Eocene Corals from Eua, Tonga

GEOLOGICAL SURVEY PROFESSIONAL PAPER 640-G

Eocene Corals from Eua, Tonga

By JOHN W. WELLS

With a statement on EOCENE FISH FAUNA OF EUA, TONGA, BASED UPON ADDITIONAL OTOLITHS

By JOHN E. FITCH

LATE EOCENE FOSSILS FROM EUA, TONGA

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Descriptions and paleoenvironmental analysis of 23 ahermatypic corals from off-reef tuffaceous limestone

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LATE EOCENE FOSSILS FROM EUA, TONGA—FOREWORD

One of the most widespread units of the Cenozoic section in the islands of the open Pacific is a series of limestones assigned to the upper Eocene (Tertiary *b*). Such limestones, containing diagnostic larger Foraminifera, have been reported in many parts of an area spreading 4,000 miles across the tropical Pacific (fig. 1), from Palau and the Mariana Islands on the northwest through the Marshall Islands (Eniwetok) to Fiji and Tonga on the southeast (Whipple, in Hoffmeister, 1932, p. 79–86; Asano, 1939; Cole, 1950, 1957a, 1957b, 1960). In almost all the islands the limestones are dense and crystalline. Foraminifera and algae are abundant locally, but in most places fossils cannot be extracted and must therefore be studied in random thin sections. On the little island of Eua, Tonga, a locality was recently found where the Eocene limestone is tuffaceous, considerably weathered, and richly fossiliferous. Abundant fossils that represent a dozen organic groups were found. Such abundance and diversity signaled the find as a remarkable one that would add greatly to our knowledge of life in the western Pacific during the Eocene.

The island of Eua measures only 12 by 5 miles but it rises 1,000 feet above sea level. It occupies an interesting position tectonically, as its steep eastern side faces the Tonga Trench. In addition, Eua is the oldest island in the Tonga group that has a plutonic core (Guest, 1959) and a series of associated volcanic rocks, which are partly blanketed by thick limestones of late Eocene age. Younger volcanic rocks and sediments of late Tertiary age are also present (Hoffmeister, 1932).

This series of reports is concerned with one facies of the upper Eocene limestone. After the limestone series was deposited, Eua was uplifted periodically and a sequence of six terraces was cut in the limestones on the windward (eastern) side. Hoffmeister was the first to recognize the Eocene age of the main limestone of the terraces, three of which have veneers of Pliocene reef corals. He made a planetable map of the terraced eastern ridge and recorded the average altitudes of the terraces as 100, 200, 340, 400, 550, and 760 feet. The east-facing "rocky backbone" of Eua thus looks in profile like a giant staircase facing the Tonga Trench. The Eocene limestone may once have covered all of Eua but is now largely limited to the eastern ridge (Hoffmeister, 1932; the Eocene Foraminifera were described by Whipple in this same report, p. 79–86).

The fossils described in this series of reports were obtained from an outcrop on the 400-foot terrace about a quarter of a mile north of Vaingana (fig. 2). At this locality, the limestone lies close to the underlying volcanic rock and is tuffaceous and partly weathered; almost everywhere else on Eua the limestone is pure, hard, and crystalline.

In 1943, Harold T. Stearns, then of the U.S. Geological Survey, also served as a consultant to the Armed Forces at Pacific bases and made a brief visit to Eua. He collected a sample that contained half a dozen fossil brachiopods from the 400-foot terrace on the eastern side of the island. Stearns recorded the locality as: "Tele-a-hiva at elevation of 400 feet about ½ mile north of army lookout tower, at the second stream north of Vaigana [sic]." The brachiopods were examined by G. A. Cooper of the U.S. National Museum. Some years later when I was studying other island fossils collected by Stearns, Cooper showed me the brachiopods and expressed a desire for additional specimens so that he could continue his study of their internal structures.

In 1966, I learned that Yoshio Kondo of the Bernice P. Bishop Museum in Honolulu intended to visit Eua in connection with his studies of living Pacific island land snails (under National Science Foundation grant GB-3974). I sent Stearns' locality data and marked copy of Hoffmeister's Eua map to Kondo, and I informed Stearns of the plan to collect additional material.

Late in August 1967, Kondo reached Eua and, aided by a Tongan guide, Tomiki, and an interpreter, Mosese Vea, spent 2 days searching for the fossil locality. The lookout tower mentioned by Stearns no longer exists and Kondo found that Tele-a-hiva translates to "Nine Gulches." Traveling northward from "Vaigana" (Otu Vaingana) through heavy brush on exceedingly rugged karst topography for about 1,000 feet, he reached the first of the gulches. There he found a soft fossiliferous layer between two harder limestones and collected a

40-pound sample of the material. This gulch locality is probably not the exact spot visited by Stearns. The two collections have minor differences in nature of preservation, but they obviously came from the same formation.

In 1969 Wilfred Bryan of the Carnegie Institution of Washington collected additional material from the locality sampled by Kondo. Bryan's material was taken from soft calcareous tuffs 2–3 feet in thickness that dipped 30°–40° E. These calcareous tuffs were

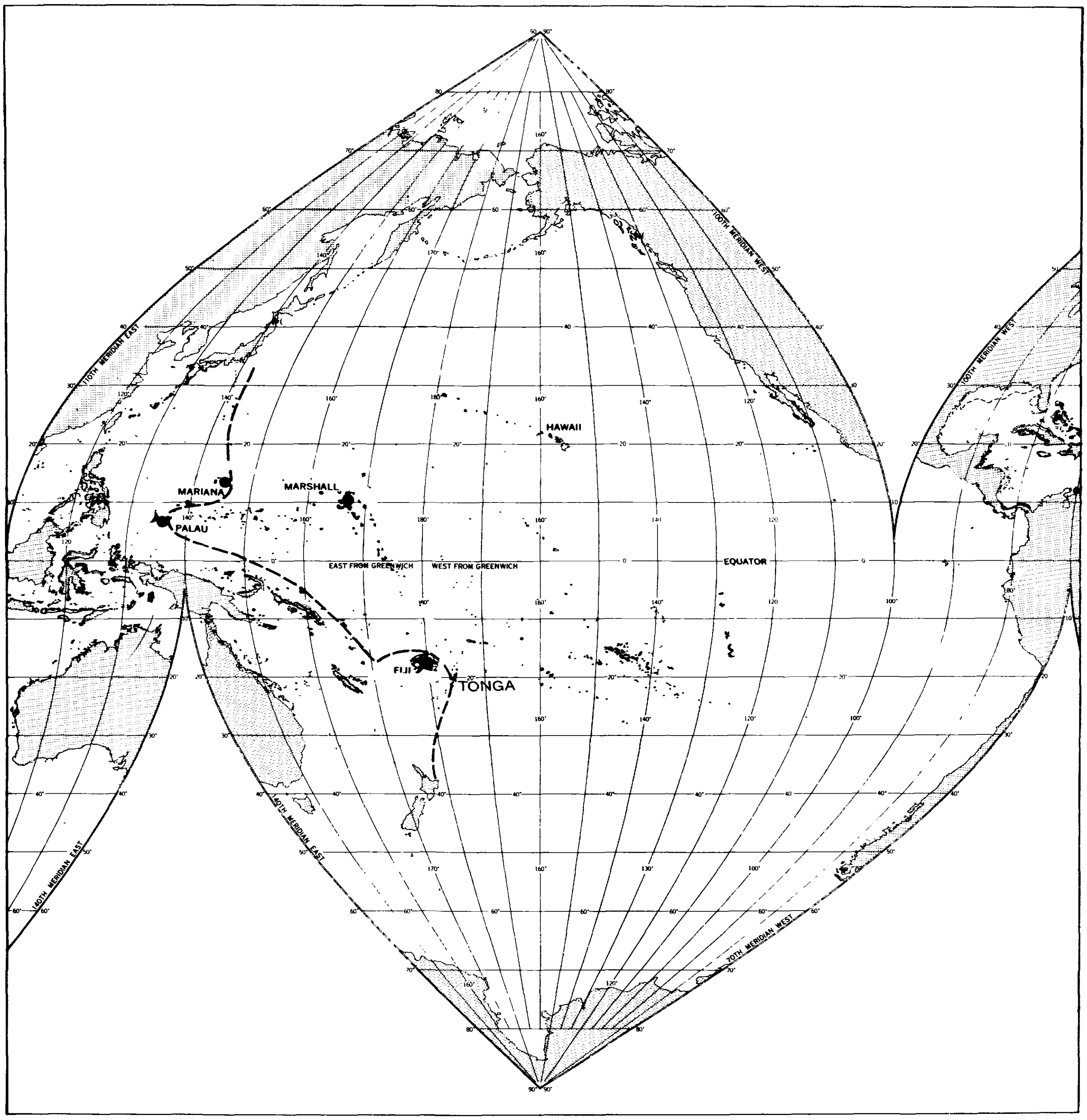

FIGURE 1.—Location of Tonga and other island groups in the southwest Pacific where upper Eocene limestone has been identified. Dashed line marks structural boundary of the Pacific Basin (andesite line). Islands shown include the surrounding reefs.

directly underlain by several feet of harder fossiliferous material that, in turn, lay above agglomerate with truncated dikes. The horizon sampled was at an altitude of about 355 feet in a gully notched into the 400-foot terrace.

The exact extent of the richly fossiliferous bed is not known. In 1926, when Hoffmeister made his map of the terraces, he did not come upon this facies, and in 1928 when I spent 2 weeks on Eua with Hoffmeister, reviewing his mapping, no exposures of this zone were seen although we visited Vaingana. Additional fieldwork in the area of the rugged "Nine Gulches" would be worthwhile.

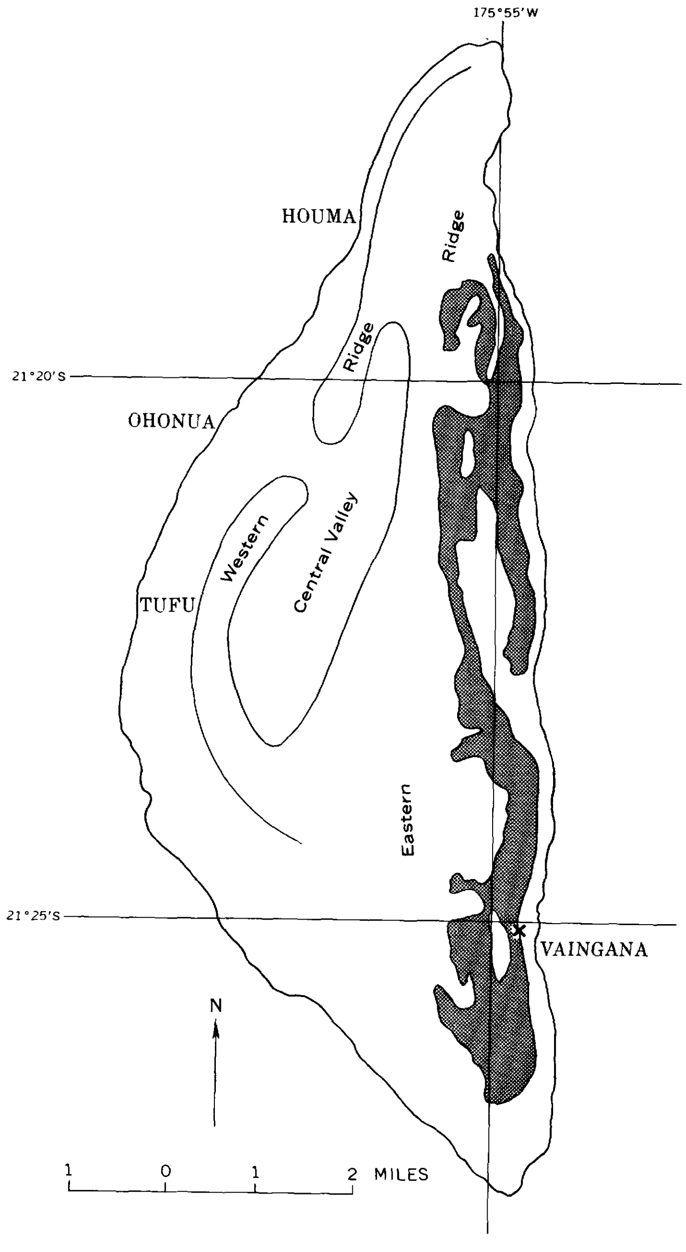

FIGURE 2.—Map of Eua, Tonga, showing the location of the recently discovered fossil outcrop (×) and the main mass of Eocene limestone (patterned area) on the east side of the island, as mapped by Hoffmeister (1932).

William Melson of the Smithsonian Institution examined hand specimens and thin sections of the tuffaceous limestone and noted that the volcanic constituents are highly altered, making it difficult to determine their original nature. The rock is composed of 50 percent or more of volcanoclastic debris, much of which has been replaced by calcite. The predominant volcanic fragments are of porphyritic pumiceous glassy material; most of the phenocrysts are plagioclase, now largely replaced by calcite. The original groundmass of pumiceous glass is now devitrified and dark brown. Fragments of tuff are rare. There appears to be a large and varied assemblage of secondary minerals. The volcanic fragments are mainly porphyritic andesitic rocks, or possibly plagioclase-bearing dacites. The presence of abundant fossils suggests that the volcanic material has been reworked.

The soft tuffaceous limestones collected on Eua were treated with a wetting agent and penetrant in the laboratory. The material broke down easily, revealing a variety of fossil remains: Foraminifera, discoasters, corals, hydrozoans, brachiopods, bryozoans, annelids, crinoids, echinoids, ostracodes, barnacles, decapod crustaceans, mollusks, shark teeth, otoliths, and spores and other plant microfossils.

W. Storrs Cole has described the larger Foraminifera; these fossils suggest to him a depth of deposition of about 200 feet, but other groups—notably the smaller Foraminifera, the corals, brachiopods, bryozoans, mollusks, ostracodes, and barnacles—point to a considerably greater depth of deposition.

Material representing a total of 17 organic groups was distributed to paleontologists for study and report. Seven of these collections were small or were made up of incomplete specimens leading only to summary reports, but the others, except for the larger Foraminifera, contained much new material. The brachiopod, bryozoan, ostracode, barnacle, and mollusk collections contained the first identifiable Eocene species from the islands of the open Pacific, an area extending 4,000 miles from Palau to Tonga.

HARRY S. LADD

SUPPLEMENTARY NOTES

In 1971, Harold Stearns published a detailed account of the 5 days he spent on Eua in 1943, during the course of which he discovered the Eocene fossil deposit. In 1972, Bryan and others (Bryan, Stice, and Ewart; Ewart and Bryan) published articles dealing with the volcanic rocks of Eua.

In 1971, I visited Eua with Frank I. Coulson of the Fiji Geological Survey. Our purposes were to check on the stratigraphic relations of the fossiliferous horizon in the gully visited by Kondo and by Bryan, to search for other exposures of the horizon in gullies to the north, and to check all elevations in the immediate area. We were aided by aerial photographs and were able to determine key elevations with the help of controlled surveying aneroids.

Though the age of the Eua deposit seemed clearly determined by Foraminifera (U.S. Geol. Survey Prof. Papers 640–A, B) as late Eocene, we recognized that a mixture of much younger shallow-water forms might have been carried seaward to mingle with still-unburied late Eocene fossils. To test this possibility, five specimens of a small shallow-water brachiopod having tightly closed valves were opened, and the material filling them was examined for calcareous nannofossils. Mr. David Bukry of the U.S. Geological Survey recognized 10 species suggesting early Oligocene or latest Eocene age (written commun., 1972). The examination confirmed the earlier interpretation that the assemblage, though a mixture of shallow and deep forms, is *not* a mixture of young and old forms.

Most of the fossils described in the published chapters of Professional Paper 640 are assigned to one of three U.S. Geological Survey Cenozoic locality numbers. Actually, all three represent the same locality: 24686, collected by Yoshio Kondo in 1967; 25745, collected by Wilfred Bryan in 1969; and 25147, collected by H. S. Ladd and F. I. Coulson in 1971. All the corals described by John Wells in chapter G were assigned number 24686.

As mentioned in the "Foreword," fossils representing more than a dozen organic groups were distributed to paleontologists for study and report. Eight of these groups contained sufficiently numerous and varied fossils to warrant separate chapters, and work on seven of these has now been completed (U.S. Geol. Survey Prof. Papers 640A–G); study of the barnacles is continuing. The study of seven smaller groups has led to summary statements that have been attached to larger reports. Chapter G, dealing with the corals, is accompanied by a supplementary report on the otoliths.

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EOCENE CORALS FROM EUA, TONGA

By John W. Wells

ABSTRACT

Twenty-three ahermatypic corals are described from tuffaceous limestone of late Eocene age. Four are stylasterine hydrozoans, 3 of which are new species; 2 are octocorals; 17 are scleractinians, 13 of which are described as new. The assemblage indicates a cool bathyal thicket assemblage at depths greater than 200 m (650 ft).

INTRODUCTION

Ahermatypic corals of Eocene age have not heretofore been found in the Pacific, except in New Zealand, and their discovery in Eua adds a significant new dimension to the history of corals in this vast area.

Compared with Eocene ahermatypic coral faunas elsewhere, the Eua corals do not have the "Eocene Look," an aspect noted by Ladd (1970) for the mollusks of Eua. However, the Eua corals are a deep-water assemblage, whereas most, if not all, other Eocene ahermatypic faunas are from the neritic zone. Further, deep-water faunas in general are cosmopolitan on the generic level, both geographically and stratigraphically (table 1). None of the genera from Eua are extinct, and all are widespread in deep water in present seas. Comparisons and correlations with other Eocene ahermatypes are not productive at present. The only possibly similar fauna is that described by Squires (1958, 1962) from the Eocene Arnold Group of New Zealand. This fauna is a cool (10°–16°C.), shallow-water (20–40 m) assemblage of different generic composition.

ACKNOWLEDGMENTS

The writer is indebted to H. S. Ladd for the opportunity of studying this unusual coral fauna, to those who painstakingly picked out the several thousand bits and pieces of coral, and to F. M. Bayer for advice on the octocorals.

MATERIAL AND PRESERVATION

The Eua tuffaceous deposit and the method of recovering the embedded fossils have been described by Ladd (1970). The samples were broken up, releasing the fossils, which were sorted into the various taxa. Thousands of remains of corals, mostly small fragments (fig. 3), were turned over to the writer, and from these, several hundred specimens were selected for study and are the subject of this report. All material bears U.S. Geological Survey Cenozoic locality No. 24686.

All specimens are more or less worn and fragmentary, and on many of them, detail and structures are obscured by remnants of tightly cemented matrix; sufficient morphologic features, however, can be distinguished to substantiate generic assignments. All original aragonite has been altered to calcite, obscuring very fine detail. Many specimens are stained or coated with iron-manganese compounds, the significance of which is uncertain though such coatings are common on Holocene corals from the deep bathyal and abyssal zones.

PALEOENVIRONMENT

PREVIOUS WORK

Studies of other fossil taxa from Eua have provided somewhat conflicting interpretations of the environment of these fossils although there is no doubt that it was quite different from the contemporary reef biocoenose.

Todd (1970), on the basis of the depth ranges of the Holocene genera of Foraminifera found in the Eua beds, concluded that the depth was not less than about 200 m. Cole (1970), who studied the larger Foraminifera, noted the lack of abrasion of these forms which suggested to him that they were not subjected to extensive wave or current action, either because of water depth or because of dense mats of algae; Cole (p. B3) opted for "warm, shallow water (about 200 ft in depth) in a lagoon or protected situation on the outermost part of a reef." Kier (1970) thought that the fragmentary echinoderm material indicated water deeper than 80 m. Roberts (1970) thought that the decapod crustacean fragments accumulated in either the littoral or sublittoral zone. Ladd (1970, p. C2), from the evidence of the molluscan fauna, favored "deposition at a depth of about 100 fathoms (180 m)." The ostracodes were analyzed by Hazel and Holden (1971), who recognized two assemblages, one autochthonous, indicative of the upper bathyal zone, and the other allochthonous, from the sublittoral environment. The small brachiopod fauna, as deduced from the meager data on living brachiopods, was thought by Cooper (1971) to be a mixture of shallow- and deep-water forms. Fitch (1971) thought that the teleostean otoliths indicated depths of more than 182 fathoms (325 m). The Eua cheilostome bryozoans studied by Cheetham (1972) included both allochthonous shallow-water and autochthonous deep-water genera, the latter much more abundant and interpreted as having lived at depths exceeding 200 m and in water cooler than 13°C. The coral fauna considered in the present paper favors the bathyal zone below 200 m (650 ft).

Thus, the Eua thanatocoenose as a whole seems to contain a mixture of neritic and bathyal elements. The coral thicket environment, now almost wholly represented by worn, poorly sorted fragments, may have shoaled to its demolition, permitting an admixture of neritic types, many of which are less worn, but in fact, forms of corals characteristic of the neritic zone are lacking.

THE CORAL FAUNA

The Eua Eocene ahermatypic coral fauna is clearly a thanatocoenose that probably accumulated close to its life habit. The very high proportion of fragments of dendroid colonial forms (*Madrepora, Enallopsammia,* and stylasterids, fig. 3) to the varied but relatively small number of solitary types is indicative of derivation from banks or thickets (Squires, 1964). The banks or thickets developed on a muddy or silty bottom, as suggested by the presence of occasional specimens of such eleutherozoic genera as *Fungiacyathus, Anthemiphyllia, Deltocyathus,* and *Paradeltocyathus.* The environment of the banks or thickets was similar to that of the Holocene banks on the Blake Plateau at depths of around 750 m, as shown in photographs by Stetson, Squires, and Pratt (1962). Solitary corals that adhered to the branches of the thicket-formers, such as *Caryophyllia, Desmophyllum, Crispatotrochus, Cyathoceras,* and *Javania,* are more common than the free-living forms.

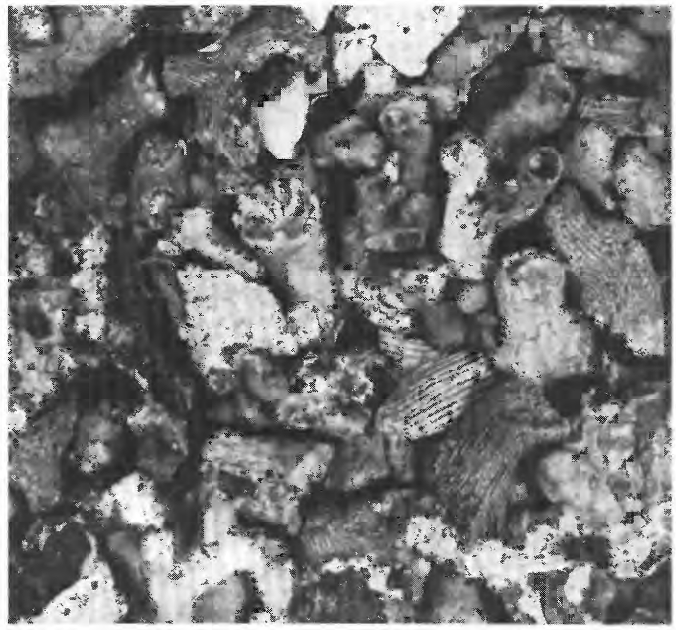


FIGURE 3.—Concentrate of Eocene corals from Eua, Tonga: mainly worn fragments of *Madrepora* sp., a few of *Enallopsammia eocenica,* n. sp., and one of *Desmophyllum lirioides,* n. sp. × 2.

A Holocene Pacific assemblage comparable with the Eua coral fauna was found in a dredge sample obtained during the Mid-Pacific Expedition in 1950 from a depth of 720 m on the outer slope of Bikini Atoll east of Enyu Island. It consists of a handful of worn fragments of *Enallopsammia, Madrepora, Desmophyllum, Stenocyathus,* and the stylasterines *Distichopora* and *Errina* (*Lepidopora*) (fig. 4).

The relative abundance and variety of stylasterine hydrozoans (four of the 18 recognized genera) is significant. The only other comparable hydrocoral assemblage is that from the Paleocene (younger Danian) of Denmark described by Nielsen (1919), which also contains the only other fossil occurrence of the rare genus *Astya.* On the other hand, the cosmopolitan genus *Flabellum,* species of which are common throughout the Cenozoic, is notably absent. Eocene species of *Flabellum* are neritic types having stout coralla, as contrasted with the more delicate structures and generally larger size of modern bathyal forms. These forms may have been present in the Eua community but failed to survive the wear and tear that affected the corals; more likely, the thicket environment was unfavorable for such bathyal types, as at the present time.

FIGURE 4.—Sample of Holocene ahermatypic corals from off-reef slope east of Enyu Island, Bikini Atoll, depth 720 m, dredged by Mid-Pacific Expedition, 1950: mostly worn but a few fresh fragments of *Madrepora* sp. and a few of *Enallopsammia amphelioides* (Alcock) and *Desmophyllum* sp. × 2.

Table 1 shows the nonneritic character of the Eua coral fauna, in which 13 of the 18 genera are recorded for the first time from the Eocene. Bathymetric ranges of the corals are summarized in table 2, where again the deep-water aspect is evident. With one or two exceptions, specimens of the genera from less than 100 m deep are very few, and most of the genera, especially *Enallopsammia* and *Madrepora*, the thicket formers, are commonest below 200 m. Table 3 shows the temperature ranges of the same genera. In general, the genera that are eurybathic are eurythermic, and the thicket formers are found only at or below 16°C and commonly below this maximum.

The data in tables 2 and 3 seem to show that the paleoenvironment of the Eua fauna was that of thickets, coppices, or banks in the bathyal zone below 200 m, in temperatures of less than 16°C. The paleoenvironment could have been much deeper, for with the exception of three genera having very few records, all the genera today occur in depths of more than 900 m in temperatures as low as 4°C.

UNDETERMINED CORALS

In addition to the corals described below, many fragments are too poorly preserved to be identified with any certainty, although several genera are represented: several very small, bowl-shaped turbinoliids, possibly *Peponocyathus;* many small turbinate coralla, probably caryophylliids, in the form of internal molds; a single specimen of a small solitary dendrophylliid; and several small, cylindrical-scolecoid types.

SYSTEMATIC PALEONTOLOGY

Class HYDROZOA
Order STYLASTERINA
Family STYLASTERIDAE
Genus STYLASTER Gray 1831
Stylaster sp.

Plate 1, figures 1, 2

Some fragments of branchlets are referred to this genus, which was previously unrecorded earlier than Oligocene (*S. antiquus* Sismonda, Oligocene, Italy). All are worn, and most structures are poorly preserved. The branchlets range in diameter from 1 to 2.5 mm, and have fine longitudinal striae alternating with fine perforations. Cyclosystems more or less regularly alternating on right and left sides, 0.75 mm in diameter, slightly elevated. Gastrostyles not observed. Dactylopores about 11 in number, regularly enclosing gastropore. Many fragments with scattered hemispherical ampullae, commonly broken and appearing as rimmed pits.

Material.—Figured specimens, USNM 208294; and 32 other fragments.

Remarks.—*S. mooraboolensis* (Hall), Miocene of Australia, redescribed by Boschma (1953), has more slender branchlets and cyclosystems of the same size with an average of 12.5 dactylopores, but the latter do not completely encircle the gastropores. *S. antiquus* is as yet unfigured and known only from a brief description.

Genus STENOHELIA Kent 1870
Stenohelia boschmai Wells, n. sp.

Plate 1, figures 3–6

Branchlets slender, 1–1.5 mm in diameter, bearing large expanded cyclosystems on anterior surface, closely spaced about 1–1.5 mm apart. Coenosteum coarsely striate, with one or two rows of perforations between the subacute striae. Cyclosystems slightly compressed transversely, 1.5×2–3 mm in diameter. Gastropores deep, sides gently sloping, 1 mm in diameter. Gastrostyles not observed. Dactylopores 15–19 in number, wider than intervening "septa," prominent with minute, rarely preserved dactylostyles. Margins of one or two lower dactylopores in some cyclosystems elevated and inclined inward. Ampullae large, hemispherical, with irregularly

TABLE 1.—*Geologic ranges of genera and subgenera of corals from Eua, Tonga*

[×, first record from the Eocene]

	Cretaceous	Paleocene	Eocene	Oligocene	Miocene	Pliocene	Pleistocene	Holocene
Caryophyllia								
Desmophyllum								
Deltocyathus	?	?						
Fungiacyathus								
Astya			×					
Stenocyathus			×					
Madrepora								
Anthemiphyllia			×					
Cyathoceras			×					
Crispatotrochus			×					
Notocyathus (Paradeltocyathus)			×					
Stylaster			×					
Enallopsammia			×					
Javania			×					
Goniocorella			×					
Anomocora			×					
Stenohelia			×					
Crypthelia			×					

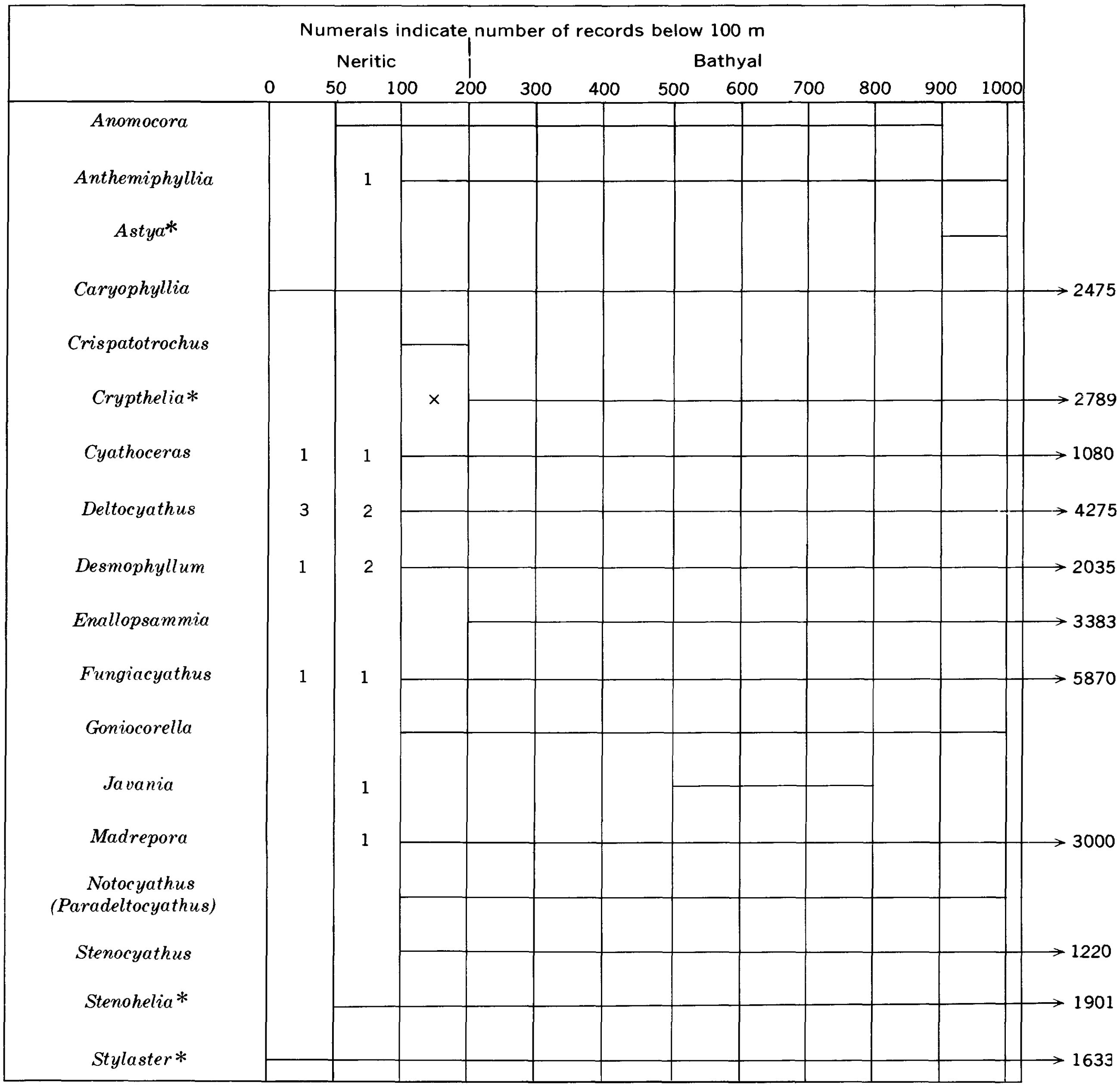
reticulate coenosteal striae, strongly porous when worn, commonly one or two borne on undersides of cyclosystems.

Material.—Holotype, USNM 208295; paratypes, USNM 208296; and 13 other fragments.

Remarks.—This is the first record of fossil *Stenohelia*. All specimens are fragments, and none show the mode of branching. This species is distinguished from the 10 Holocene species by the very coarse coenosteal striae, the large ampullae on the underside of the cyclosystems, and large open dactylopores.

The species is named for Dr. H. Boschma of Leiden, the leading authority on the stylasterine hydrocorals.

Table 2.—*Bathymetric ranges (in meters) of genera and subgenera of Eocene corals from Eua, Tonga*



*, Stylasterid
×, One record between 100 and 200 m

Genus CRYPTHELIA Milne Edwards and Haime 1849

Crypthelia vetusta Wells, n. sp.

Plate 1, figures 7, 8

Branchlets 0.7–1.15 mm in diameter, finely and evenly striated longitudinally as in *Astya nielseni*, bearing cyclosystems on the anterior surface commonly at points of origin of new branchlets. Cyclosystems slightly elevated, 1–1.75 mm in diameter, short lids inclined upwards at about 60°. Cyclopores deep, sides nearly vertical. Dactylopores 10–17 in number, commonly 16–17. Ampullae large, domed, developed on lids, leaving an irregular pit where broken.

Material.—Holotype, USNM 208297; paratypes (4), USNM 208298; and 35 other fragments.

Remarks.—*Crypthelia* has previously been reported only from the Holocene, 12 species having been listed by Boschma (1957). *C. vetusta* is closest to such Pacific species as *C. pudica* Milne Edwards and Haime and *C. japonica* Milne Edwards and Haime.

Table 3.—*Thermometric distribution (°C) of genera and subgenera of Eocene corals from Eua, Tonga*

	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	
Caryophyllia		—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	→
Deltocyathus		—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	→
Stylaster *		—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	→
Anthemiphyllia						—	—	—	—	—	—	—	—	—	—	—	—	—	—	→
Desmophyllum						—	—	—	—	—	—	—	—	—	—	—	—	—	—	→
Notocyathus (Paradeltocyathus)						—	—	—	—	—	—	—	—	—	—	—	—	—	—	→
Cyathoceras							—	—	—	—	—	—	—	—	—	—	—	—	—	→
Fungiacyathus							—	—	—	—	—	—	—	—	—	—	—	—	—	→
Crypthelia *										—	—	—	—	—	—	—	—	—	—	→
Goniocorella										—	—	—	—	—	—	—	—	—	—	→
Javania											—	—	—	—	—	—	—	—	—	→
Anomocora												—	—	—	—	—	—	—	—	→
Stenohelia *												—	—	—	—	—	—	—	—	→
Enallopsammia													—	—	—	—	—	—	—	→
Madrepora													—	—	—	—	—	—	—	→
Stenocyathus															—	—	—	—	—	→
Crispatotrochus																			1	
Astya *																				2

*, Stylasterids
1, One record
2, One record (7°C)

Genus ASTYA Stechow 1921

Astya nielseni Wells, n. sp.

Plate 1, figure 9

Branchlets 0.5–1.25 mm in diameter, thickest near base of attachment of corallum, strongly striated longitudinally, bearing cyclosystems on anterior surface, most commonly at points of origin of new branchlets. Cyclosystems slightly elevated above surface of branchlets, 1.5–4 mm apart, scarcely compressed, 0.75–1.75 mm in diameter, the large ones bearing ampullae. Gastropores circular with nearly vertical sides. No gastrostyles seen. Dactylopores 17–19 in number. Ampullae encircling cyclosystems; when broken, they roughen the exteriors of the cyclosystems.

Material.—Holotype, USNM 208299; paratypes (3), USNM 208300; and 53 other fragments.

Remarks.—The rings of ampullae around the cyclosystems and apparent absence of gastrostyles are typical of the sole living species, *A. subviridis* (Moseley), to which the present species is closely related; *A. nielseni* differs mainly in having smaller cyclosystems and more delicate branchlets. In *A. crassa* (Nielsen) from the Paleocene of Denmark, the cyclosystems do not appear to be confined to the anterior surface of the branchlets.

This species is named for K. Brünnich Nielsen (1872–1942), who studied the coral faunas of the Danish Paleocene.

Class ANTHOZOA
Subclass OCTOCORALLIA
Order GORGONACEA
Suborder SCLERAXONIA

Undetermined octocorals

Plate 1, figure 10

Some fragments of octocoral axes are referable to the suborder Scleraxonia, but identification below this level is uncertain, as these supporting structures rank low among the criteria of classification. A few specimens are illustrated (USNM 208301). Solid, smooth or thorny unjointed axes are probably *Corallium*, and ridged internodal segments appear to be *Parisis*.

Material.—About 50 fragments. USNM 208301.

Subclass ZOANTHARIA
Order SCLERACTINIA
Family FUNGIIDAE
Genus FUNGIACYATHUS G. O. Sars 1872

Fungiacyathus euaensis Wells, n. sp.

Plate 1, figures 11–14

Corallum small, cupolate, diameter four to five times the height. Base flat, imperforate, with low, thin, acute, equal costae extending to the center. Costae of fifth cycle in some specimens tending to break up into elongate granules near the center. Septa (96) in five complete cycles, thin, laterally with thin alternating trabecular ridges giving a zigzag aspect to the septa in plan. Margins of the 12 first- and second-cycle septa elevated midway between margin and axis, dissected into several lobulations. Three or four concentric rings of synapticulae. Columella not observed but apparently in a small axial depression.

Measurements.—Holotype, USNM 208302: height 3 mm, diameter (restored) 14 mm; paratypes, USNM 208303, 208304: height 3 mm, diameter 10.5 mm.

Remarks.—For practical purposes, the species of *Fungiacyathus* ("*Bathyactis*") can be arranged in two groups: (1) those having four cycles of septa (48), including most of the fossil species, and (2) those having five cycles of septa (96). The latter group includes *F. hawaiiensis* (Vaughan), Holocene, Hawaii; *F. stephana* (Alcock), Holocene, Indian Ocean; *F. palifera* (Alcock), Holocene, Malaysia, Japan, South Australia; *F. sibogae* (Alcock), Holocene, Malaysia; and *F. kikaiensis* (Yabe and Eguchi), Pleistocene (Ryukyu Limestone), Ryukyu Islands. *Bathyactis eocenica* Gerth, Eocene, Java, is probably not *Fungiacyathus*. *F. euaensis* differs from all of these by having the equal, low, acute costae.

Material.—In addition to the holotype and paratypes, nine fragments show some details of septa and costae.

Family OCULINIDAE
Subfamily OCULININAE
Genus MADREPORA Linnaeus 1758

Madrepora sp.

Plate 2, figures 1–3

Many small fragments, mostly representing small distal branchlets 1.5–4 mm in diameter, are characteristic of this genus. Corallites are budded alternately in one plane, walls faintly costate in young corallites, smooth and thickened by external stereome on larger branchlets. Calices deep, 2 mm in diameter. Septa thin, laterally granulated, in three cycles arranged 6/6/12, the last cycle very short, free on their inner edges. Upper margins of septa thickened at calicular margin. First two cycles unite deep in the calice to form a weak columella. Corallites on larger branches filled with stereome.

Material.—Figured branchlet, USNM 208305; figured section, USNM 208306, and about 100 small fragments.

Remarks.—At least 30 Tertiary "species" of *Madrepora* ("*Amphelia*") have been described, six of them from the Eocene, but species discrimination is unresolved, and the Tongan form is not named here. It could be related to *M. granulata* (Tenison-Woods) of the Eocene and Oligocene of New Zealand (Squires, 1958), but that form is based on larger fragments.

Family ANTHEMIPHYLLIIDAE
Genus ANTHEMIPHYLLIA Pourtalès 1878

Anthemiphyllia catinata Wells, no. sp.

Plate 2, figures 4, 5

Corallum bowl-shaped, small, diameter 7–8 mm, height 4.5–5 mm. Wall thick, costate. Costae equal, thick, rounded, finely granulated, extending part way to center of base. Calice shallow. Three cycles of septa with a variable number of fourth-cycle septa (32–40). Septa thick, slightly exsert, those of first three cycles extending to columella, upper margins bearing 5 or 6 thick granulated dentations. Columella large (2 mm), papillate.

Material.—Holotype, USNM 208307; paratype, USNM 208339; and two smaller, worn coralla.

Remarks.—Coralla of this species are about the size and shape of the type species, *A. patera* of the Caribbean, but have fewer septa, fewer and coarser septal dentations, and a papillary rather than spongy columella. The living Indo-Pacific species, *A. dentata* (Alcock), is larger, more patellate, and has more septa. The latter species has been reported previously (Yabe and Eguchi, 1937) as fossil from the Ryukyu Limestone (Pleistocene) of Kikai-Zima. *A. patella* Gerth (1921) from the late Oligocene of Java, like *A. dentata,* is larger and more patellate. *A. verbeeki* Gerth (1921), is a large turbinate epithecate form, possibly a *Cynarina.*

Family CARYOPHYLLIIDAE
Subfamily CARYOPHYLLINAE
Genus CARYOPHYLLIA Lamarck 1801

Caryophyllia denaria Wells, n. sp.

Plate 2, figures 6–10

Corallum cornute, fixed by a small base. Exterior nearly smooth, with very faint low equal broad costae corresponding to all septa, commonly obliterated by stereome. In very small corallites (1.5 mm) the costae are thin with single rows of granulations. Calice round or slightly ovate, shallow. Septa slight- and nearly equally exsert, laterally granulate, very thick at calicular margin, thinning axially. Septa 40 in number, arranged 10/10/20, the third group fused to the second. Ten prominent thick solid pali before the second group of 10 septa. Columella composed of one or two thick elongate laths.

Measurements.—

Specimen	Height (mm)	Diameter of calice (mm)	
		Internal	External
1. Holotype, USNM 208308	19	7.5	10
2. Paratype, USNM 208309	14	7	10
3. Paratype, USNM 208310	23	5.5	8.5
4.	15	5.5	8
5.	14	5	6.5
6.	5	3 × 3.5	3.5 × 4

The decameral arrangement of the septa and pali and obsolescence of the costae by stereome accumulation distinguish this species from Pacific species of *Caryophyllia.* The closest relationship appears to be with such Holocene species as *C. octopali* Vaughan.

Material.—Represented by 23 specimens, all more or less worn and basal attachment broken.

Caryophyllia sp. cf. C. japonica von Marenzeller

Plate 2, figures 11, 12

Caryophyllia japonica Squires 1958. New Zealand Geol. Survey, Palaeontology Bull. 29, p. 46, pl. 7, figs. 8–14, text fig. 15.

Four specimens may represent this species, reported from the Miocene and Pliocene of New Zealand by Squires, and known from Holocene localities in the Indian Ocean, East Indies, and Japan. They are larger than *C. denaria* and have more septa (44), which are more exsert and have thinner corallite walls. The calicular structures are poorly preserved but there appear to be 11 or 12 thin pali and a crispate columella.

Measurements.—Figured specimen, USNM 208312: height 22 mm, diameters 12×13; another specimen: height 19 mm, diameter 10 mm.

Genus CYATHOCERAS Moseley 1881

Cyathoceras kondoi Wells, n. sp.

Plate 2, figures 13, 14

Corallum trochoid-conical, attached by a small base. Wall thick, smooth, costate near calice. Costae low, rounded, faintly and minutely granulated. Septa (48) in four complete cycles, thin internally, thickened at calicular margin, those of the first two cycles equal and exsert, those of the third and fourth cycles less exsert. Calice shallow, with prominent chicoraceous columella about a third the diameter of the calice.

Measurements.—Holotype, USNM 208313: height 18 mm, diameter 14 mm; paratype USNM 208314: 16 mm, diameters 13 × 14 mm; paratype USNM 208340: height 15 mm, diameter 11 mm.

The earliest previously known occurrence of *Cyathoceras* is *C. periallus* Squires (1962) from the lower Oligocene of New Zealand, from which the present species differs by having fewer septa and broader rounded calice.

Material.—Three slightly worn specimens with bases broken at diameter 2.5 mm.

The species is named for Dr. Yoshio Kondo of the Bernice P. Bishop Museum, Honolulu, Hawaii, who collected much of the Tongan material.

Genus DELTOCYATHUS Milne Edwards and Haime 1848

Deltocyathus sp.

Plate 2, figures 15, 16

A single worn patellate corallum is referred to this genus. Septa in four complete cycles, the first cycle extending to the columella, the remaining cycles regularly uniting. Pali and columella not discernible. Costae equal, with traces of granulations, arranged following the septal plan.

Measurements.—Figured specimen, USNM 208315: height 2 mm, diameter 12 mm.

Remarks.—*Deltocyathus* is fairly common from the Miocene and is widespread in modern seas, but pre-Miocene records are sparse and dubious: *D.*

fontinalis Dennant 1904 from the Australian Miocene; *D.* sp. cf. *D. italicus* Hegedüs 1962 from the Oligocene of Hungary; *D.* sp. Kolosváry 1964, Cretaceous of Hungary; *D.? complectus* Squires 1958, Cretaceous of New Zealand; *D.? whitei* Durham 1943, Paleocene of California. The Eua specimen is the first record from the Eocene.

Genus CRISPATOTROCHUS Tenison-Woods 1878

Crispatotrochus tenison-woodsi Wells, n. sp.

Plate 2, figures 17–19

Corallum cornute, attached in early stages by a small base. Exterior faintly granularly costate in small specimens, thickened and smoothed by stereome in larger coralla. Epitheca lacking. Calice circular or slightly ovate, deep. Septa 32, arranged 8/8/16, correspondingly exsert, very thick and coarsely granulated at the wall, thin axially, only the 16 septa of the first two groups reaching the small, deep, coarsely trabecular columella.

Measurements.—Holotype, USNM 208316: height 27 mm, diameter 12 × 14 mm; paratype, USNM 208317: height 20 mm, diameter 8 mm.

Remarks.—*Crispatotrochus* groups with *Ceratotrochus* and *Conotrochus;* it resembles the latter but lacks the stout epitheca as well as the pali that occur in some species. *C. tenison-woodsi* differs from the type species, *C. inornatus* Tenison-Woods from the Holocene of Australia, by the extensive development of external stereome with obliteration of costae and much smaller columella. *Ceratotrochus exiguus* Squires 1958 from the New Zealand Oligocene appears to be a *Crispatotrochus* with flangelike major costae near the upper margin of the calice.

Material.—Represented by nine specimens. This species is named for the Reverend J. E. Tenison-Woods (1832–1889), pioneer student of Australian Tertiary and Holocene corals.

Subfamily TURBINOLIINAE
Genus NOTOCYATHUS Tenison-Woods 1880
Subgenus PARADELTOCYATHUS Yabe & Eguchi 1937

Notocyathus (Paradeltocyathus) orientalis (Duncan)

Plate 3, figures 1–3

Deltocyathus orientalis Duncan, 1876, Zool. Soc. London Proc., p. 431, pl. 38, figs. 4–7.

D. (*Paradeltocyathus*) *orientalis* Yabe and Eguchi, 1937, Tohoku Univ. Sci. Repts., ser. 2, v. 19, p. 131, pl. 20, figs. 1–10.

N. (*Paradeltocyathus*) *orientalis* Squires, 1958, New Zealand Geol. Survey Palaeontology Bull. 29, p. 55, pl. 9, figs. 19–22.

Squires and Keyes, 1967, New Zealand Oceanog. Inst. Mem. 43, p. 24, pl. 3, figs. 1–7.

Ten small specimens have the characteristic bowl shape with sharply incised grooves between the thick, finely granulated costae of this widespread species, known from the Oligocene and Miocene of New Zealand; Miocene and Pleistocene of Japan; Pliocene of Ceram; and Holocene of Japan, Formosa, New Zealand, eastern Indian Ocean, Atlantic, and Caribbean.

N. (*P.*) *australiensis* (Duncan) from the Miocene of Australia, originally described as *Deltocyathus italicus* var. *australiensis,* is very similar to *N.* (*P.*) *orientalis* and may prove to be the same, in which case Duncan's earlier name will take precedence.

Measurements.—Figured specimens, USNM 208323: height 2 mm, diameter 4 mm.

Subfamily DESMOPHYLLINAE
Genus DESMOPHYLLUM Ehrenberg 1834

Desmophyllum decuplum Wells, n. sp.

Plate 3, figures 4, 5

Corallum trochoid, straight or cornute, fixed by expanded base. Wall moderately thick, covered by densely distributed fine granulations. Costae corresponding to septa developed only at or near calicular margins. Calice circular or slightly compressed. Septa 40, decamerally arranged 10/10/20, those of the first group of 10 more exsert than the rest and extending nearly to the axis. Septa of the second and third groups weakly developed, extending less than one-fourth the distance to the axis. Columella absent or a very deep, very weak tangle.

Measurements.—

Specimen	Height (mm)	Diameter (mm)	Septa arrangement
Holotype, USNM 208324	15	5 × 7	10/10/20
Paratype, USNM 208325	11	6.5	10/10/20
Another specimen	6.5	5	10/10/20

Most species of *Desmophyllum* have the normal hexameral septal arrangement.[1] *D. decuplum* is thus distinguished from the other Eua species, *D. lirioides* and *D. coulsoni,* and is allied to *D. taurinense* (Michelin) from the Miocene of Italy, which has septa arranged 10/10/20/40, according to Chevalier (1961).

Desmophyllum lirioides Wells, u. sp.

Plate 3, figures 6, 7

Corallum tall, trochoid, straight or slightly cornute, attached by a small base. Wall thin, granular below, costate near calicular margin. Calice circular to slightly ovate, very deep. Septa thin, regularly slightly exsert according to cycle, upper margins

[1] *D. quinarium* Tenison-Woods 1879, Holocene of Fiji, is not *Desmophyllum,* but a juvenile *Plerogyra.*

falling steeply towards axis, internal margins extending not more than two-thirds of the distance to the axis. Septa in five cycles, arranged 12/12/24/48 in largest calices. Columella absent, the axial space being empty nearly to the base.

Measurements.—

Specimen	Height (mm)	Diameter (mm)	Septa arrangement
Holotype, USNM 208326	25	14 × 23 (crushed)	12/12/24/48
Paratype, USNM 208341	14	13 × 15	12/12/24/20
		8 at base	12/12/24, all very short
Other specimens	30	10 × 12	12/12/24
	15	9 × 11	12/12/24
	13	7	12/12/24
	6	3 × 4 (crushed)	6/6/12

Remarks.—This species is distinguished by the relatively fragile corallum and by the empty axial space. The holotype is compressed and crushed, as are several other equally large but poorly preserved specimens. In most species of *Desmophyllum*, at least the first, or first and second, cycle septa extend to the axis. In the only other Pacific Eocene *Desmophyllum*, *D. sp.* Squires 1958 from the Bortonian of New Zealand, which is otherwise much like *D. lirioides*, the 12 septa of the first two cycles reach the axis.

Material.—Represented by 28 specimens.

Desmophyllum coulsoni Wells, n. sp.

Plate 3, figures 8, 9

Corallum elongate-conical, slightly curved. Wall costate near calice, finely granular below, thickened by stereome. Calice circular or slightly compressed, very deep axially. Septa arranged 12/12/24, those of the first two cycles equally slightly exsert, thickened at the wall, and extending nearly to the axis deep in the calice but not uniting. Third cycle shorter, nonuniting, and the fourth cycle very short. Columella absent.

Measurements.—Holotype, USNM 208327: height 27 mm (incomplete), diameter 8.5 mm; paratype, USNM 208342: height 42 mm, diameter 10 mm; another specimen: height 12 mm (incomplete), diameter 6 × 8 mm.

This species is distinguished from *D. decuplum* by the hexameral septal arrangement, and from *D. lirioides* by the elongate-conical, thick-walled corallum.

Material.—Represented by seven specimens.

Named for Frank I. Coulson of the Fiji Geological Survey, who assisted in the investigation of the Eua deposit.

Subfamily PARASMILIINAE

Genus GONIOCORELLA Yabe and Eguchi 1932

Goniocorella eguchii Wells, n. sp.

Plate 3, figures 12, 13

Corallum subdendroid. Corallites cylindrical or slightly expanding, diameter 2–4.5 mm, new corallites branching at right angles. Wall faintly costate, internally thickened in older corallites. Calice deep. Septa (24) thin, in three cycles, regularly arranged with only those of the first cycle extending to or nearly to the axis.

Measurements.—Holotype, USNM 208330: height 20 mm, diameter of main corallite 4 mm, of lateral buds (incomplete) 1.75–3 mm; paratype, USNM 208331: height 17 mm, diameter of main corallite 4.5 mm, of lateral bud 3 mm.

Remarks.—This species is distinguished from the type- and only known species, *G. dumosa* (Alcock) from the Holocene of Indonesia, Japan, and New Zealand, by its feeble growth form and more completely developed septation.

Occurrence.—Represented by 10 specimens, all fragmentary and more or less worn.

This species is named for Dr. Motoki Eguchi, long associated with study of Pacific corals.

Genus ANOMOCORA Studer 1878

Anomocora exilis Wells, n. sp.

Plate 3, figures 10, 11

Growth-form quasicolonial, consisting of elongate conical corallites with small offsets at right angles from the edge-zone below the calices. Wall thick, with rounded, lightly granulated subequal costae corresponding to all septa. Septa in holotype 32 in number, in two groups, arranged 6/6/12 in offsets. Larger septa thick at the wall, thinning axially, inner edges dropping steeply into the calice and extending a little more than halfway to the axis. Septa of the second group short, thin, not uniting to larger septa. Deep in the calice, the larger septa barely meet to form a weak trabecular columella. Endotheca very sparse.

Measurements.—Holotype, USNM 208328: height (incomplete) 27 mm, diameter (just below calice) 9 mm; paratype, USNM 208329 (an offset with two minor offsets): height 17 mm, diameter of calice 3.5 mm, septa arranged 6/6/12.

Remarks.—*Anomocora,* although widespread in present seas, has not previously been recorded as fossil. *A. exilis* differs from the common *A. fecunda* (Pourtalès) in having thicker walls, fewer septa, and low rounded rather than thin acute costae.

Material.—Represented by seven specimens.

Family FLABELLIDAE

Genus JAVANIA Duncan

Duncan, 1876. Zool. Soc. London Proc., p. 435.

Type (by monotypy): *J. insignis* Duncan. Holocene, Japan.

Javania, by its primarily epithecal and secondarily thickened wall, appears to be closely related to *Flabellum* rather than to *Desmophyllum*, in which the costate wall is septothecal.

Javania duncani Wells, n. sp.

Plate 3, figures 14–16

Corallum elongate conical, cornute basally in some cases. Wall thickened by stereome but in some specimens shows traces of external epithecal festoons between outer ends of the septa. Calice ovate, deep. Septa (12) of first two cycles equally exsert, very thick at the wall, thinning inwardly. Septa of third cycle free, very short and thin. Columella absent, but near the base, six stout primary septa fuse axially.

Measurements.—Holotype, USNM 208332: height (incomplete) 17.5 mm, diameter 7 × 8 mm; paratype, USNM 208333: height (incomplete) 17 mm, diameter 7 × 8.5 mm.

Remarks.—At present, pending the revision of *Javania* and related flabellid genera by H. Zibrowius, the only positively known species is the type, from which *J. duncani* differs by the proportionally taller but smaller corallum and by the development of only three cycles of septa.

Material.—Represented by seven specimens.

The species is named for Peter Martin Duncan (1824–1891), who described many fossil and living ahermatypic corals.

Family GUYNIIDAE

Genus STENOCYATHUS Pourtalès 1871

Stenocyathus hoffmeisteri Wells, n. sp.

Plate 2, figures 20–24

Corallum elongate-cylindrical to scolecoid. Wall thin, epithecal but internally thickened by stereome. External surface not preserved but with single rows of small pores, about 4 per millimeter, in the thickened wall. Septa 14–16, in two groups arranged 8/8 or 7/7, the 7 or 8 larger septa thick, extending to the axis to weakly join a small columella. Septa of the second group very short and thin.

Measurements.—Holotype, USNM 208318: length 11 mm, diameter 1.8 mm, septa arranged 8/8; paratype *a*, USNM 208319: length 9 mm, diameter 2 mm, septa arranged 8/8; paratype *c*, USNM 208321: length 5.5 mm, diameter 1.7 mm, septa arranged 7/7.

All specimens are worn, and calicular structures are not preserved. Basal or early stages are lacking, and the living attitude is uncertain. Several fragments are internal molds that show clearly the deep pits extending into the internally thickened wall between septa, toward the site of the thin spots in the epitheca. These molds are markedly like the decalcified specimens "showing the complete cast of the inside cavity" of *S. vermiformis* figured by Pourtalès (1880, p. 101, pl. 1, fig. 15).

Stenocyathus is marked not only by the pseudoperforate epithecal wall but more particularly by a single crispate columellar lath surrounded by five or 6 pali. The apparent absence of pali in these specimens, however, is expectable, as they are observable only in intact calices. Worn or broken fragments of the Holocene *S. vermiformis* show little or no trace of pali or columella.

S. hoffmeisteri differs from *S. vermiformis*, the type species which is widespread in the Caribbean, Atlantic, and Mediterranean, by the presence of only 14–16 septa rather than 20–24; it differs also from the only other Holocene species *S. decamera* Ralph and Squires (1962) from New Zealand, the septa of which number about 30 and are decamerally arranged.

The only described fossil species is *S. alabamiensis* Wells (1947), reported originally from the Upper Cretaceous of Alabama but now known to be of Paleocene (Clayton Formation) age; it has septa arranged 12/12, plus a few of the fourth cycle. Another fossil species, still undescribed, from the upper Oligocene (Spring Creek) of Australia, has septa arranged 6/6/12.

Material.—Represented by 20 specimens.

The species is named for Dr. J. Edward Hoffmeister who first mapped the island of Eua.

Family DENDROPHYLLIIDAE

Genus ENALLOPSAMMIA Sismonda and Michelotti 1871

Enallopsammia laddi Wells, n. sp.

Plate 3, figures 17–22

Corallum dendroid, branches apparently not anastomosing. Calices on distal and terminal branches regularly alternating in one plane; on thick (6–8 mm) proximal branches, calices tend to be on one face, united by extensive costate coenosteum. Costae distinct, thick, and rounded, each bearing a single row of low granulations, the narrow intercostal grooves pierced by perforations. Calices deep, moderately salient on terminal branches, slightly elevated on thick branches, 3.5 mm outside diameter, 2 mm internally. Septa in three complete cycles (24), free on upper part, thickened at calicular margin, internally thin. The six primary septa of some calices more exsert at margins than those of the other two cycles. Deep in calice, third-cycle septa united with those of second. Columella very deep, composed of a few trabecular processes.

Measurements.—Diameter of proximal branches 5–8 mm, of terminal branchlets, 2.5–3 mm; outer diameter of calices 3.5 mm, internal 2 mm; depth of calices 2 mm; costae 12 in 5 mm.

Remarks.—In addition to the five Holocene species of *Enallopsammia* recently revised by Zibrowius (1973), several fossil forms have been recorded, mostly from Europe: the type species, *E. scillae* (Seguenza), Miocene-lower Pliocene, *E. poppelachii* (Reuss), Miocene, *E.* sp. Squires, Miocene, New Zealand, and *E. payricardensis* Chevalier, Miocene. The last is better placed in *Tubastraea*. *E. laddi* is very similar to *E. scillae,* differing mainly in having less salient calices, weaker columella, and coarser costae.

Material.—Represented by several hundred small fragments, mostly of distal and terminal branchlets, all rather rolled and worn. Holotype, USNM 208334; paratypes, USNM 208335–208338.

The species is named for Dr. Harry S. Ladd of the U.S. Geological Survey.

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EOCENE FISH FAUNA OF EUA, TONGA, BASED UPON ADDITIONAL OTOLITHS

By JOHN E. FITCH[2]

After the publication of my report on fish otoliths from Eua (Fitch, 1971), I examined three additional small lots from the same locality. These three supplementary collections (USGS 24686, 24745, 25147) contained 129 recrystallized otoliths and otolith fragments. Although many were so badly deteriorated that it was difficult to determine whether they actually were otoliths, 48 had retained enough characters to be placed into families or family groups. These included at least 12 kinds of fishes belonging to seven "families" (Berycidae, Congridae, Diretmidae, Macrouridae, ?Melamphaidae, Myctophidae, and Sternoptychidae) and one kind from an unknown family. Table 4 shows the number of otoliths (by family) in each collection.

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TABLE 4.—*Number of teleost otoliths (by family) in each collection from Eua, Tonga*

Family	Collection			
	USGS [1] 24686	USGS 24745 (Fitch, 1971)	USGS [2] 24745 (this report)	USGS [3] 25147
Berycidae	1	--	--	--
Congridae	3	--	--	1
Diretmidae	2	--	1	--
Flatfishes	--	3	--	--
Macrouridae	9	5	9	--
?Melamphaidae	1	--	--	--
Myctophidae	15	13	--	1
Sternoptychidae	1	--	--	--
Unknown	4	5	--	--
Unidentifiable	37	26	44	5
Totals	73	52	54	7

[1] 1,000 ft north of Vaingana, Eua, in first gulch: collected by Yoshio Kondo 1967.
[2] Same locality as USGS 24686; collected by Wilfred Bryan, 1969
[3] North of Vaingana, Eua; altitude 400 ft; collected by H. Ladd and F. Coulson, 1971.

FAMILY ACCOUNTS

BERYCIDAE

One fragment, constituting approximately the anteriormost two-thirds of a relatively large right sagitta, is from a berycid. It has a very distinct ostium (name applied to the front part of the sulcus or groove on the inner face of an otolith), and much of the ventral profile is still intact.

In a recent review of the family, Woods and Sonoda (1973) stated that two genera, *Beryx* and *Centroberyx*, compose family Berycidae. Stinton (1967, 1968) has illustrated otoliths from both of these genera; his *Trachichthodes affinis* is *Centroberyx*. In making direct comparisons, the deeply rounded ventral profile of the fossil fragment from Eua is most nearly like sagittae from *Beryx*, but it is quite thick, and in this respect it is closest to *Centroberyx*. The ostium in berycid sagittae has a very distinctive shape and usually composes at least 50 percent of total otolith length. Thus, as the ostium on the fossil fragment is 8.1 mm long, this otolith, if entire, probably would have been between 14 and 17 mm long. At that size, it obviously was from an adult.

As adults, most members of the family attain lengths of 350 to 500 mm and inhabit deep water. Maul (1954) reported that in Madeiran waters *Beryx* usually is captured 400 to 600 m beneath the surface. On the other hand, *Centroberyx* sometimes is found in water as shallow as 20 m (Munro, 1938).

The fossil record for the family is extensive, beginning as early as the Upper Cretaceous, on the basis of skeletal remains (Berg, 1940), and as early as the Eocene, on the basis of otoliths (Weiler, 1968b).

CONGRIDAE

Four of the recrystallized sagittae from Eua were from eels, and although characters of the sulcus are eroded and vague, their overall shape and thickness permit their assignment to this family. Although present-day members of this large and well-known family of eels are abundant in the meso- and bathypelagic realms of the world oceans, only one specimen has been captured in water as deep as 1,800 m (Grey, 1956). On the other hand, many congrids are found inside the Continental Shelf, some in water as shallow as 20 m. Kotthaus (1968) has illustrated sagittae of several deep-dwelling congrids that were trawled in the Indian Ocean.

The family has a long and continuous fossil record. Berg (1940) reported their skeletal remains from the Upper Cretaceous, but congrid otoliths did not appear until the Paleocene (J. E. Fitch, unpub. data, 1975). Congrid otoliths are extremely abundant in Eocene deposits throughout the world (Frizzell and Lamber, 1962; Weiler, 1968b) and have been fossilized during all subsequent geologic periods.

The four sagittae from Eua are quite small (1.8–2.5 mm long), and judged by their lobular margins, they probably are from juvenile eels.

DIRETMIDAE

Three of the better preserved otoliths from Eua were from an unknown diretmid. The largest of these measured 7.8 mm long by 12.0 mm high (sagittae in my comparative collection from an adult *D. argenteus*, 251 mm standard length, which was trawled off the Oregon coast, are 7.5 mm long by 11.8 mm high); the other two were only slightly smaller. There is no previously published fossil record for the family, but I have found diretmid otoliths in Eocene deposits near San Diego, Calif., and in Miocene deposits at Bowden, Jamaica (Fitch, unpub. data, 1975).

In a recent review of the family, Woods and Sonoda (1973) assign to it only a single genus, *Diretmus*. Although they do not state how many species compose the genus, their synonymies indicate that they recognize only the two that they discuss. Specimens of *Diretmus* are relatively rare in collections, most having been netted from 200 to 2,000 m beneath the surface. However, judging by the number of diretmid otoliths I have seen in dolphin, swordfish, and shark stomachs, I believe that the absence of *Diretmus* specimens in museum collections indicates the fish's ability to avoid nets rather than any actual scarcity. The sagittae of *Diretmus* are quite distinctive, and on the basis of those in my comparative collection as well as those I have seen in predators' stomachs, *D. aureus* from New Zealand is valid, and probably two or three additional species are extant.

MACROURIDAE

Previously, I recognized five macrourid sagittae among the identifiable otoliths from Eua but would not speculate as to their generic affiliation (Fitch, 1971). Among the 48 identifiable otoliths that I have subsequently examined, 18 are from macrourids, and these represent at least three species. One of these is almost square in outline but has rounded corners. Although it compares favorably with sagittae from an extant species of *Coryphaenoides* (that is, *C. armatus*), I do not feel that I could justify assigning it to this genus. The other two kinds match almost perfectly the angular outline of sagittae from *Coelorinchus*, differing from each other primarily in ratio of height to length.

?MELAMPHAIDAE

Melamphaid otoliths have a very distinctive sulcus and can be recognized from that alone. In addition, sagittae of all melamphaid genera except *Scopelogadus* have one or more hairlike projections from one or both corners of the ventral margin which are equally distinctive. Unfortunately, in the single recrystallized otolith from Eua, these characters can not be observed, so its provisional assignment here is based mostly upon outline and intuition, neither of which is diagnostic nor infallible.

According to Ebeling and Weed (1973), the Melamphaidae are one of the largest and most varied of all bathypelagic families of fishes. Adults and half-grown individuals usually are found below 100 to 200 m, although larvae and young may occur nearer the surface. Weiler (1968a) illustrated sagittae from the five genera of melamphaids and speculated upon their systematic position.

The fossil record of the family is not extensive, probably because melamphaid hard parts are delicate and fragile and do not preserve well. A skeletal imprint is known from the Miocene of California (Ebeling, 1962), and I have seen otoliths from the Miocene of Jamaica (Fitch, unpub. data, 1975); otherwise, otoliths of *Melamphaes* and *Scopelogadus* are known from the lower Pleistocene of California (Fitch, 1968). The Eua specimen (2.6 mm long) is closest to *Melamphaes* among the five extent genera.

MYCTOPHIDAE

Sixteen of the 48 identifiable otoliths that I examined for this report were from four kinds of lanternfish. The sagittae of several myctophid genera have spines along the ventral margin and are easily distinguished when these are present. Unfortunately, none of the recrystallized otoliths had retained these spines, if they ever had them, so generic assignment is impractical for many of these. One otolith, by its elongate shape, broadly rounded posterior end, and typical strong rostrum, resembles *Ceratoscopelus,* and several of the larger otoliths would be difficult to distinguish from *Symbolophorus;* however, the other two kinds were most similar to *Diaphus* and *Benthosema,* both having otoliths with spinose ventral margins.

Although these Eua fossils are much like these four genera, I do not believe that the quality of the fossils is sufficient to justify making firm assignments. The 13 myctophid otoliths previously described from Eua (Fitch, 1971) represented three of the same four types noted above.

STERNOPTYCHIDAE

One otolith was unquestionably from an ancestral form of *Ichthyococcus,* a small luminescing meso- and bathypelagic fish found in most world oceans. *Ichthyococcus* has a very distinctive sagitta which is extremely large for the size of the fish and has a very thin bladelike rostrum projecting from the lower third of the otolith. Although Kotthaus (1967) illustrated sagittae of *I. ovatus,* his figures are unreliable because the preservative (formalin) used on the fish had dissolved the rostra before the otoliths were removed. The *Ichthyococcus* sagitta illustrated by Fitch and Brownell (1968), although taken from the stomach of a pygmy sperm whale, was little affected by digestive juices and shows a typical rostrum. The only difference I can find between fossil and living *Ichthyococcus* otoliths is a more deeply channeled sulcus in the fossil.

Although the genus is unreported as a fossil (Andrews and others, 1967), R. J. Lavenberg of the Natural History Museum of Los Angeles County, Calif. (oral commun., 1975) has informed me that *Xyrinius houshi,* which has been considered an extinct Miocene wrasse, is actually a species of *Ichthyococcus.* Interestingly, in their description of this California fossil, Jordan and Gilbert (1919) gave details concerning its eye and mouth, yet an examination of the unique holotype shows that the anterior part of the head, to a point just behind the eye, is entirely lacking and has been since the day it was collected. In addition, many photophores can be discerned along the ventral profile of the body, a feature unknown in family Labridae.

Ichthyococcus otoliths are abundant in an Eocene deposit near San Diego, Calif., and in Miocene deposits north of Auckland, New Zealand (Fitch, unpub. data, 1975) ; they very likely have gone unrecognized in other deep-water deposits throughout the world.

UNKNOWN FAMILY

Four otoliths are almost oval in outline and have a straight, deeply channeled sulcus along the midline of the horizontal axis. The outer faces of these otoliths are evenly convex. Unfortunately, none of these otoliths has retained any indication of an ostium, so it is impossible to make a familial assignment. Sagittae of several extant genera in an equal number of families are oval in outline and have a straight deep sulcus but show differences in the shape and proportions of the ostium. The largest of these four otoliths is 3.7 mm long.

UNIDENTIFIABLE SAGITTAE

Eighty-one otoliths were either too fragmentary or too poorly preserved to offer any clues to family affiliation.

DISCUSSION

The 48 identifiable otoliths reported here bring to 14 the kinds of bony fishes from the Eocene of Eua that can be assigned to families or family groups. An additional five kinds, including four mentioned in my earlier report (Fitch, 1971), could not be so placed but were different from those that could be assigned. Of the eight families involved, only two ("flatfishes" and Congridae) contain extant members which, as adults, are not inhabitants of meso- or bathypelagic environments.

On the basis of otoliths alone, one would have to conclude that deposition took place at considerable depth, probably even deeper than the 182 fathoms postulated in my earlier report (Fitch, 1971).

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[Italic page numbers indicate descriptions and major references]

PLATES 1-3

Contact photographs of the plates in this report are available, at cost, from U.S. Geological Survey Library, Federal Center, Denver, Colorado 80225

PLATE 1

FIGURES 1, 2. *Stylaster* sp. (p. G3).
× 8, USNM 208294.

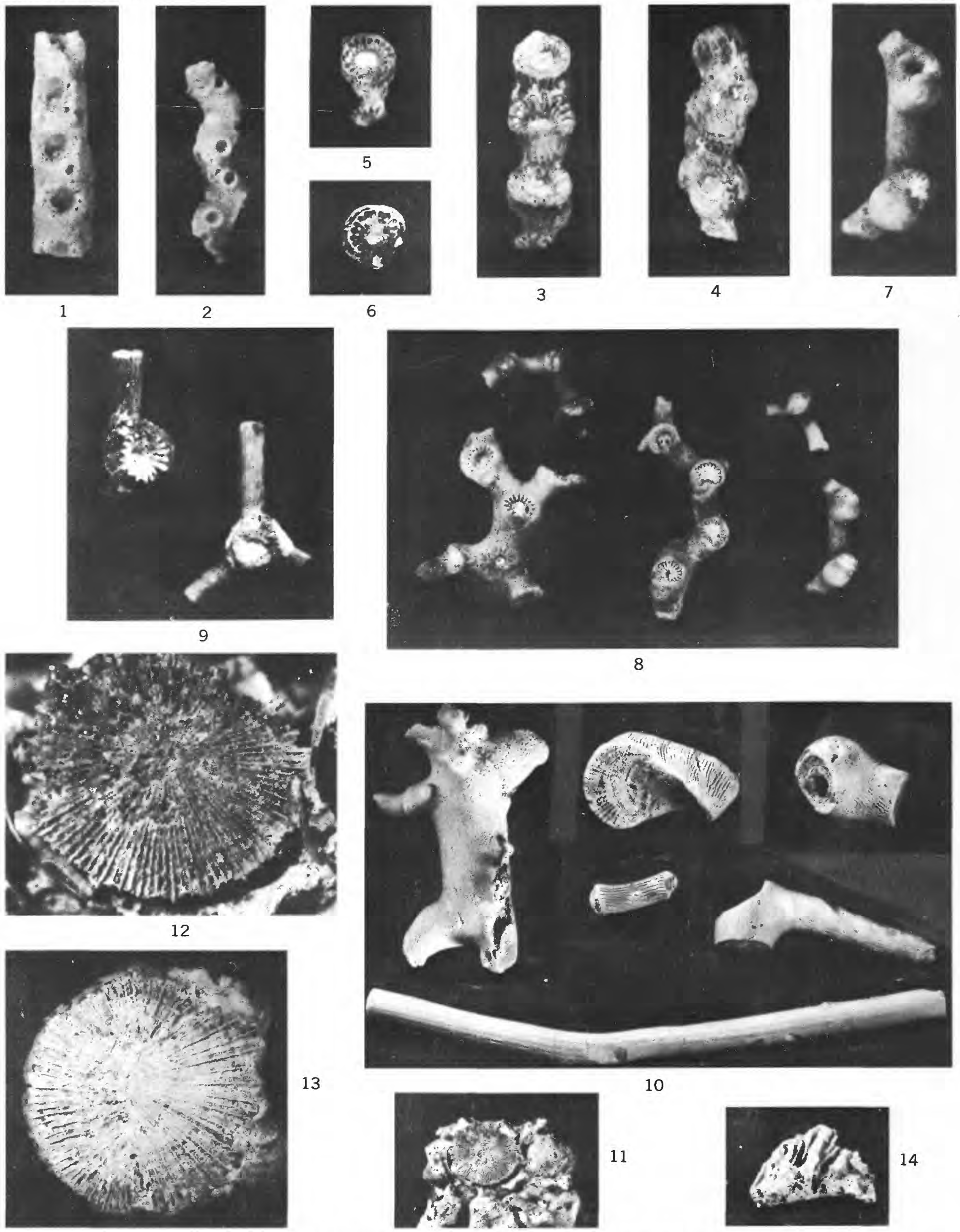
3–6. *Stenohelia boschmai* Wells, n. sp. (p. G 3).
3, 4. Holotype, anterior surface; posterior surface with large ampullae, × 4, USNM 208295.
5–6. Paratypes, cyclosystems, × 4, USNM 208296.

7, 8. *Crypthelia vetusta* Wells, n. sp. (p. G5).
7. Holotype, upper surface with large ampullae, × 8, USNM 208297.
8. Holotype (lower right) and paratypes, anterior surfaces, × 4, USNM 208297, 208298.

9. *Astya nielseni* Wells, n. sp. (p. G6).
Holotype (left), × 6, USNM 208299; paratype (right) × 6, USNM 208300.

10. *Corallium* (left and bottom), and *Parisis* (other four specimens). (p. G7).
× 2, USNM 208301.

11–14. *Fungiacyathus euaensis* Wells, n. sp. (p. G 7).
11, 12. Holotype, basal aspect, × 1, × 5, USNM 208302.
13. Paratype, basal aspect, × 4, USNM 208303.
14. Paratype, lateral aspect of septum and synapticulae, × 4, USNM 208304.



STYLASTER, STENOHELIA, CRYPTHELIA, ASTYA, CORALLIUM, FUNGIACYATHUS, AND *PARISIS*

PLATE 2

FIGURES 1–3. *Madrepora* sp. (p. G7).
- 1. Branchlets, × 1, USNM 208305.
- 2. Calice, × 4, USNM 208305 (part).
- 3. Polished transverse section below calice, × 4, USNM 208306.

4, 5. *Anthemiphyllia catinata* Wells, n. sp. (p. G7).
Holotype, basal and calicular aspects, × 4, USNM 208307

6–10. *Caryophyllia denaria* Wells, n. sp. (p. G8).
- 6, 7. Holotype, lateral and calicular aspects, × 1, × 2, USNM 208308.
- 8, 9. Paratypes, × 1, USNM 208309, 208310.
- 10. Paratype, polished section at base of calice, × 4, USNM 208311.

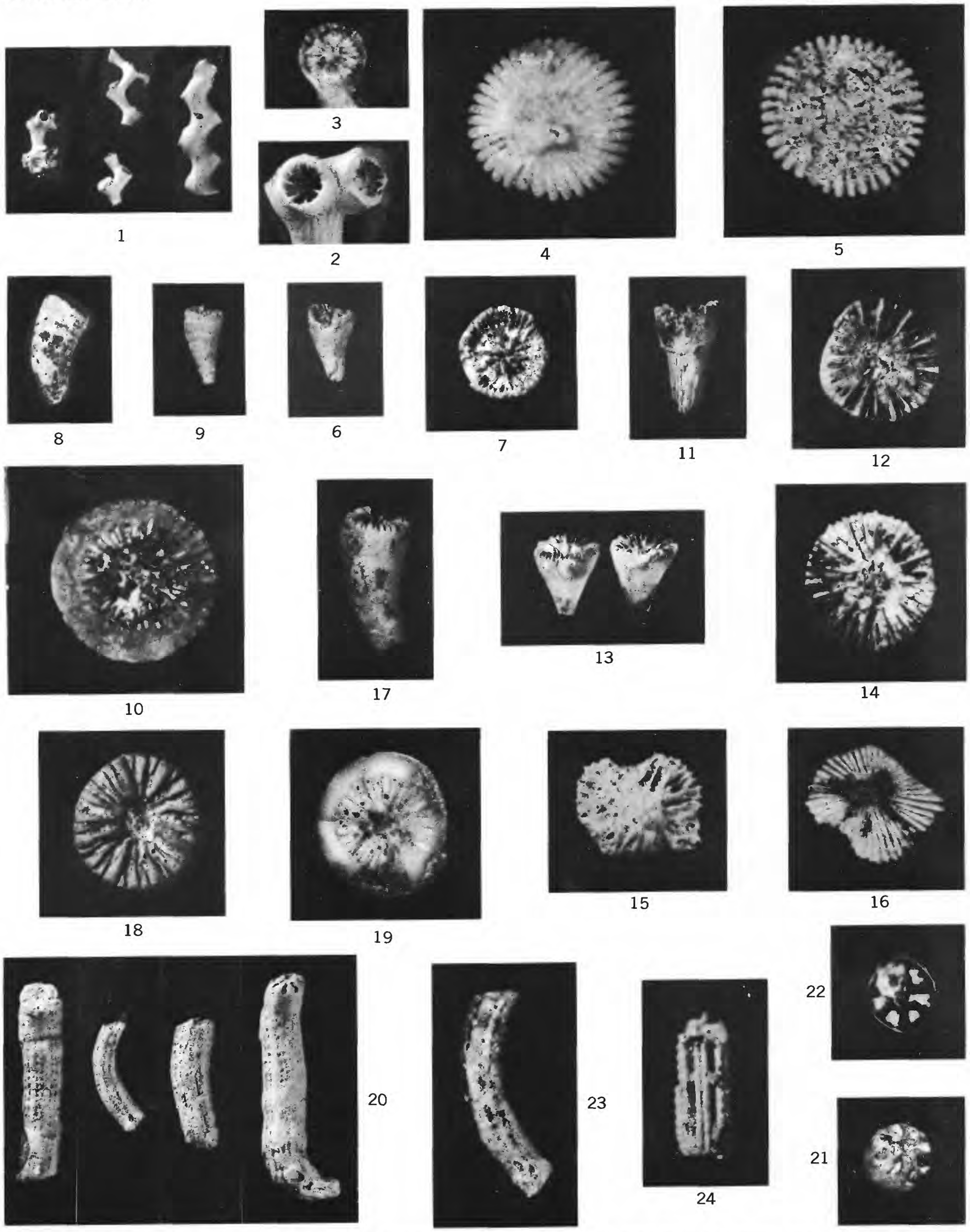
11, 12. *Caryophyllia* sp. cf. *C. japonica* von Marenzeller. (p. G8).
Lateral and calicular aspects, × 1, × 2, USNM 208312.

13, 14. *Cyathoceras kondoi* Wells, n. sp. (p. G8).
- 13. Holotype (right), × 1, USNM 208313; paratype (left), × 1, USNM 208314.
- 14. Holotype, calice, × 2.

15, 16. *Deltocyathus* sp. (p. G8).
Calicular and basal aspects, × 4, USNM 208315.

17–19. *Cristpatotrochus tenison-woodsi* Wells, n. sp. (p. G9).
- 17, 18. Holotype, lateral and calicular aspects, × 1, × 2, USNM 208316.
- 19. Paratype, polished section below calice, × 4, USNM 208317.

20–24. *Stenocyathus hoffmeisteri* Wells, n. sp. (p. G11).
- 20. Holotype (right), × 4, USNM 208318; paratypes *a*, *b*, *c* (left three), × 4, USNM 208319, 208320, 208321.
- 21. Septa (8) of holotype, × 8.
- 22. Septa (7) of paratype *c*, × 8.
- 23. Paratype *b*, dark spots are sites of mural pits, × 8.
- 24. Paratype, internal mold, short spines are filling of mural pits, × 8, USNM 208322.



MADREPORA, ANTHEMIPHYLLIA, CARYOPHYLLIA, CYATHOCERAS, DELTOCYATHUS, CRISPATOTROCHUS, STENOCYATHUS

PLATE 3

FIGURES 1–3. *Notocyathus (Paradeltocyathus) orientalis* (Duncan) (p. G9).
USNM 208323.
1, 2. Basal aspects, × 4.
3. Calicular aspect, × 4.

4, 5. *Desmophyllum decuplum* Wells, n. sp. (p. G9).
4. Holotype (left), × 1, USNM 208324;
paratype (right), × 1, USNM 208325.
5. Calice of holotype, × 4.

6, 7. *Desmophyllum lirioides* Wells, n. sp. (p. G9).
Holotype, lateral and calicular aspects, × 1, USNM 208326.

8, 9. *Desmophyllum coulsoni* Wells, n. sp. (p. G10).
Holotype, lateral and calicular aspects, × 1, × 2, USNM 208327.

10, 11. *Anomocora exilis* Wells, n. sp. (p. G10).
10. Holotype (right), × 1, USNM 208328;
paratype (left), × 1, USNM 208329.
11. Polished section of holotype, × 2.

12, 13. *Goniocorella eguchii* Wells, n. sp. (p. G10).
12. Holotype (left), × 1, USNM 208330;
paratype (right), USNM 208331.
13. Polished section of holotype, × 4.

14–16. *Javania duncani* Wells, n. sp. (p. G11).
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16. Paratype, calice, × 2, USNM 208333.

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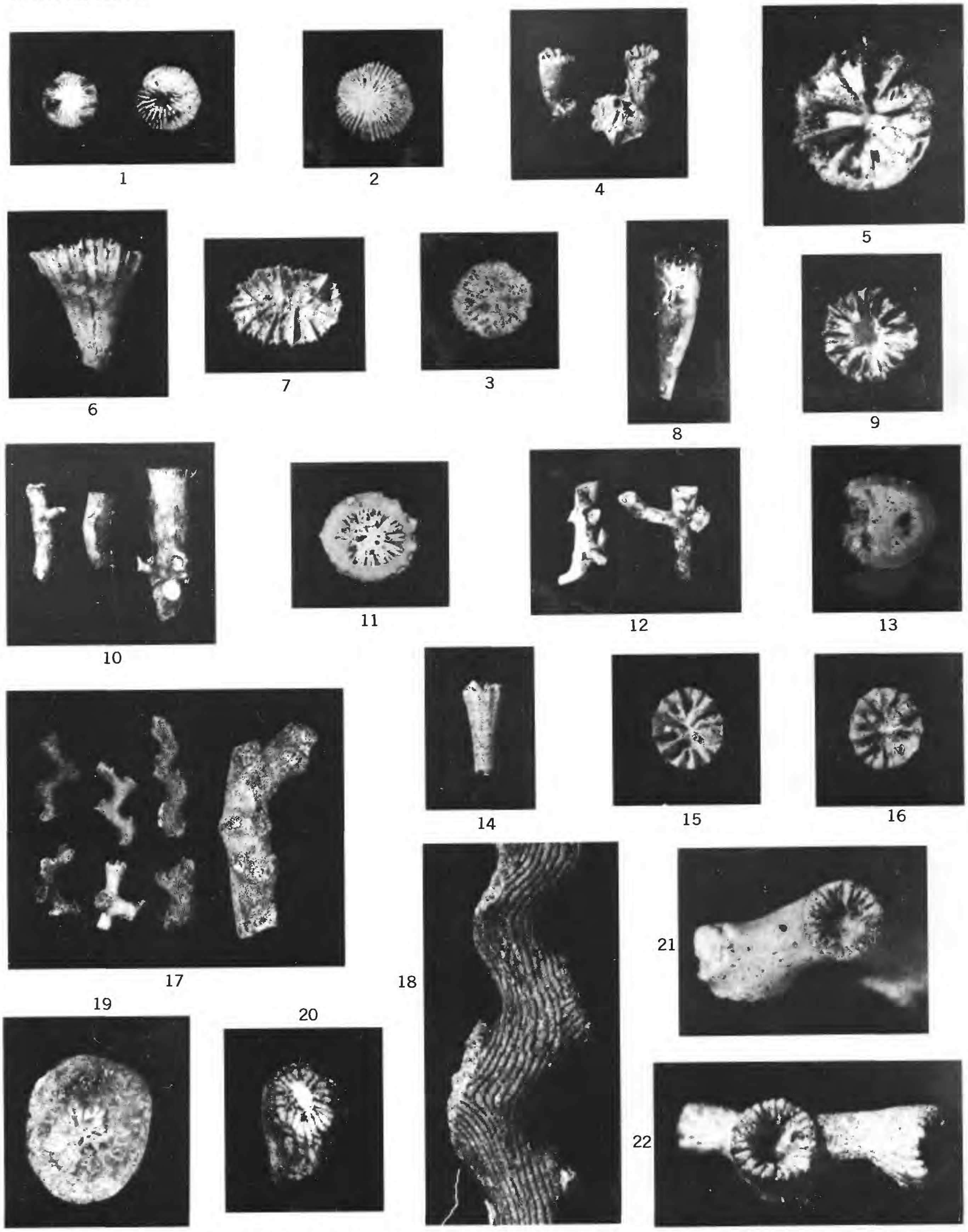
paratypes (right, left, and lower center), × 1, USNM 208335.
18. Holotype, × 4.
19. Paratype, polished section, × 4, USNM 208336.
20. Paratype, polished section, × 4, USNM 208337.
21. Paratype, calice, × 4, USNM 208338.
22. Paratype, calice, × 4, USNM 208335.



NOTOCYATHUS, DESMOPHYLLUM, ANOMOCORA, GONIOCORELLA, JAVANIA, ENALLOPSAMMIA