihyal attached to each of the branches. The other elements are wanting (pl. XLII, fig. 12).

Vertebræ.—The vertebræ are procœlous. The presacrals vary in number from 71 to 74, and all have simple ribs attached except the first two. In a single specimen Baur found that there was a short rib present on one side only of the second vertebra. The neural spines are well developed and directed posteriorly (pl. XLII, figs. 21 and 22). No zygosphene is present on the cervicals, which are distinguished by the presence of ventral processes. The processes diminish posteriorly, and that of the first vertebra is bilobed. The transverse processes arise from the anterior portion of the vertebræ (fig. 19).

There are four sacral vertebræ with no ribs attached, but with the transverse processes much developed. The first has a simple process directed slightly backwards; the second has the process split distally, the posterior prong being smaller and variable in position. The third has the same form as the second, but the notch at the extremity of the transverse process is deeper. It also shows the first indication of a chevron in the form of two parallel plates placed lengthwise on the ventral side of the centrum and not uniting distally. In one specimen these plates were wanting. The fourth is similar to the third but the chevron is complete. Baur ('94) found the chevron incomplete as in the preceding and the splitting of the transverse process only on one side. The first caudal and all the succeeding have simple caudal ribs, diapophyses, directed anteriorly, and completely formed chevrons pointing posteriorly. The chevrons are situated at the posterior ends of the centra and not intercentrally. The transverse splitting of the vertebræ in the tail commences at the third caudal. A portion of the base of the transverse process is included in the small anterior segment; the posterior segment is procœlous (figs. 23 and 24). The number of caudals varies. In one specimen with a moderately long tail there were 36.

Ribs.—The ribs are slender, gradually tapering and curved (pl. XLII, fig. 13). They increase in length to the tenth and then gradually diminish. The anterior ribs incline more posteriorly than the rest. The articular facet is triangular with the apex of the triangle directed ventrally. There is a single rounded notch at the middle of the base of the triangular facet, which is slightly concave. Posteriorly they become circular. The last two ribs are considerably shorter and slightly stouter than the rest.

Pelvis.—The shoulder girdle is entirely wanting. The pelvic girdle is very rudimentary and is represented solely by a pair of somewhat flattened, rod-like bones (pl. XLII, fig. 14) attached by ligaments to the extremities of the transverse processes of the second sacral vertebra and extending medially and anteriorly in front of the cloacal aperture. The anterior ends of the pelvic rods are not constant in the degree to which they approach each other, but they never come in contact. Each presents a slight triangular process on its ventral and inner side about one third the distance from the anterior to the posterior end. Baur states that he found in a macerated skeleton that the girdle was differentiated into an ilium, ischium, and pubis, but in a careful study of the adult and in sections of late embryos I have been able to find but a single bone and have seen no indication whatever of more than one center of ossification. Baur also found an obturator foramen, which does not appear in my preparations. Serial sections of the embryos and adults showed a simple cylindrical rod of cartilage with rounded ends situated in the middle line ventral to the bladder and anterior to the pelvic bones. It probably represents the epipubis.

III.—UROGENITAL ORGANS.

W. R. COE AND B. W. KUNKEL.

Pl. XLIII, figs. 25, 26; Pl. XLIV, figs. 27–32; Pl. XLV, figs. 33–37; Pl. XLVI, figs. 38–43; Text-figs. 14, 15.

The material on which these studies were made was collected at Pacific Grove, California, during the months of August and September, 1901. At this time of the year the female lizards give birth to their young. Some of the females collected had already discharged their young while others still carried embryos, all of which were in an advanced stage of development. Some of the embryos, however, represented a much later period of embryonic life than did others, so that we have been able to follow the later development of the copulatory and other reproductive organs through their final stages of development and to compare them with the similar organs of the newly-born young and with those of the adult. We are therefore unable to give any account of the earlier stages of development either of the reproductive organs or of any of the organs of the body.

The most striking feature of the well-advanced embryos is the possession of a pair of very conspicuous copulatory organs, which project from the sides of the cloacal opening and strongly resemble a pair of limbs. When most prominent these appendages project from the ventral side of the body for a distance fully one third as great as the diameter of the body itself in the same region. They are then gradually withdrawn into the cloacal aperture, and at the time of birth are fully concealed beneath the lips of this opening. Such appendages occurred in all embryos of a certain stage of development, and were apparently as conspicuous in females as in males.

It was to study the structure and subsequent fate of these organs in both sexes that our studies were undertaken. This led naturally to an examination of the other reproductive organs of the adult animals, and in this connection a number of interesting peculiarities in which these lizards differ from others have been revealed. Some of these peculiarities are briefly described in two preliminary papers already published (Coe and Kunkel, **:04** and **:05**), but are here given in greater detail.

In the following account of the urogenital organs, including the peculiar structure of the two cloacal chambers and the copulatory organs, most of the details of structure will be omitted except where peculiarities are described which are different from those of the closely related European limbless lizard, *Anguis*, and other lizards. For a general treatise on the anatomy of *Anguis* the reader is referred to the admirable accounts given by Leydig (**'72**) and Braun (**'77**).

Testes and Sperm Ducts.

As is the rule in the lizards and many other reptiles, the right genital gland is situated more anteriorly than the left, so that the right genital duct is the longer. In *Anniella* the right testis is usually about its own length in advance of the left (pl. XLVI, fig. 38).

These glands are in life creamy white in color and are situated at an average distance of about 3^{cm} anterior to the cloacal aperture in the adult lizards. Each gland is oval in shape, of regular outline, about 5^{mm} in length when mature and about half as wide. The tubules of which it is composed are loosely coiled, and can be seen with a hand lens, the connective tissue tunic being much less firm than in many lizards.

At the anterior end of the testis the tubules enter a very fine, much convoluted duct, forming the epididymis, which passes forward as far as the adrenal body, and then bends abruptly backward, passing along the lateral face of the testis to join the vas deferens.

The *vas deferens* is likewise much convoluted. It receives the epididymis on the lateral border of the testis, and, with many convolutions in its anterior half, passes back to open at the summit of a longitudinal ridge or papilla situated on the dorsal wall of the dorsal cloacal chamber (pl. XLV, fig. 35, *v.d*) a little in advance of the opening of the ureter, as will be described below. The opening of the vas deferens into the cloaca is guarded by a strong sphincter of circular muscular fibers (pl. XLV, fig. 35), the contraction of which also raises the posterior end of the ridge on which the opening is situated into a prominent papilla. This papilla is doubtless greatly enlarged at the time of copulation.

The epididymis is lined with a single layer of flattened or cuboidal cells, while the vas deferens has a lining of a single layer of columnar cells, and these increase in height toward the posterior end of the duct.

Ovaries and Oviducts.

As is the case with *Anguis* and numerous other lizards, *Anniella* is ovoviviparous, usually giving birth to two well formed young at each breeding season. These young are very vigorous and active from the moment of their birth. Externally they resemble the adults in almost every particular except as to size and in some cases color, for all the young appear to be of the gray or silvery variety, while the adults exhibit two well marked color varieties as described on the preceding pages.

The genital glands of the female are situated in a position similar to those of the male, but are considerably larger. Their size naturally varies directly with the increase in size of the ova as the time approaches for the discharge of the eggs into the oviducts. As a rule the right ovary is slightly larger than the left, although in all probability both produce an equal number of eggs.

Since only one egg is usually matured in each ovary at each breeding season, as a rule one ovum in each ovary is distinctly larger than the others. The ovary is irregular in shape, conforming to the uneven arrangement of the larger and smaller ova, so that this gland is naturally smallest immediately after the discharge of its one large ovum. We are unable to state the time of year when such discharge takes place or the actual size or appearance of the egg on reaching the oviduct. As will be described below, the left oviduct is aborted and functionless in all of the individuals which we have examined, so that both the eggs discharged from the ovaries must enter the right oviduct.

Microscopic sections of the ovary indicate that the ova develop in a manner quite similar to that described for *Lacerta* by Hoffmann ('89). The conspicuous zona radiata of the partly developed ovum is surrounded by a single layer of smaller cells, each of which is very similar to the egg itself. Among these smaller follicular cells, as well as on their internal and external faces, are minute nuclei of cells which form a sort of capsule for the follicular cells. As the ovum increases in size and acquires more yolk, the follicular cells, which were previously so very similar to the ovum itself, become gradually smaller and more numerous. Their function is evidently to elaborate food materials which pass through the zona radiata to the ovum. The presence of a capsule about the follicular cells indicates that they are merely degenerate ova which contribute their food materials to the support of the single ovum which reaches maturity.

Oviducts.—The most striking peculiarity of the oviducts is the fact that the right oviduct only is capable of receiving the eggs discharged from the ovaries, and it is, therefore, in the right alone that the embryos develop. In every one of the numerous females examined the left oviduct was much aborted, seldom exceeding a few millimeters in length (pl. XLIII, figs. 25, 26) and entirely incapable of performing its normal functions.

The *right oviduct* is very similar to one of the oviducts of *Anguis* and other lizards. When without eggs it is a long slender tube, exhibiting numerous convolutions in its anterior half, and extending forward anterior to the ovary. Its anterior end usually lies near the posterior end of the liver, and opens into the body cavity by a large, funnel-shaped opening (pl. XLIII, figs. 25, 26, *o*) as in other lizards. This terminal ostium is supported by strong mesenteries, forming the broad ligament, and commonly lies several times its own length in front of the ovary.

The ostium leads into a narrow, much convoluted tube which passes backward on the lateral face of the ovary. If there are no eggs or embryos in the oviduct this tube retains an almost uniform diameter throughout its whole length. It opens posteriorly at the summit of a small papilla (pl. XLV, fig. 34, *g.p*) situated on the ventral wall of the dorsal cloacal chamber, as described below. When eggs or embryos are present, however, the oviduct swells out to form a broad uterine sac in the region occupied by them.

The exact shape and size of the egg in life has not been carefully noted, the drawing on plate XLIII having been made from a specimen after preservation. In this specimen (fig. 26), and in several others similar, the two eggs occupied almost the whole length of the uterus between the ovary and the anterior end of the kidney. The eggs were separated from each other by a marked constriction in the uterine wall, and the wall was similarly sharply constricted both in front of the eggs and behind them. Each of these eggs was long and elliptical, but was decidedly narrower in the middle than toward the ends.

Left oviduct.—As stated above, the left oviduct remains through life in a very rudimentary condition and even atrophies to such an extent that it reaches in adult females a length scarcely exceeding that of the kidney, as shown in figs. 25, 26, pl. XLIII. The average length is about 20^{mm}, but varies widely in different individuals even when sexually mature. In a single specimen the length was 40^{mm}, and in another equally large specimen it was but 15^{mm}. These were the limits of variation, but these extremes are much greater than is the case of any other organ. This condition would indicate a very recent degeneration of this functionless oviduct.

A consideration of the condition of the oviducts in *Anguis* and other reptiles further emphasizes the fact that we have in this organ in *Anniella* a much more advanced stage of degeneration than occurs in any other reptile, while the degeneration is along the same lines as in the large number of reptiles in which the left oviduct presents various degrees of diminution in size as compared with the right. *Lacerta* and most other lizards have the left oviduct more or less conspicuously shorter and smaller than the right, corresponding with the different position of the two ovaries.

This aborted oviduct is slender and cylindrical, and is of about the same diameter throughout. At its anterior end, however, it usually bends on itself sharply and either ends abruptly (pl. XLIII, fig. 25) or extends for a millimeter or two farther as a very narrow tube with one or two sharp turns (pl. XLIII, fig. 26). It is supported anteriorly by a delicate mesentery which runs forward toward the ovary in the position which the oviduct would occupy if it were fully developed.

We found it difficult to determine whether this aborted oviduct in all cases opens into the body cavity. In the case noted above, where it was exceptionally long, such an opening could be distinctly made out. Several shorter oviducts, however, were so small and delicate at their anterior terminations that serial sections failed to show clearly whether a minute ostium was present or not.

It should be emphasized, however, that this left oviduct corresponds closely in shape, position and general appearance with that terminal portion of the right oviduct which lies posterior to the uterus. Its histological structure, too, is practically the same, for it is provided with an abundance of compound tubular glands (pl. XLV, fig. 37). These glands extend through about two thirds of the thickness of the wall of the oviduct, and discharge their secretions into its lumen by means of rather large ducts. The epithelial lining of the oviduct consists of medium-sized columnar cells, which become more or less cuboidal in the glands themselves. In the posterior portions of the oviduct the glands increase so greatly in number and complexity as to form an almost continuous layer beneath the epithelium of the lumen. Toward the posterior openings of the oviducts, however, the glands disappear, the lumen becomes much smaller, and a distinct layer of circular muscles is formed outside the epithelium of the lumen.

The aborted oviduct thus appears to have retained in some measure its secretory function, even though it is of little importance in the economy of the body. Like many structures which show evidence of recent degeneration, this rudimentary organ exhibits a very considerable variation in length and size in different individuals. While its average length is about equal to that of one of the kidneys, yet in several instances it has been found to be much shorter, and in the single case referred to above it was considerably longer than usual, and had a distinct anterior ostium. It is conceivable that in an exceptional case it might actually remain of sufficient size to receive and support an egg.

The openings of both oviducts are side by side on the summit of a pair of closely united papillæ situated in the median line of the body on the dorsal side of the thick horizontal partition separating the dorsal from the ventral cloacal chambers (pl. XLV, fig. 34 and pl.

XLVI, fig. 40). These will be described in detail below. In the papilla itself the lumen of the oviduct is much reduced in size.

It should be noted that in the closely allied *Anguis* both oviducts are well developed, and both bear an approximately equal number of embryos, some 15 to 20 young being produced in a single season (Leydig, '72, p. 180). In *Amphisbaena* both oviducts are likewise of about the same size (Bedriaga, '84, p. 67), as is also the case in *Anops* and *Trogonophis* (Smalian, '85, p. 191).

It is to be remembered that it is the left oviduct which is aborted in *Anniella*, while in birds it is the right which has degenerated even more completely. In numerous reptiles the left oviduct is shorter than the right, but so far as we can learn retains its normal functions in all lizards except *Anniella*.

Cloaca.

The cloaca in *Anniella* is made up of three more or less well demarcated chambers, of which two constitute the anterior portion of the cloaca and the third the posterior portion. The two anterior chambers are separated by a thick horizontal partition (pl. XLV, fig. 35, *h*), so that one of them lies directly dorsal to the other. We shall therefore refer to these three chambers as ventral, dorsal, and posterior (*v.c*, *d.c*, and *p.c*, pl. XLVI, fig. 40).

The ventral cloacal chamber (pl. XLV, fig. 35, *v.c*) is a narrow tube with rather thick muscular walls. Its mucosa is thrown up into high longitudinal ridges so that the lumen of the tube is comparatively small. It leads from the opening of the large intestine, described in a preceding chapter, to the posterior cloacal chamber. The urinary bladder enters this chamber by a narrow opening in its ventral wall near its anterior end (pl. XLVI, fig. 40, *bl*). The columnar epithelium lining this tube is not very different from that of the large intestine.

The dorsal cloacal chamber is a rather large space lying directly dorsal to the thick horizontal partition which separates it from the ventral chamber. On the walls of this cavity the openings of the ureters, Wolffian, and genital ducts are situated.

In the male, as described above, the sperm ducts open on the summit of a pair of longitudinal ridges (pl. XLV, fig. 35, *v.d*), situated on the dorsal surface of the chamber. The ureters open directly posterior to them.

In the female the conditions are somewhat more complex, for the oviducts have their openings close together on the summit of a pair of closely united papillæ which are situated on the dorsal wall of the horizontal partition and thus on the *ventral* wall of the dorsal cloacal chamber (pl. XLV, fig. 34). In some individuals the papillæ extend backward and project slightly beyond the posterior end of the partition, so that their tips are visible when the posterior chamber is opened. In most cases, however, such is not the case, the tips of the papillæ being hidden from view by the horizontal partition. Although in ordinary cases a pair of such papillæ is present, yet the state of contraction of the parts may be such that both oviducts lie very close together and apparently form but a single papilla. Each of the oviducts is surrounded by a firm layer of circular muscular fibers, which are nearly as well developed in the left as in the right oviduct, although the lumen of the left is usually smaller than that of the right.

The ureters, on the other hand, open on the dorso-lateral aspect of the dorsal chamber very much as in the male. Their openings are thus widely separated from those of the oviducts, although both lie in a frontal plane passing through the posterior extremity of the horizontal partition (pl. XLV, fig. 34, *u*). Thus the openings of the ureters really lie on the boundary between the dorsal and posterior chambers.

The posterior cloacal chamber is about as wide and as deep as it is long; its walls are very distensible and are commonly thrown up into fairly distinct longitudinal folds. Its epithelial lining is composed mainly of large, clear mucous cells, the nuclei of which are situated in the bases of the cells and appear to be irregularly arranged in two or more layers. The opening of this chamber to the exterior is guarded by strong circular muscles, and when contracted its epithelial lining shows conspicuous longitudinal folds (pl. XLVI, figs. 40–43).

The general relations of the cloacal chambers and the ducts opening therein are shown in text-figures 14 and 15 for both embryo and adult female. In the ideal sagittal section of the cloaca of the late embryo (text-fig. 14), the ureter (*u*) and the Wolffian duct (*W.d*) both open directly into the dorsal cloacal chamber (*d.c*) somewhat laterally, while the oviduct (*od*) is indicated by dotted lines as it opens on the dorsal side of the thick horizontal partition (*h*) very near the median line of the body. The ventral cloacal chamber (*v.c*) is very broad and directly continuous with the narrow rectum (*r*).

In the adult female (text-fig. 15) the horizontal partition separating the dorsal from the ventral chamber forms a broad shelf and the oviduct (*od*) opens near its free posterior margin, instead of at its base as in the embryo.

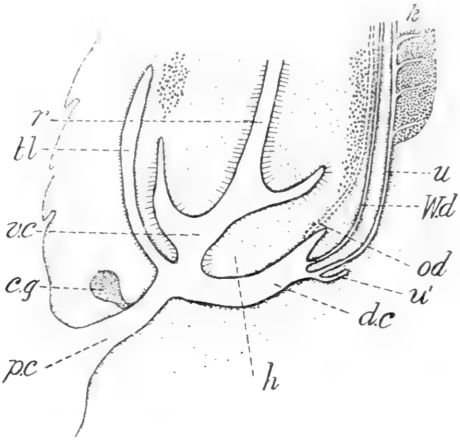

Figure 14.—Ideal sagittal section of cloaca of female embryo: *bl*, bladder; *c.g*, cloacal gland; *d.c*, dorsal chamber; *h*, horizontal partition between cloacal chambers; *k*, kidney; *od*, oviduct; *p.c*, posterior chamber; *r*, rectum; *u*, ureter; *u'*, diverticulum of ureter; *v.c*, ventral chamber; *W.d*, Wolffian duct. ×14.

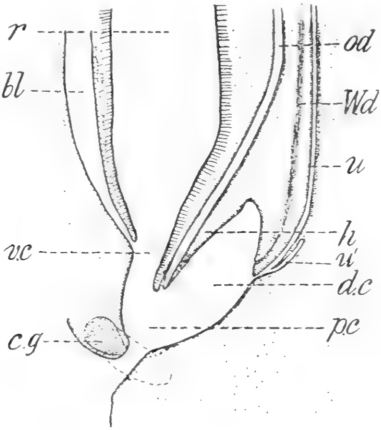

Figure 15.—Ideal sagittal section of cloaca of adult female. Reference letters as in preceding figure. ×7.

The copulatory organs in both sexes are situated in the posterior wall of the posterior cloacal chamber, as described below, and well-developed anal glands pour their secretions into it near its external opening.

Kidneys.

The kidneys are elongated oval bodies, about 9 to 12^{mm} in length, and 3 to 4^{mm} in width. They are much flattened dorso-ventrally and slightly concave ventrally and convex dorsally to correspond with the curvature of the body wall against which they lie. They are situated dorsal to the rectum, which they approximately equal in length. They also lie somewhat obliquely in the body, their posterior ends coming nearly in contact in the median line, while their anterior ends are somewhat more widely separated.

The posterior end of each kidney (pl. XLIII, figs. 25, 26, *k*) lies very near the dorsal wall of the cloaca, so that the ureter, which passes along the whole length of the median face of the kidney, is a very short tube.

Ureters.

From the median faces of the kidneys the ureters pass directly to the dorsal cloacal chamber, where they open slightly posterior to the openings of the genital ducts. In the male the sperm ducts open on the dorsal wall of the cloacal chamber, so that the openings of the ureters lie directly posterior to those of the sperm ducts; whereas in the female the oviducts open on the ventral wall of the dorsal chamber, so that these two sets of openings are separated by the dorsoventral diameter of this chamber.

Immediately before opening into the cloaca, each ureter has a small diverticulum (pl. XLV, fig. 35, *u'*) which passes anteriorly parallel to the uterer and close beside it for a short distance, and ends blindly (text-figs. 14, 15).

The openings of the ureters are near the lateral borders of the dorsal wall of the cloaca, and well separated from the median line. The oviducts, on the other hand, open close together near the median line, as described above. Osawa ('98) describes a similar relation in *Hatteria*. Leydig ('72), however, has the relative position of the openings of oviducts and ureters in *Anguis* the reverse of that found in *Anniella*.

The position of the openings of the ureters relative to those of the genital ducts is considerably different in the two sexes. In the male these openings are situated on the summits of the urogenital papillæ immediately posterior to those of the genital ducts (pl. XLV, figs. 35, 36), while in the female they retain a similar position as regards the cloacal chambers but are separated from the openings of the oviducts, as described above, by the lumen of the dorsal cloacal chamber (fig. 34). The openings differ further in the two sexes in that those of the male open on papillæ, the urogenital papillæ, while those of the female do not.

Urinary Bladder.

This organ lies on the ventral side of the rectum and although its opening into the anterior end of the ventral cloacal chamber is in the median line, yet its main portion usually lies on the right side of the rectum (pl. XLIII, figs. 25, 26: pl. XLVI, fig. 38). In but a single individual out of upward of twenty which were examined was the bladder situated on the left side of the rectum, and in no case did it lie in the median line.

Its walls are thin, and were collapsed in every individual examined. In no case did the bladder contain any appreciable amount of fluid.

In length it is usually somewhat less than that of the rectum and its diameter about one fourth as great as that of the rectum, so that in shape it is a rather slender cylinder slightly larger at the rounded blind anterior end than elsewhere.

Wolffian Ducts.

The Wolffian body is highly developed in the half-grown embryos and the Wolffian duct becomes of considerable size. This duct, as is well known, later forms the genital duct of the adult male, while in the female of most animals it degenerates and disappears. In *Anniella*, however, as in certain other lizards, it persists throughout life in females as well as in males, although in the former it is apparently quite functionless.

In the adult female this tube follows closely the course of the ureter, but is situated a little more ventrally and nearer the median line (pl. XLV, fig. 34 *W.d*). It is lined with a low columnar epithelium. Its lumen is narrow and completely filled with a clear homogeneous secretion which takes the ordinary plasma stains with avidity. The orifices by which these Wolffian ducts open into the cloaca are very inconspicuous, and can be distinguished only by means of serial sections. Even with these it is difficult to determine that actual openings are present, for the lumen of the tube becomes obliterated near its opening into the cloaca.

These openings in the adult female (pl. XLV, fig. 34) lie closely anterior to the openings of the ureters into the cloaca. Thus in cross sections of the body of the female in the region between the kidney and the openings of the ureters into the cloaca, three pairs of tubes are to be observed (pl. XLV, figs. 33, 34); situated most dorsally and most widely separated are the ureters, lined with rather tall columnar epithelium; rather close to these but ventral and nearer the middle line appear the very small Wolffian ducts, and very close to the middle line and considerably ventral are the two oviducts with the large racemose glands opening into their lumens. The relations of the ducts opening into the cloaca in the late embryo and the corresponding relations in the adult are shown in text-figures 14 and 15.

Cloacal Glands.

Conspicuous racemose glands are situated in a crescent-shaped mass on the ventral and lateral faces of the posterior cloacal chamber immediately anterior to the cloacal aperture, and extend dorsally and posteriorly as a pair of narrow horns which form a nearly complete ring about the posterior cloacal chamber (pl. XLIV, figs. 27, 28).

They are conspicuous in both sexes, but appear to be much more highly developed in mature males than in females or in young of either sex.

They consist of two more or less distinct varieties of glands, of which one type apparently secretes a serous fluid and the other a distinctly mucous fluid.

The serous glands consist of a single pair of oval masses of racemose acini situated immediately dorsal to the spiral groove which passes along the border of the phallus and discharge their secretions by a pair of short ducts opening at the bases of the phalli.

The mucous glands are much more extensive and are situated on the ventral side of the grooves leading to the phalli and on the ventral side of the posterior cloacal chamber. They are likewise of a racemose form and open by several ducts through the ventral wall of the cloaca in close relationship with the phallus grooves. The glands continue much farther anteriorly than those of the serous type, extending forward as far as the openings of the sperm ducts and ureters. In their posterior portions the mucous glands are situated laterally to the cloaca, but more anteriorly those of the two sides approach beneath the cloaca and eventually unite into a single mass beneath this chamber. This median mass constitutes the body of the crescentic mass referred to above, while the paired posterior portions make up the horns of the crescent.

From their high state of development it is obvious that these cloacal glands must play an important part in the economy of the body. Their function is doubtless in large measure connected with the reproductive processes. At the time of copulation the secretion of a great amount of serous and mucous fluids at the base of the phalli and into the cloaca in the male doubtless facilitates the transference of the spermatozoa to the cloaca of the female. A further discharge of fluids on the part of the female might conceivably aid the spermatozoa in reaching the anterior cloacal chamber, from whence they enter the right oviduct to fertilize the two eggs which may be discharged therein.

Copulatory Organs.

One of the most striking features of all embryos at a well advanced stage of development is the presence of a pair of conspicuous projections from the lateral borders of the cloacal aperture. When well developed they have an appearance strikingly suggestive of a pair of rudimentary hind limbs. These projections, however, are the copulatory organs, or phalli, as they are termed by Gegenbaur, which in these and certain other lizards develop primarily as external appendages, and which about the time of birth are withdrawn into the cloaca. Until near the time of birth there appears to be no marked distinctions between the phalli of the two sexes. After birth those of the male increase in size to become the highly specialized copulatory organs of the adult, while those of the female remain in a rudimentary condition, although they are retained throughout life.

When withdrawn into the cloaca the phallus is tubular, with a narrow lumen, and extends from the posterior-lateral borders of the posterior cloacal chamber backward parallel with the vertebral column, as in other lizards. The minute structure and development of the phalli have been described by Unterhössel (: **02**) for several snakes and lizards, including *Anguis fragilis*, which latter presents conditions very similar to those found in *Anniella*.

In well-advanced embryos of *Anniella* the two phalli project from the cloacal aperture for a distance more than one third as great as the diameter of the body in the same region (pl. XLIV, figs. 30–32). They appear as a pair of stout plugs extending from the lateral borders of the cloacal aperture, from which they are directed ventrally and laterally, and then bend anteriorly (pl. XLIV, figs. 27, 28).

Each phallus bears a spiral groove along its posterior and outer borders (pl. XLIV, fig. 27, *g*), which extends to the somewhat swollen distal end of the organ, where it ends between two glandular pits. This groove is very narrow and deep, and passes directly from the lateral borders of the cloacal opening. Proximally it occupies the median and posterior borders of the phallus, but ascends spirally toward the summit, making a turn of nearly 180° (pl. XLIV, fig. 32). A cross section of the phallus near its proximal end shows that the groove is not radial in position but nearly tangential, cutting into the body of the organ very obliquely. The bottom of the groove is considerably broader than the superficial portion. In certain reptiles the groove is so broad at its bottom as to become T-shaped or even anchor-shaped in cross section. Toward its distal end, however, the groove becomes shallower, and situated more nearly radially (pl. XLIV, fig. 29). The phallus is somewhat swollen distally, and is terminated by a broad, flattened face, across which the spiral groove continues as a shallow depression (pl. XLIV, fig, 32). This depression divides the terminal face of the organ into two practically equivalent portions, in each of which is situated a conspicuous pit-like depression of somewhat irregular shape, which may be called the terminal pit (pl. XLIV, figs. 29, 32, *t.p*).

These terminal pits are much more conspicuous in the embryos than in the retracted phallus of the adult male, so that we do not ascribe to them any very important function. In the embryos the pits are glandular in structure, but in the adult they are lined with stratified epithelium not very different from that which covers the body of the phallus. Since the phalli arise as outgrowths from the lateral borders of the cloacal aperture, they are covered externally with ectodermic epithelium continuous with that of the outside of the body, as shown in pl. XLIV, fig. 27. The ectoderm of the phalli, however, is naturally much thinner and more delicate than that forming the scaly covering of the body, although it is made up of stratified scaly epithelium. The deeper cells of this epithelium form a well marked Malpighian layer, while the superficial scaly cells are reduced to one or two layers.

The phallus is redrawn into its position posterior to the cloaca by means of two retractor muscles, the larger of which—the *retractor phalli magnus*—extends quite to the distal end of the organ, where it is inserted immediately beneath the two terminal pits. By the contraction of this muscle the terminal portion of the phallus is redrawn into the more proximal by a process of invagination similar to that of the invagination of the finger of a glove. The epithelium which covers the phallus in its everted condition thus comes to occupy the center of the invaginated or retracted organ, and forms the lining of a slender tube extending throughout its length. This tube extends far behind the cloacal aperture and lies parallel with the longitudinal axis of the body and directly internal to the superficial or ventral musculature of the anterior portion of the tail. The posterior end of the tube is divided into two cup-like terminal sacs (pl. XLVI, fig. 39, *t.p*), representing the two terminal pits of the everted phallus. To these terminal sacs is attached directly the large retractor muscle. The main portion of the central tube of the phallus is extremely irregular in outline, due in part to the presence of the spiral groove and in part to the fact that the invagination takes place on the internal and median borders of the organ to a much greater extent than on the lateral border.

In transverse section of the retracted phallus the spiral groove appears as a deep slit varying greatly in outline and position at different points throughout its length. At its proximal end it continues directly into a conspicuous groove which passes along the latero-ventral wall of the posterior cloacal chamber, and thus, when the phallus is everted in the act of copulation, the genital fluid is conveyed from the cloaca to the spiral groove of the phallus and thence to the cloaca of the female.

The ectodermic lining of the retracted adult phallus is, as stated above, composed of stratified scaly epithelium continuous with that of the outer covering of the body. The superficial scaly cells, however, are reduced to one or two inconspicuous layers, so that it closely resembles irregularly stratified columnar epithelium. The scaly cells are sloughed off from time to time and collect in masses in certain portions of the lumen of the retracted phallus, particularly in the two terminal sacs, which in some cases are completely filled with these discarded scaly cells.

The tissues of the phallus both in the retracted and in the everted condition are permeated with large, irregular, anastomosing blood spaces, forming a sort of erectile tissue, which, when distended with blood, causes the rigidity of the organ and aids in its eversion.

The musculature consists of the *retractor phalli magnus* described above as extending from well back in the tail to the very distal end of the phallus, where it divides into two portions which are attached directly beneath the two terminal sacs or glands; and of a short *retractor basalis* which is attached to the lateral border of the basal portion of the phallus. These muscles are similar to those described by Unterhössel (:**02**) for several reptiles. A third muscle of small size—the *rectus phalli*—connects the basis of the phallus with the neighboring muscles of the cloacal aperture.

From its everted condition it is easy to understand the manner in which the retractor muscles cause the invagination or retraction of the phallus, but the mechanism by which the retracted organ is everted is much less readily understood.

Situated immediately lateral to the phalli are very strong semicircular muscles (pl. XLVI, fig. 39, *c.m*) arranged in a single band between the phalli and the longitudinal caudal muscles which form an irregular layer beneath the integument of the tail. As suggested by Unterhössel (:02, p. 578), these muscles when contracted are capable of exerting a very considerable pressure on the posterior portions of the phalli and thereby initiate the process of eversion of the organs.

The *retractor basalis* muscles may aid to some extent in the process of eversion as well as in drawing back the organ after its full extension.

The withdrawal of blood from the sinuses of the rigid, everted organ allows it to return to a comparatively small size, after which the *retractor magnus* invaginates the organ to its ultimate position posterior to the cloaca.

Although the phalli of the female remain in a rudimentary condition throughout life, they are in this sex apparently functionless and quite incapable of being everted.

At the time of copulation the phalli are doubtless everted, as has been witnessed in other forms, and inserted into the cloaca of the female. The spiral groove with which each phallus is provided then leads directly from the cloaca of one animal to that of the other. A slight elevation of the urogenital papilla, on which the opening of the sperm duct is situated, would bring this opening in close proximity to the base of the spiral groove. An abundant discharge of fluids from the cloacal glands would furnish a ready vehicle by which the spermatozoa ejected at the base of the groove might pass along the length of this canal to the cloaca of the female, whence the right oviduct is the ultimate destination of such as are to fertilize the two eggs which will develop therein.

IV.—BRAIN AND PINEAL APPARATUS.

B. W. KUNKEL.

Pl. XLI, figs. 1–3; Pl. XLVI, figs. 44 and 45; Pl. XLVII, figs. 46–51; Pl. XLVIII, figs. 52–54.

The brain of *Anniella*, like that of the reptiles generally, possesses well developed cerebral hemispheres and a comparatively small cerebellum. The brain on the whole is rather elongated and compressed laterally.

The olfactory lobes (pl. XLI, figs. 1, 2, 3, *olf*) are of regular ovoid shape, about twice as long as broad. The olfactory nerves come off from the anterior end in a ring of a diameter about one half that of the lobes. The lobes are closely applied to each other in the middle line except at the extreme anterior end, where they taper more abruptly.

The cerebral hemispheres (*c.h*) are very large and very much elongated. These are also ovoid in form with the greatest diameter at the posterior end. The cerebral hemispheres are differentiated from the olfactory lobes by a marked constriction which, however, allows of a rather wide connection between the two.

The thalamencephalon is very small and is almost completely concealed by the neighboring parts of the brain. The pineal body is more or less pear-shaped and lies with its broad end directed posteriorly and dorsally between the posterior ends of the cerebral hemispheres. A mass of blood vessels forming the choroid plexus of the third ventricle overlies the structure and is enclosed in the same mass of connective tissue with the epiphysis, so that superficially only a single structure is seen. On the ventral side of the thalamencephalon is a well developed infundibulum (*in*) with the pituitary body attached distally. The anterior portion of the infundibulum is marked by four or five longitudinal folds which produce a corresponding number of scallops on the anterior end between two rather prominent ridges with rounded anterior ends, from which the optic nerves proceed. These lateral ridges continue into the ventral sides of the optic lobes. The infundibulum is of a regular conical form with an axis somewhat shorter than the diameter of the base. The apex of the cone is marked by a slight depression with a longitudinal slit at the bottom of the cup marking the attachment of the pituitary body. The pituitary body is not represented in the figures.

The optic lobes (*o.l*) are rather small and placed very close together in the middle line, the two forming a more or less hemispherical mass. From the exterior their paired nature is only slightly indicated. Apparently this compression is due to the great development of the internal ears, which lie slightly posterior and dorsal to this part of the brain and approach each other very closely on the dorsal side.

The cerebellum (*c.b*) is very small and has the form of a transverse ridge lying posterior to the optic lobes, somewhat shorter than the diameter of this portion of the brain, and overhanging the anterior portion of the fourth ventricle. The medulla (*md*) is large and is characterized especially by its strong ventral flexure and the relative straightness of the ventral side in a transverse section.

From a superficial examination of the brain without the use of sections, the anatomy of the thalamencephalon cannot be ascertained at all because of the blood vessels and the large amount of connective tissue which form a thick sheath about the organ on the dorsal side. A large blood vessel (pl. XLI, fig. 1, *b.v*) is often found leading from beneath the anterior end of the pineal body to the region of the pineal eye, which resembles very closely the pineal stalk or nerve as figured by Spencer ('86) in several instances. Sections have proven beyond a doubt that in the late embryos and adults of *Anniella* this "stalk" is simply a blood vessel. In other specimens in which this vessel was not distended with blood it was scarcely noticeable.

Thalamencephalon.

Although several facts of more or less interest have been noted in this region of the brain of *Anniella*, which have not been described for any other lizard, the pineal body is very similar to that of the closely related *Anguis* which has been carefully described by Francotte ('96), Béraneck ('87), and others.

Sagittal sections of the head of a number of very late embryos from 45 to 70^{mm} in length and of several adult individuals have furnished the material for studying with some degree of accuracy the anatomy of this part of the brain. The thalamencephalon is very much compressed laterally and the third ventricle is a rather narrow cleft extending dorso-ventrally between the optic thalami. The lateral walls of this region are in the form of a pair of more or less ovoid masses of nervous tissue with their long axes nearly horizontal. These two masses, the *ganglia habenulæ*, or optic thalami, form protuberances dorsally just beneath the posterior ends of the cerebral hemispheres. The superior and posterior commissures in the embryos at hand are placed very close together, being separated by a very inconspicuous mass of cells apparently similar to the ordinary molecular cells of the adjacent parts of the brain. The posterior is somewhat the thicker of the two and is situated ventrally and posteriorly with respect to the other. Both lie in the dorsal and posterior part of the lateral wall of the thalamencephalon. The roof of the third ventricle is non-nervous in nature; a single layer of cells similar in general appearance to the ependyma forms an irregular much sacculated covering, the post velar arch of Minot (:01), or the "Zirbelpolster" (pl. XLVII, fig. 47, *e'*) and the paraphysis (*py*). Both of these lie in the middle line, the post velar arch immediately behind the paraphysis, and separated from the latter by only the velum transversum (*v.t*). These evaginations are somewhat constricted at their bases but become slightly wider distally, forming long tubular sacs. The velum hangs down from the dorsal wall of the ventricle in a transverse position and bears a commissure (*c.a*) at its free distal end.

The exact significance of this commissure has not yet been determined. There can be but little doubt that what has here been termed the velum transversum is actually that structure. The velum has a position immediately posterior to the paraphysis and anterior to the post velar arch throughout the Vertebrate series. v. Kupffer ('93) figures a sagittal section of the brain of a four weeks embryo of *Acipenser* which shows this relation. De Graaf ('86a) does the same for *Triton.* In the lizards this structure is also described by Burckhardt ('94) in an embryo *Lacerta.* A similar structure is shown but not named in a number of Baldwin Spencer's drawings of the epiphysis of adult lizards. Francotte ('88) gives photomicrographs of sagittal sections of the brain of *Anguis* which show the velum and the structure running along its distal margin very much as in *Anniella*, but he does not mention the commissure in his description. The only reference we have seen to a commissure in this situation is by Rabl-Rückhard ('81), who finds in the brain of *Psammosaurus terrestris* such a structure lying immediately behind the connection between the third and the lateral ventricles, the foramen of Monro, and having the form of a small bundle of fibers stretching across the narrow cavity of the third ventricle and lying upon the dorsal surface of the optic thalami. Rabl-Rückhard considers it to be a rudiment of the posterior portion of the fornix and homologous with the transverse tract of fibers of the same. As Rabl-Rückhard has no figure of the structure in question, it is impossible to be certain about the homology, but from his rather brief description this commissure corresponds closely with the rudiment of the fornix and will be so designated for the present.

The post velar arch is a simple unbranched tubular sac which extends slightly posteriorly and dorsally and lies immediately in front of and in partial contact with the epiphysis. The cells (pl. XLVI, fig. 44, *e'*) forming this sac are slightly differentiated from the ependyma cells (fig. 45, *e*) in shape and staining qualities, being more nearly cubical and exhibiting nuclei which do not stand out as sharply from the cytoplasm as in the ependyma proper. The cytoplasm is rather denser and the nuclei do not take the nuclear stains so readily.

Paraphysis.—The paraphysis, or choroid plexus of the third ventricle (fig. 44, *py*) is in general similar to the post velar arch, but differs from the latter by becoming more branched distally and more tubular in shape. It extends dorsal to the post velar arch and backwards till it lies over the epiphysis (fig. 48, *py*). The epithelium of this sac resembles the ependyma more than do the cells of the previously mentioned region, but in general the cells of the paraphysis are larger and the nuclei are arranged more regularly (fig. 44, *py*).

The two cavities of the post velar arch and paraphysis are apparently unconnected, although from a close study of sections it is possible that there is a very small secondary opening between the two near the distal end of the post velar arch.

Epiphysis.—The epiphysis (*ep*) of *Anniella* is very similar in structure to that of *Anguis.* It is a hollow oval vesicle of somewhat larger size than the pineal eye, but showing considerable variation in extent. It is situated in the middle line and is inclined posteriorly so that although the whole structure lies behind the posterior commissure, its long axis, produced ventrally, passes between the superior and the posterior commissures. The epiphysis thus rests upon the anterior part of the optic lobes in the middle line and in the posterior portion of the pineal body as a whole.

The form is quite regularly oval and the walls are of uniform thickness throughout, so that the cavity of the vesicle is also quite regular. In several of the series of sections examined, the cavity of the epiphysis exhibited, near the distal end on the anterior side, a slight depression as if a portion of the vesicle had been pinched off. This scar resembles quite closely that figured by Klinckowström ('93) in *Iguana* at the point where the pineal eye is cut off from the pineal body in the development of the organs. The epiphysis and neighboring parts are all supplied by large blood vessels and held in place by a great amount of connective tissue which gives the pineal body its characteristic external form.

Histologically the epiphysis resembles very closely the pineal eye devoid of pigment (fig. 46, *ep*). It is made up of several layers of cells, of which the innermost are tall, slender columns with oval nuclei toward their outer ends. At the bases of these tall columnar cells is an irregular row or two of closely packed oval nuclei. Externally is a single layer of more cuboidal cells, very similar to those of the pineal eye, possessing spherical nuclei which stand out very clearly, being well separated from each other. The free borders of the innermost layer of cells show numerous cilia-like processes similar to those in the cavity of the pineal eye. Whether these processes are really cilia or not is rather difficult to determine. In the preparations studied, they were rather irregular in length and somewhat tapering in form instead of being uniform in diameter like true cilia. The cavity of the epiphysis contains, also like the pineal eye, a coagulum in the form of a loose network. The epiphysis is entirely closed in late embryos and in the adult, and its cavity exhibits no structural connection with either that of the brain or of the pineal eye. This also corresponds to what has been determined for *Anguis* by Francotte ('96).

In median sagittal sections of the thalamencephalon the posterior and superior commissures are seen lying close together a short distance in front of the optic lobes, the superior being the smaller and situated dorsally. The epiphysis is a hollow oval body lying entirely separate from the brain proper except for the connective tissue sheath around it. The cavity of the third ventricle is extended dorsally as a fingerlike evagination, the post velar arch, reaching as far as the dorsal limit of the epiphysis and lying in contact frequently with the anterior wall of the latter. The velum transversum hangs down from the dorsal wall of the third ventricle in front of the "Zirbelpolster" and bears at its ventral edge a commissure corresponding probably with the rudiment of the fornix described by Rabl-Rückhard ('81). Immediately in front of this the evagination of the paraphysis passes dorsally and posteriorly and extends dorsal to both the post velar arch and epiphysis. The cerebral hemispheres lie in front of the paraphysis. Projecting from the roof of the ventricle immediately in front of the opening of the paraphysis is a portion of the ependyma which supports the choroid plexus of the lateral ventricles.

Pineal Eye.

As in a large number of other lizards, the presence of a pineal eye is indicated on the exterior by a scale which is differentiated to form a kind of "cornea." In *Anniella* it is the interparietal plate which bears an unpigmented area in its central portion, beneath which the deeply pigmented pineal eye is visible (pl. XLII, fig. 10). Usually, in the adult at least, the eye is situated in the anterior portion of the plate in the middle line, but in some of the embryos at hand it lies more posteriorly. The unpigmented area is circular in outline, although its outline is not absolutely definite because of the gradual disappearance of pigment from the browspot. The eye has a diameter of about 0.2^{mm} and the unpigmented area a diameter approximately twice as great.

Apparently in the specimens examined, the eye in the paler variety (*pulchra*) was not as clearly seen as in the darker variety (*nigra*), in which the pigment seemed to be much more completely removed from the "cornea."

As in all lizards probably that possess a pineal eye, the skin is firmly attached to the underlying bone in this region. Spencer ('86) mentions that this peculiarity is constant, even in those forms in which the parietal organ is exceedingly rudimentary. The parietal bone over the pineal eye has the appearance of being etched when examined with a hand lens. Sections through this region (Pl. XLVII, fig. 49) show the presence of rather stout, straight connective tissue fibers (*c.t*) which pass in a vertical or slightly oblique direction completely through the bone and are continuous with the fibers in the dermis. The laminae of the bone (*pa*), which elsewhere are very prominent, are interrupted and obliterated by these fibers.

There is no parietal foramen, but the fused parietal bones contain an excavation on the under side in which the pineal eye lies. This pit is in the middle line, near the anterior margin. There is a slight bulging corresponding to the pit on the dorsal side and around the depression internally is a marked thickening, so that the pineal eye lies in a cavity much deeper than the average thickness of the bone in that region. Careful measurements of the bones in one specimen showed that the elevation around the pit had a thickness nearly five times that of the parts of the parietal bone adjacent and eight times that of the bony cap over the foramen. The pit is elliptical in shape, with its long axis parallel to the axis of the lizard and of about twice the length of the short axis.

The pineal eye is situated at the bottom of the pit, pressed against the parietal bone dorsally. It is somewhat more flattened in the adult than in the embryo. Béraneck ('87) has noted that in *Anguis* the cavity is somewhat smaller in older embryos than in young ones, and although this has not been observed in the material examined, it seems probable that the flattening of the eye in the adult may be of the same significance. The eye is slightly smaller than the pit, so that there is a considerable space surrounding it which is filled with a much vacuolated tissue (*v*), similar to that described by Spencer for *Anolis* and *Anguis*, consisting of a loose network of fibers and large vacuolated cells containing very little cytoplasm.

In the embryos studied, in which the cranial cartilages were only partially laid down and were entirely absent in the region of the pineal eye, this organ was situated in the ventral portion of the dorsal wall of the head, embedded in connective tissue and separated from the cranial cavity by a thin, slightly differentiated layer of the same.

With relation to the brain, the pineal eye has a position just dorsal to the constriction which marks the boundary between the cerebral hemispheres and the olfactory lobes (fig. 51, *pin*). Because of the length of the cerebral hemispheres and the posterior inclination of the epiphysis, *Anniella* shows a much wider separation between the pineal eye and epiphysis than any other lizard.

In shape, the pineal eye is a much flattened circular vesicle, the axis of rotation of which is vertical. The diameter of the vesicle is from 0.18 to 0.20^{mm} and the thickness 0.06 to 0.07^{mm}.

The blood vessels in the region of the parietal eye show very great variation. In some specimens the blood supply is very inconspicuous while in others there is a very much distended vessel extending along the mid-dorsal line of the brain, from the choroid plexus of the third and fourth ventricles anteriorly to a point just ventral to the pineal eye (fig. 50). Here it forms a distinct enlargement and breaks up into a number of branches which in general are distributed over the surface of the brain in this region, between the cerebral hemispheres and the olfactory lobes. A small branch also enters the vacuolated tissue surrounding the pineal eye. Just at the point of this vessel's breaking up into its terminal branches, it presses into the pit in a semicircle and becomes somewhat enlarged. Notwithstanding its similarity in outward appearance to a stalk connecting the pineal eye and the epiphysis, sections show conclusively that it is a blood vessel. It seems quite possible that some of the parietal nerves shown in Spencer's drawings of the pineal eye of a number of lizards, may be nothing but blood vessels, and that in this respect his figures are misleading.

The hollow vesicle, forming the eye, may be differentiated into two quite distinct parts, which, however, are perfectly continuous, as Francotte ('87) and Béraneck ('87) have shown in the papers already mentioned for *Anguis*, and not discontinuous, as de Graaf ('86) has figured them.

Retina.—As mentioned above, the pineal eye and especially its retinal portion, shows a structure very similar to that of the epiphysis. The quantity of pigment, however, obscures the details somewhat, so that the structure cannot be so certainly ascertained. Externally is a single layer of cuboidal cells with rather large nuclei. These cells contain less pigment than the inner retinal layers, so that they are frequently very distinct, forming an outside wall to the vesicle. As far as could be made out through the pigment, in the polar region there is a single layer of rather tall columnar cells with nuclei situated in the basal portions of the cells; in the equatorial region, however, where the wall of the vesicle is somewhat thicker than elsewhere, the increased thickness is due to an intermediate layer of cuboidal cells between the outermost layer and the columnar cells. This middle layer is rather irregular, but the presence of pigment interferes considerably with the accurate determination of the structure. The pineal eye of *Anniella* (pl. XLVIII) and *Anguis*, according to the beautiful photomicrographs of Francotte ('88), show striking similarity. Francotte describes three layers of cells in the retina of *Anguis* as follows: 1, an outer layer of cuboidal cells forming the external wall; 2, a layer of spherical cells on which the rods rest; and 3, a layer of fusiform, ciliated rods lining the vesicle. In the specimens at hand there was so much pigment present that the second layer could not be distinguished except in the equatorial region. Francotte's figures of *Anguis* show the retina almost free from pigment, there being only a little at the inner ends of the columnar cells next the cavity, so that the three layers are very clearly shown. Because of the general similarity in other respects of these closely related forms, *Anguis* and *Anniella*, this may be the structure of the specimens examined, but so obscured as not to be determinable. The columnar cells are not ciliated, although in nearly every case a coagulum, in the form of a network having the appearance of cilia, is found in the cavity ventrally in contact with the retina.

Differing from *Anguis*, the pineal eye of *Anniella* exhibits a marked thickening of its wall in the equatorial region. In some cases the wall is twice as thick here as in the ventral portion of the vesicle.

The pigment is present in the retina as fine granules of fairly uniform size, packed together to form irregular masses. In general it is concentrated principally along the lateral cell walls. In the cells of the lower pole it is more abundant than in the equatorial region and occupies practically the entire thickness of the retinal wall with the exception of the outermost layer of cells, and even here some pigment is often found. The equatorial region of the vesicle contains less pigment than the rest of the retina, and it is confined principally to the middle part of the columnar cells. In a ring surrounding the lens there is a large quantity of pigment, forming quite a distinct frame for the lens.

Lens.—The lens, while perfectly continuous with the retina, is strikingly differentiated from it by the absence of pigment. It lies on the side of the eye toward the exterior, and while the retina becomes more heavily pigmented in the course of its development, in many respects the two exhibit some similarity in structure.

The cells of the lens, in contrast with those of the retina, are less dense in nature, more homogeneous, and free from pigment. Strahl and Martin ('88) describe pigment in the lens of *Anguis*, but this has not been substantiated by other investigators. Essentially, there is the same arrangement as in the rest of the eye, a layer of fairly tall columnar cells toward the cavity and a rather irregular layer of shorter ones on the outside. Francotte describes in the lens two layers of fusiform cells, which probably correspond to the single layer which has been found here in *Anniella.* The cells are somewhat more slender and longer than in the retina, and the nuclei apparently are more crowded and elongated and occupy more nearly the central portions of the cells, although frequently a nucleus is found pushed to one end or the other. External to the columnar cells is an incomplete layer of cuboidal cells, smaller than the corresponding ones in the retina and much more irregularly disposed, not forming apparently a continuous layer. These cells are not at all numerous and can be distinguished from the columnar ones only by the spherical nuclei, the cell outlines of all the cells being somewhat indistinct in these preparations. Béraneck's ('87) description of the histological structure of the eye in *Anguis* agrees with that of *Anniella* very closely.

The lens is biconvex ; peripherally it has the same thickness as the retina surrounding it, and is in perfect continuity with the latter. The curvature of the two surfaces is usually different. The dorsal surface corresponds in curvature to that of the vesicle on the ventral side, so that ordinarily there is no bulging dorsally. Occasionally, however, there is a slight increase in the convexity of this part. On the ventral side, toward the cavity of the eye, there is considerable variation in the curvature, as may be seen in figs. 52–54. In one or two cases the convexity of the two sides of the lens was the same, but usually the inner surface was more strongly convex, forming a decided protuberance on the dorsal side of the cavity. The cell walls facing the cavity in general are delicate, so that the coagulum in contact with the cells has somewhat the appearance of streaming out from the cells.

Projecting into the cavity of the eye from the free ends of the columnar cells of the lens are numerous processes quite similar to cilia but differing from typical cilia in their more irregular and somewhat tapering form. In Béraneck's figures of the developing pineal eye, the internal borders of the cells of the lens are provided with a "hyaline substance," forming an irregular layer of about the same thickness as the layer of processes just mentioned in *Anniella*, and it is likely that these processes are simply the coagulated "hyaline substance" of Béraneck ('87). This author states that both lens and retina secrete a substance which fills up the cavity. In nearly all cases the cavity contains some material in contact with the cells of the lens and polar region of the retina; that in contact with the inner side of the lens has an appearance that resembles cilia, while that from the retina is more of a loose reticular structure.

In summing up the characters of the pineal apparatus and related parts of the brain, *Anniella* has been found to agree very closely with *Anguis* in practically all essential points. The pineal eye is more widely separated from the epiphysis than in *Anguis*. In late embryos and adults there is no connection between the pineal eye and the epiphysis. The paraphysis of *Anniella* is rather more tubular and longer than in *Anguis*. The epiphysis is inclined posteriorly and dorsally, while in *Anguis* the distal portion is inclined anteriorly, almost at right angles to the proximal portion. The superior and posterior commissures are very closely related topographically to each other, and extend between the posterior portions of the ganglia habenulæ. In front of the epiphysis the post velar arch is very much elongated to form a tubular sac. Projecting ventrally from the dorsal side of the third ventricle immediately in front of the post velar arch is the velum transversum, along the distal margin of which is situated the commissure, which is a rudiment of the fornix. The paraphysis is a long tubular branched sac extending dorsally and posteriorly from the roof of the third ventricle, immediately in front of the velum.

It has not been deemed necessary to mention the numerous papers which have appeared upon this very interesting portion of the brain, because of the most excellent resumé of the literature and discussion of the results of investigations by Gaupp ('97).

SHEFFIELD BIOLOGICAL LABORATORY, May, 1905.

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EXPLANATION OF PLATES.

ABBREVIATIONS.

a	articular.
ad	adrenal body.
b	basipterygoid.
bl	bladder.
bo	basioccipital.
bs	basisphenoid.
b.v	blood vessel.
c	cæcum.
c.a	rudiment of fornix.
c.b	cerebellum.
cd.m	caudal muscle.
c.g	cloacal gland.
c.h	cerebral hemisphere.
cl	cloaca.
c.m	constrictor muscle.
cor	coronary.
c.p	posterior commissure.
c.s	superior commissure.
c.t	connective tissue fibers.
d	dermis.
d.c	dorsal cloacal chamber.
dn	dentary.
e	ependyma.
e'	post velar arch.
e.a	epiphysial apparatus.
ec	ectopterygoid.
ed	epidermis.
f	fat.
fr	frontal.
f.v	fourth ventricle.
g	oblique groove of phallus.
g.h	ganglion habenulæ.
g.p	genital papilla.
h	horizontal partition between cloacal chambers.
i	intestine.
in	infundibulum.
j	jugal.
k	kidney.
l	lymphoid tissue.
l.od	left oviduct.
l.ov	left ovary.
m	muscles.
md	medulla.
mx	maxilla.
n	nasal.
o	ostium.
o.l	optic lobe.
olf	olfactory lobe.
p	prefrontal.
pa	parietal.
p.c	posterior cloacal chamber.
pg	pigment.
ph	phallus.
pin	pineal eye.
pl	palatine.
pm	premaxilla.
pt	pterygoid.
py	paraphysis.
q	quadrate.
r	rectum.
r.m	retractor muscle of phallus.
r.od	right oviduct.
r.ov	right ovary.
s	supraorbital.
so	supraoccipital.

sp splenial.
sq squamosal.
st stapes.
t testis.
t.p terminal pit of phallus.
u ureter.
u′ diverticulum of ureter.
ut uterus.
v vacuolated tissue.
v.c ventral cloacal chamber.
v.d vas deferens.
vo vomer.
vr vertebra.
v.t velum transversum.
W.d Wolffian duct.
II optic nerve.
V trigeminal nerve.
VII facial nerve.

PLATE XLI.

Figs. 1–3. Brain of adult; dorsal, lateral, and ventral aspects respectively. The blood vessel (*b.v*) extending in the groove between the cerebral hemispheres (*c.h*) is shown in a very distended condition with its branches ramifying over the union of the olfactory lobes (*olf*) and cerebral hemispheres just beneath the pineal eye. The optic chiasma and the scalloped anterior edge of the infundibulum (*in*) are shown in fig. 3. The cranial nerves with the exception of the first, second (II), fifth (V), and seventh (VII) are not shown. × 7.

Figs. 4–6. Skull of adult from dorsal, ventral, and lateral aspects respectively. In fig. 4, internal to the ectopterygoid are seen the two minute bones, the postfrontal and postorbital. × 7.

Fig. 7. Left mandible seen from the right side. × 7.

Fig. 8. Dentary bone of right mandible seen from the left side, showing the shallow grooves on the recurved teeth. × 15.

PLATE XLII.

Fig. 9. Dorsal view of anterior end of 70$^{\mathrm{mm}}$ embryo, showing the large interparietal plate with the pineal eye. × 8.

Fig. 10. Interparietal plate and pineal eye of adult. × 20.

Fig. 11. Interparietal plate of embryo 60$^{\mathrm{mm}}$ long. × 20.

Fig. 12. Hyoid apparatus. × 8.

Fig. 13. Rib from left side, posterior aspect. × 17.

Fig. 14. Left pelvic bone from dorsal side. × 17.

Figs. 15–18. Dermal ossifications from scales of cervical region. × 17.

Fig. 19. Thoracic vertebra seen obliquely from above and right side, showing the transverse processes at the anterior end of the centrum. × 17.

Fig. 20. Same vertebra seen from dorsal side. × 17.

Fig. 21. Second cervical vertebra from anterior end. × 17.

Fig. 22. Same vertebra from right side. × 17.

Figs. 23, 24. Anterior and posterior segments respectively of one of the caudal vertebræ seen from the side, showing the "breaking joint." × 17.

PLATE XLIII.

Fig. 25. Urogenital organs of adult female from ventral side, showing both ovaries (*r.ov* and *l.ov*) perfectly functional and of the same size, and the left oviduct (*l.od*) very rudimentary. The cloaca is represented as if transparent so that the position of the openings of the ducts and the horizontal shelf separating the dorsal and ventral cloacal chambers are shown. × 3.

Fig. 26. Urogenital organs of adult female from ventral side, showing a slightly different form of the aborted left oviduct and also two eggs with developing embryos (*ut*, *ut'*) in the uterine portion of the right oviduct. × 3.

PLATE XLIV.

Fig. 27. Sagittal section of 60^{mm} embryo in the region of the cloaca through the phallus, showing the large retractor muscle of the phallus (*r.m*) and the large blood spaces (*b.v*). The oblique groove (*g*) is also shown in part. One of the cloacal glands is shown at (*c.g*). × 47.

Fig. 28. Transverse section of embryo of same length. × 47.

Fig. 29. Transverse section of terminal portion of phallus of embryo of same length, showing the glandlike pits on the distal end (*t.p*), the oblique groove (*g*), and blood spaces (*b.v*). × 47.

Fig. 30. Portion of ventral surface of 50^{mm} embryo shortly before birth, showing the phalli projecting from the lateral borders of the cloacal aperture and the oblique groove and terminal pits with which each is provided. × 18.

Fig. 31. Portion of ventral surface of another embryo 70^{mm} long, showing slightly different form of phalli. × 14.

Fig. 32. Slightly different aspect of phalli of another individual. × 20.

PLATE XLV.

Fig. 33. Transverse section through cloacal region of adult female, anterior to opening of oviducts (*r.od*) and ureters (*u*). The minute Wolffian ducts persisting in the female are shown below and internal to the ureters. The left oviduct is slightly smaller than the right. Masses of lymphoid tissue (*l*) are situated beneath the epithelium of the ventral cloacal chamber (*v.c*). × 32.

Fig. 34. Transverse section of same specimen somewhat more posterior. The dorsal chamber (*d.c*) is much larger, and the genital papilla (*g.p*), at the summit of which the oviducts open, is shown projecting from the dorsal surface of the horizontal shelf (*h*). External to the ureter (*u*) on the right side of the figure is shown the opening of the diverticulum of the same which is present in both sexes. × 32.

Fig. 35. Transverse section through cloacal region of adult male through the opening of the vas deferens (*v.d*) on the apex of the urogenital papilla. The diverticulum of the ureter is essentially similar to that of the female in the previous figure. The horizontal partition between the cloacal chambers is here shown as a very thick band (*h*). × 28.

Fig. 36. Transverse section of the same specimen somewhat more posterior, through the opening of one of the ureters. The posterior end of the horizontal partition (*h*) is completely surrounded by the posterior chamber. × 28.

Fig. 37. Transverse section of aborted left oviduct from near its middle portion, showing the numerous well developed glands which open into its lumen. × 146.

PLATE XLVI.

Fig. 38. Urogenital organs of adult male from ventral side. The cloaca is represented as a transparent structure so that the openings of the urinary (*u*) and genital ducts (*v.d*) and the basal portions of the retracted phalli (*ph*) may be seen. × 3.

Fig. 39. Transverse section through adult male posterior to cloaca and passing through the distal portion of the retracted phalli. The section is slightly oblique, so that the phallus on the right shows the two terminal pits (*t.p*) while that on the left does not. The strong constrictor muscles (*c.m*) are shown. Large masses of adipose tissue (*f*) are situated on either side of the middle line between the vertebral column (*vr*) and the pouches of the phalli. × 21.

Fig. 40. Ideal reconstruction of cloacal chambers of adult female. The cloaca is represented with the left half removed along the middle line, showing the relations of the posterior cloacal chamber (*p.c*) and the dorsal (*d.c*) and the ventral chambers (*v.c*). The genital papilla is seen projecting into the dorsal chamber from the dorsal side of the horizontal partition (*h*). Folded condition of posterior chamber is also shown. × 7.

Fig. 41. Cloaca of adult male. The ventral wall has been cut away, thus removing the bladder and allowing the pouches of the phalli and horizontal partition to be seen. × 5.

Fig. 42. Cloaca of adult male, contracted somewhat differently from that in the previous figure. The cloaca is represented as if split slightly to the left of the midventral line and spread open. The ventral wall of the posterior chamber has been removed so that the phallus pouches are not shown. A transverse section of the cloacal region contracted as represented would have the appearance of fig. 36. × 5.

Fig. 43. Cloaca of adult, showing the lateral pockets at posterior end of rectum. A small section of the ventral wall in which the bladder opens into the cloaca has been removed and the cut edges of the rectum have been pulled aside to expose the chambers more fully. × 5.

Fig. 44. Highly magnified portion of fig. 47, showing the differentiation of the epithelium of the paraphysis (*py*) and the post velar arch (*e'*). ×409.

Fig. 45. Another portion of fig. 47 more highly magnified, showing the rudiment of the fornix (*c.a*) and the ependyma cells (*e*) which become differentiated to form the paraphysis (*py*) and the post velar arch of the previous figure. ×409.

PLATE XLVII.

Fig. 46. A portion of fig. 47 through the epiphysis (*ep*) and the post velar arch (*e'*), showing the details of cell structure. ×437.

Fig. 47. Slightly oblique sagittal section of portion of brain of a 60^{mm} embryo, showing the relationship of the various parts of the pineal apparatus. The paraphysis (*py*) arises anterior to the velum (*v.t*), the third ventricle becomes greatly extended dorsally to form a more or less tubular sac, which lies just anterior to the epiphysis (*ep*). The superior (*c.s*) and posterior commissures (*c.p*) are situated very close together. ×67.

Fig. 48. Sagittal section of portion of pineal apparatus of a 56^{mm} embryo. The tubular distal end of the paraphysis (*py*) is shown extending posteriorly and overlying the epiphysis (*ep*). Immediately above the posterior commissure (*c.p*) is seen the smaller superior commissure. ×67.

Fig. 49. Portion of fig. 50 more highly magnified, showing the integument (*ed*, *d*) attached closely to the underlying parietal bone (*pa*) by means of very stout connective tissue fibers (*c.t*). The pigment of the skin which is absent above the pineal eye is shown at *pg*. ×325.

Fig. 50. Portion of sagittal section of head of adult, showing the pineal eye (*pin*) situated in a pit on the ventral side of the parietal bone (*pa*) embedded in vacuolated tissue (*v*). The fleck of skin which remains fast to the skull when the skin is peeled off from the rest of the body is shown and also the large blood vessel (*b.v*) which lies between the cerebral hemispheres. ×45.

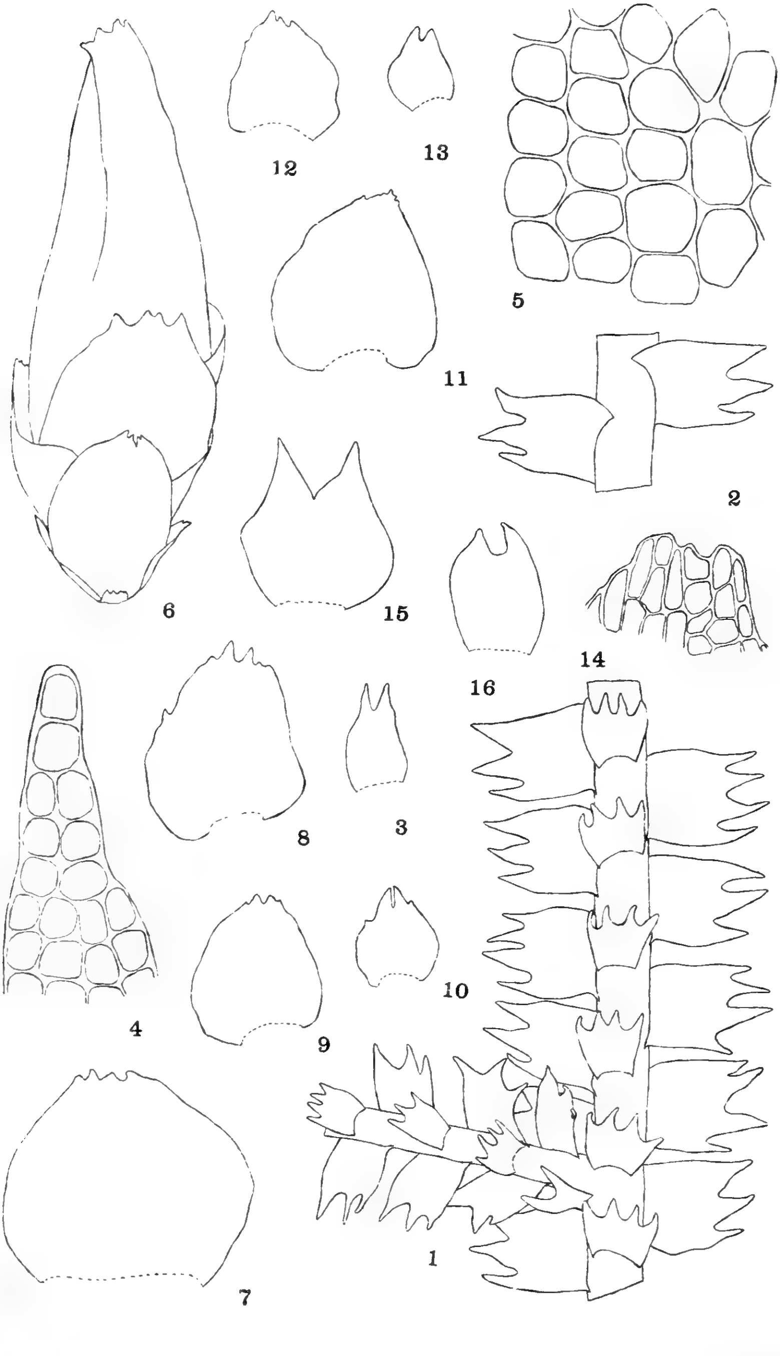
Fig. 51. Sagittal section of head of embryo, part of which is represented in fig. 47. The pineal eye is seen in the ventral portion of the dorsal wall of the head, situated just above the union of the cerebral hemispheres and olfactory lobes. ×40.

PLATE XLVIII.

Fig. 52. Sagittal section of pineal eye of 45^{mm} embryo, showing a moderately convex lens. ×437.

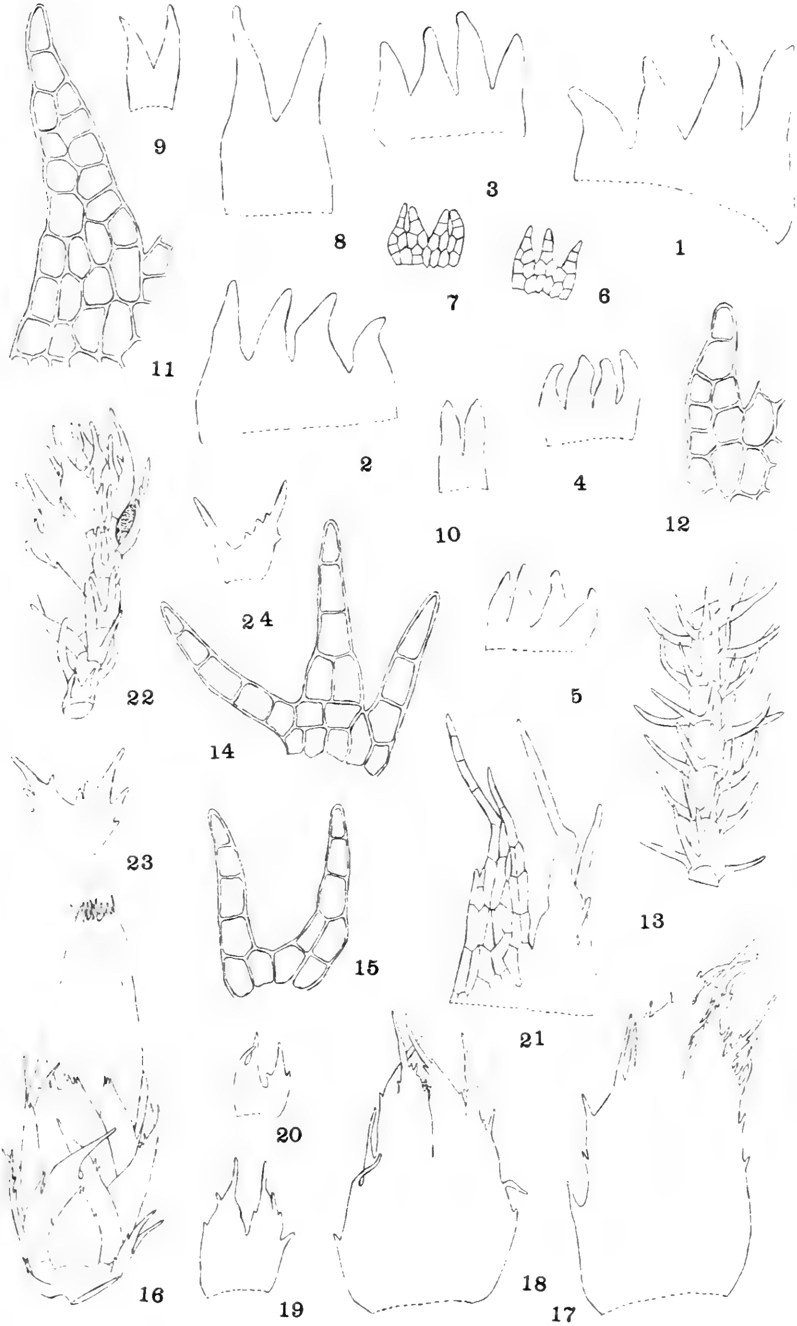
Fig. 53. Transverse section of pineal eye of embryo shortly before birth, showing a less convex lens. ×437.

Fig. 54. Sagittal section of pineal eye of 60^{mm} embryo, showing a very much flattened form with an exceedingly convex lens. ×437.



C. M. DEL. Heliotype Co. Boston.

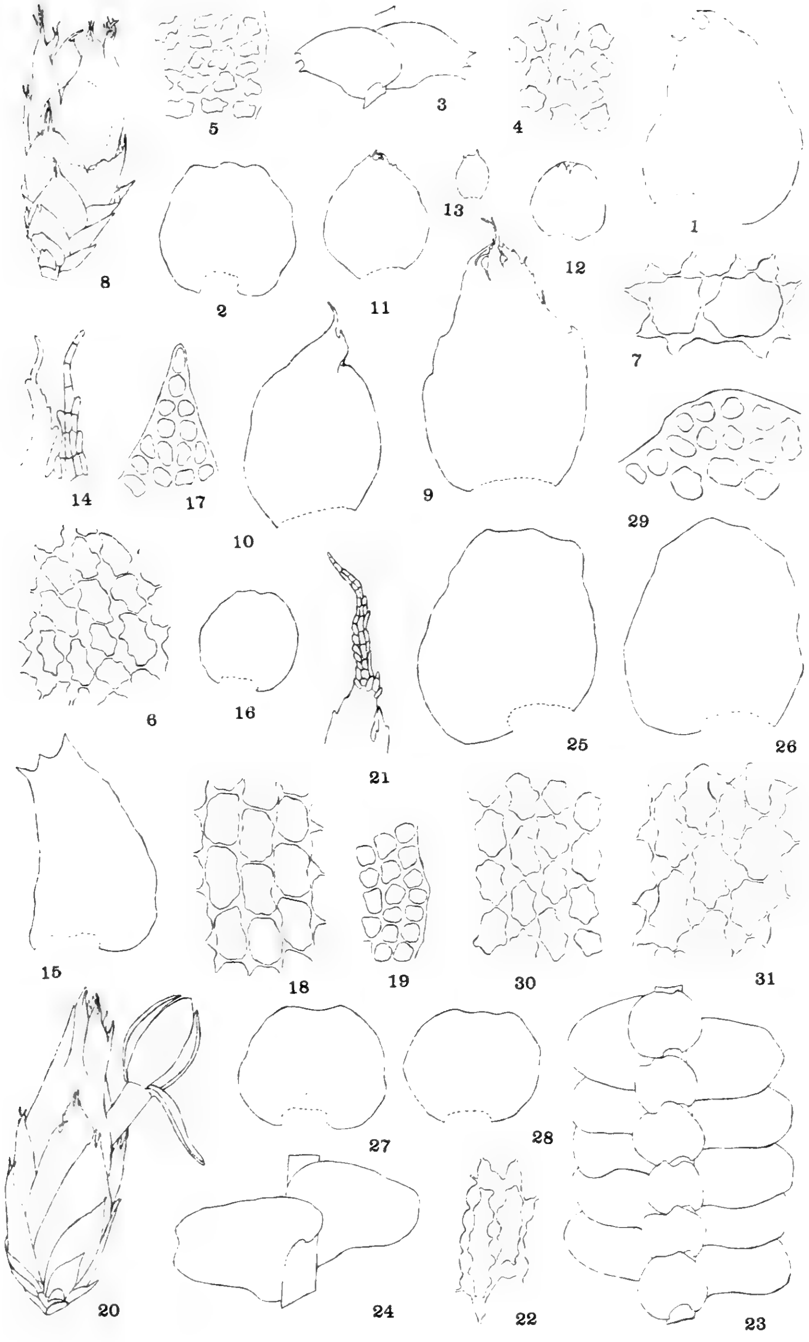
LEPIDOZIA AUSTRALIS (Lehm. & Lindenb.) Mitt.



[illegible] DEL.

Heliotype Co. Boston

1-12. LEPIDOZIA SANDVICENSIS Lindenb.
13-24. LEPIDOZIA HAWAICA Cooke.



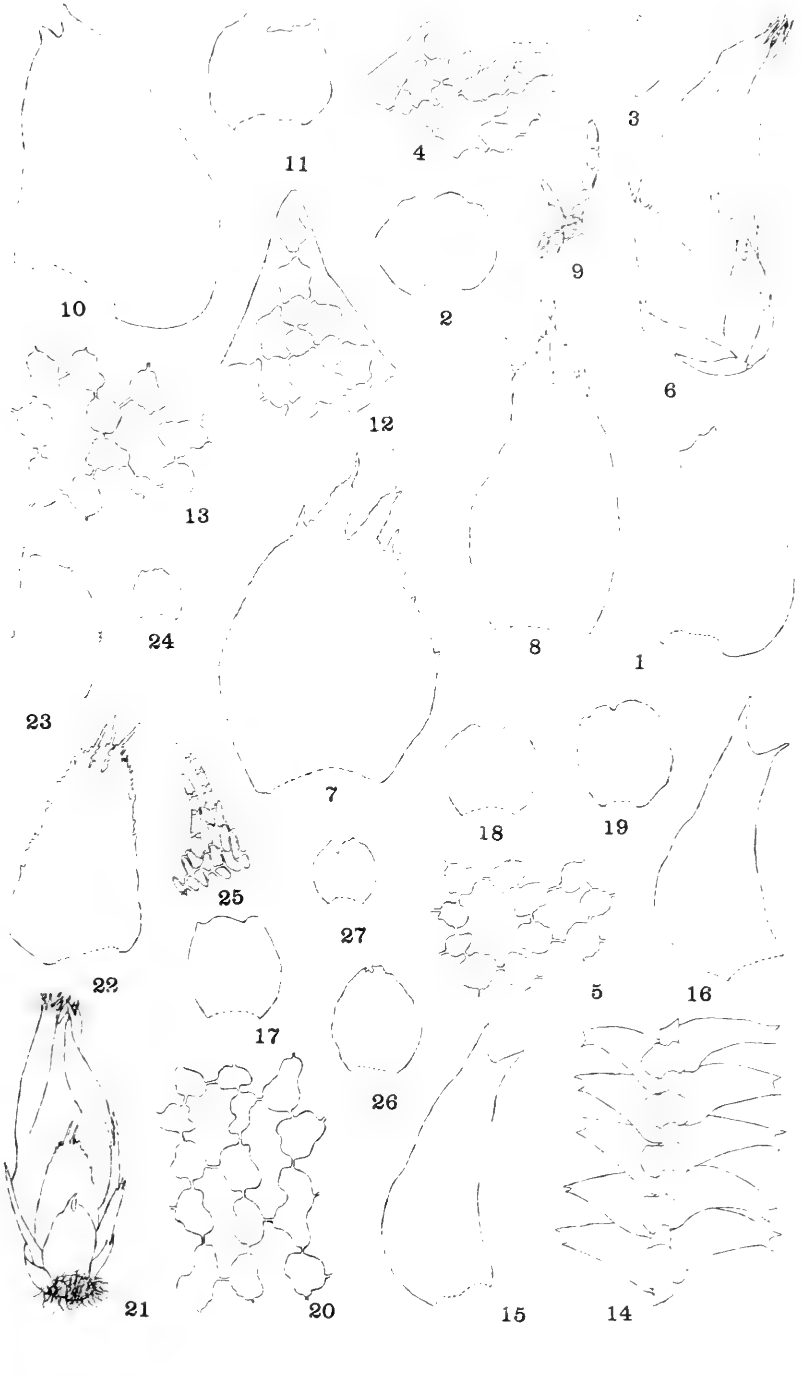
C.M.C. DEL.

Heliotype Co Boston

1-14. BAZZANIA CORDISTIPULA (Mont.) Trevis.

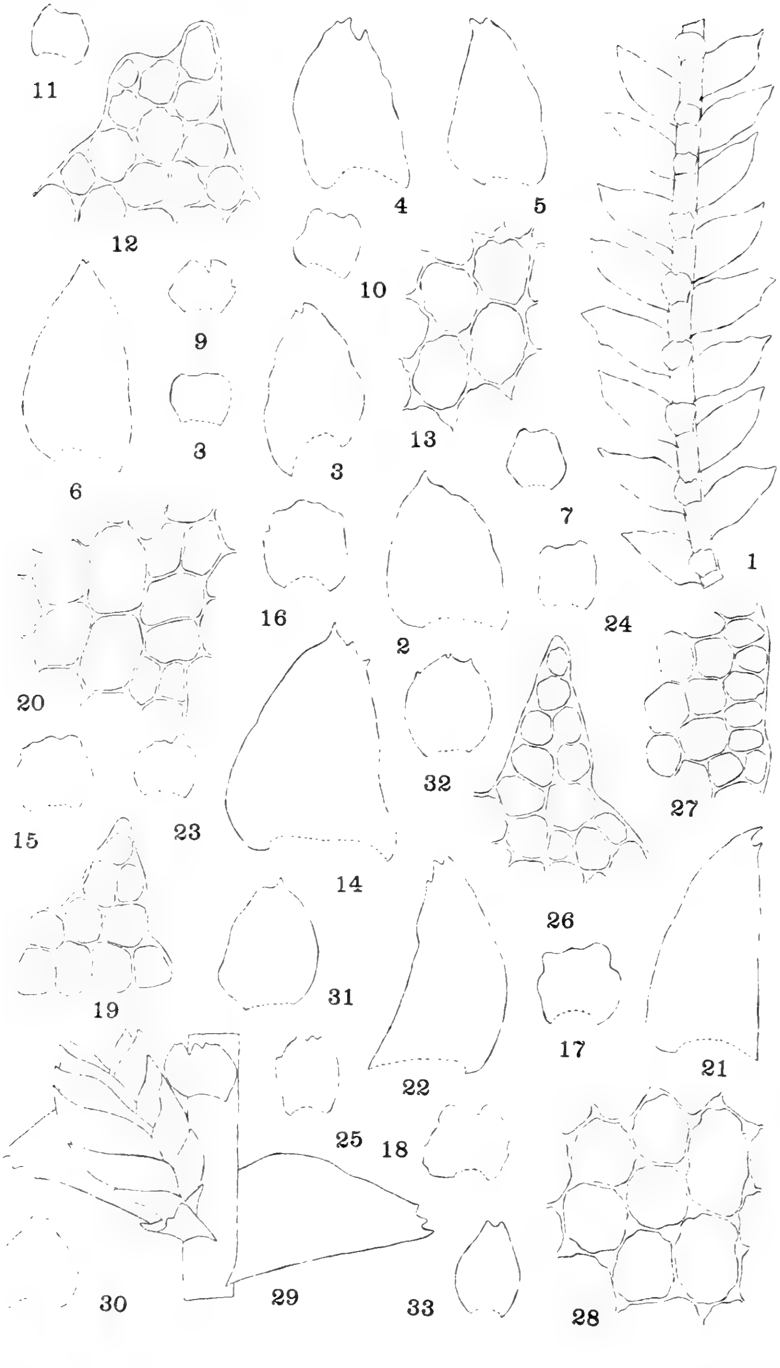
15-22. BAZZANIA SANDVICENSIS (Gottsche) Steph.

23-31. BAZZANIA NUUANUENSIS Cooke.



C.M.C. DEL. [illegible]

1-13. BAZZANIA DIDERICIANA Steph.
14-27. BAZZANIA EMARGINATA (Steph.) Cooke.

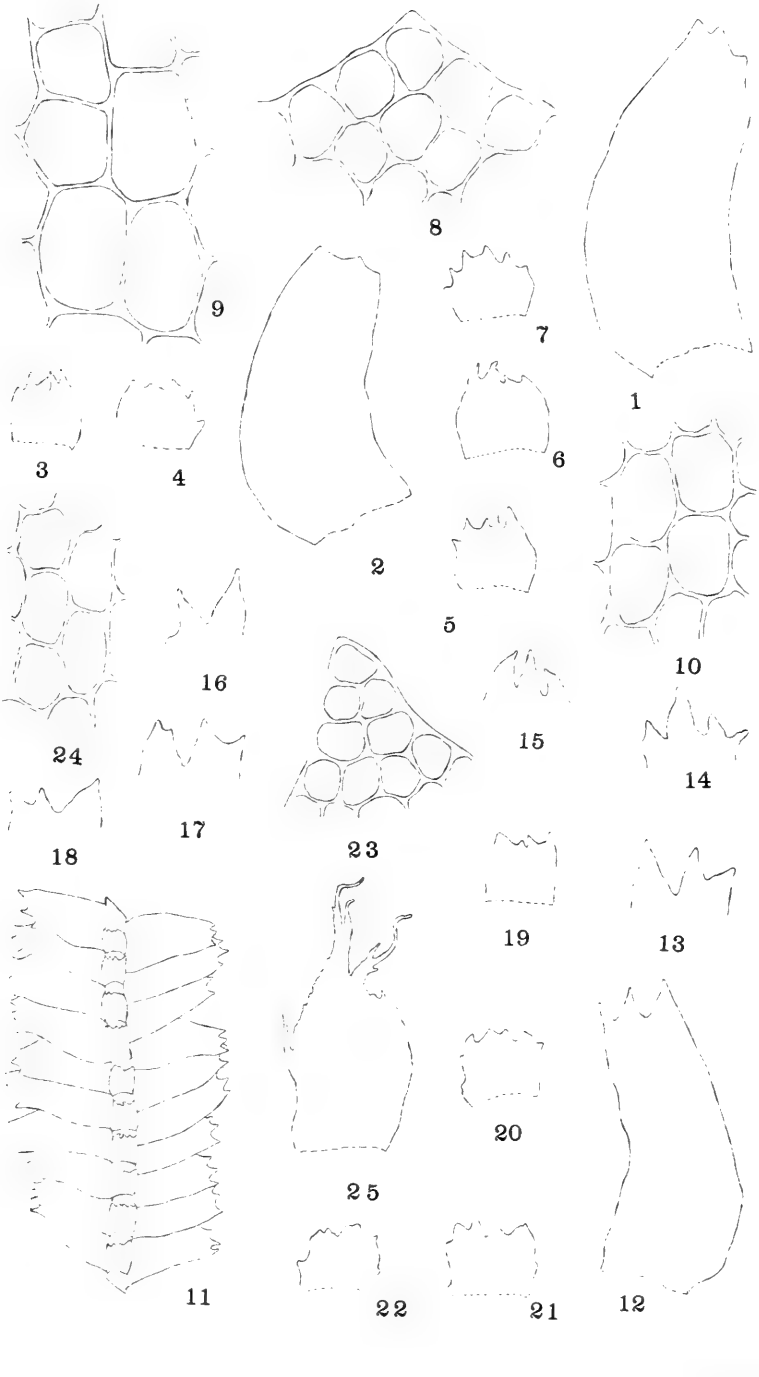


[illegible] del.

Heliotype Co.

1-13. BAZZANIA MINUTA (Aust.) Evans.

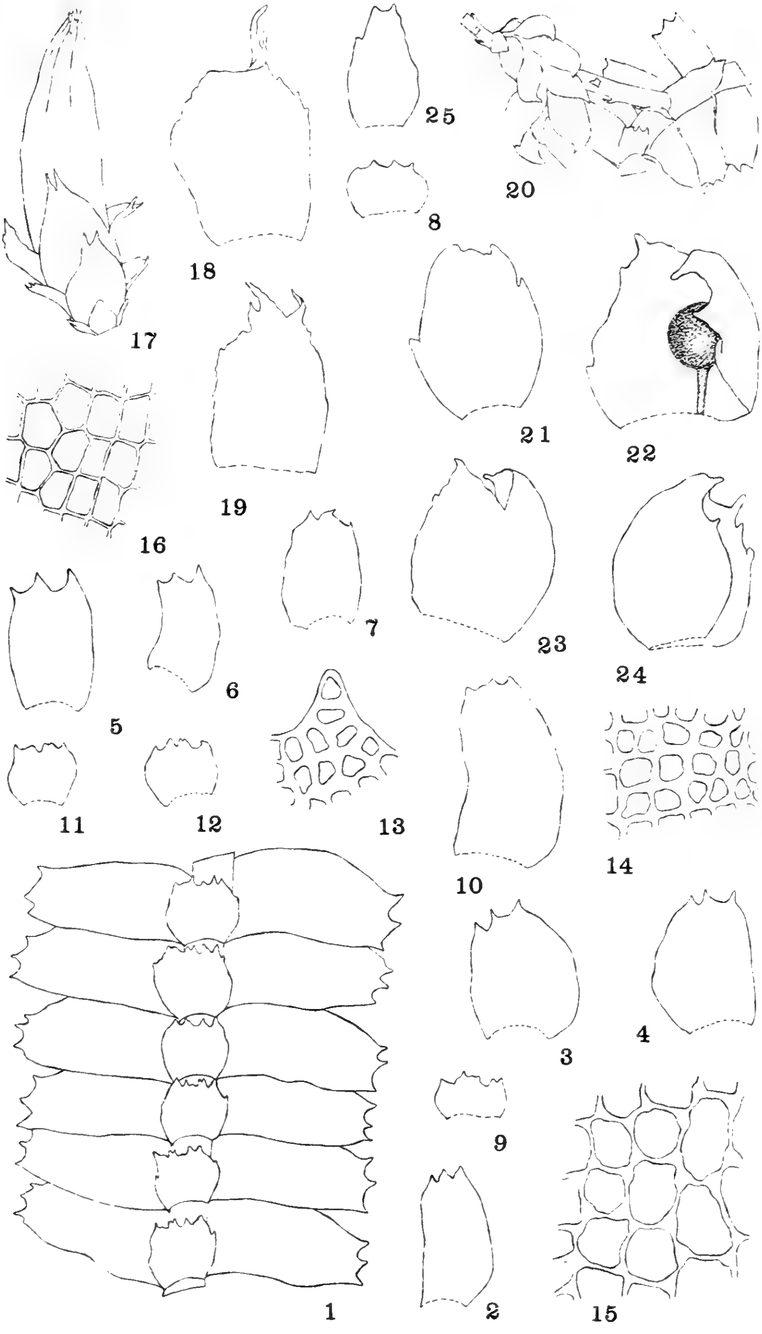
14-33. BAZZANIA BALDWINII (Aust.) Evans.



E. M. Del. Heliotype Co. Boston

1-10. Bazzania patens (Mont.) Trevis.

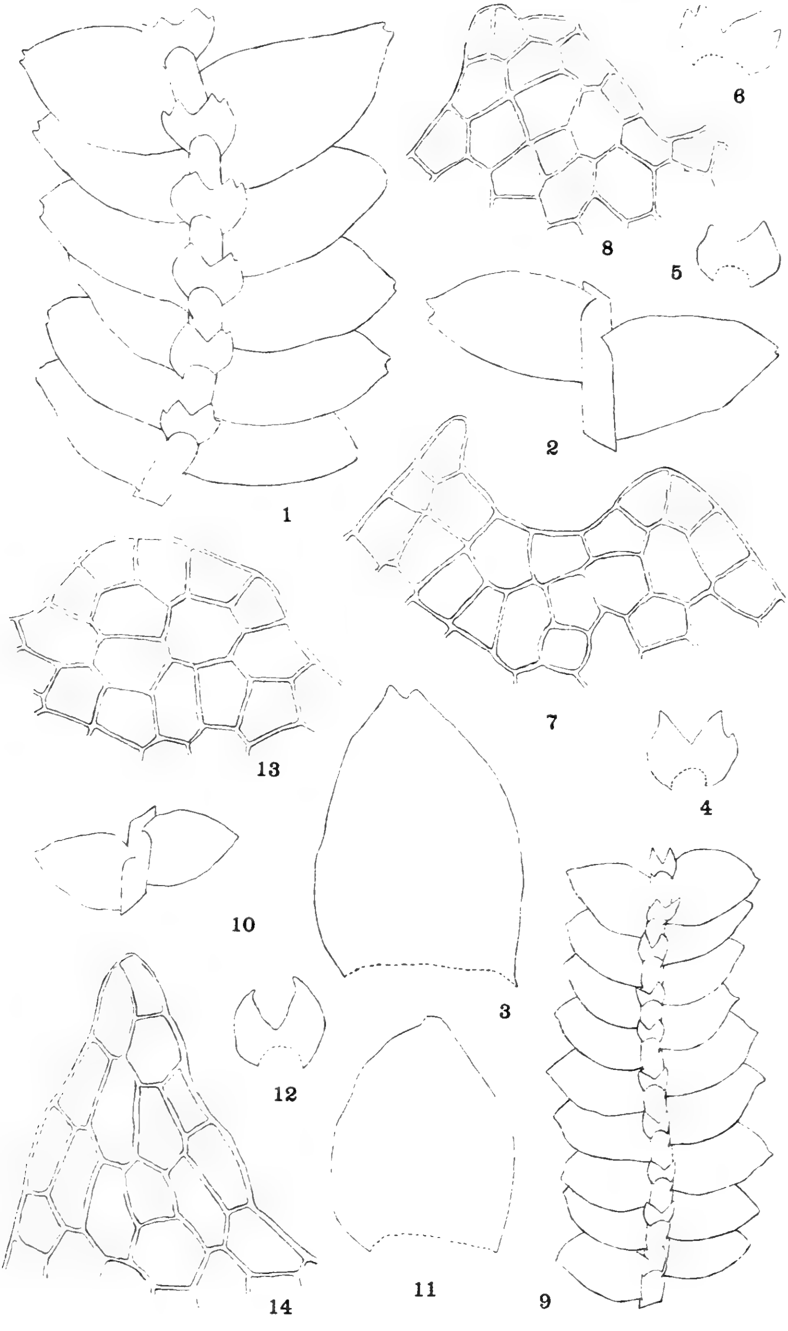
11-25. Bazzania inaequabilis Steph.



C.M.C. DEL

BAZZANIA BRIGHAMI (Aust.) Evans.

Heliotype Co. Boston

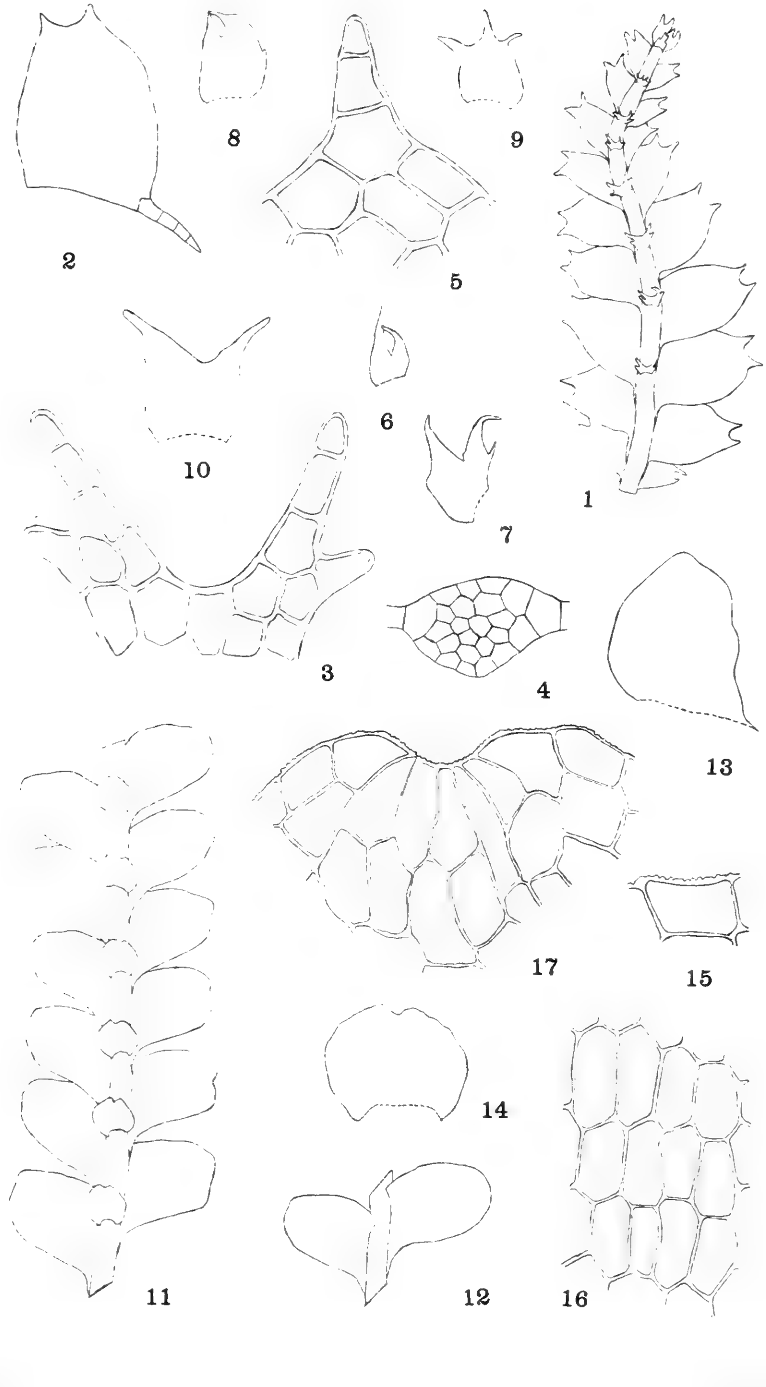


C M C DEL

Heliotype [illegible]

1-8. KANTIA TOSANA Steph.

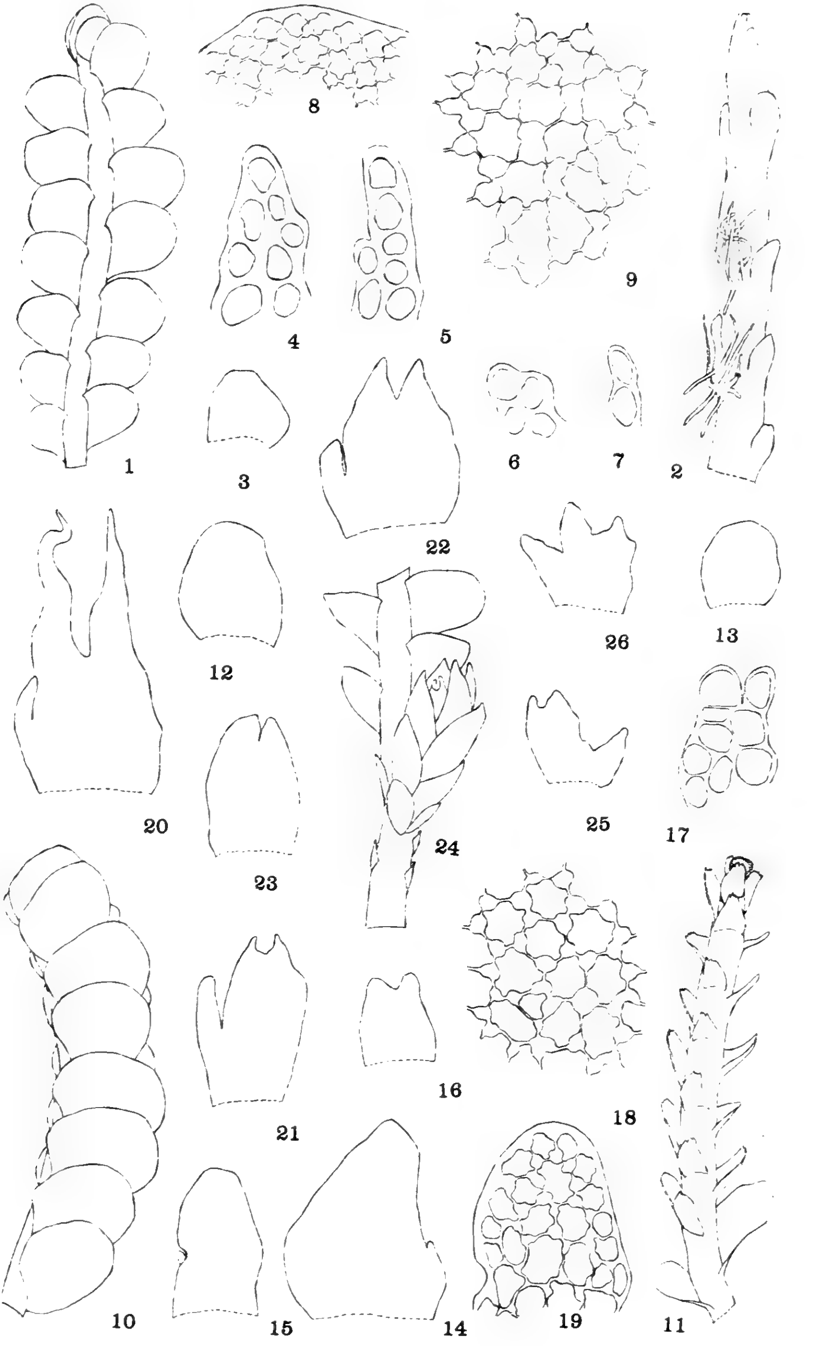
9-14. KANTIA CUSPIDATA Steph.



[illegible] Del. Heliotype Co. Boston

1-10. Kantia bifurca (Aust.) Evans.

11-17. Kantia Baldwinii (Aust.) Evans.

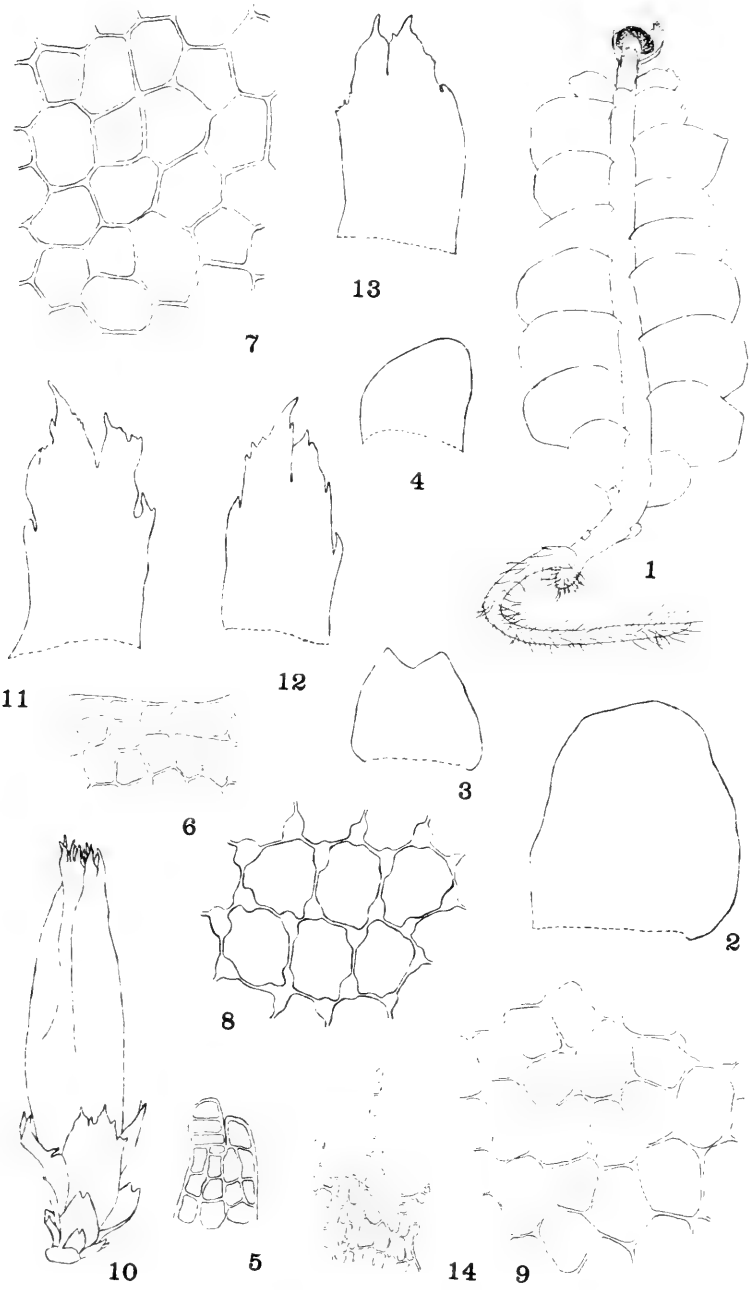


C.M.C. DEL

Heliotype Co Boston

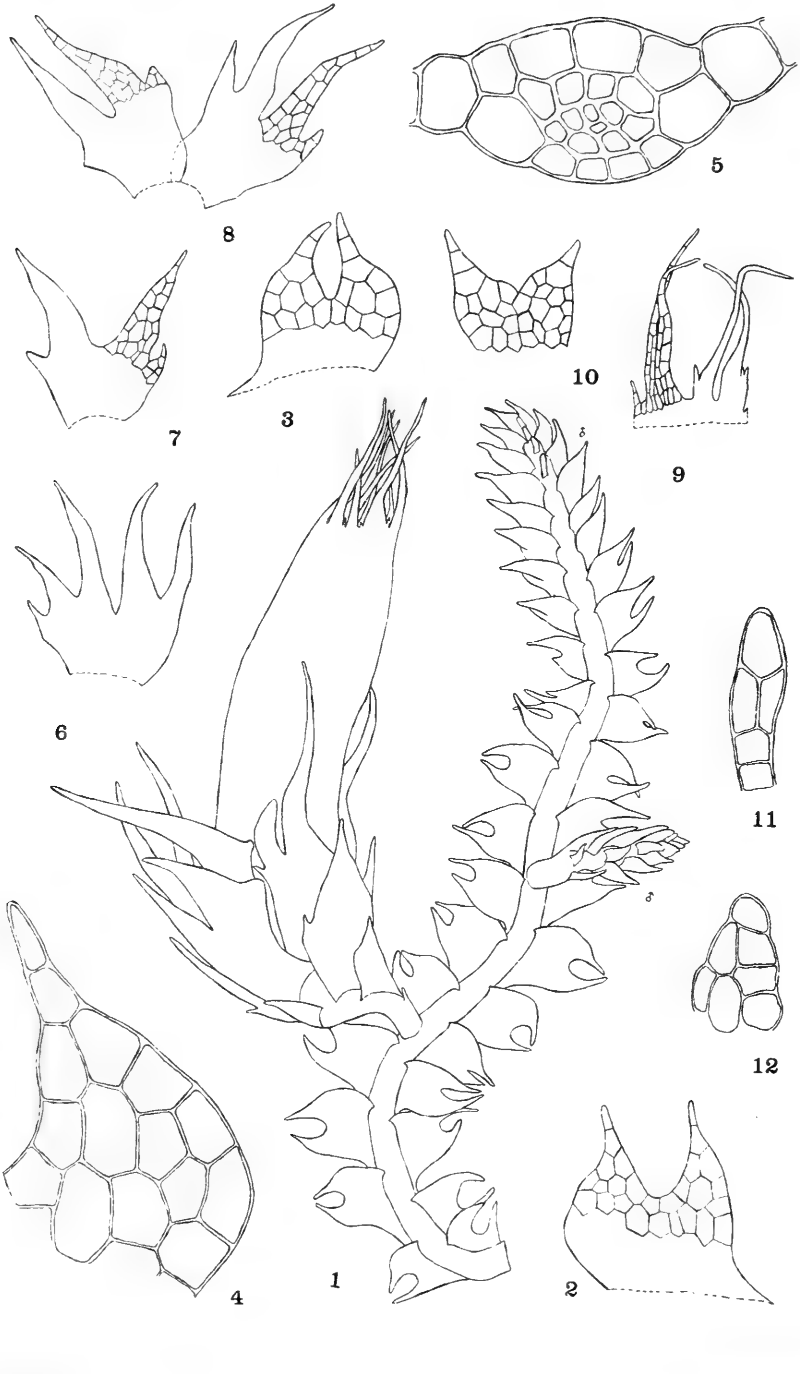
1-9. ODONTOSCHISMA GRACILE (Mitt.) Steph.

10-26. ODONTOSCHISMA SUBJULACEUM Aust.



C. M. C. DEL.
Heliotype Co Boston

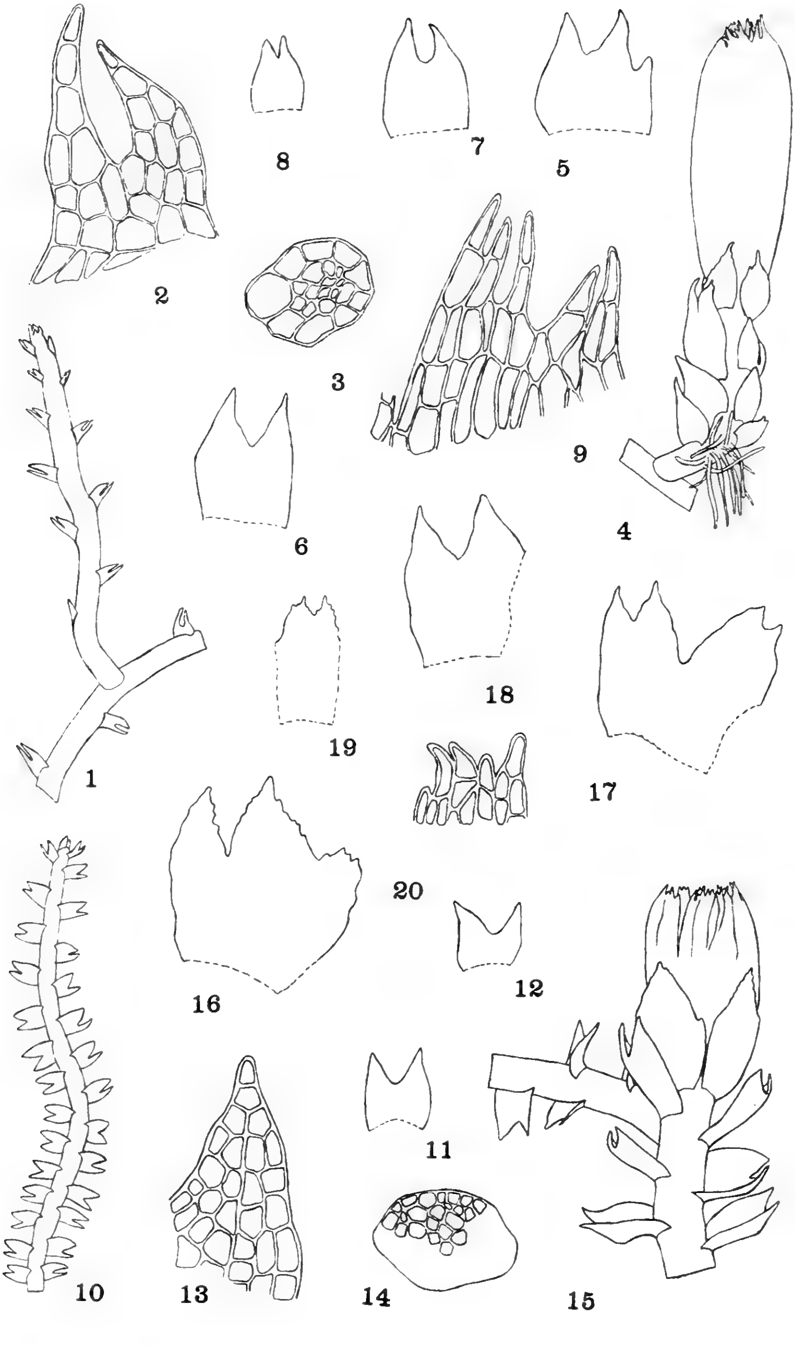
ODONTOSCHISMA SANDVICENSE (Angstr.) Evans.



C. M. [illegible] DEL.

Heliotype Co. Boston

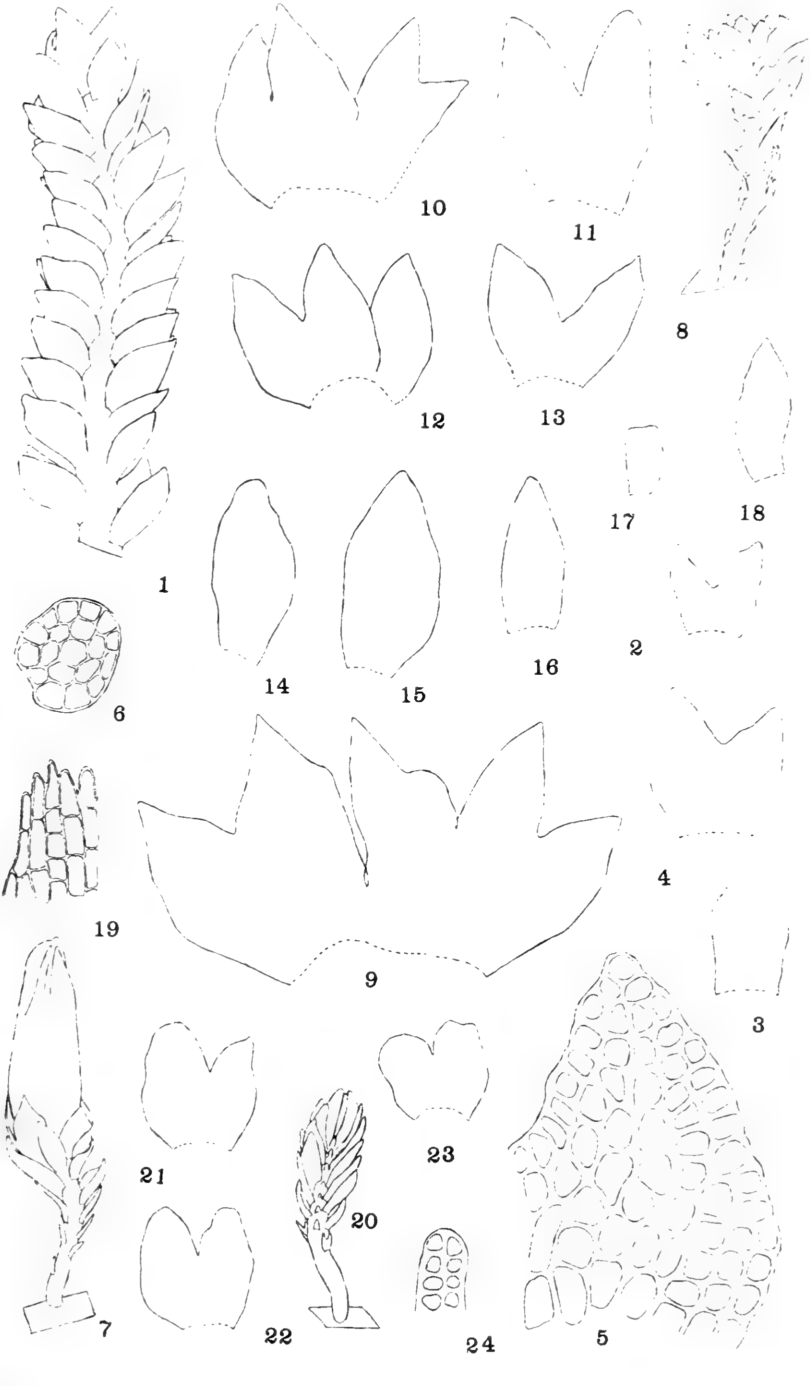
CEPHALOZIA SANDVICENSIS (Mont.) Spruce.



C.M.C. DEL Héliotype Co. Boston.

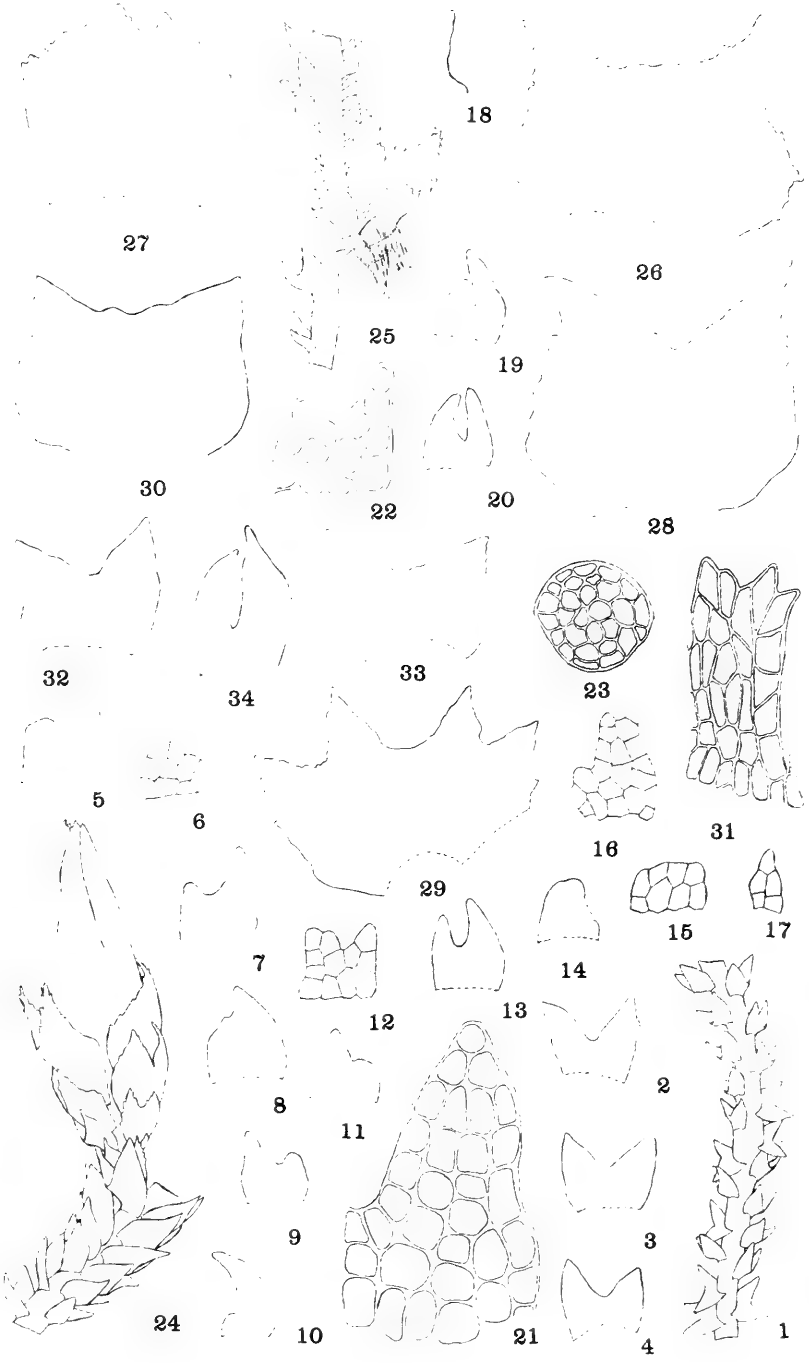
1-9. CEPHALOZIA BALDWINII Cooke.

10-20. CEPHALOZIA LILAE Cooke.



J. M. del. Heliotype Co. Boston.

CEPHALOZIA KILOHANENSIS Cooke.



C.M.C. DEL.

Heliotype Co. Boston

CEPHALOZIA HETEROICA Cooke.

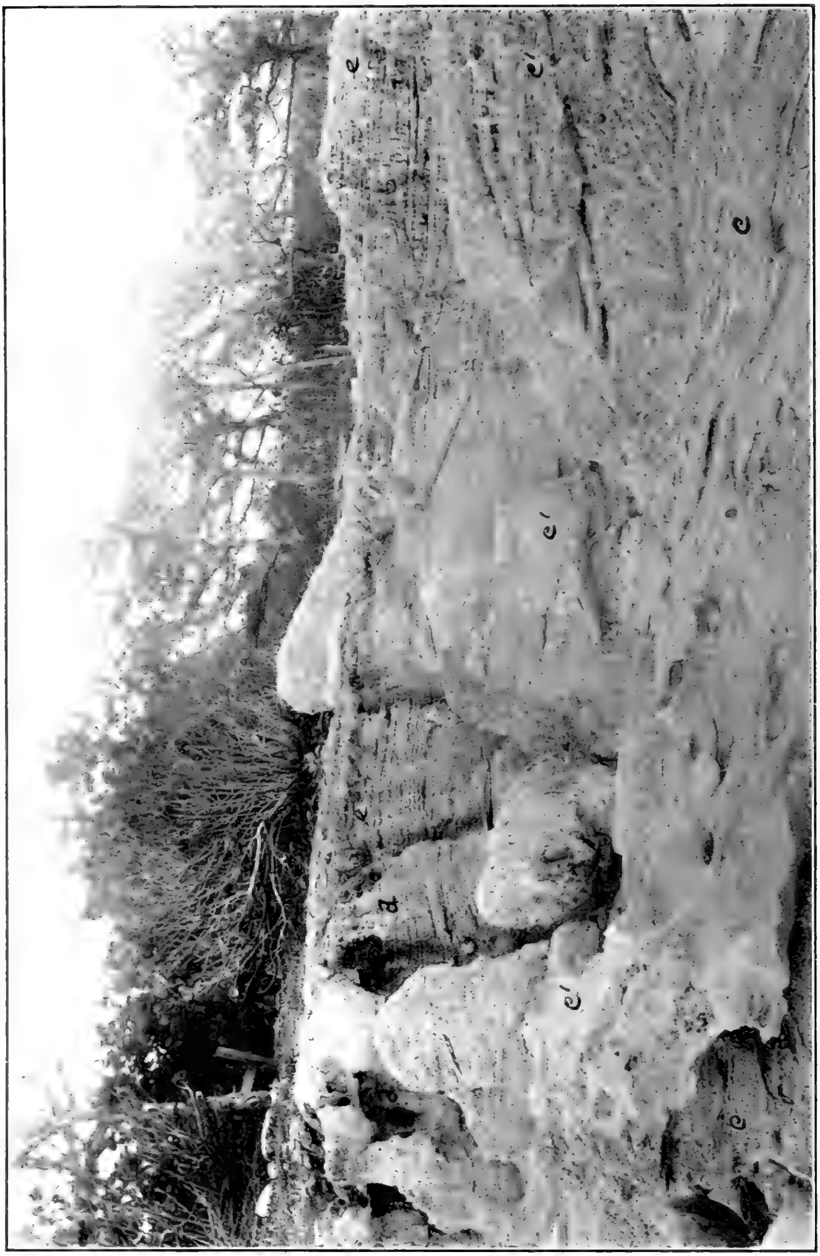
A. Hyatt Verrill, phot. Gill Eng. Co.

SOUTH SHORE NEAR HUNGRY BAY.

A. Hyatt Verrill, phot

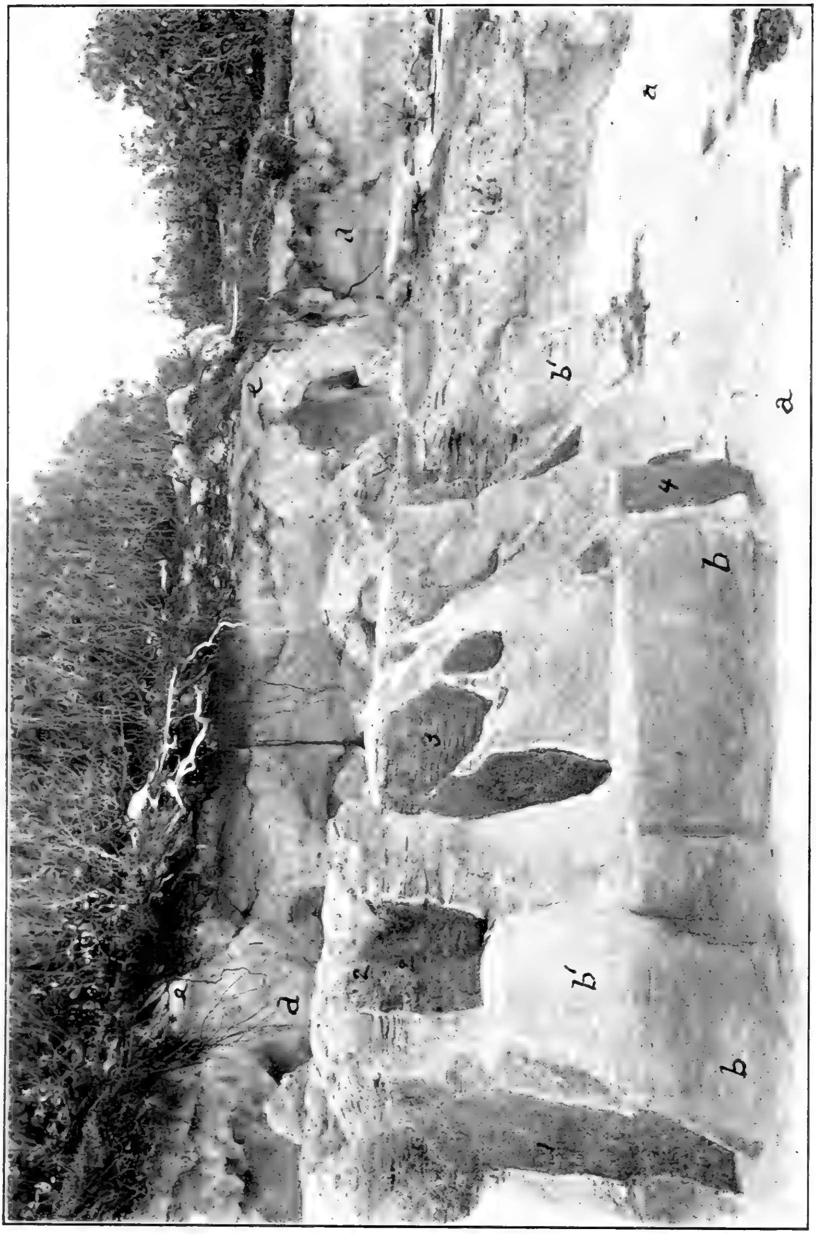
Gill Eng. Co.

SOUTH SHORE NEAR HUNGRY BAY.



A. Hyatt Verrill, phot. Gill Eng. Co.

SOUTH SHORE NEAR HUNGRY BAY.



A. Hyatt Verrill, phot.

Gill Eng. Co.

Cliff near Hungry Bay, showing sections (1–4) of "Sand-pipes" or fossil "Palmetto Stumps;" *b*, *b′*. Walsingham limestone; *d*, *e*. Paget formation; *a*. Beach sand.

A. Hyatt Verrill, phot.

Gill Eng. Co.

Surface of Walsingham limestone at cliff shown in Plate XIX, illustrating various forms of "Sand-pipes."

2

1

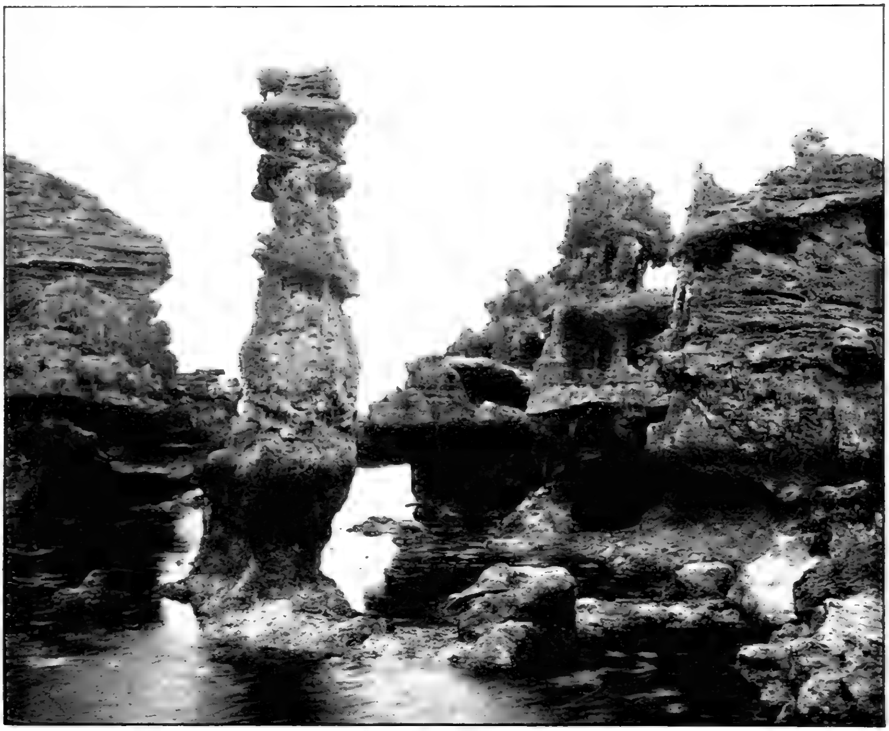
A. Hyatt Verrill, phot. 2

Stoddard & Brown, eng.

1. A Walsingham Cave. 2. Sand Dunes at Tucker's Town.

1

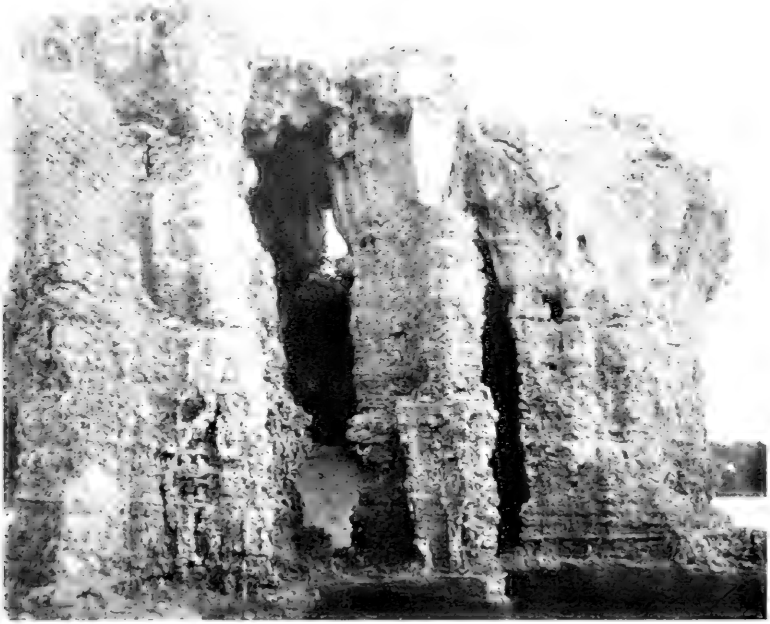
2



CASTELLATED ROCKS AND PINNACLES.

1. Tobacco Bay, St. George's I. 2. South Shore.

1



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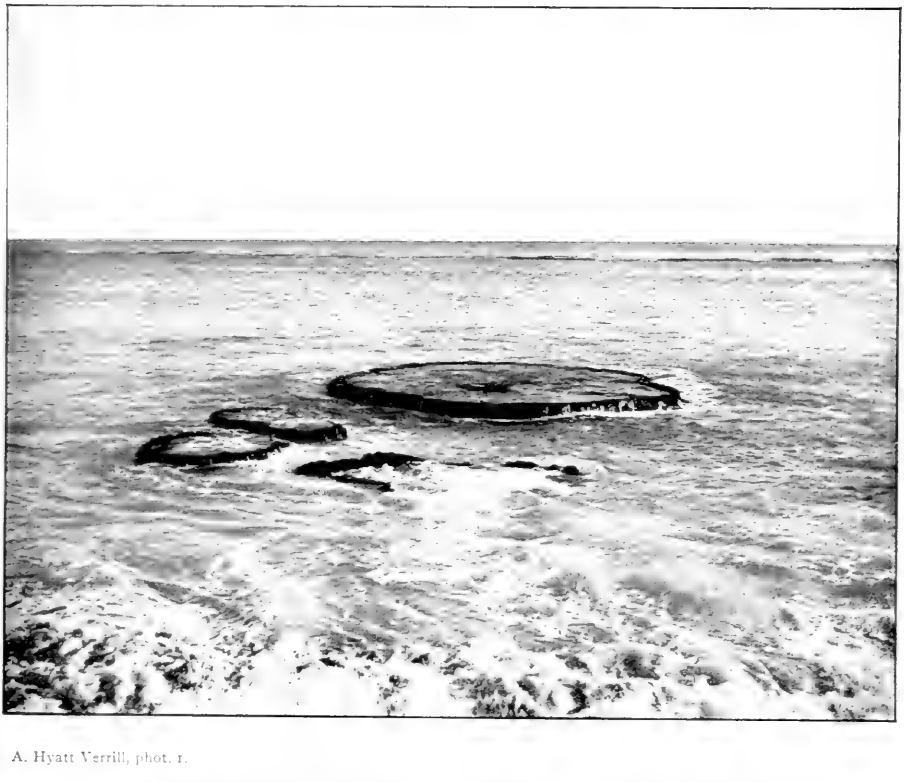
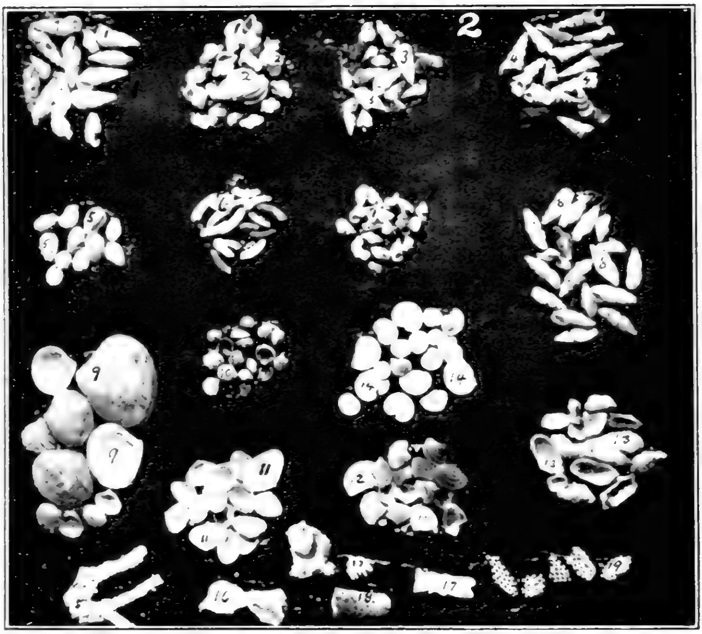


A. Hyatt Verrill, phot. I.

1. Cathedral Rocks, Somerset I. 2. Serpuline Atolls, South Shore.



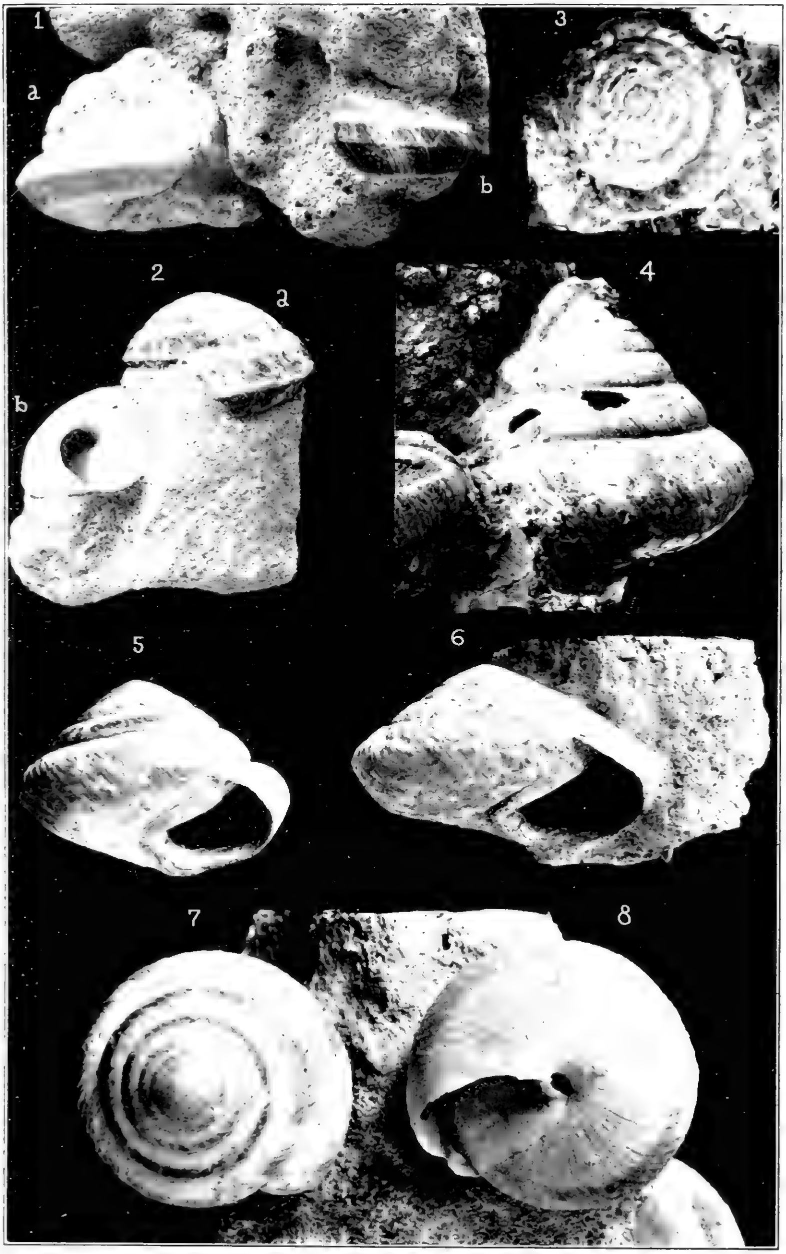
A. H. Verrill, phot. Hill Eng. Co.

1. Shell sand from shallow water. 2. Small shells, etc., from shell sand.

A. H. Verrill, phot. Gill Eng. Co.

FOSSIL LAND SHELLS IN ROCK.

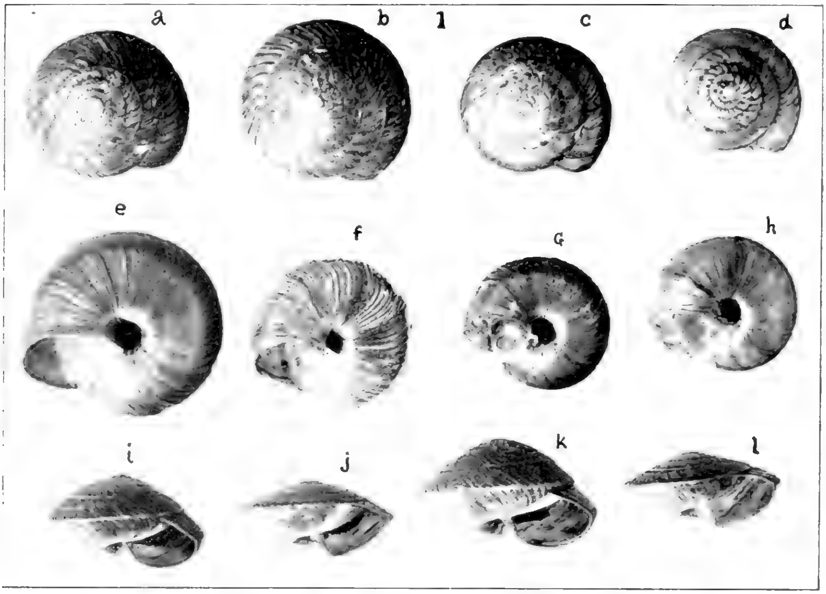
Pœcilozonites Nelsoni, var. *conoides*.

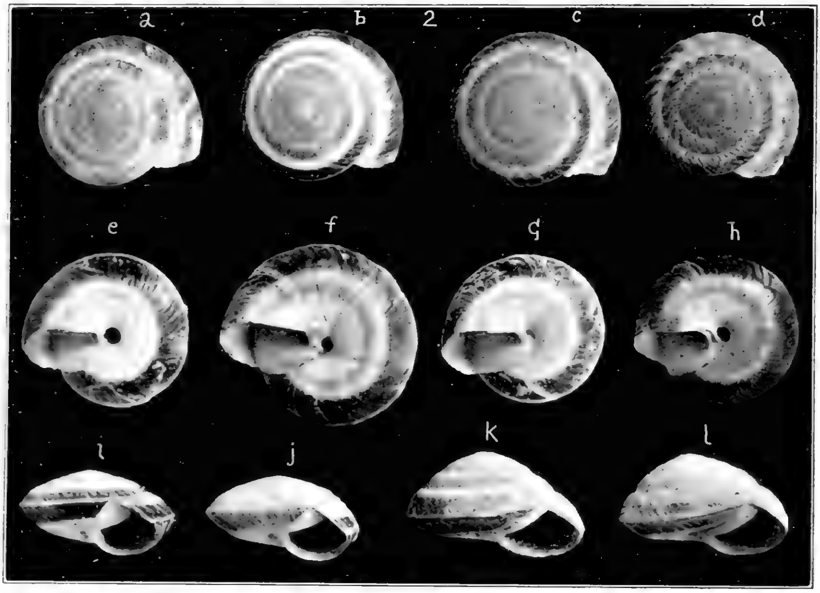


A. H. Verrill, phot. Stoddard & Brown, eng.

FOSSIL LAND SHELLS.

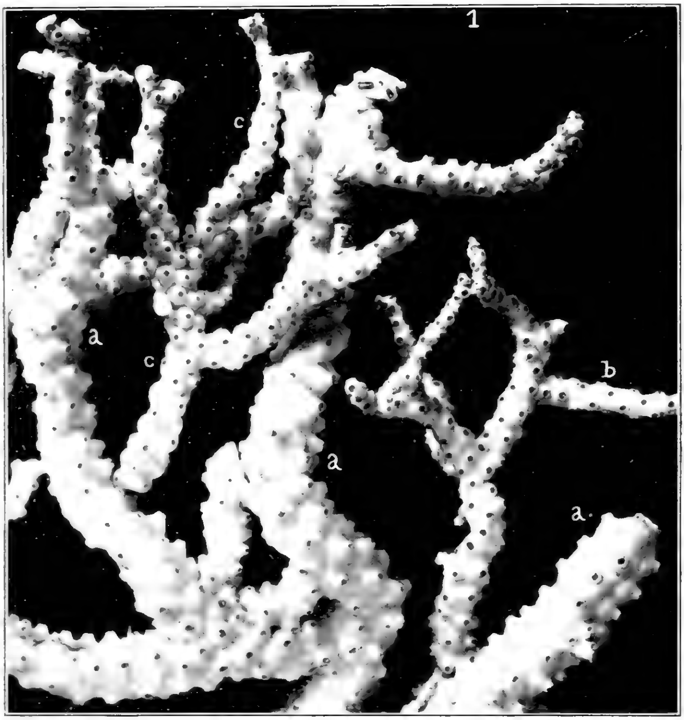
1, 2. *Pœcilozonites bermudensis*, var. *zonatus*; 3. *P. Reinianus, antiquus*; 4–8. *P. Nelsoni*.





A. Hyatt Verrill, phot. Gill Eng. Co.

1. *Pœcilozonites bermudensis*, recent. 2. *P. bermudensis*, var. *zonatus*, fossil.
To show variations.



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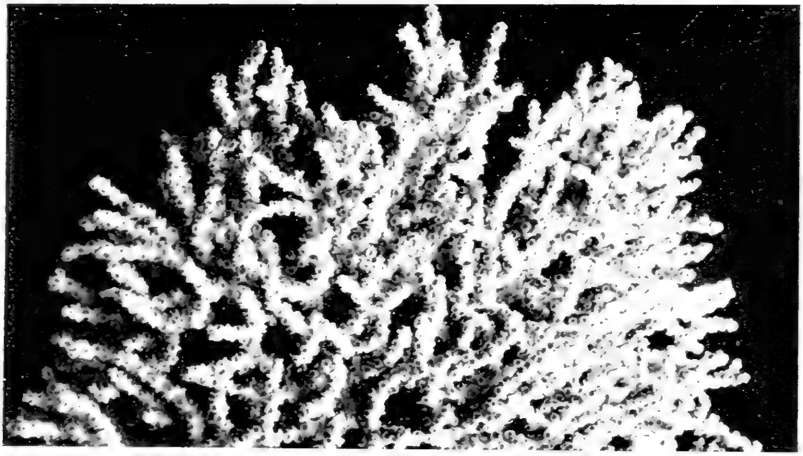
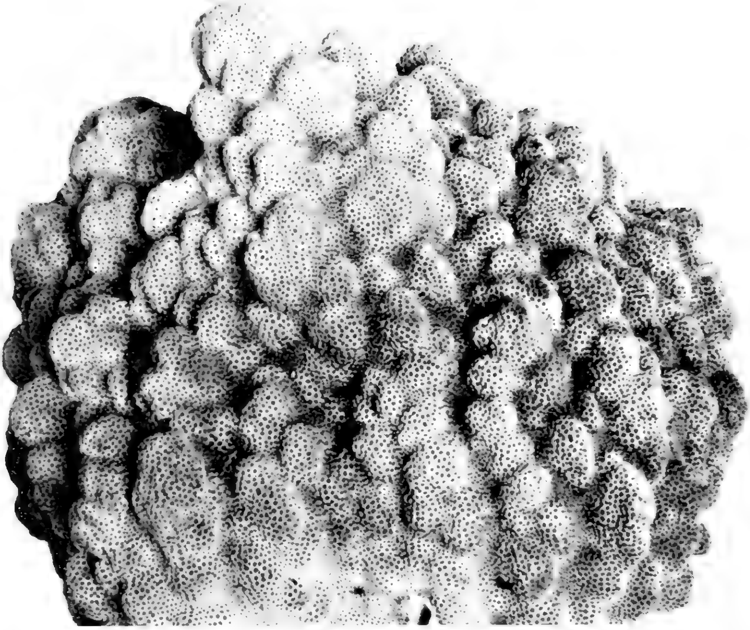


A. H. Verrill, phot. Stoddard & Brown, eng.

BERMUDA REEF CORALS.

1. *Oculina varicosa.* 2. *Oculina diffusa.*

1



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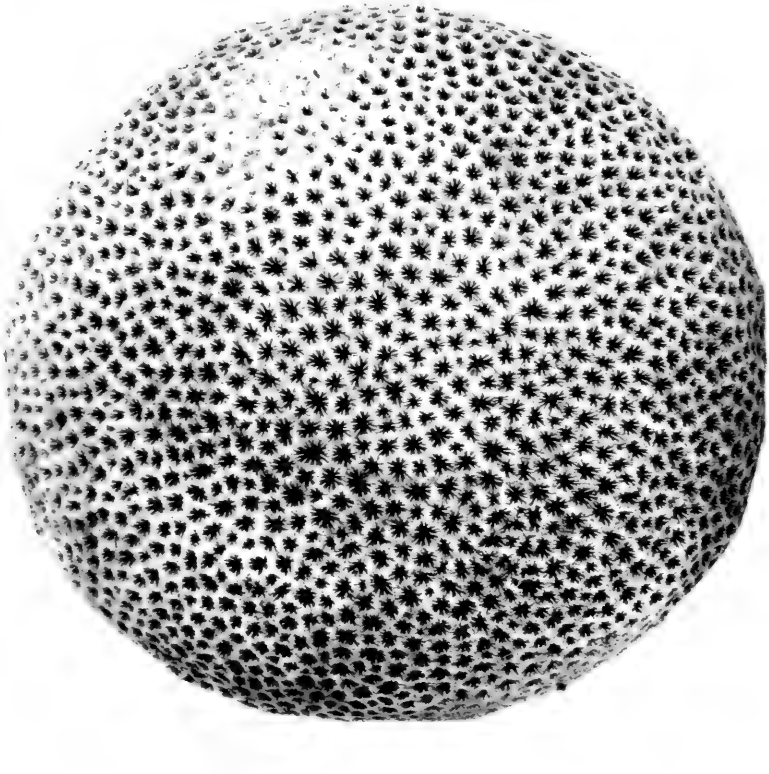
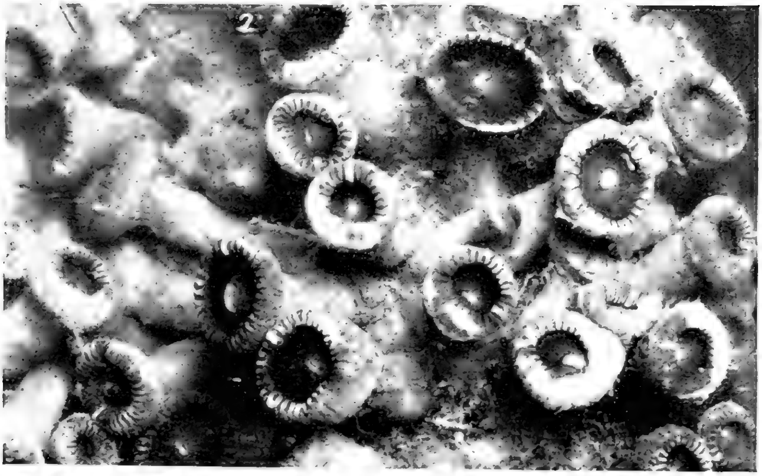


A. Hyatt Verrill, phot. Stoddard & Brown, eng.

BERMUDA REEF CORALS.

1

2

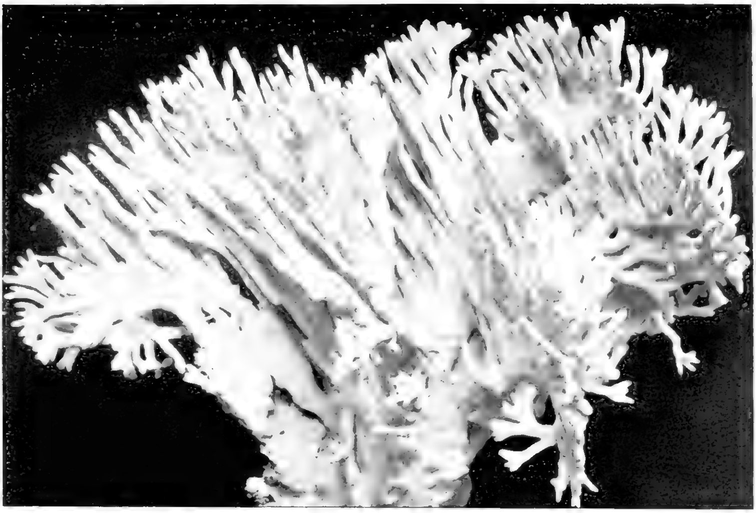


A. Hyatt Verrill, phot.

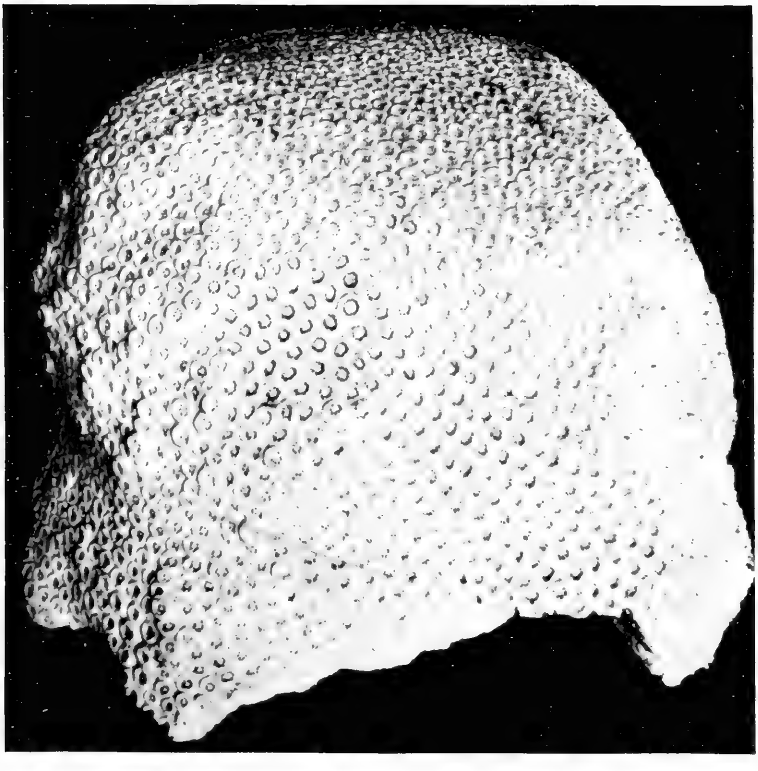
Stoddard & Brown, eng.

BERMUDA SOCIAL ACTINIANS, Etc.

2



1



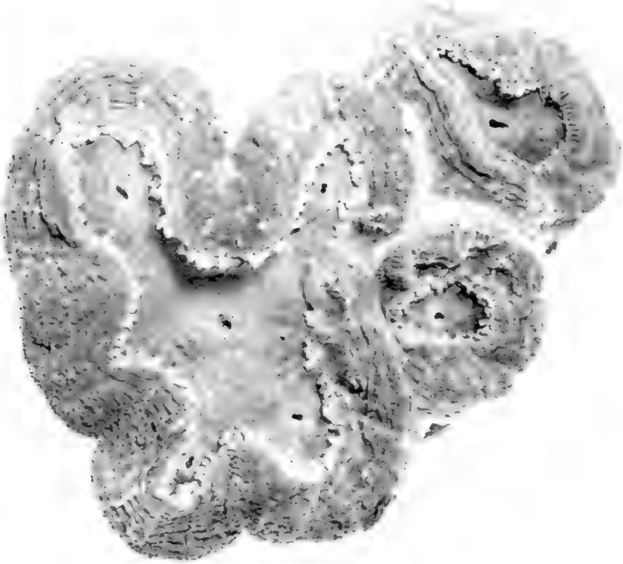
A. Hyatt Verrill, phot.

Stoddard & Brown, eng.

BERMUDA REEF CORALS.

1. *Orbicella cavernosa.* 2. *Millepora alcicornis.*

1



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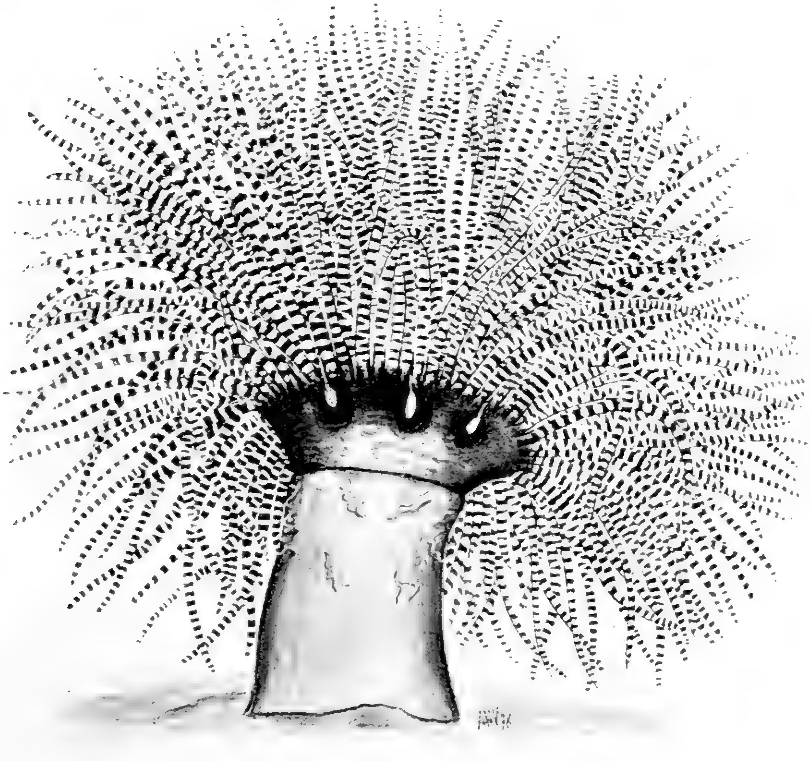


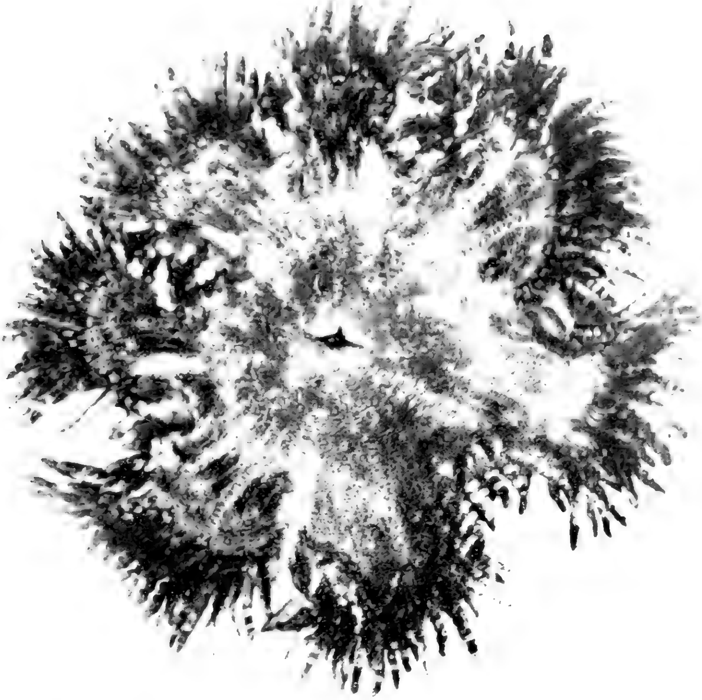
A. Hyatt Verrill, phot. and del.

Stoddard & Brown, eng.

BERMUDA CORAL AND ACTINIAN.

1. *Mussa fragilis*, from life. 2. *Aiptasia annulata*, var. *solifera*. Both about nat. size.

1



2

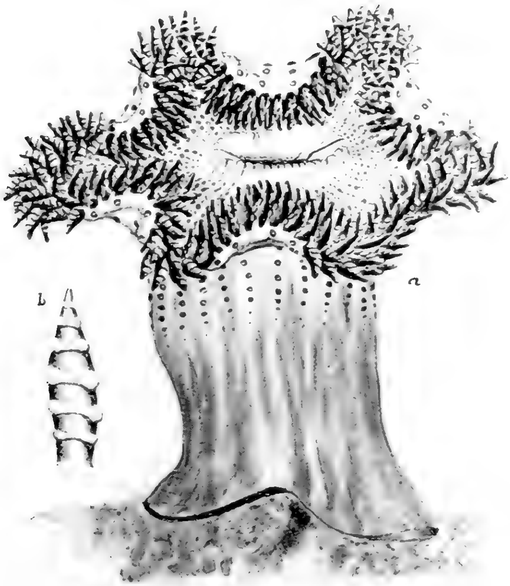
A. Hyatt Verrill, phot. from life.

Stoddard & Brown, eng.

BERMUDA ACTINIANS.

1. *Epicystis crucifera*. 2. *E. formosa*.

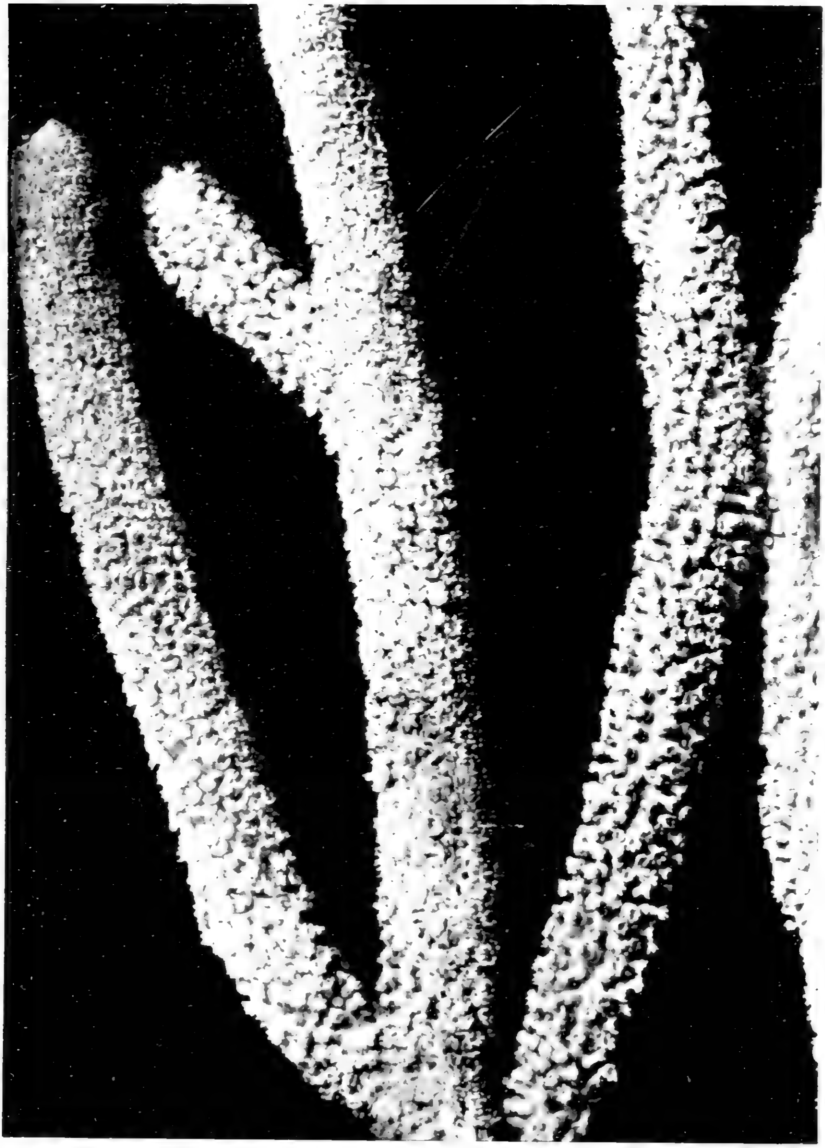
1



2

A. Hyatt Verrill, del. and phot. Stoddard & Brown, eng.

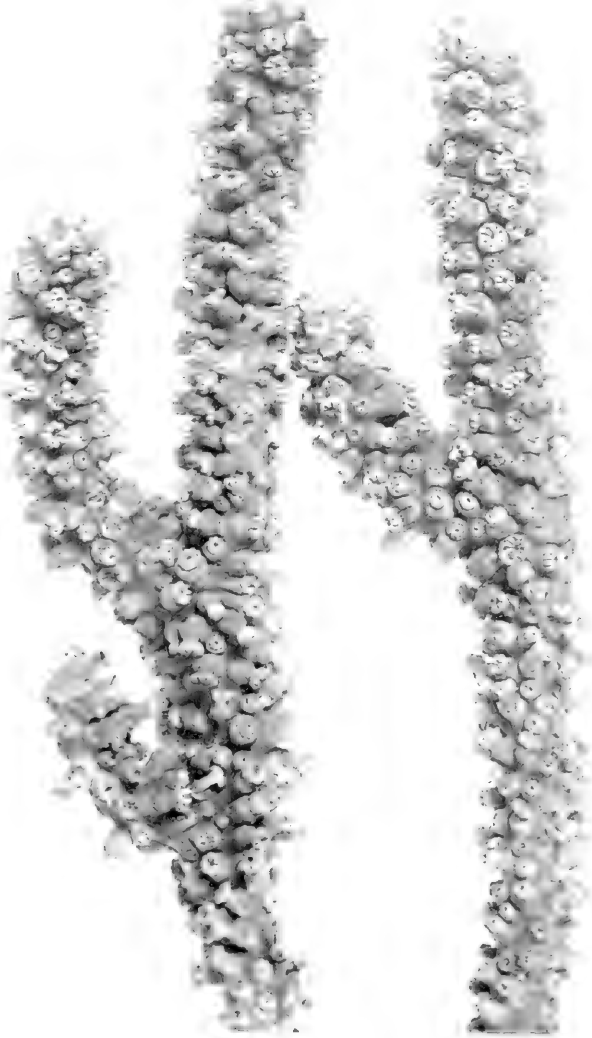
BERMUDA ACTINIANS.



[illegible] [illegible]

BERMUDA GORGONIAN CORAL.

Pseudoplexaura crassa, with polyps partially expanded.

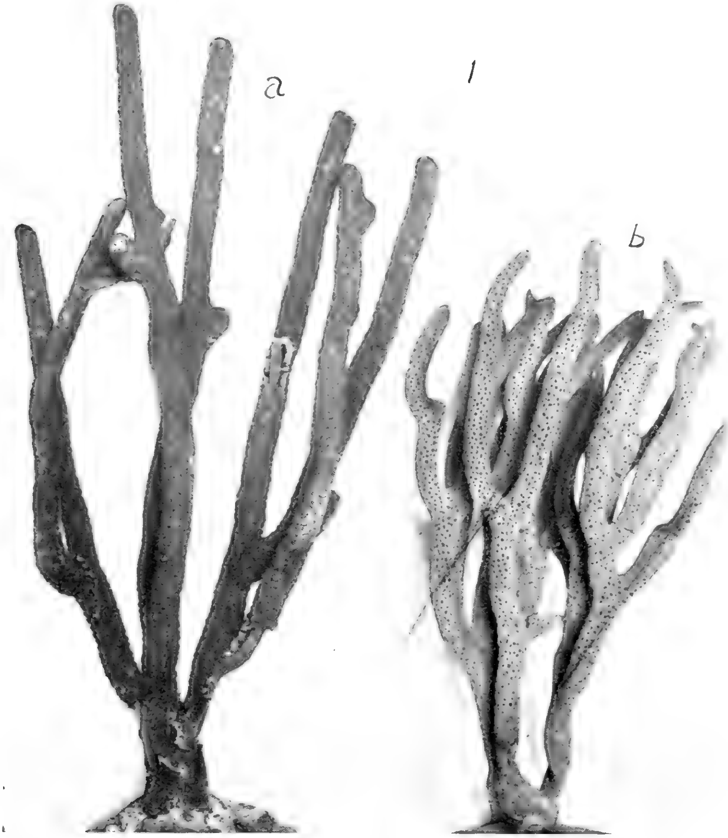


A. Hyatt Verrill, phot. from life. Stoddard & Brown, eng.

BERMUDA GORGONIAN CORAL.

Euniceopsis grandis, with polyps partially expanded.

1



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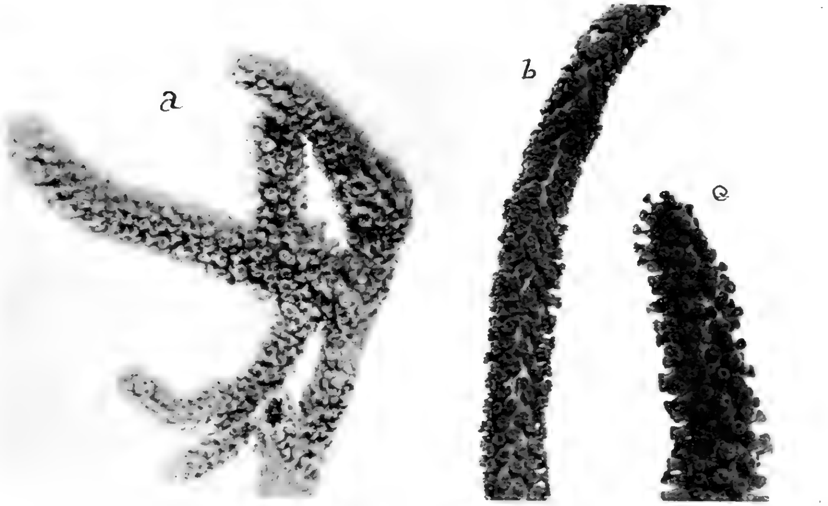


A. Hyatt Verrill, phot. Stoddard & Brown, eng.

BERMUDA GORGONIAN CORALS.

1. *a. Euniceopsis grandis; b. Plexaurella dichotoma;* about ¼ nat. size. 2. *a. Muricea muricata,* with expanded polyps; *b, c. Plexauropsis bicolor* V.: nat. size.

PLATE XXXIII C

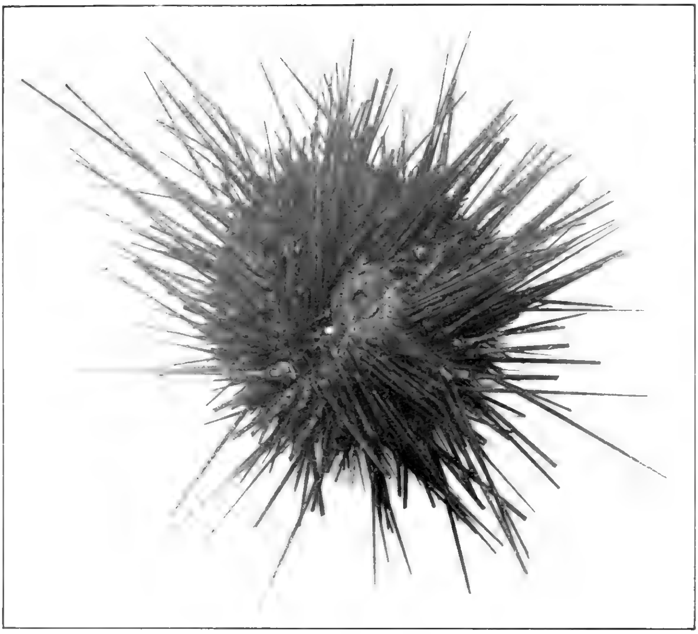
4

A. Hyatt Verrill, phot.

Stoddard & Brown, eng.

BERMUDA GORGONIAN CORALS.

1



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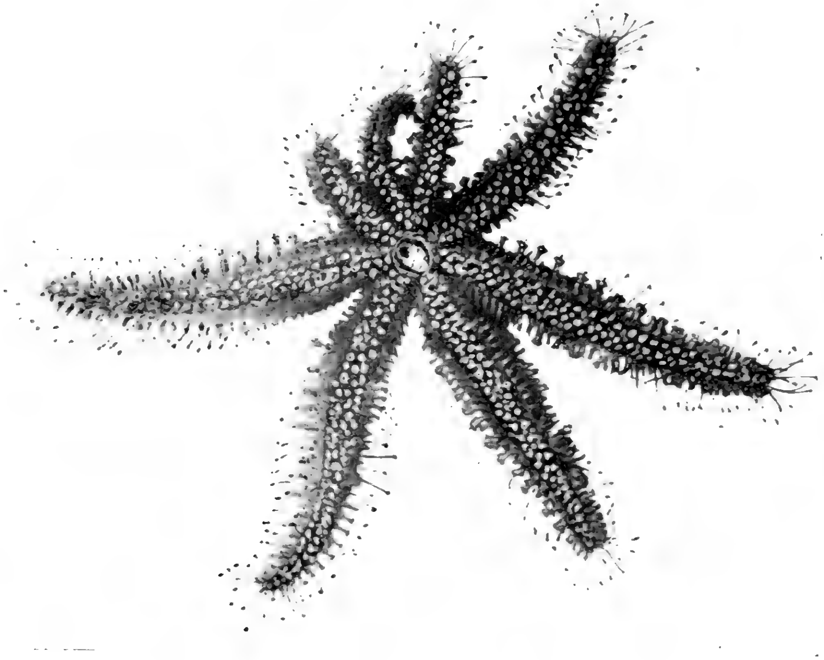
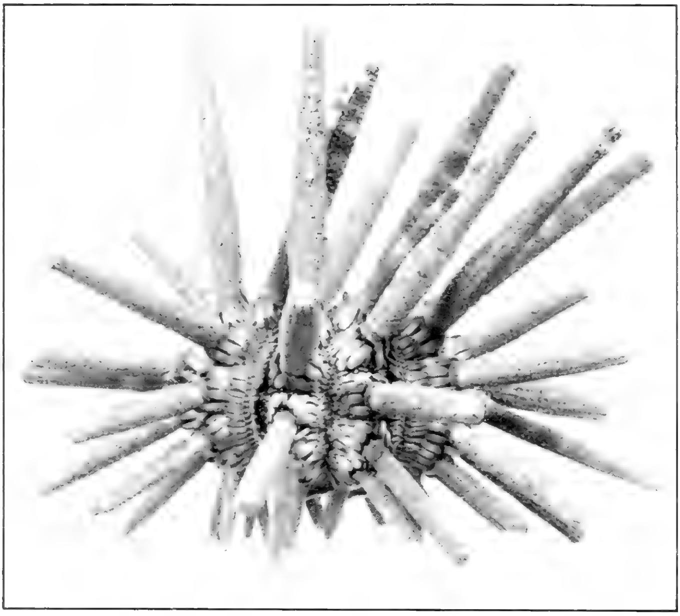


A. Hyatt Verrill, phot. Stoddard & Brown, eng.

BERMUDA ECHINODERMS.

1. *Diadema setosum.* $\frac{2}{3}$. 2. *Asterias tenuispina*, with expanded sucker-feet.

1



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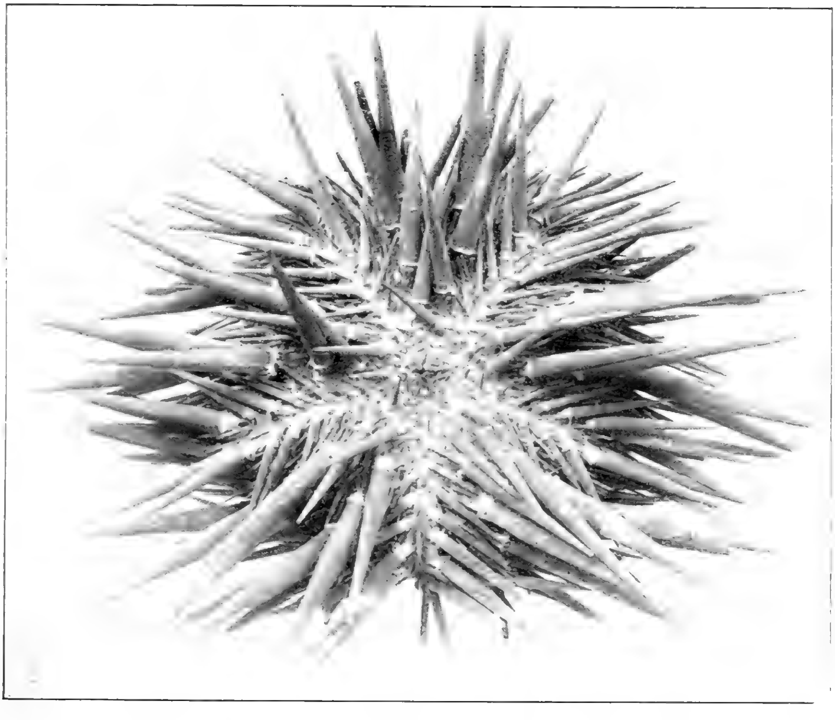
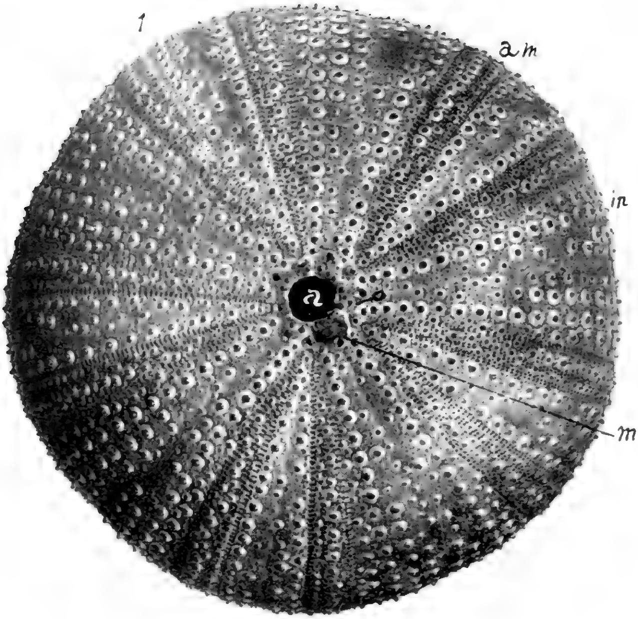
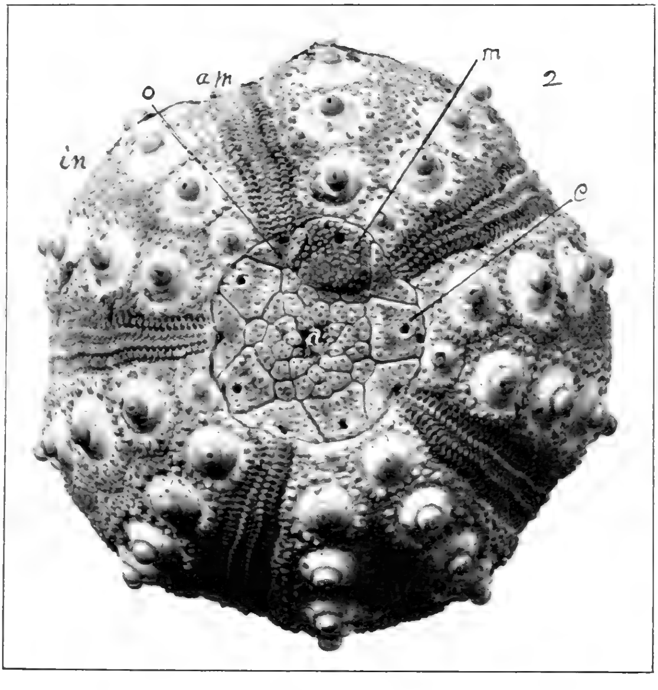


A. Hyatt Verrill, phot. Gill Eng Co.

BERMUDA ECHINODERMS: SEA URCHINS.

1. *Cidaris tribuloides.* 2. *Echinometra subangularis.*



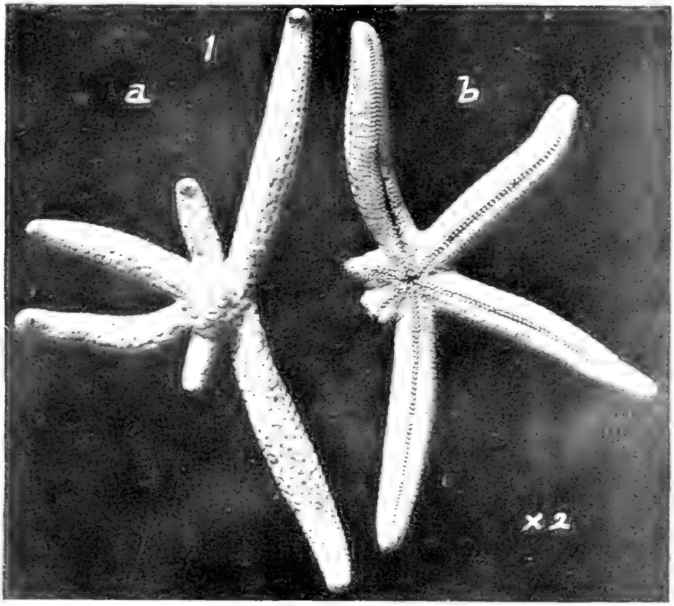


A. Hyatt Verrill, phot.

Stoddard & Brown, eng.

BERMUDA ECHINOIDS.

1. *Hipponoë esculenta*, $\frac{3}{4}$. 2. *Cidaris tribuloides*, × $1\frac{1}{2}$.



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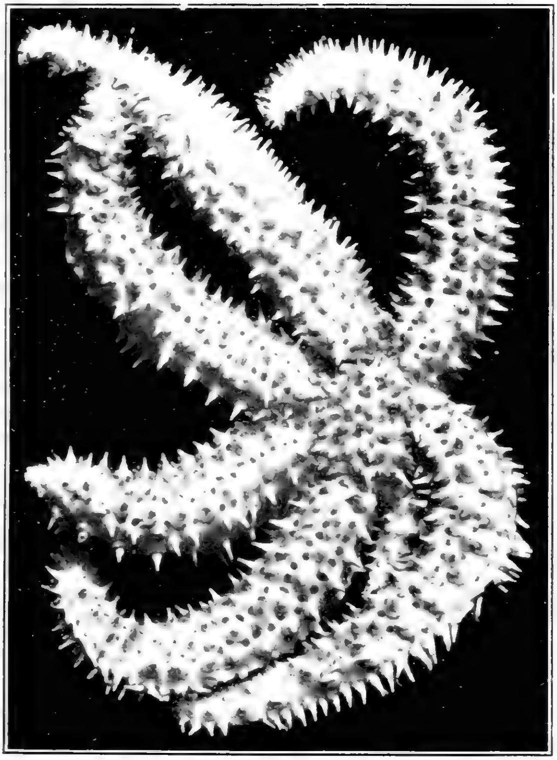
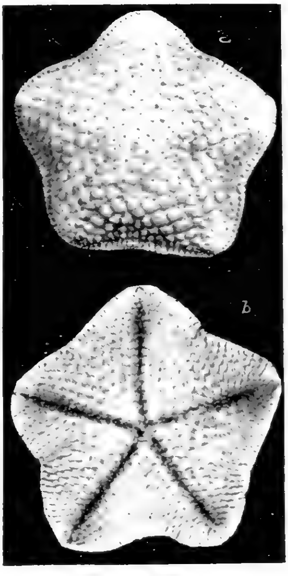


3

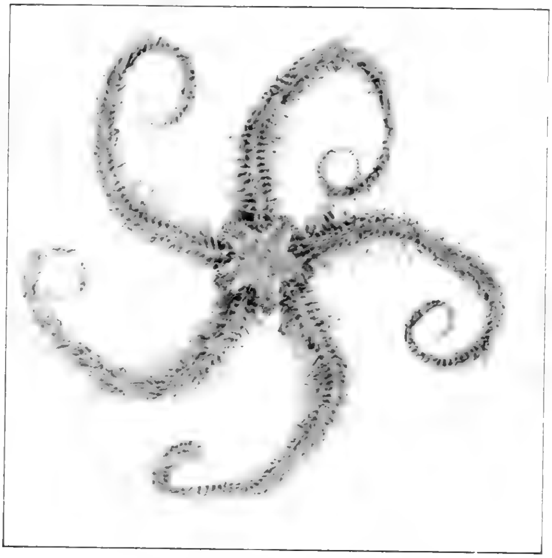


A. Hyatt Verrill, phot. [illegible]

BERMUDA STARFISHES.

1. *Linckia Guildingii.* 2. *Asterias tenuispina,* $\frac{1}{1}$. 3. *Asterina folium,* × 3.

1



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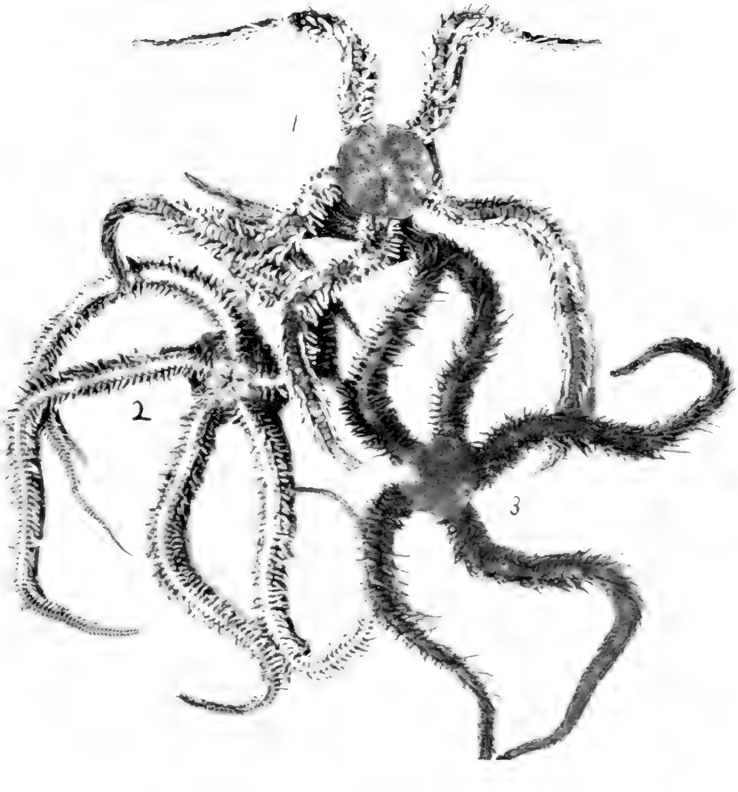
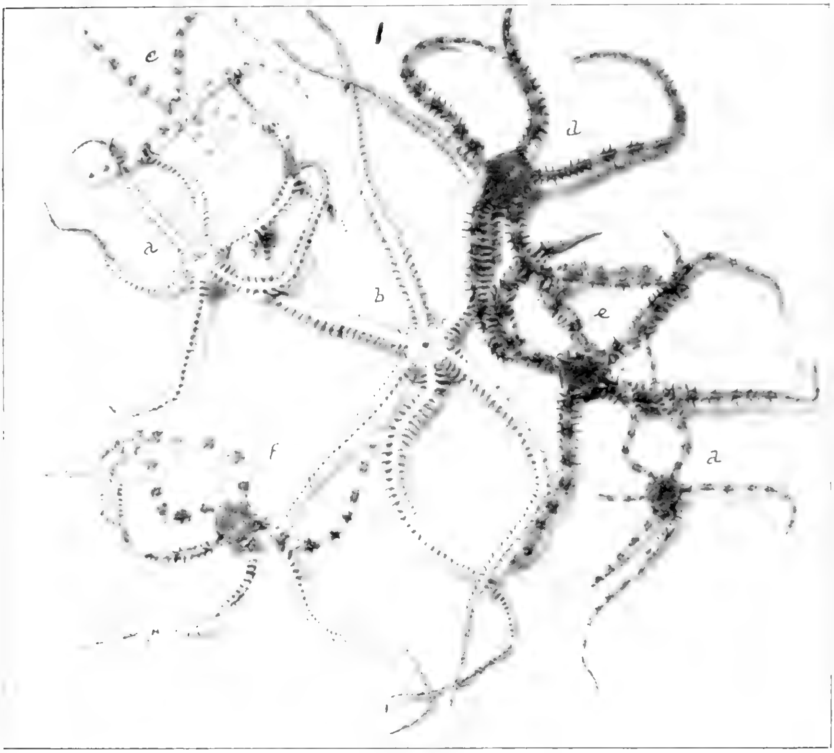
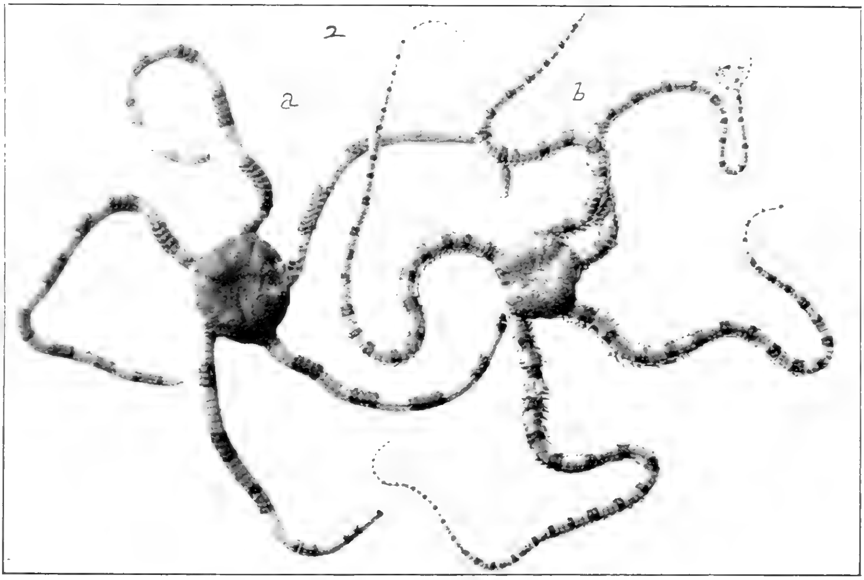


A. Hyatt Verrill, phot.
Stoddard & Brown, eng.

BERMUDA ECHINODERMS; OPHIURANS.

1. *Ophiothrix angulata.* 2. (1, 2), *Ophiocoma echinata* ; (3), *O. Riisei.*

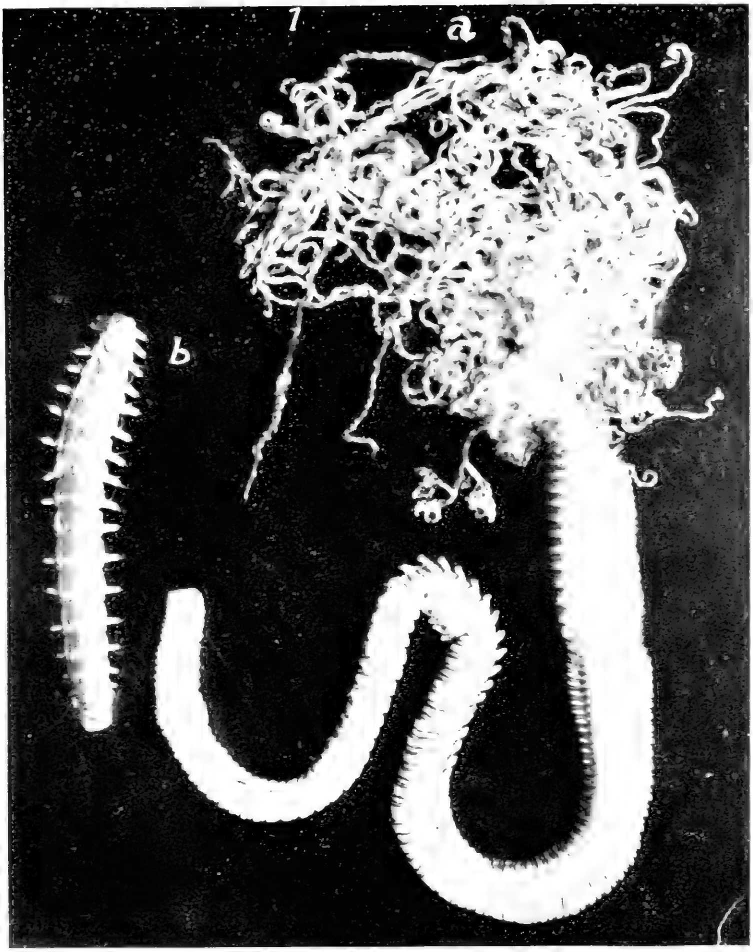


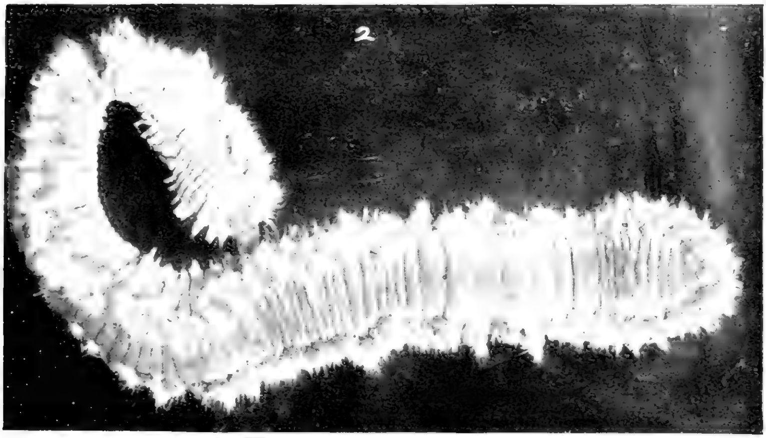


A. Hyatt Verrill, phot. Stoddard & Brown, eng.

BERMUDA OPHIURANS.

1. *Ophiocoma pumila*, $\frac{1}{1}$. 2. *a*. *Ophiura brevispina*; *b*. *Ophionereis reticulata*, $\frac{3}{4}$.

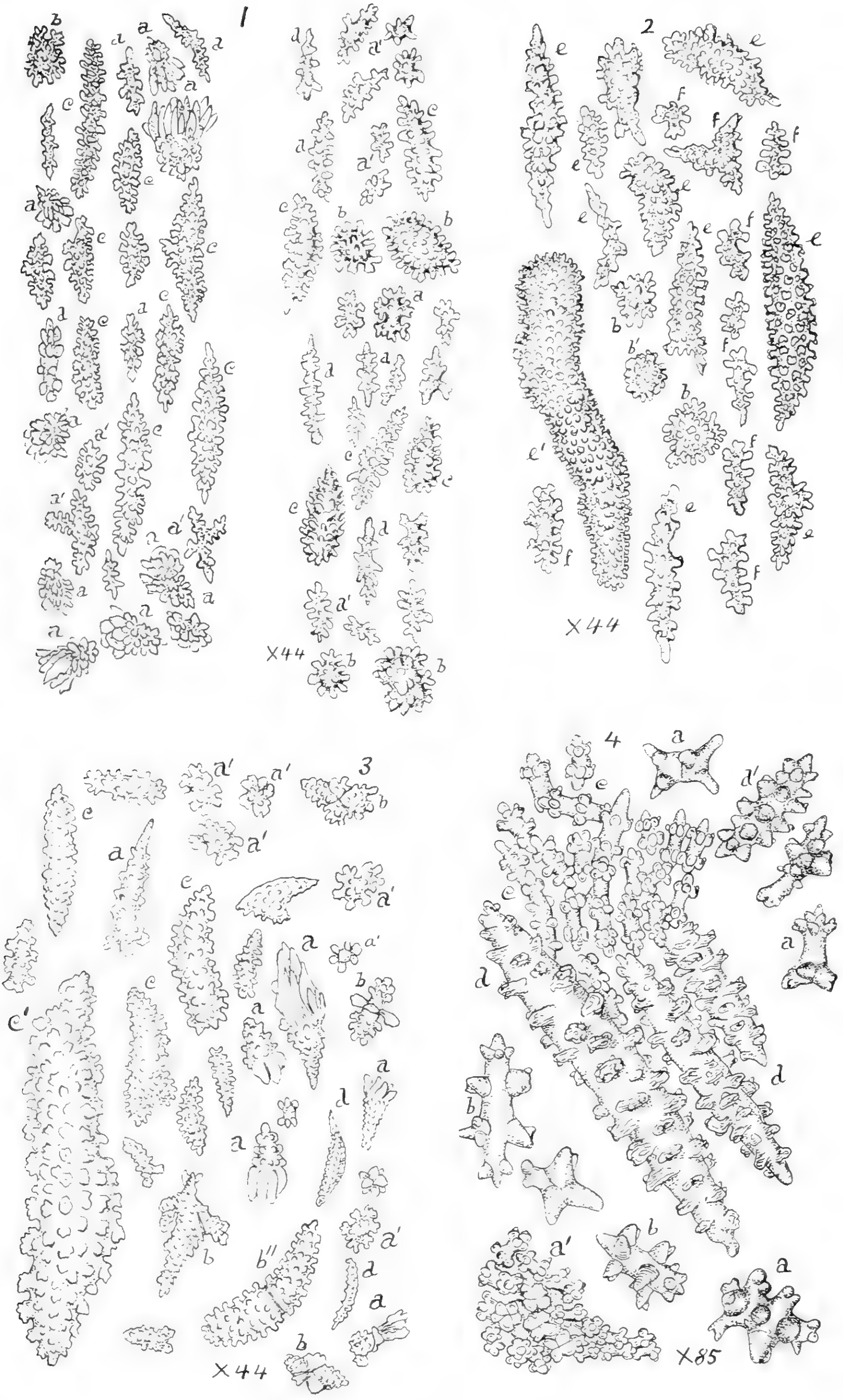




A. Hyatt Verrill, phot. Stoddard & Brown, eng.

BERMUDA ANNELIDS.

1. *a. Eupolymnia magnifica; b. Hesione prætexta.* 2. *Hermodice carunculata.*



A. Hyatt Verrill, del.

SPICULES OF BERMUDA GORGONIANS.

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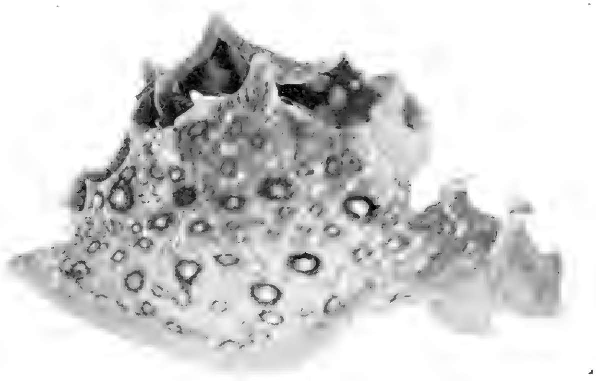

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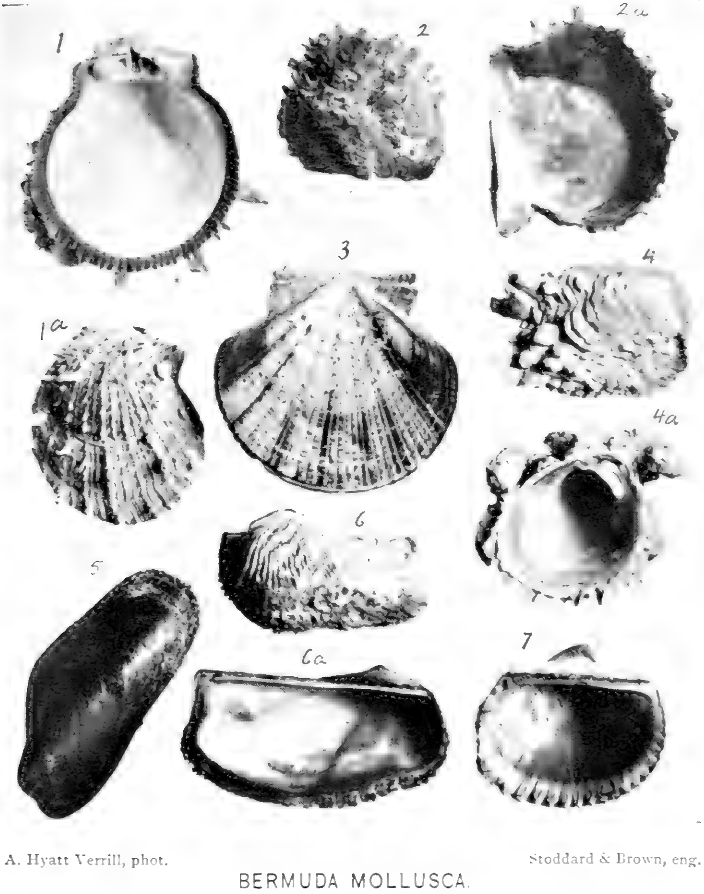
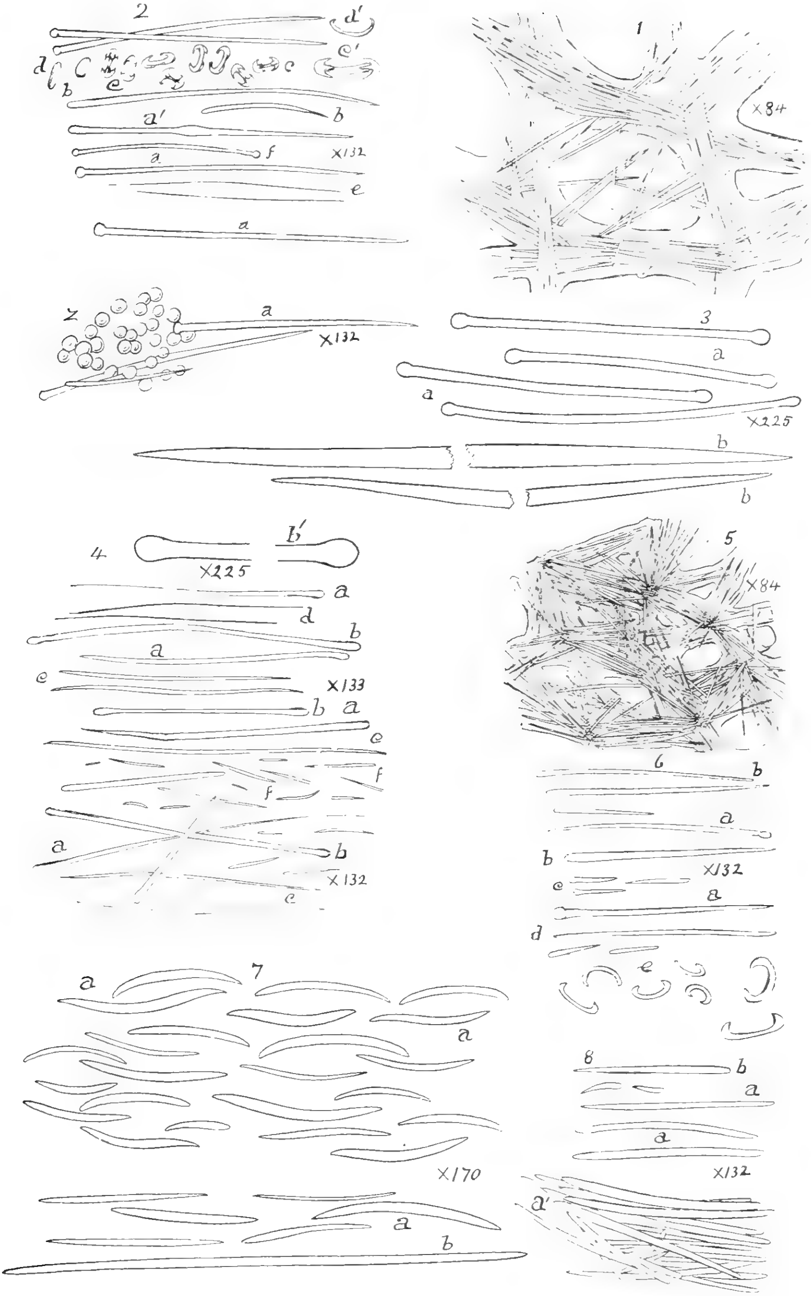


A. Hyatt Verrill, phot. Stoddard & Brown, eng.

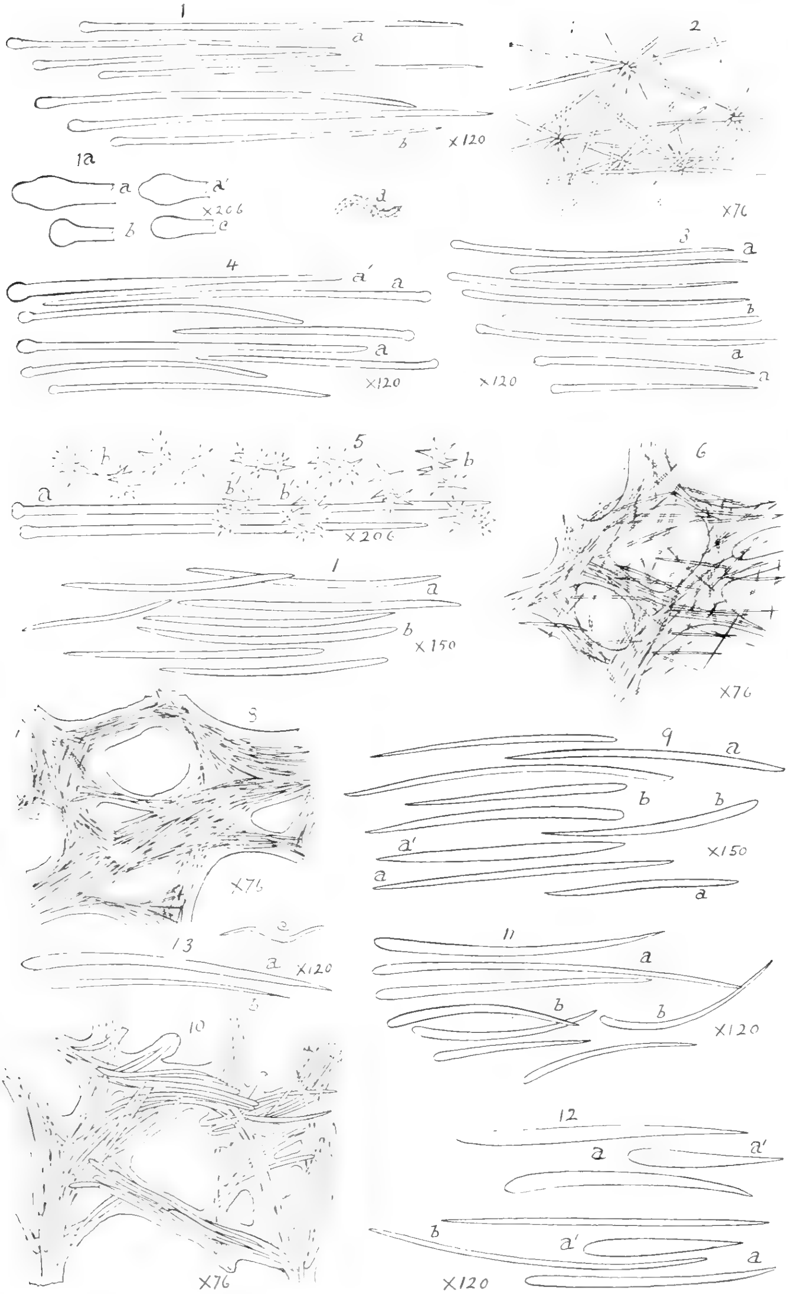
BERMUDA MOLLUSCA.

1. Sea-cat=*Tethys dactylomela*. 2. Common bivalves: 1, 1*a*. *Spondylus*; 2, 2*a*. Pearl Oyster; 3. Scollop=*Pecten ziczac*; 4, 4*a*. "Rock Cockle"=*Chama*; 5, True mussel=*Modiola tulipa*; 6, 6*a*. "Mussel"=*Arca noæ*; 7. *A. Secticostata*. See expl. plates.



A. Hyatt Verrill, del.

BERMUDA SPONGES: SPICULES.



A. Hyatt Verrill, del.

BERMUDA SPONGES: SPICULES.

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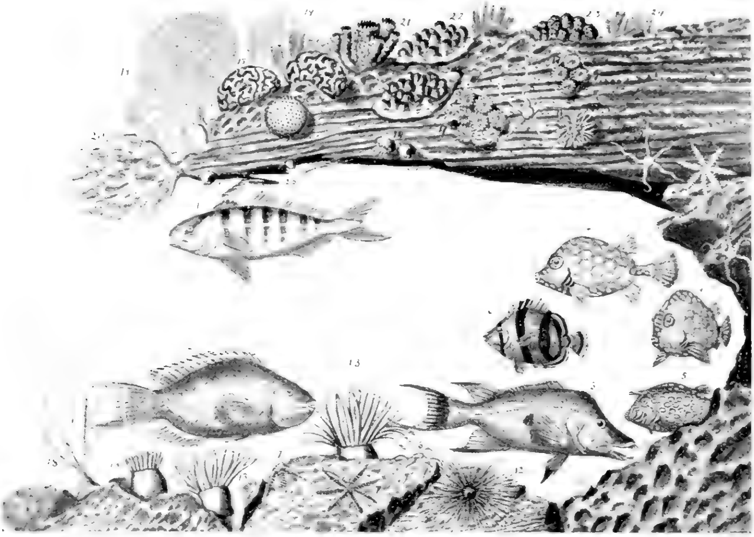

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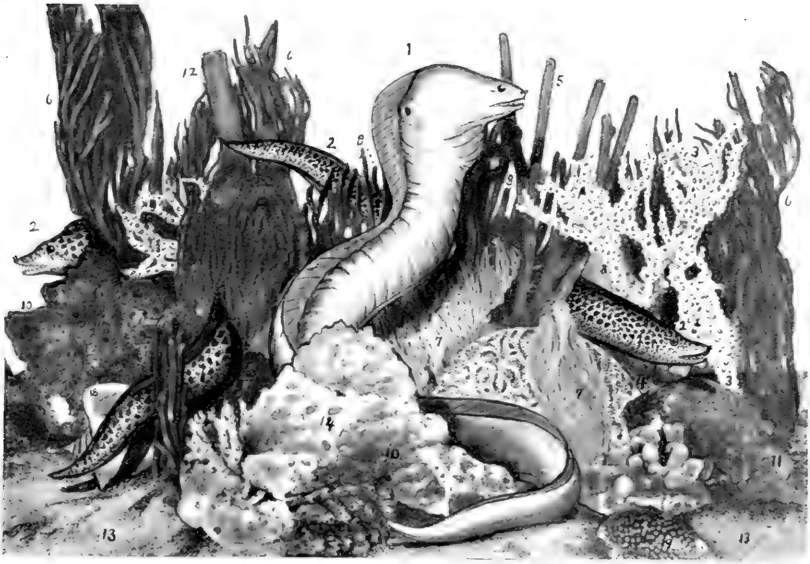


A. Hyatt Verrill, phot. and delin.

Stoddard & Brown, eng.

BERMUDA FISHES, CORALS, Etc.

1. Group of reef fishes, actinians, sponges, etc. 2. (1), Green moray; (2), Spotted moray, with a group of gorgonians, corals, etc. See expl. plates.

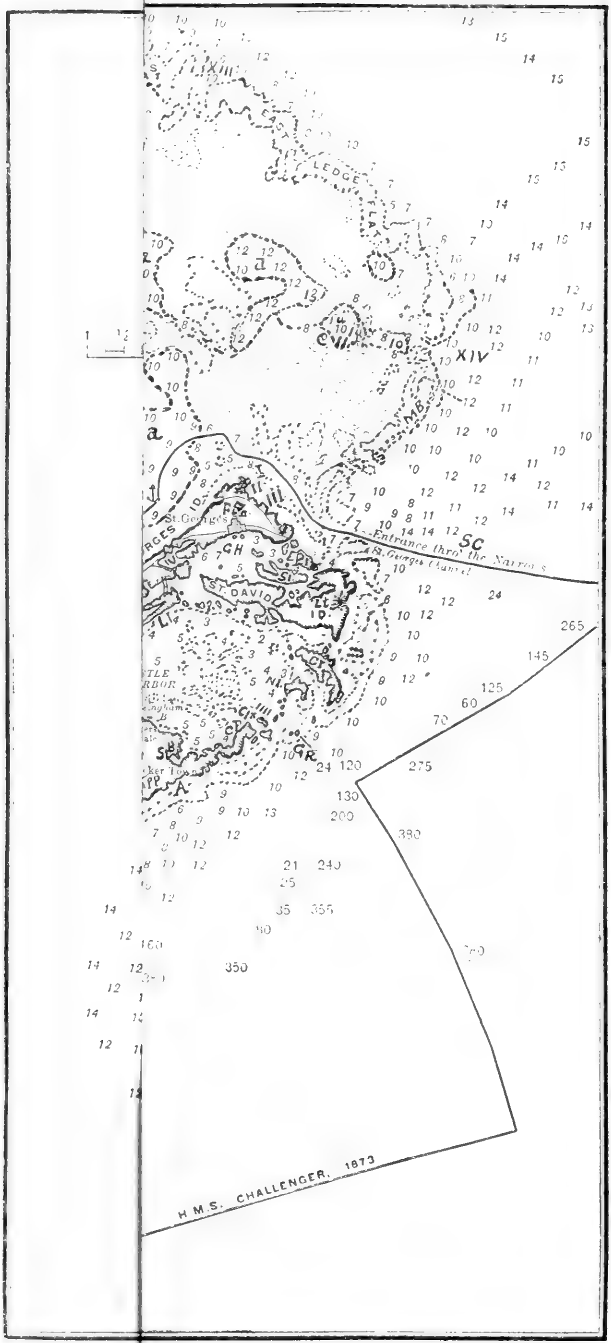
A. Hyatt Verrill, del.

SPICULES OF BERMUDA GORGONIANS.

A. Hyatt Verrill, del.

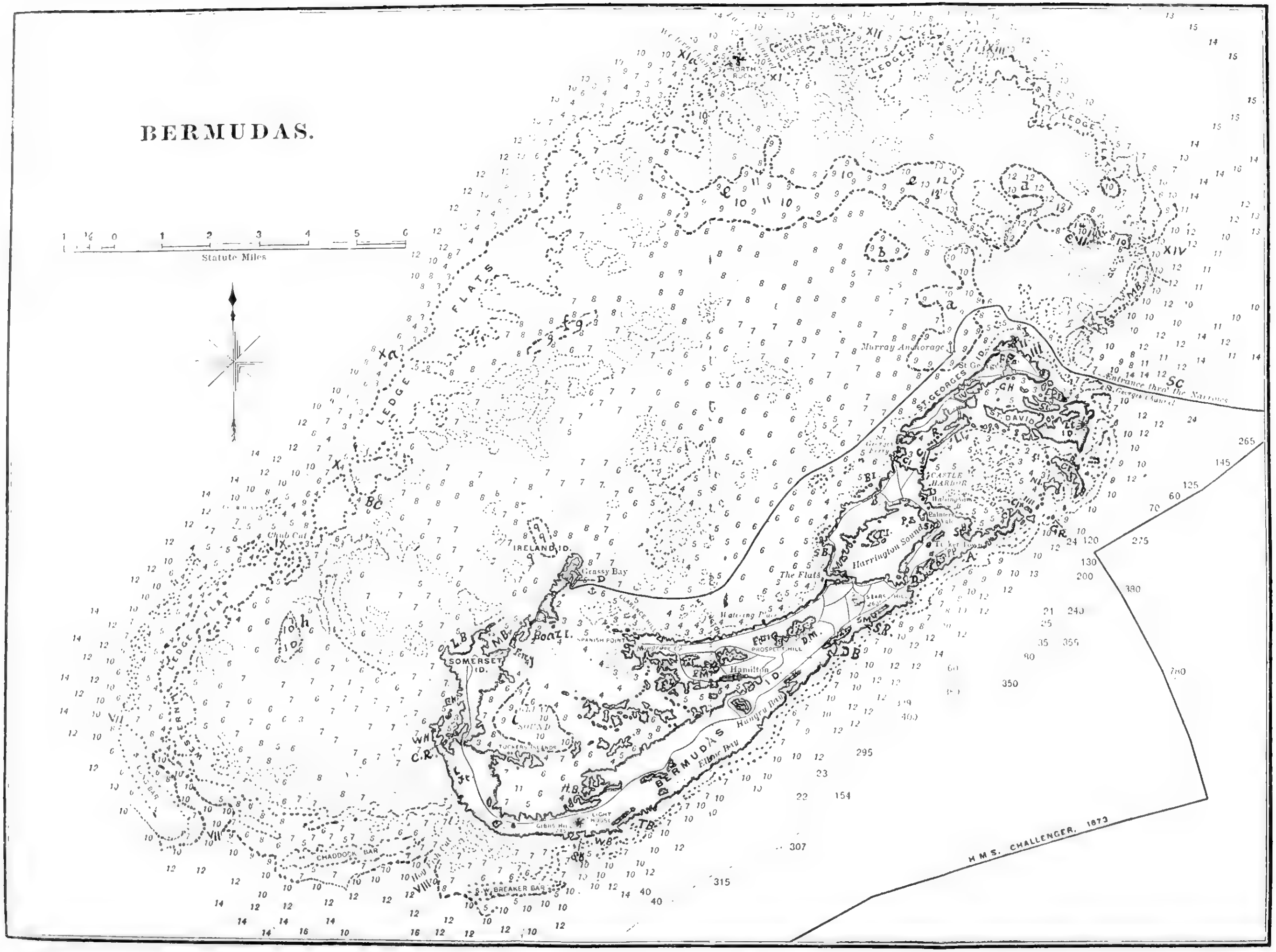
SPICULES OF BERMUDA GORGONIANS.

PLATE XXXVII.



EXPLANATION: I, Catherine Point and Fort; II, Hospital; III, Building Bay; IV, Mullet Bay; GH, St. George's Harbor; F, Victoria Fort; PI, Paget I.; SI, Smith's I.; C, Causeway; CI, Coney I.; R, The Reach; LI, Long Bird I.; CI, Cooper's I.; CIX, Castle I.; GR, Gurnet Rock; IIII, Southampton I.; NI, Nonesuch I.; CP, Castle Point; A, Natural Arch; D, Devil's Hole; PP, Peniston's Pond; S, Stokes Bay; SH, Sharks Hole; TI, Trunk I.; P, Pear I.; B, Bailey Bay; BI, Bailey Bay I.; SB, Shelly Bay; DM, Devonshire Marsh; PM, Pembroke Marsh; Ft., Fort; FL, Fairy Land; HB, Heron Bay; D, Dry Dock; MB, Mangrove Bay; LB, Long Bay; EH, Elies' Harbor; WH, Watch Hill; CR, Cathedral Rocks; SB, Sinky Bay; WB, Whale Bay; TB, Turtle Bay; DB, Devonshire Bay; SM, Smith's Marsh; SR, Spanish Rock.

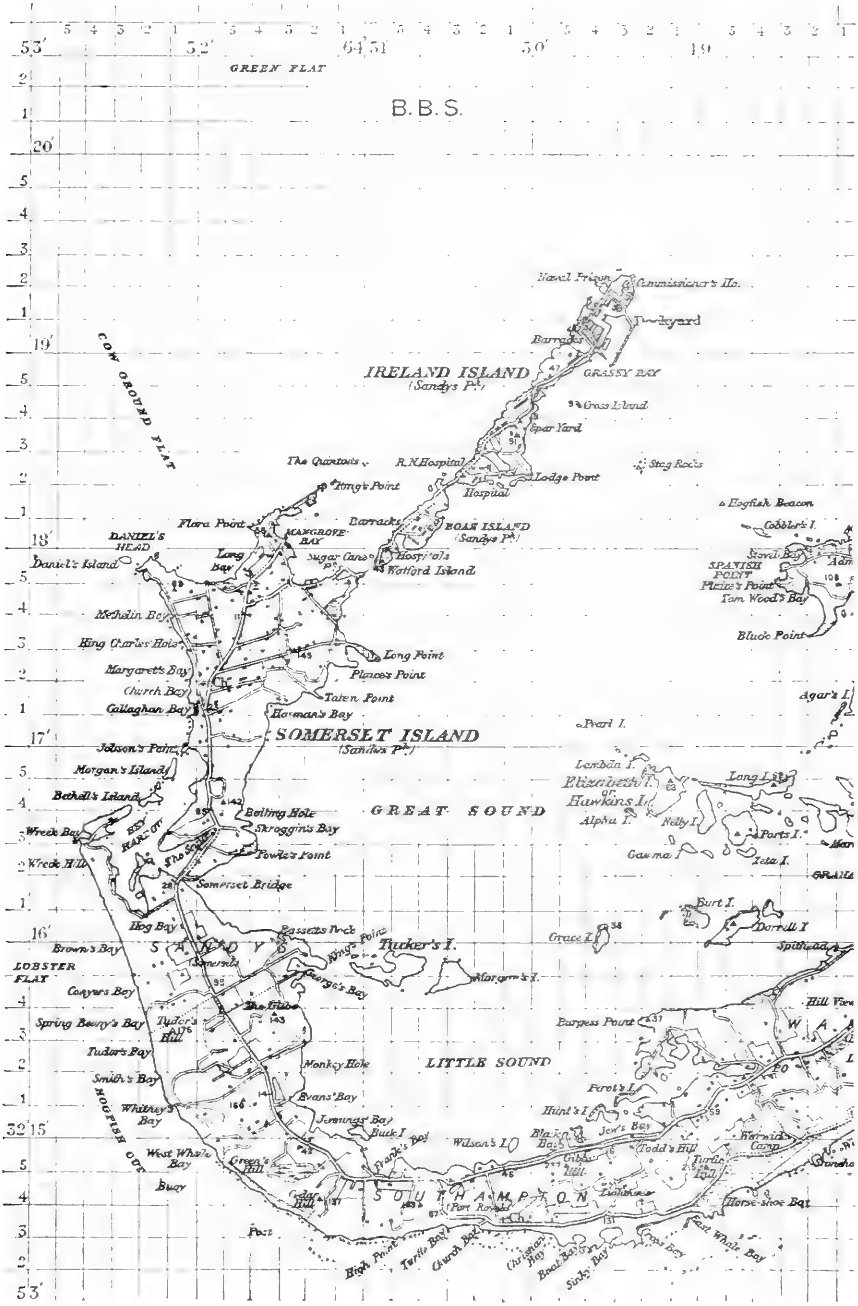
The deepts or channels through the reefs are S.C., Main ship channel oern do.; XI, eastern Channel near North Rocks; XI*a*, western d



MAP II. THE BERMUDAS AND OUTER REEFS.

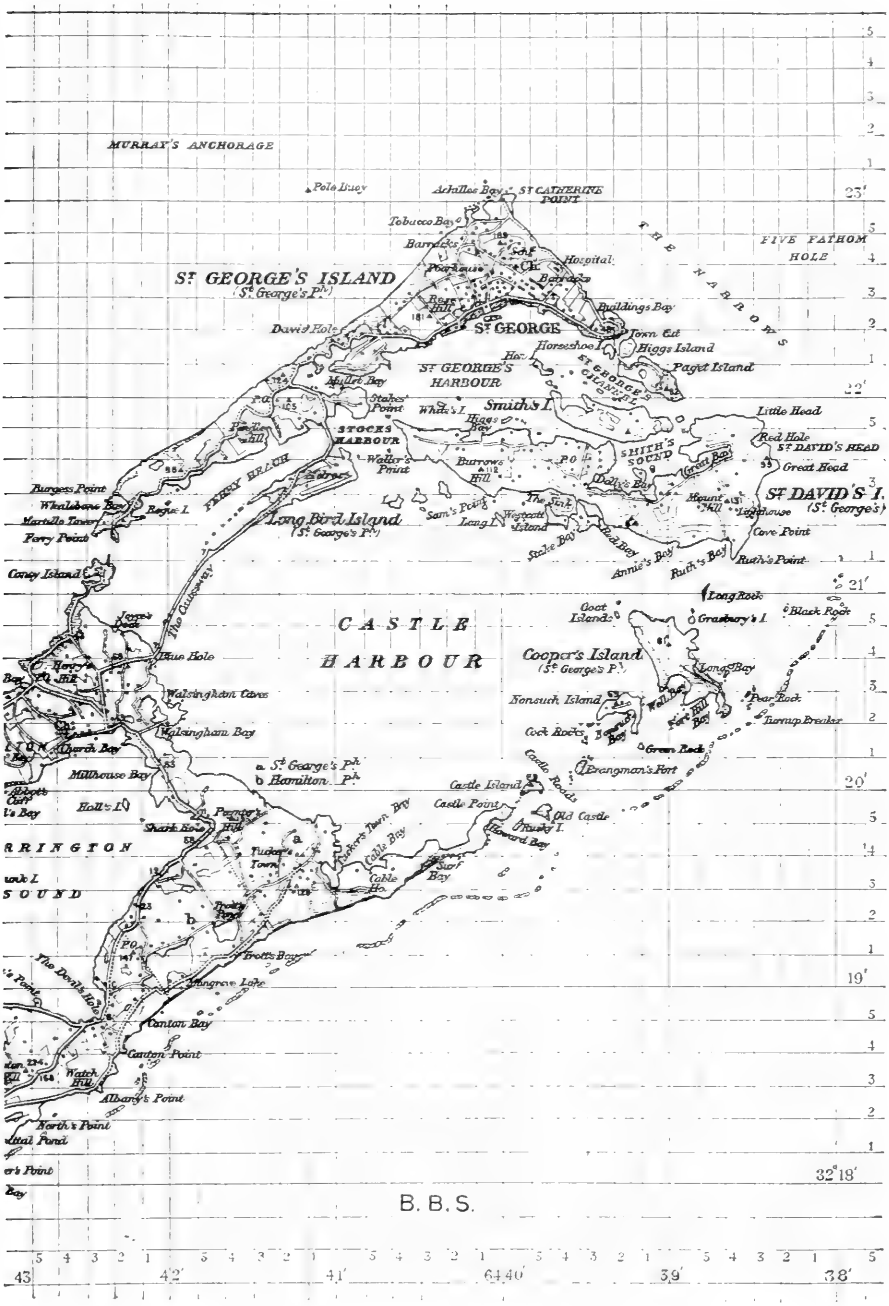
The deeper parts of the enclosed lagoons or Sounds (a–i) are indicated by dotted contour lines of about 50 feet (8⅓ fathoms). The cuts or channels through the reefs are S.C., Main ship channel or "Narrows"; VI, VII, cuts through Long Bar; VIII, Hog-fish Cut; IX, Chub Cut; X and BC, western Blue Cut; Xa, eastern do.; XI, eastern Channel near North Rocks; XIa, western do.; XII, XIII, Ledge-flat Cuts; XIV, Mills Breaker Cut. Altered from Stevenson, after Sir C. Wyville Thomson.

EXPLANATION: I, Catherine Point and Fort; II, Hospital; III, Building Bay; IV, Mullet Bay; GH, St. George's Harbor; F, Victoria Fort; PI, Paget I.; SI, Smith's I.; C, Causeway; CI, Coney I.; R, The Reach; LI, Long Bird I.; CI, Cooper's I.; CIX, Castle I.; GR, Gurnet Rock; IIII, Southampton I.; NI, Nonesuch I.; CP, Castle Point; A, Natural Arch; D, Devil's Hole; PP, Peniston's Pond; S, Stokes Bay; SH, Sharks Hole; TI, Trunk I.; P, Pear I.; B, Bailey Bay; BI, Bailey Bay I.; SB, Shelly Bay; DM, Devonshire Marsh; PM, Pembroke Marsh; Ft., Fort; FL, Fairy Land; HB, Heron Bay; D, Dry Dock; MB, Mangrove Bay; LB, Long Bay; EH, Elies' Harbor; WH, Watch Hill; CR, Cathedral Rocks; SB, Sinky Bay; WB, Whale Bay; TB, Turtle Bay; DB, Devonshire Bay; SM, Smith's Marsh; SR, Spanish Rock.

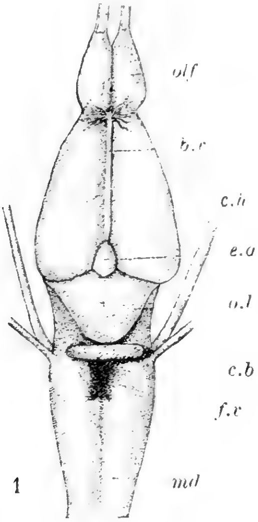


MAP III. THE BERMUDAS. SOUTHWEST SECTION.

MAP IV. THE BERMUDAS. MIDDLE SECTION.



MAP V. THE BERMUDAS. NORTHEAST SECTION.



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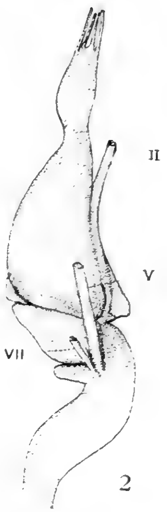

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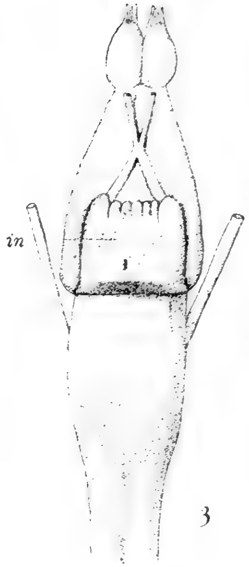

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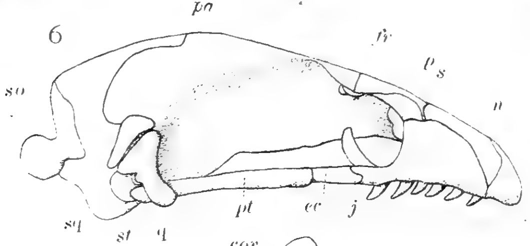

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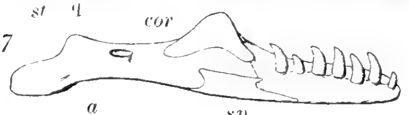

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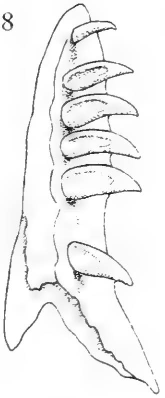

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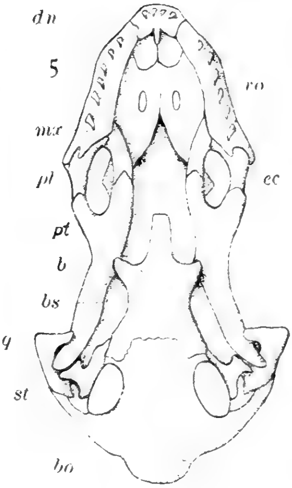

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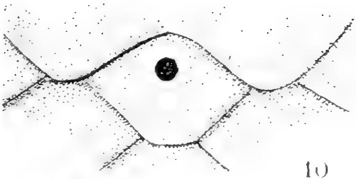
Heliotype Co., Boston.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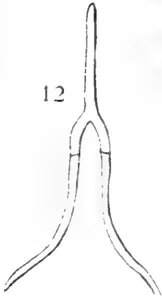
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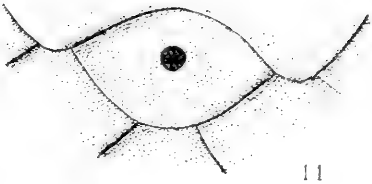
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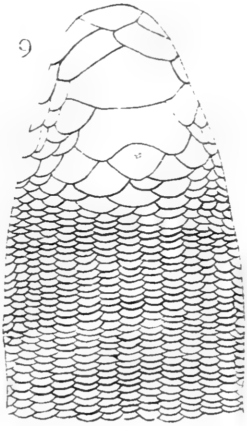
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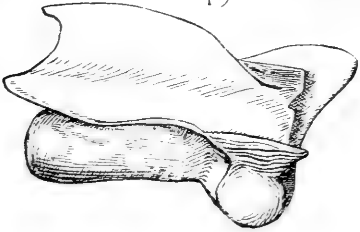
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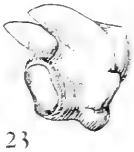
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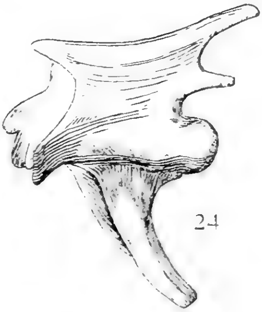
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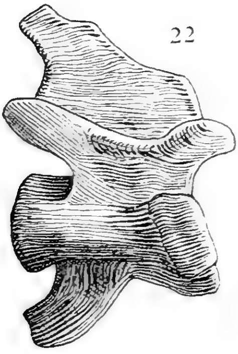
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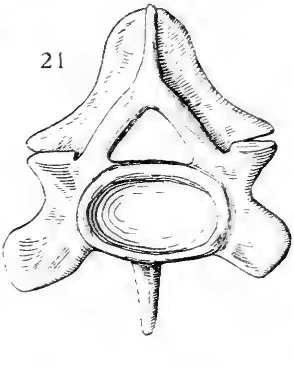
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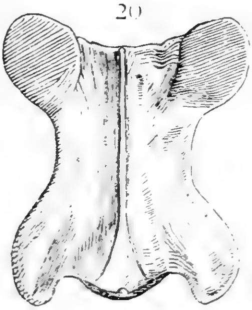
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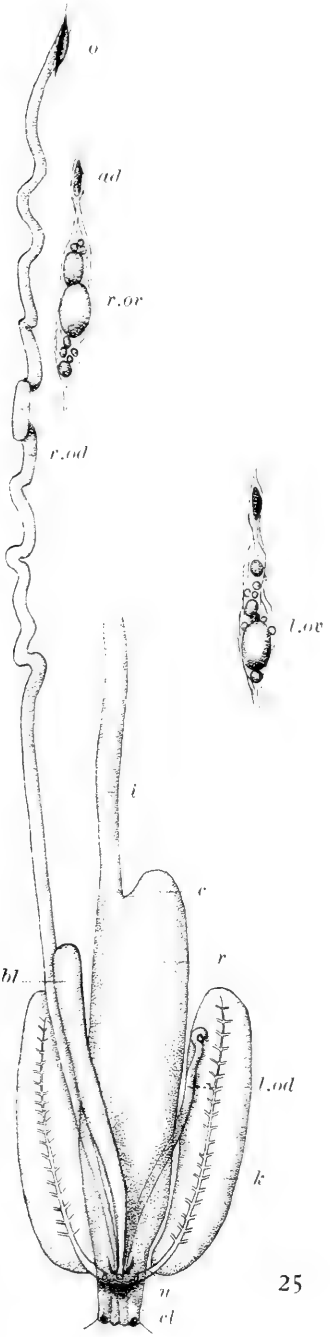

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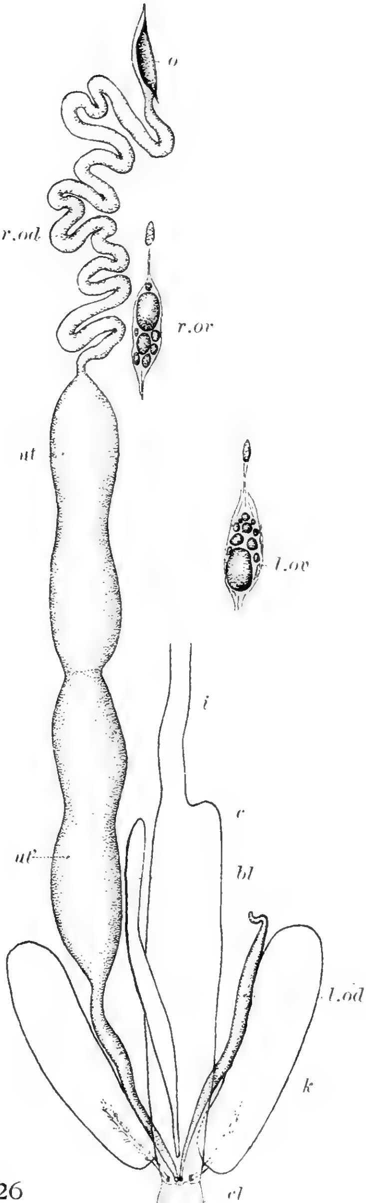

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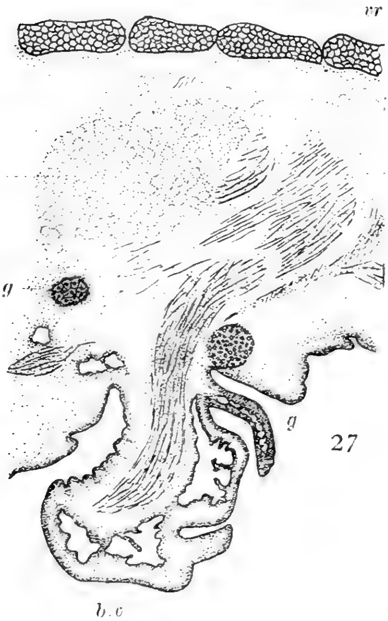

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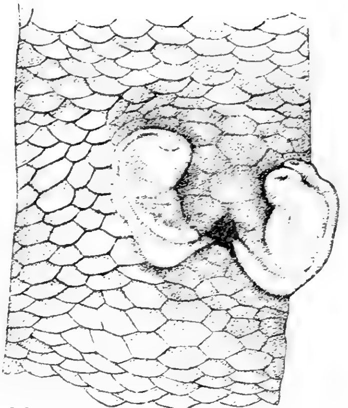

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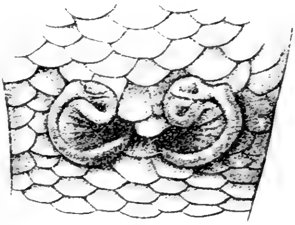

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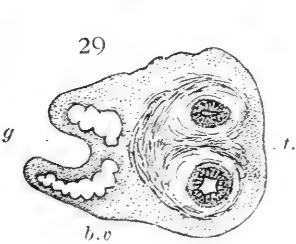

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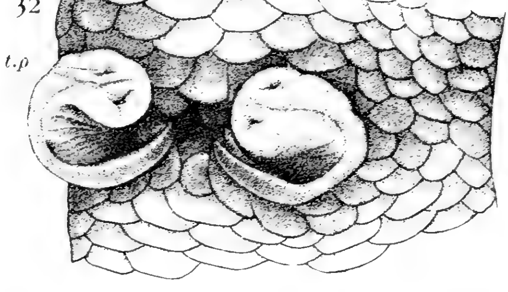

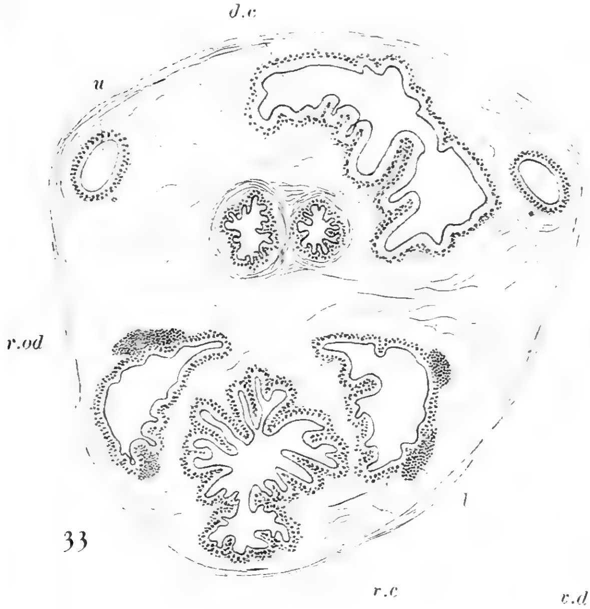

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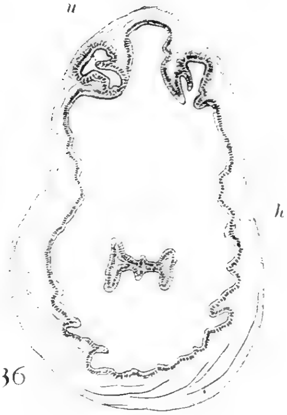

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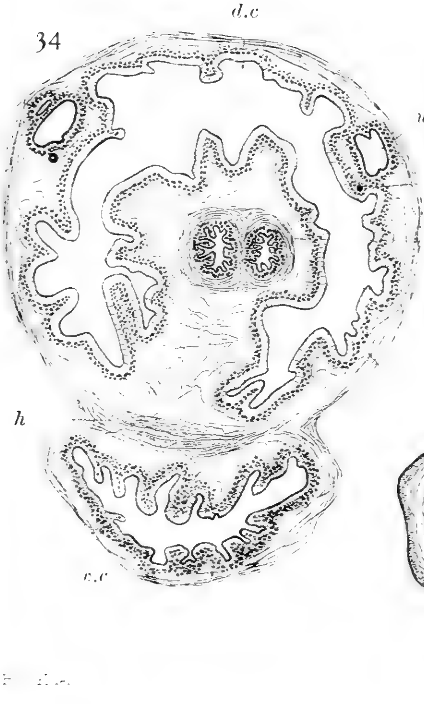

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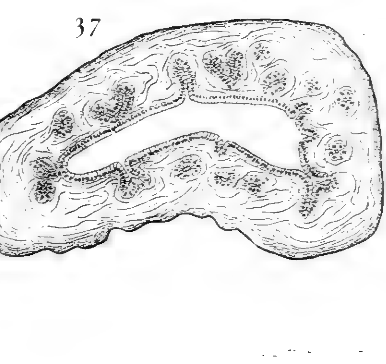

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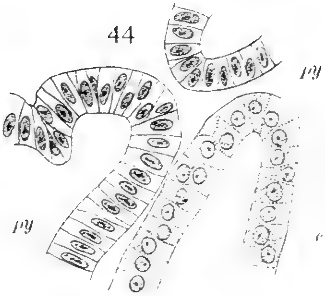

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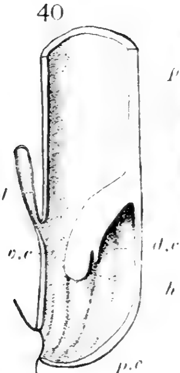

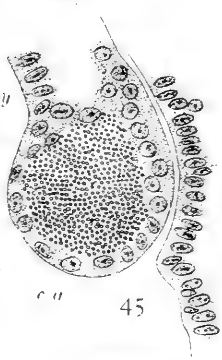

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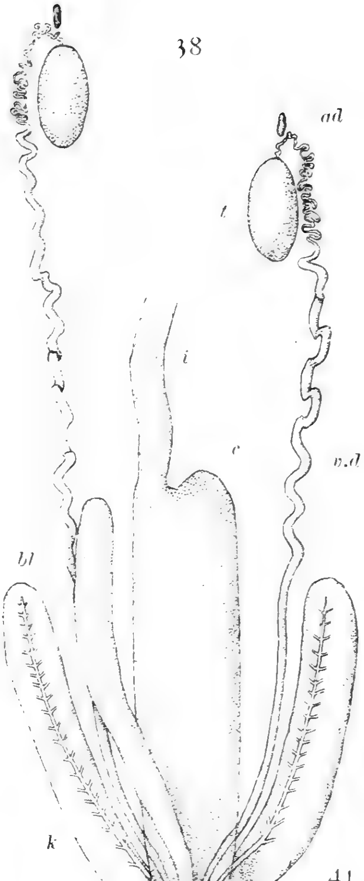

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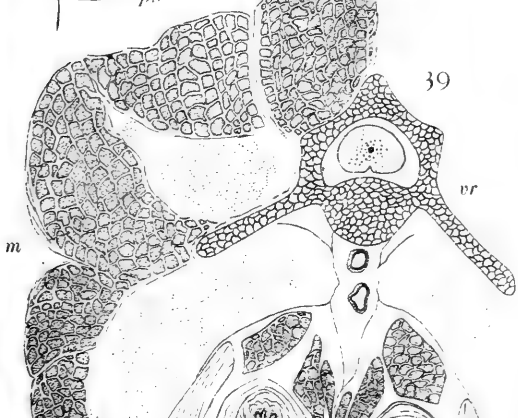

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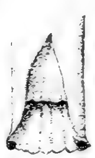

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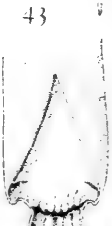

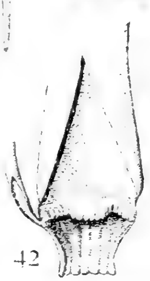

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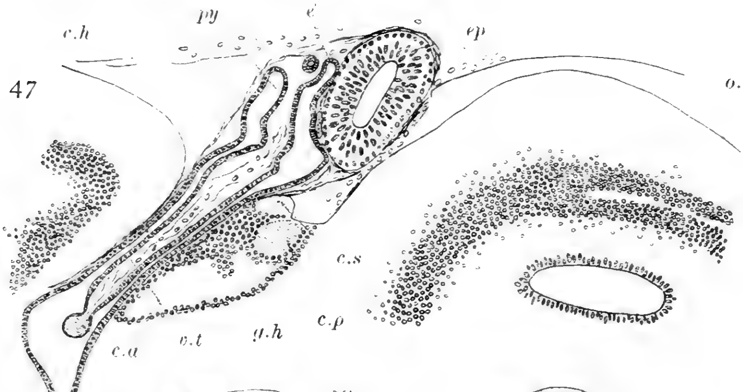

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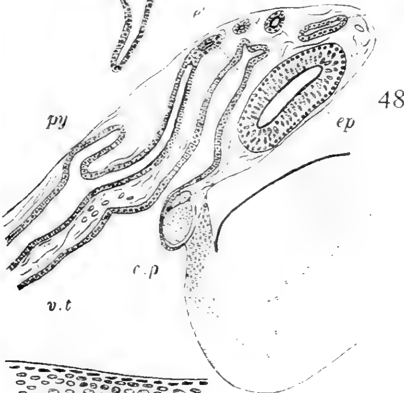

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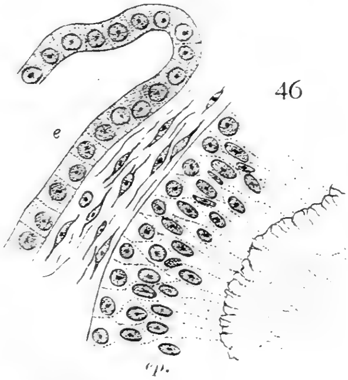

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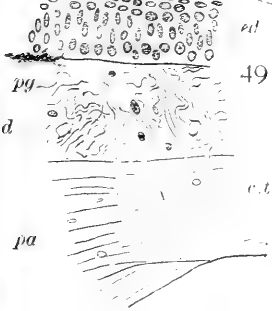

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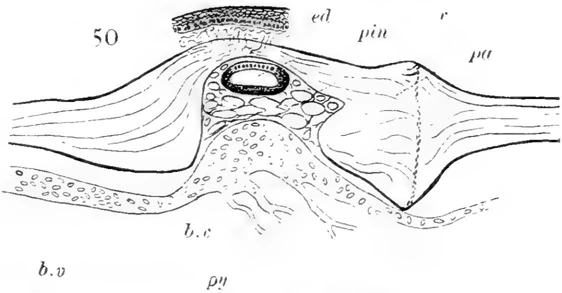

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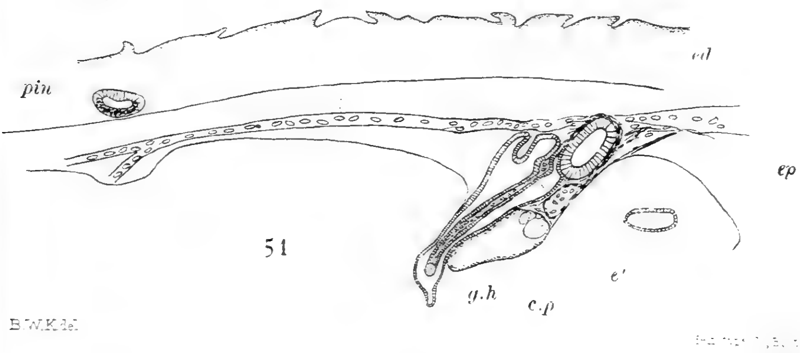

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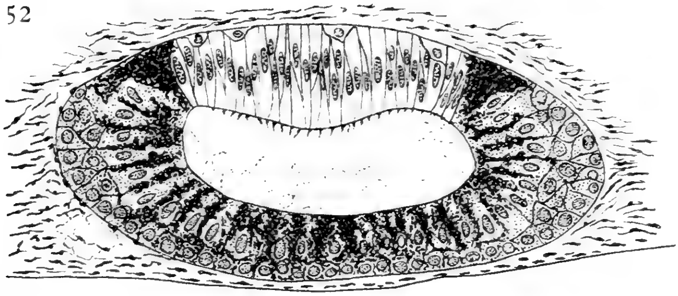

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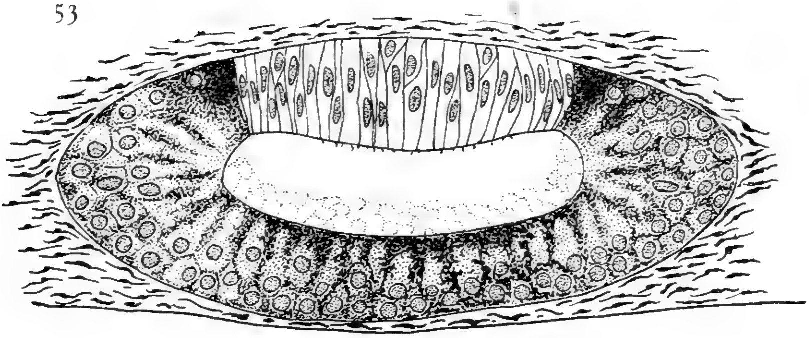

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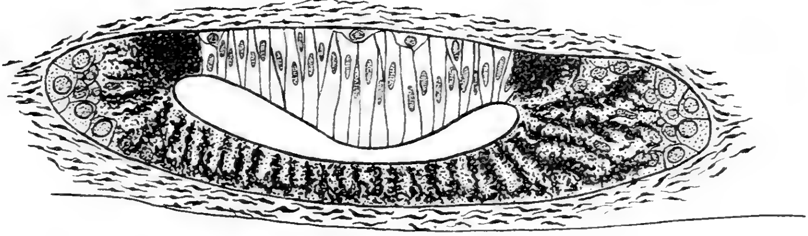

INDEX TO ARTICLE I.—HAWAIIAN HEPATICÆ.

BY C. M. COOKE, JR.

The page numbers in italics refer to the pages on which the descriptions occur.

Index to Article II.—The Bermuda Islands, Parts IV and V.
Geology and Paleontology.

The page numbers printed in italics refer to the pages where illustrations occur. In the author's edition the original paging is placed at the inner margins.

Index to Article II.—Part V. Characteristic Life of the Bermuda Coral Reefs.—By A. E. Verrill.

The numbers in italics refer to pages on which illustrations occur.

ERRATA.

Page 64 [20], line 4, from bottom, for xxiii, read xxii.

Page 65 [21], line 21, for lime, read limestone.

Page 71 [27], line 3 from bottom, for *zonata*, read *zonatus*.

Page 77 [33], line 23, for *adustus*, read *exustus*.

——— [33], line 24, for *Polytremacis*, read *Polytrema*.

Page 150 [106], line 4, for *Lithophaga*, read *Lithophagus*.

——— line 5, for *nigra*, read *niger*.

——— line 7, for *appendiculata*, read *appendiculatus* and for *bisulcata*, read *bisulcatus*.

Page 216, line 9; 219, line 17; 233, line 9; 235, line 14; 241, line 18; 244, line 21, for 1902 read 1901.

Plates XXXIV D and XXXIV E were erroneously numbered.

INDEX TO ARTICLE III.—STUDIES ON THE CALIFORNIA LIMBLESS LIZARD, ANNIELLA. BY W. R. COE AND B. W. KUNKEL.

Page numbers in italics refer to pages on which illustrations occur.