Larger Foraminifera of Late Eocene Age From Eua, Tonga

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By W. STORRS COLE

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Study of eight species characteristic of upper Eocene (Tertiary b) *stage*

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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, Moese 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.

The exact extent of the richly fossiliferous bed is not known but it is probably limited both horizontally and vertically. 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. Addi-

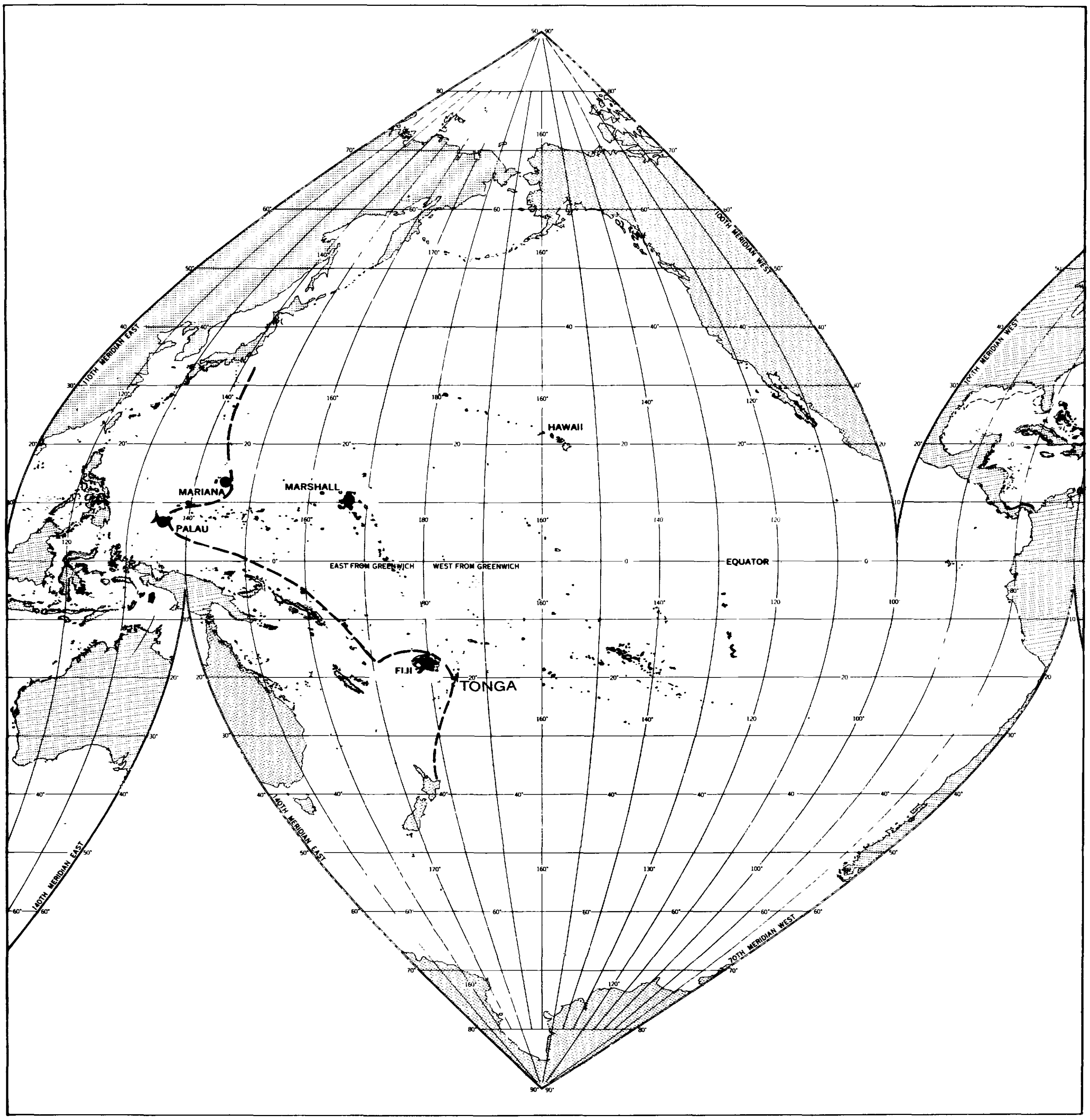

FIGURE 1.—Location of Tonga and other island groups in the southwest Pacific where upper Eocene limestone has been identified. Dashed line marks structural boundary of the Pacific Basin (andesite line).

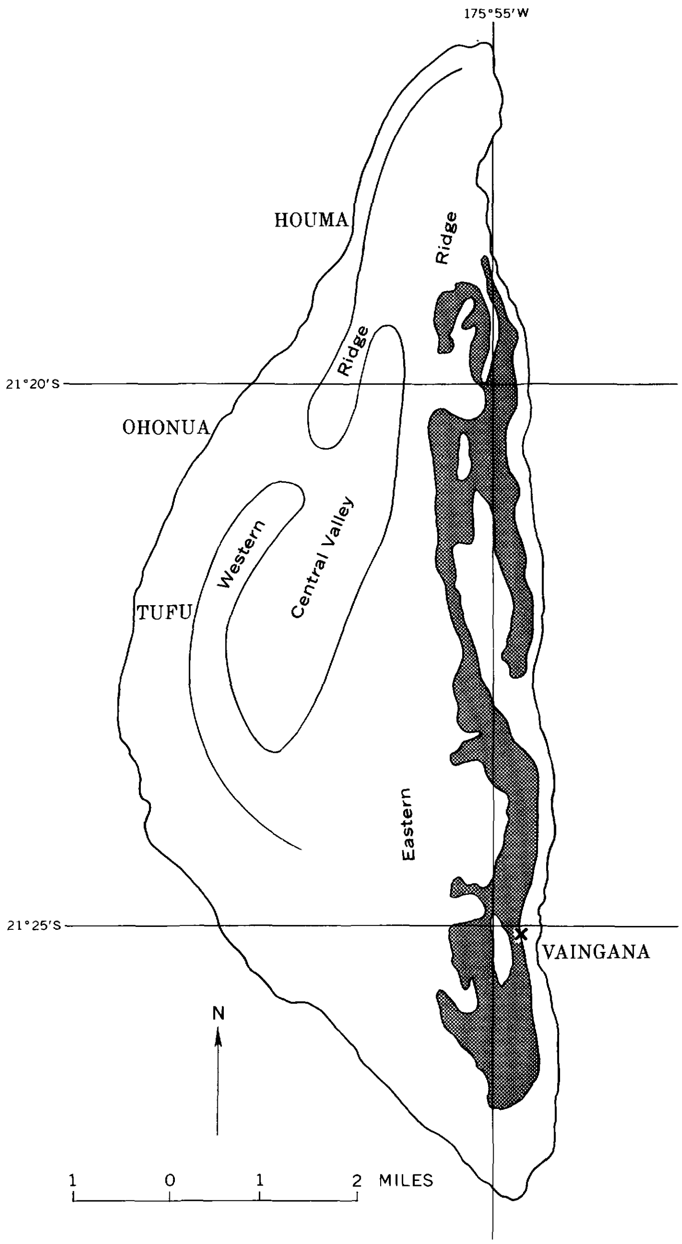

FIGURE 2.—Map of Eua, Tonga, showing the location of the recently discovered fossil outcrop (×) and the main mass of Eocene limestone (patterned area) on the east side of the island, as mapped by Hoffmeister (1932).

tional fieldwork in the area of the rugged "Nine Gulches" would be worthwhile.

William Melson of the Smithsonian Institution examined hand specimens and this section 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 garments 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 limestone collected by Kondo was 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 island of the open Pacific, an area extending 4,000 miles from Palau to Tonga.

HARRY S. LADD

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LARGER FORAMINIFERA OF LATE EOCENE AGE FROM EUA, TONGA

By W. Storrs Cole

ABSTRACT

Eight species of larger Foraminifera characteristic of the Tertiary *b* (upper Eocene) stage of the Indo-Pacific region were recovered from a sample collected at an elevation of 400 feet about one-quarter mile north of Vaingana, Eua, Tonga. The most abundant specimens in this fauna are *Pellatispira. Heterostegina* and *Asterocyclina* were found in moderate numbers, but *Camerina* and *Spiroclypeus* were uncommon. This fauna developed in warm, shallow waters (about 200 feet in depth) in a protected ecologic niche.

The genus *Biplanispira* Umbgrove, 1938, is demonstrated to be a synonym of *Pellatispira* Boussac, 1906. Specimens previously identified as *Pellatispira fulgeria* Whipple (synonym: *Biplanispira absurda* Umbgrove) are considered to be aberrant forms of *Pellatispira madaraszi* (Hantken).

INTRODUCTION

In 1932, Hoffmeister published a report on the geology of Eua, Tonga, one section of which was an analysis of larger Foraminifera prepared by G. Leslie Whipple. Species of larger Foraminifera from Tertiary *b* (upper Eocene) were described and illustrated, and "Recent species—In the younger limestones" (Whipple, in Hoffmeister, 1932, table 5) were listed without discussion or illustrations.

Cole (1957a, p. 333, 334) examined the types of certain of the species described by Whipple and referred specimens from Saipan Island to these species. Later, Cole (1960a, p. A3) wrote:

Whipple (1932, *in* Hoffmeister, p. 79) described several species from the Tertiary *b* (upper Eocene) of Eua, Tonga. Certain of these species were identified incorrectly and others were inadequately described. A revised list of certain of these species follows:

Names used by Whipple	*Names used in this report*
Camerina pengaronensis (Verbeek)	*C. pengaronensis* (Verbeek).
Pellatispira fulgeria Whipple	*Biplanispira fulgeria* (Whipple).
Discocyclina (*Discocyclina*) *fritschi* (H. Douvillé).	*D.* (*D.*) *omphala* (Fritsch).
euaensis Whipple	*D.* (*D.*) *omphala* (Fritsch).
(*Asterocyclina*) *stellata* (d'Archiac).	*A. matanzensis* Cole.

Harry S. Ladd of the U.S. Geological Survey sent the author abundant, excellently preserved, matrix-free specimens of larger Foraminifera collected by Yoshio Kondo of the Bernice P. Bishop Museum at an elevation of 400 feet about one-quarter mile north of Vaingana, Eua, Tonga (fig. 2). This locality would be at the eastern edge of the Eocene limestone on the areal geologic map prepared by Hoffmeister (1932, p. 19, fig. 3) and associated with the 400-foot terrace (Hoffmeister, 1932, p. 14, fig. 2).

The most abundant specimens in the sample were *Pellatispira madaraszi* (Hantken). Whipple (in Hoffmeister, 1932, p. 81) identified specimens in the samples he studied as *P. rutteni* Umbgrove, a species which is considered to be a junior synonym of *P. madaraszi.* Whipple wrote: "This species occurs abundantly at an altitude of 840 feet (E–390), associated with *Camerina pengaronensis* on the highest ridge of the island." In addition, specimens of *Heterostegina* sp. (= *H. saipanensis* Cole) were recorded from this locality (E–390).

The present sample seemingly represents the same or nearly the same ecological situation as the one in which Whipple found abundant *Pellatispira* and some specimens of *Camerina* and *Heterostegina.* However, the sample on which this report is based contained, in addition, many specimens of *Asterocyclina* and rare specimens of *Spiroclypeus.*

The specimens in the sample from Eua, Tonga, were sorted into groups based on external appearance. Selected specimens from each group were sectioned. Wherever possible, pairs of specimens that were identical in external appearance were selected from each group—one of which was made into an equatorial section, and the other into a vertical section. A sufficient number of pairs of specimens were sectioned from each group to establish with certainty that the internal structures were similar. In total, over 150 oriented thin sections were made and photographed by the writer.

An attempt was made to obtain the specimens upon which Whipple (in Hoffmeister, 1932) based his report. However, these specimens have been misplaced, as they could not be located either at the University of Rochester or in the collection of the U.S. National Museum.

THE FAUNA

On first analysis, nine supposedly valid species (table 1), all of which had been reported from other Indo-Pacific localities assigned to the Tertiary *b* (upper

Eocene) stage, were recognized. In addition one small specimen (pl. 2, fig. 18) of *Discocyclina* (*Discocyclina*), which could not be identified specifically, was found. Detailed study resulted in the reduction of the nine species to eight, as specimens identified as *Pellatispira fulgeria* Whipple were combined with *P. madaraszi* (Hantken). For clarity, however, in this analysis of the fauna, the name *P. fulgeria* (synonym: *Biplanispira absurda* Umbgrove) will be used, as this form has been reported as a valid species in many articles.

TABLE 1.—*Distribution of larger Foraminifera in the Tertiary* b *(upper Eocene) sample from Eua, Tonga, and elsewhere*

Species found in the sample	Occurrence elsewhere			
	Saipan	Eniwetok	Viti Levu, Fiji	Indonesia
Asterocyclina matanzensis Cole	x	x	x	----------
penuria Cole	x	x	----------	x
praecipua Cole	----------	x	----------	----------
Camerina pacifica (Whipple)	x	x	x	----------
pengaronensis (Verbeek)	x	x	x	x
Heterostegina saipanensis Cole	x	x	----------	----------
Pellatispira fulgeria [1] Whipple	x	x	x	x
madaraszi (Hantken)	x	x	x	x
Spiroclypeus vermicularis Tan	x	x	x	x

[1] In the following section an attempt will be made to demonstrate that specimens previously identified as *Pellatispira fulgeria* (synonym: *Biplanispira absurda*) are aberrant forms of *Pellatispira madaraszi*. The specific name *P. fulgeria* is used in this section for comparative purposes only.

In the Tertiary *b* (upper Eocene) sediments of Saipan Island (Cole, 1957a, p. 322), 20 species of larger Foraminifera were identified in the examination of samples from 98 localities. In nine cores from Eniwetok Atoll drill hole F–1, 18 species of larger Foraminifera were recovered (Cole, 1957b, p. 749). Core 12 (4,316–4,341 ft.) in this drill hole contained 10 of the 18 species, which was the largest number recovered in any of the cores examined. This same core contained *Pellatispira madaraszi* (Hantken)—identified as *P. orbitoidea* (Provale)—in abundance.

In addition to *P. madaraszi*, core 12 of Eniwetok Atoll drill hole F–1 had five other species which occur in the sample from Eua, Tonga. These species are: *Asterocyclina matanzensis* Cole, *A. penuria* Cole, *A. praecipua* Cole, *Camerina pacifica* (Whipple) (identified in core 12 as *Operculinoides saipanensis* Cole), and *Heterostegina saipanensis* Cole. Three species, *Camerina pengaronensis* (Verbeek), *Pellatispira fulgeria* Whipple, and *Spiroclypeus vermicularis*, which occur in the sample from Eua, Tonga, were not recovered from core 12; of these, however, *C. pengaronensis* and *S. vermicularis* occurred in core 11 (4,197–4,222 ft) of Eniwetok Atoll drill hole F–1.

Thus, in the 144-foot interval from the top of core 11 (4,197 ft) to the bottom of core 12 (4,341 ft) in Eniwetok Atoll drill hole F–1, the nine species in the sample from Eua, Tonga, occurred. These data suggest that the ecological conditions under which the fauna of the sample from Eua, Tonga, formed were similar to those of the interval represented by cores 11 and 12 of Eniwetok Atoll drill hole F–1.

Although the sample from Eua, Tonga, may be most satisfactorily correlated with this interval in Eniwetok Atoll drill hole F–1 because of the number of species which are common, it is not implied that this fauna represents a distinct zone in the Tertiary *b* (upper Eocene) stage. For example, Whipple (in Hoffmeister, 1932, table 5) recorded *Discocyclina s. s.* at four localities on Eua, Tonga, and Cole (1960a, p. A3) identified *Discocyclina* (*Discocyclina*) *omphala* (Fritsch) at one locality on Viti Levu, Fiji. As *Pellatispira* was not found in association with *Discocyclina* at these localities, the assumption might be made that two stratigraphically separate zones formed in the Tertiary *b* (upper Eocene) stage.

In the 98 samples from Saipan Island (Cole, 1957a, p. 322), *Pellatispira* and *Discocyclina* were both reported from 44 localities; however, *Pellatispira* and *Discocyclina* occurred in association at only 16 of these localities. These data suggest that the stratigraphic range of *Pellatispira* is the same as that of *Discocyclina*, but that *Pellatispira* favors one ecological situation and *Discocyclina* another.

Although there are sufficient data available to correlate the Tertiary *b* (upper Eocene) faunas throughout the Indo-Pacific region, our present knowledge does not indicate the possibility of subdivision of this stage into distinct and stratigraphically separate paleontologic zones characterized by one species or group of species.

As noted previously, only one small specimen that could be referred to the genus *Discocyclina* was found in the Eua, Tonga, material. Hoffmeister (1932, p. 25) wrote that he collected *Discocyclina* along a small stream which had eroded a ravine in the 100-foot terrace, at which place "* * * the genus *Discocyclina* was found in the foraminiferal limestone beneath the thin coral reef of the lowest terrace." In discussing a high pinnacle of limestone Hoffmeister (1932, p. 26) wrote: "The rock at the base of the pinnacle is hard and compact, showing mainly foraminifera of the genus *Discocyclina*." The genus *Discocyclina* without question occurs in the Tertiary *b* (upper Eocene) limestones of Eua, Tonga, but it seemingly has a limited distribution which may be due to ecological controls.

Another large distinctive species which did not occur in the present sample is *Pellatispira hoffmeisteri* Whipple. This species, however, was reported by Cole (1957a, p. 334) from Saipan Island and is, in the writer's present evaluation of it, a valid species.

PALEOECOLOGICAL IMPLICATIONS

This fauna is dominated by abundant specimens of *Pellatispira*, which have an extensive variety of shapes and sizes. Specimens of *Heterostegina* and *Asterocyclina* are present in moderate numbers, but representatives of the genera *Camerina* and *Spiroclypeus* are rare. Of these genera, only *Camerina* and *Heterostegina* have species still living.

Few, if any, of the tests of the larger Foraminifera in this fauna show any evidence of abrasion. The thin rims and elongate delicate rays of the *Asterocyclina* (pl. 4, fig. 3) are perfectly preserved. The fragile margins (pl. 1, figs. 2, 4) of *Pellatispira* are intact. Thus, the situation in which these large Foraminifera lived and their tests accumulated must have been protected from extensive wave or current action. Such protection might have been provided by the water depth, by a dense mat of seaweed, or by some favorable combination of these.

R. D. Norton (1930, p. 347) wrote: "*Heterostegina* seems to thrive in temperatures from about 22°C to 27°C and in depths down to perhaps 40 fathoms." Cole (1957b, p. 750) analyzed the occurrence of certain Holocene genera of larger Foraminifera in the vicinity of the Philippine Islands and Bikini Atoll. He wrote: "The abundant or common occurrence of *Heterostegina* at average depths of 25–32 fathoms agrees with the 40 fathoms given by R. D. Norton."

Cushman, Todd, and Post (1954, p. 320) wrote concerning the faunas of the lagoons of certain of the Marshall Islands: "In the lagoon fauna as a whole, the dominant species is *Amphistegina madagascariensis* D'Orbigny. Next in abundance in the lagoons is *Heterostegina suborbicularis* D'Orbigny * * *." Myers (1943, p. 29) observed that *Heterostegina* is "* * * found on firm sandy mud bottoms and are most numerous near patches of weeds where the juveniles may be taken in considerable numbers."

Genera such as *Camerina* seem to have a greater depth range than *Heterostegina* (Cole, 1957b, p. 750), as abundant specimens of *Camerina* have been reported at depths of 10 fathoms or less to 70 fathoms or more. Myers (1943, p. 29) found, moreover, that *Camerina* (= *Operculina*) flourished best on "soft mud bottoms."

The composition of this fauna in comparison with the ecological conditions under which living species of *Heterostegina* and *Camerina* exist suggests that it formed in warm shallow water (about 200 ft in depth) that had a moderately firm substratum upon which extensive patches of weeds grew. These conditions could be satisfied best in a lagoon but possibly could prevail in a protected situation on the outermost part of a reef.

DESCRIPTION OF SPECIES

Family CAMERINIDAE
Genus CAMERINA Bruguière, 1792

Camerina pacifica (Whipple)

Plate 2, figures 1–5

1932. *Operculina pacifica* Whipple, *in* Hoffmeister, Bernice P. Bishop Mus. Bull. 96, p. 83, pl. 20, figs. 1, 8.
1953. *Operculina* sp., *in* Cole and Bridge, U.S. Geol. Survey Prof. Paper 253, p. 21, pl. 4, fig. 15.
1957. *Operculinoides saipanensis* Cole, U.S. Geol. Survey Prof. Paper 280–I, p. 331, pl. 102, figs. 15, 16.
1957. *Operculinoides saipanensis* Cole. Cole, U.S. Geol. Survey Prof. Paper 260–V, p. 755, pl. 232, figs. 7–14; pl. 233, figs. 31, 32.
1959. *Operculina eniwetokensis* Cole, U.S. Geol. Survey Prof. Paper 260–V, p. 756, pl. 232, figs. 15–23 [imprint date 1957].
1960. *Operculina saipanensis* (Cole). Cole, U.S. Geol. Survey Prof. Paper 374–A, p. A4.
1963. *Operculina saipanensis* (Cole). U.S. Geol. Survey Prof. Paper 403–E, p. E3.
1963. *Operculina eniwetokensis* Cole. Cole, U.S. Geol. Survey Prof. Paper 403–E, p. E3, E16, pl. 5, figs. 11, 12, 25.

The test is small and has an inflated subcentral area over the embryonic chambers surrounded by a rim which progressively widens distally. The sutures of the chamber walls show on the surface of the flat rim as slightly raised, gently recurved lines.

Measurements of thin sections of Tongan specimens, to which have been subjoined measurements made from the median section of the type published by Whipple (*in* Hoffmeister, 1932, pl. 20, fig. 1), follow.

Measurements of sections of Camerina pacifica (*Whipple*)

	Specimen shown on pl. 2—					Type specimen of Whipple (*in* Hoffmeister, 1932, pl. 20, fig. 1)
	Fig. 1	Fig. 2	Fig. 3	Fig. 4[1]	Fig. 5	
Height (mm)	2.18	2.2	2.1	2.1	1.9+	4.0
Width (mm)	1.83+	1.9	1.55	1.7+		3.2
Thickness (mm)					.5	
Embryonic chambers:						
Diameters of first chamber (μ)	55x60	50x50				
Diameters of second chamber (μ)	40x90	40x70				
Distance across both chambers (μ)	100	100				125(?)
Number of whorls	3	3.75		5		2.5
Number of chambers in first volution	10	7				7
Number of chambers in final volution	22	10	25	31		15
Number of chambers in all volutions	50	31		90		34
Surface diameter of axial plug (μ)					220	

[1] Microspheric specimen.

Remarks.—Since 1932 three specific names, *Operculina pacifica* Whipple (in Hoffmeister, 1932, p. 83), *Operculinoides saipanensis* Cole (1957a, p. 331), and *Operculina eniwetokensis* Cole (1957b, p. 756), have been given to small operculine camerinids from Tertiary *b* (upper Eocene) sediments. All these specimens seemingly should be referred to one species, *Camerina pacifica* (Whipple).

In part, the separation of the specimens into three species resulted from an attempt to use an artificial generic classification in which such inexactly defined genera as *Operculina* and *Operculinoides* were recognized (Cole, 1966). In addition, minor variations in size, number of chambers, and similar features were given exaggerated importance.

Megalospheric specimens (pl. 2, figs. 1, 5) as well as microspheric specimens (pl. 2, fig. 4) in the sample from Eua, Tonga, are similar to the types of *Operculinoides saipanensis* Cole (1957a, pl. 102, figs. 15, 16) from Saipan Island and to specimens assigned to that species from Eniwetok Atoll drill hole F–1 (Cole, 1957b, pl. 232 figs. 7–14; pl. 233, figs. 31, 32). The types and the specimens from Eniwetok Atoll drill hole F–1 were assigned to the genus *Operculinoides*.

Other specimens recovered from Eniwetok Atoll drill hole F–1 (Cole, 1957b, p. 756, pl. 232, figs. 15–23), which had fewer chambers and a thinner subcentral umbonal area, were assigned to the genus *Operculina* and described as a new species, *Operculina eniwetokensis* Cole. One figured specimen (pl. 2, fig. 2) is similar to the types of this species.

Later detailed studies (Cole, 1960b, 1961, p. 377–383; 1966) of large suites of specimens from many geographic areas and from various stratigraphic horizons have demonstrated that the assumed structural differences upon which many of the supposedly valid generic names for camerinids were based are common to all these specimens. Cole (1961, p. 377) wrote: "These genera have been defined in terms of intergradational features which are specific rather than generic differences."

Although the postulate that the specimens under consideration should be assigned to the genus *Camerina* may not be acceptable, it is evident from the structure and development of the test that they cannot be placed in two genera.

The test of the specimens which Whipple (1932, in Hoffmeister, p. 83) named *Operculina pacifica* is about twice as large as that of *O. eniwetokensis*, but the number of coils, chambers per volution, and certain other features of *O. pacifica* are similar to those of *O. eniwetokensis*. The distal chambers of *O. pacifica* are slightly over twice as high and are twice as wide as those of *O. eniwetokensis*. Thus, the only difference between these two species is the size of the chambers.

A possible explanation of this increase in size of the chambers in *O. pacifica* is that these specimens developed in a more favorable ecological situation than did the smaller specimens named *O. eniwetokensis*. Moreover, large and small specimens of a species often occur together (Cole, 1958, pl. 18, figs. 7, 9).

The only significant differences between specimens named *Operculinoides saipanensis* and *Operculina eniwetokensis* are the number of chambers per volution and the total number of chambers in the test. The chambers in *O. saipanensis* have approximately the same height as those of *O. eniwetokensis*, but the chambers in *O. saipanensis* are narrower, thus more chambers developed per volution.

As the differences in the number of chambers and in their size can readily be controlled by ecologic and other factors, such as the availability of food and rapidity of test development, all these specimens are considered to be ecological variants of one species.

The chamber walls of the one available median section of *Camerina pacifica* (Whipple) (1932, in Hoffmeister, pl. 20, fig. 1) are irregularly thickened on the distal side. This same kind of development occurs occasionally in specimens formerly referred to *Operculinoides saipanensis* (see Cole, 1957b, pl. 232, fig. 12) and in specimens (pl. 2, fig. 2) in the present fauna.

Camerina pengaronensis (Verbeek)

Plate 3, figures 10, 11, 13–16

1871. *Nummulites pengaronensis* Verbeek, Neues Jahrb. Mineralogie, Geologie, u. Palaeontologie, Jahr. 1871, p. 3–6, pl. 1, figs. 1a–k.

1892. *Nummulites nanggoelani* Verbeek, Natuurk. Tijdschr. Nederlandsche-Indië, v. 51, no. 2, p. 116, 118 [imprint date 1891].

1932. *Camerina pengaronensis* (Verbeek). Doornink, Geol.-Mijnb. Genoot. Nederland en Kolonien Verh., geol. ser., v. 9, p. 283, 284, pl. 4, figs. 1–3; pl. 6, fig. 12 [references].

1932. *Camerina semiglobula* Doornink, Geol.-Mijnb. Genoot. Nederland en Kolonien Verh., p. 292–295, pl. 7, figs. 1–14; text figs. d, e.

1932. *Camerina pengaronensis* (Verbeek). Whipple, in Hoffmeister, Bernice P. Bishop Mus. Bull. 96, p. 80.

1953. *Camerina saipanensis* Cole, in Cole and Bridge, U.S. Geol. Survey Prof. Paper 253, p. 20, 21, pl. 2, figs. 7–19.

1957. *Camerina saipanensis* Cole. Cole, U.S. Geol. Survey Prof. Paper 280–I, p. 330, pl. 102, fig. 20.

1957. *Nummulites striatus* Hanzawa, Geol. Soc. America Mem. 66, p. 41, 42, pl. 1, figs. 1–3, 9–11 [not *Camerina striata* Bruguière, 1792].

1957. *Nummulites pengaronensis* (Verbeek). Hanzawa, Geol. Soc. America Mem. 66, p. 43, pl. 1, fig. 8.

1959. *Camerina pengaronensis* (Verbeek). Cole, U.S. Geol. Survey Prof. Paper 260–V, p. 753, 754, pl. 231, figs. 1–17 [imprint date 1957].

1963. *Camerina pengaronensis* (Verbeek). Cole, U.S. Geol. Survey Prof. Paper 403–E, p. E3.

As the specimens in this collection are identical with those illustrated and described from Saipan Island (Cole, in Cole and Bridge, 1953, p. 20) and Eniwetok Atoll drill hole F–1, particularly from core 13 at 4,406–4,431 feet, the specimens are illustrated, but not described.

However, certain measurements made from thin sections of these specimens are given.

Measurements of sections of Camerina pengaronensis (*Verbeek*)

	Specimen shown on pl. 3—					
	Fig. 10	Fig. 16	Fig. 11	Fig. 15	Fig. 14	Fig. 13
Height (mm)	2.6	3.0	2.45	1.85	2.5	3.45
Width (mm)	2.45	2.7				
Thickness (mm)			1.4	1.2	1.71	2.45
Embryonic chambers:						
Diameters of initial chamber (μ)	110x160	90x110		130x160		
Diameters of second chamber (μ)	70x160	80x170		80x160		
Distance across both chambers (μ)	190	180		220		200
Number of whorls	4.75	6.125				
Number of chambers in first volution	8	9				
Number of chambers in final volution	24	23				
Number of chambers in all volutions	83	108				
Surface diameter of axial plug (μ)			1,115	1,000	1,400	1,000

Occurrence elsewhere.—Saipan Island (Cole, 1957a, p. 330); Eniwetok Atoll drill hole F–1 (Cole 1957b, p. 753); Guam Island (Cole, 1963, p. E3); Viti Levu, Fiji (Cole, 1960a, p. A4); Java (Doornink, 1932, table 2, p. 306, 307); Borneo (van der Vlerk, 1929, p. 20).

Remarks.—Doornink (1932, p. 283) and Cole (1957b, p. 753) have discussed this species in detail. Sen Gupta (1965, p. 91) placed *Camerina pengaronensis* (Verbeek) in the synonymy of *Nummulites beaumonti* d'Archiac and Haime. This Lutetian species is much larger than, and internally has only a superficial resemblance to, *C. pengaronensis*—particularly in transverse sections. Because of the stratigraphic occurrence of *C. beaumonti* in the Lutetian of India, it is more logical to consider *C. beaumonti* as the ancestor of the late Eocene *C. pengaronensis* than to combine these species.

Nagappa (1959, pl. 10, fig. 5) has figured specimens from the Kopili stage, upper Eocene, Jaintia Hills, Assam, which are without question *C. pengaronensis.* His illustrations compare favorably in number of coils, size, and number of chambers with illustrations of specimens of *C. pengaronensis* from Saipan Island and Eniwetok Atoll drill hole F–1.

The data available suggest that *C. beaumonti* is not only a stratigraphically older species than *C. pengaronensis,* but also that the two species can be distinguished by differences in size, number of whorls, number of chambers, and other structures, such as the internal striated axial plug in *C. pengaronensis.*

Genus PELLATISPIRA Boussac, 1906

1906. *Pellatispira* Boussac, Soc. Géol. France Bull., 4th ser., v. 6, p. 91 [type: *P. douvillei* Boussac = *Nummulites madaraszi* Hantken, 1876].

1936. *Heterospira* Umbgrove, Leidsche Geol. Mededel., v. 8, no. 1, p. 156 [type: *Heterospira mirabilis* Umbgrove, 1936].

1937. *Biplanispira* Umbgrove, Leidsche Geol. Mededel., v. 8, no. 2, p. 309 (name substituted for *Heterospira* Umbgrove, 1936, not *Heterospira* Koken, 1896).

The structure of the test of the genus *Biplanispira* is the same as that of *Pellatispira,* except the primary revolving spire of chambers in *Biplanispira* becomes a double row of chamberlets on each side of the marginal cord (see Cole, in Cole and Bridge, 1953, pl. 6, figs. 9–19; Cole, 1957a, pl. 99, figs. 1–6, pl. 100, figs 1–3). In *Pellatispira* the primary revolving spire of chambers is continuous to the periphery of the test (pl. 1, fig. 7; Cole, 1957a, pl. 96, all figs.). Thus, in specimens of *Pellatispira* the marginal cord occupies the area between the chambers of the spire, whereas in specimens of *Biplanispira* the marginal cord is continuous and has bilaterally symmetrically arranged chamberlets on each side of it.

In certain specimens assigned to *Pellatispira* (pl. 2, figs. 20, 23; pl. 1, figs. 3, 8), the marginal cord penetrates deeply into the proximal side of some of the spiral chambers, and in a few specimens (Cole, 1957a, pl. 97, fig. 1) the marginal cord completely bisects the spiral chamber so that two chamberlets are produced. This same kind of arrangement of chamberlets and chambers is shown on the lower end of the specimen illustrated as figure 10, plate 1.

Some specimens assigned to *Biplanispira* have a sequence of small supplemental chambers at the periphery of the test (Cole, 1957a, pl. 99, fig. 2). This feature is found in specimens of *Pellatispira* (pl. 1, fig. 8, upper left side; fig. 10, top) and in specimens assigned to *Biplanispira absurda* (Umbgrove, 1938, fig. 15).

Inasmuch as the basic structures and arrangement of these structural elements in the test are so similar in specimens which have been separated previously into two genera, it seems best to consolidate these two genera. A description of the redefined genus *Pellatispira* (synonym: *Biplanispira*) follows: Test discoidal, or lenticular, often bilaterally symmetrical; embryonic chambers bilocular, large in megalospheric specimens; embryonic chambers followed by an evolute planispiral coil of median chambers in which the coils are separated from each other by an expanded marginal cord, or by an initial short coil of median chambers beyond which there are two layers of closely coiled chamberlets which are separated by an intervening sheetlike marginal cord; covering wall on each side of the median zone is composed of many pillars between which are outwardly radiating coarse canals.

Available data suggest that certain specimens which previously have been referred to *Biplanispira mirabilis* (Umbgrove) represent a valid species. However, these specimens should be referred to the redefined genus *Pellatispira*.

Biplanispira has the same geographic distribution and stratigraphic range in the Indo-Pacific region as *Pellatispira*. Although the proposed consolidation of these two genera expresses best the biologic relationship of the species, this proposal does not affect either the stratigraphic range or geographic distribution of the species, all of which would be assigned to *Pellatispira*.

In the Indo-Pacific region, three species of *Pellatispira* seemingly are valid. They are: *P. madaraszi* (Hantken), *P. hoffmeisteri* Whipple, and *P. mirabilis* (Umbgrove). A detailed analysis of *P. madaraszi* and its synonyms follows.

Pellatispira madaraszi (Hantken)[1]

Plate 1, figures 1–13; plate 2, figures 19–23

1876. *Nummulites madaraszi* Hantken, Kgl. Ungarischen Geol.-anst. Mitt. Jahrb., v. 4, p. 86, pl. 16, figs. 7a–c [imprint date 1875].
1906. *Pellatispira douvillei* Boussac, Soc. Géol. France Bull., 4th ser., v. 6, p. 91, 92, pl. 2, figs. 10–13.
1906. *Pellatispira madaraszi* (Hantken). Boussac, Soc. Géol. France Bull., 4th ser., v. 6, p. 92, 93, pl. 2, fig. 14.
1909. *Assilina madaraszi* (Hantken). Provale, Riv. Italiana Paleontologia, v. 14, p. 66–70, pl. 4, figs. 21–24; pl. 5, figs. 1–4 [imprint date 1908].
1909. *Assilina madaraszi orbitoidea* Provale, Riv. Italiana Paleontologia, v. 14, p. 71, pl. 5, fig. 5 [imprint date 1908].
1921. *Pellatispira madaraszi* von Hantken var. *provalei* Yabe, Tohoku Imp. Univ. Sci. Repts., 2d ser. (geology), v. 4, no. 4, p. 108.
1928. *Pellatispira madaraszi* von Hantken var. *provalei* Yabe. Umbgrove, Dienst Mijnb. in Nederlandsch-Indië, Nederlandsche Akad. Wetensch. Mededel., no. 10, p. 17, 18, figs. 27–33.
1928. *Pellatispira orbitoidea* (Provale). Umbgrove, Dienst Mijnb. in Nederlandsch-Indië, Nederlandsche Akad. Wetensch. Mededel., no. 10, p. 18, 19, figs. 2, 3, 5, 7, 9, 11–26, 34–41.
1928. *Pellatispira rutteni* Umbgrove, Dienst Mijnb. in Nederlandsch-Indië, Nederlandsche Akad. Wetensch. Mededel., no. 10, p. 20, 21, figs. 57–61.
1928. *Pellatispira inflata* Umbgrove, Dienst Mijnb. in Nederlandsch-Indië, Nederlandsche Akad. Wetensch. Mededel., no. 10, p. 21, figs. 42–56.
1928. *Pellatispira glabra* Umbgrove, Dienst Mijnb. in Nederlandsch-Indië, Nederlandsche Akad. Wetensch. Mededel., no.10, p. 22, figs. 62–68.
1928. *Pellatispira irregularis* Umbgrove, Dienst Mijnb. in Nederlandsch-Indië, Nederlandsche Akad. Wetensch. Mededel., no. 10, p. 23, 24, figs. 69–74.
1928. *Pellatispira crassicolumnata* Umbgrove, Dienst Mijnb. in Nederlandsch-Indië, Nederlandsche Akad. Wetensch. Mededel., no. 10, p. 24, 25, figs. 75–80.
1932. *Pellatispira rutteni* Umbgrove. Whipple, *in* Hoffmeister, Bernice P. Bishop Mus. Bull. 96, p. 81, pl. 21, fig. 6.
1941. *Pellatispira madaraszi* (Hantken) var. *indica* Rao, Mysore Univ. Jour., sec. B (sci.), v. 2, pt. 2, p. 13, 14, pl. 1, figs. 2, 5; pl. 2, fig. 3.
1941. *Pellatispira orbitoidea* (Provale). Rao, Mysore Univ. Jour., sec. B (sci.), v. 2, pt. 2, p. 14, 15, pl. 1, figs. 1, 3, 4, 6, 8; pl. 2, fig. 4.
1941. *Pellatispira inflata* Umbgrove var. *minor* Rao, Mysore Univ. Jour., sec. B (sci.), v. 2, pt. 2, p. 15, figs. 3, 7.
1947. *Pellatispira reticularis* Hanzawa, Japanese Jour. Geology and Geography, v. 20, nos. 2–4, p. 59, 60, pl. 14, figs. 1–3; pl. 15, fig. 1.
1957. *Pellatispira orbitoidea* (Provale). Cole, U.S. Geol. Survey Prof. Paper 280–I, p. 333, pl. 96, figs. 3–5, 7–9; pl. 97, figs. 1–12; pl. 99, figs. 7–11.
1957. *Pellatispira provaleae* Yabe. Cole, U.S. Geol. Survey Prof. Paper 280–I, p. 333, pl. 96, figs. 1, 2, 6; pl. 98, figs. 1–12.

An attempt will be made to demonstrate that large, distinctive specimens which previously have been identified either as *Biplanispira absurda* Umbgrove, 1938, or as *Pellatispira fulgeria* Whipple (in Hoffmeister, 1932) are aberrant specimens of *Pellatispira madaraszi* (Hantken)—or, in some cases, that they may be exceptional specimens of *Pellatispira mirabilis* (Umbgrove). For convenience, *P. madaraszi* will be discussed first, followed by an analysis of *P. fulgeria*—of which *B. absurda* is a synonym (Cole, 1957a, p. 333). Separate synonymies are given.

Remarks.—In 1908, Provale (p. 66, pl. 5, figs. 1–4) identified specimens from the upper Eocene of Borneo as *Assilina madaraszi* (Hantken), a European species. These specimens are compressed, highly ornamented, and have a distinct spiral surface depression which reflects the internal coil of median chambers. Associated with these specimens were others (Provale, 1908, pl. 5, fig. 5) which are inflated and evenly biconvex and have the surface covered by distinct papillae. Provale (1908, p. 71) designated this kind "*Assilina madaraszi* var. *orbitoidea* n. f."

[1] *Pellatispira fulgeria* Whipple (synonym: *Biplanispira absurda* Umbgrove) is considered to be an aberrant form of *Pellatispira madaraszi*. *P. fulgeria* is discussed separately after typical specimens of *P. madaraszi* are analyzed.

Yabe (1921, p. 106–108) figured specimens of *Pellatispira* from the upper Eocene of Hillsborough Island (Bonin Island) and Ishigaki-jima, Ryukyu Islands. He stated (Yabe, 1921, p. 108): "The Bornean form which Provale called *P. madaraszi* is distinguished from the type of the above named species and its variety *douvillei* by the more densely pustulated surface of the shell, and may conveniently be distinguished as *P. madaraszi* var. *provalei.*" In this same article Yabe (1921, p. 108) referred to "*Assilina*" *madaraszi* var. *orbitoidea* Provale as *Pellatispira orbitoideus* (Provale).

Umbgrove (1928) studied specimens of *Pellatispira* from Java, Borneo, and Celebes. He accepted Yabes' definition of *P. madaraszi provalei* and *P. orbitoidea* (Provale). In addition Umbgrove (1928) distinguished five new species: *P. rutteni, P. inflata, P. glabra, P. irregularis,* and *P. crassicolumnata.* Hanzawa (1947, p. 59) named specimens from Nakanai, New Britain, as *P. reticularis,* a species which Cole (in Cole and Bridge, 1953, p. 22) recognized as a synonym of *P. rutteni* Umbgrove, an opinion with which Hanzawa (1957, p. 53) later agreed.

In his initial study of the larger Foraminifera of Saipan Island, Cole (in Cole and Bridge, 1953, p. 21, 22) identified two species of *Pellatispira—P. crassicolumnata* Umbgrove and *P. rutteni* Umbgrove. As more specimens from Saipan Island became available, Cole (1957a, p. 333) revised his concept of certain species of *Pellatispira.* In addition to *P. reticularis* Hanzawa, he assigned *P. rutteni* Umbgrove and *P. inflata* Umbgrove to the synonymy of *Pellatispira orbitoidea* (Provale). Cole (1957a, p. 333) wrote: "The name *P. orbitoidea* has been given to compressed lenticular individuals. More inflated individuals have been called *P. inflata,* and larger indiv duals with an umbonate central area which is surrounded by a rim have been termed *P. rutteni.* All of these form an integrated series and are grouped together."

At the same time Cole (1957a, p. 333) recognized *P. provaleae* Yabe as a distinct species. He wrote: "*P. provaleae* differs from *P. orbitoidea* in possessing pillars of two different sizes, the larger of which project irregularly above the surface of the test." However, Cole recognized that *P. crassicolumnata* Umbgrove was a synonym of *P. provaleae* Yabe.

Thus, by 1957, eight species of *Pellatispira* had been recognized in the Indo-Pacific upper Eocene. Of these, *P. inflata, P. reticularis,* and *P. rutteni* had been assigned to the synonymy of *P. orbitoidea,* and *P. crassicolumnata* had been placed in the synonymy of *P. provaleae.*

In the matrix-free larger Foraminifera fauna from Eua, Tonga, specimens of *Pellatispira* are the most abundant element. The majority of these specimens could be identified readily as *P. orbitoidea* (Provale). Another group of specimens could be recognized as *P. provaleae* Yabe. However, specimens occurred which were intermediate in all respects between these two supposedly valid species.

The following comparison should be made between the specimens illustrated on plate 1 (this report) from Eua, Tonga, and Umbgrove's illustrations (1928).

Eua, Tonga, specimens, pl. 1, fig.—	Compare with Umbgrove's (1928) illustration, fig.—	Umbgrove's identification
1	33	*P. madaraszi provaleae.*
2	76, 78	*crassicolumnata.*
3, 4	57, 59	*rutteni.*
6	37	*orbitoidea.*
9	54, 56	*inflata.*

Comparison of Umbgrove's illustrations (1928, figs. 50–56) of *P. inflata* with his illustrations of *P. glabra* (1928, figs. 62–65) will demonstrate that these specimens are similar, particularly when one notes that the illustrations of *P. inflata* are from oriented thin sections whereas most of those of *P. glabra* are from oblique thin sections.

All the supposedly valid species have similar median sections. The differences upon which the various species have been based are observed in the external ornamentation and transverse sections. Yet, when many specimens and thin sections are examined, a completely gradational series is found in a single population. Therefore, the conclusion has been reached that only one species is represented. However, the question remains concerning the specific name which should be applied to this species.

Rao (1941) discussed and illustrated specimens of *Pellatispira* from near Surat and Broach, western India. He identified *P. orbitoidea* (Provale) and described *P. madaraszi indica* Rao and *P. inflata minor* Rao as new varieties. The specimens which Rao illustrated can be duplicated by specimens in the series from Eua, Tonga. Thus, the geographic range of this Indo-Pacific species, as defined in this report, can be extended to western India through Assam, where Nagappa (1959, pl. 11, figs. 6–12) found specimens of *Pellatispira* which he illustrated under the names *P. glabra* Umbgrove and *P. inflata* Umbgrove.

Grimsdale (1952, p. 225) reported that the European species *P. madaraszi* (Hantken) occurs in the upper Eocene of Kirkuk, Iraq. Aubouin and Neumann (1959, pl. 1, figs. 1, 2) identified specimens from Greece as *P. madaraszi indica* Rao.

Although more records would be desirable, the localities at which *Pellatispira* has been found suggest a continuous distribution of this genus in the upper Eocene from southern Europe to the central Pacific at Eniwetok Atoll (Cole, 1957b, p. 765).

Boussac (1906, p. 91) based the genus *Pellatispira* on a new species, *P. douvillei*, which he described from the Priabonian (upper Eocene) of Italy, and assigned *Nummulites madaraszi* Hantken to this new genus. Later authors (see summary by Roveda, 1961, p. 205, 206) considered that *P. douvillei* Boussac (1906) was a synonym of *P. madaraszi* (Hantken, 1876).

The illustrations of European specimens (Boussac, 1906, pl. 2, figs. 10–14; Tobler, 1929, pl. 17, figs. 1–4; Roveda, 1961, pl. 16, figs. 1–5; pl. 17, figs. 4–6) of *P. madaraszi* are similar to Indo-Pacific specimens which have been identified previously as *P. provaleae* Yabe. Detailed study has convinced me that *P. provaleae* is a synonym of *P. madaraszi* and that Provale (1908, p. 66) was correct when she assigned specimens from Borneo to the European species.

P. provaleae is without question a synonym of *P. madaraszi.* The series of specimens from Saipan Island (Cole, 1957a, p. 333) and Eua, Tonga (pl. 1, figs. 1–9), show complete gradation from the *P. madaraszi* kind (compressed, highly ornamented) to the inflated kind (*P. rutteni, P. orbitoidea,* and *P. inflata*). Although the Indo-Pacific specimens from a given locality have a variety of shapes and sizes, illustrations of the European specimens seem to indicate that only the compressed, highly ornamented kind is present.

Many specimens of *Pellatispira* from many localities on Saipan Island (Cole, 1957a, table 1) were analyzed. *P. provaleae* (based on thin, compressed specimens) was recorded from 33 localities. *P. orbitoidea* (based on inflated specimens) occurred at 23 localities—at each of which *P. provaleae* also occurred.

At most localities where abundant specimens of *Pellatispira* are present, the specimens run the gamut of shape and size, whereas at localities that have fewer specimens, there is more consistency in shape and size. This relation suggests that in an extremely favorable ecological situation maximum diversity and development occurs, whereas other situations may impose limitations on shape and size. Nevertheless, all these specimens form a continuous, gradational series and thus represent only one species, *P. madaraszi.*

One specimen (pl. 1, fig. 5) that externally resembles the "*inflata*" kind of Umbgrove is interesting in that it has "twinned" embryonic chambers. It is the first specimen of this kind encountered.

A discussion of *P. fulgeria* Whipple, 1932, a synonym of *P. madaraszi* (Hantken) (1876) follows:

Plate 1, figures 10–13

1932. *Pellatispira fulgeria* Whipple, *in* Hoffmeister, Bernice P. Bishop Mus. Bull. 96, p. 82, figs. 2, 3, 5–7.

1938. *Biplanispira absurda* Umbgrove, Leidsche Geol. Mededel., v. 10, p. 82–89, figs. 1–17.

1957. *Biplanispira fulgeria* (Whipple). Cole, U.S. Geol. Survey Prof. Paper 280–I, p. 333, pl. 98, figs. 13–18.

1960. *Biplanispira fulgeria* (Whipple). Cole, U.S. Geol. Survey Prof. Paper 374–A, p. A5, pl. 1, fig. 2; pl. 2, fig. 3.

Certain distinctive specimens (pl. 1, figs. 11–13) have long been considered to represent a valid and easily recognized species. Umbgrove (1938) described similar specimens from the Eocene of Borneo as *Biplanispira absurda.* Earlier, Whipple (*in* Hoffmeister, 1932, p. 82 pl. 20, figs. 2, 3, 5–7) had named similar specimens from, Eua, Tonga, *Pellatispira fulgeria.* Although Umbgrove (1938, p. 83) was familiar with Whipple's work, he did not correlate his specimens with the species named by Whipple. Cole (1957a, p. 333) wrote: "Comparison of Umbgrove's illustrations of *B. absurda* with those given by Whipple of *P. fulgeria* indicates that only one species is represented."

All these assignments may be incorrect in view of the data which have accumulated since that time. Specimens of this kind may represent aberrant forms of *P. mirabilis* (Umbgrove) and *P. madaraszi* (Hantken), which resemble each other.

Umbgrove (1938, p. 84) listed the species which occurred with the type specimens of *B. absurda.* The lists include several species of *Pellatispira* as recognized by Umbgrove at that time, but he did not record "*Biplanispira*" *mirabilis* in these samples. It is significant that Umbgrove (1938, p. 89) suggested that "* * * a few sections of foraminifera, which I described formerly, in 1928, as *Pellatispira crassicolumnata,* belong to the present species [*B. absurda*]."

Whipple (in Hoffmeister, 1932, table 5) found *P. fulgeria* at three localities on Eua, Tonga. Although Whipple found specimens of *P.* "*rutteni*" and *P. hoffmeisteri* Whipple at several localities, he did not record or illustrate any specimens which might be identified as "*Biplanispira*" *mirabilis.*

The present collection from Eua, Tonga, contains abundant specimens of *Pellatispira* and about seven specimens that are identical with those identified by Whipple as *Pellatispira fulgeria.* These large, compressed, strongly papillate specimens having an inflated periphery are recognized readily, even before they are sectioned.

One specimen (pl. 1, fig. 10) selected for sectioning appeared externally to be a rather large specimen of *P. madaraszi.* However, the transverse thin section of this specimen has internal structures which resemble both *P. madaraszi* and *P. fulgeria.* The central area resembles that of typical specimens of *P. madaraszi* (compare this area of fig. 10, pl. 1, with the specimens illustrated as figs. 2 and 4 of pl. 1). The peripheral zone of this specimen, however, is similar to that of *P. fulgeria* and

"*Biplanispira*" *absurda* (see Umbgrove, 1938, figs. 14, 15).

The central area of *P. fulgeria* (pl. 1, fig. 13) resembles that of *P. madaraszi* (pl. 1, fig. 7), but beyond this central area in *P. fulgeria,* the marginal cord is wide, and secondary chamberlets develop on each side of the marginal cord. In *P. madaraszi* (pl. 1, fig. 7), the primary coil of chambers extends to the periphery, and secondary chamberlets are developed only rarely.

The available data suggest that typical specimens of *P. madaraszi* can be interconnected with typical specimens of *P. fulgeria* through such specimens as the one illustrated as figure 10, plate 1. It should be emphasized that these specimens of *P. fulgeria* from Eua, Tonga, are associated with abundant specimens of *P. madaraszi,* and the specimens of "*Biplanispira*" *absurda* from Borneo are likewise associated with specimens of *P. madaraszi.* "*Biplanispira*" *mirabilis* was not recorded from the type locality of *P. fulgeria* or of *B. absurda.*

Even if the suggestion that *P. fulgeria* is a synonym of *P. madaraszi* is not accepted, it should be obvious from the similarities in structures and from association that *B. absurda* is a synonym of *P. fulgeria.* Moreover, these specimens represent *Pellatispira.* Umbgrove (1938) incorrectly assigned *B. absurda* to *Biplanispira* because of the secondary chamberlets which develop.

The problem remains concerning the possibility that *P. mirabilis* may develop an aberrant form which resembles the one developed by *P. madaraszi.* Cole (1957b, p. 765; table 4, p. 749) reported the occurrence of *P. fulgeria* (rare) in association with abundant specimens of *P. mirabilis* in core 11 of Eniwetok Atoll drill hole F–1. *P. madaraszi* was not found in this core.

Cole (1957a, table 1, p. 322) found specimens identified as "*Biplanispira*" *fulgeria* at 23 localities on Saipan Island. These specimens were associated at 15 localities with "*B.*" *mirabilis,* and at 10 of these 23 localities *P. madaraszi* occurred. "*Biplanispira*" *fulgeria* and "*Biplanispira*" *mirabilis,* without any specimens of *Pellatispira,* were found at nine localities. At one locality in the upper Eocene of Viti Levu, Fiji, Cole (1960a, p. A3) found "*Biplanispira*" *mirabilis* (common) associated with rare specimens of "*Biplanispira*" *fulgeria.*

These data prove that "*Biplanispira*" *mirabilis* and *Pellatispira madaraszi* occur together, and specimens identified as *P. fulgeria* and "*Biplanispira*" *absurda* occur in association with either one or both of these species.

The structure of the test of "*Biplanispira*" *mirabilis* is essentially the same as that of *Pellatispira madaraszi.* The major difference is that *Pellatispira madaraszi* has a coil of primary chambers (pl. 1, fig. 7) which is continuous to the periphery of the test. In *Biplanispira mirabilis* there is a short coil of primary chambers around the embryonic chambers after which two coils of chamberlets develop, one on either side of a central fibrous zone (marginal cord) (Cole, in Cole and Bridge, 1953, pl. 6, figs. 9–19). Thus, aberrant growth in either *P. madaraszi* or "*Biplanispira*" *mirabilis* would result in specimens which would be so identical in internal structure that they could not be separated specifically.

It is entirely possible that continued analysis of these forms will demonstrate that specimens assigned here to *P. mirabilis* can be intergrated into the *P. madaraszi* series. Certainly, there is evidence that the *fulgeria* kind of specimen can develop either in the *P. madaraszi* or the *P. mirabilis* series.

Genus **HETEROSTEGINA** d'Orbigny, 1826

Heterostegina saipanensis Cole

Plate 2, figure 15; plate 3, figures 4–6, 8, 9, 12

1953. *Heterostegina saipanensis* Cole, *in* Cole and Bridge, U.S. Geol. Survey Prof. Paper 253, p. 23, 24, pl. 2, figs. 4, 6.
1957. *Heterostegina saipanensis* Cole. Cole, U.S. Geol. Survey Prof. Paper 280–I, p. 331, pl. 102, figs. 17–19.
1959. *Heterostegina saipanensis* Cole. Cole, U.S. Geol. Survey Prof. Paper 260–V, p. 760–762, pl. 234, figs. 13–24; pl. 235, figs. 1–13 [imprint date 1957].

Measurements of certain critical structures from thin sections of this species are given.

Measurements of sections of Heterostegina saipanensis *Cole*

	Specimens shown on pl. 3—				
	Fig. 9	Fig. 12	Fig. 6	Fig. 4	Fig. 5
Height ... mm	2.7	3.5	4.0	3.3	3.87
Width ... mm	2.1	3 2	2.7		
Thickness ... mm				1.0	1.0
Embryonic chambers:					
Diameters of initial chamber ... μ	80x70	70x70	70x70	90x95	
Diameters of second chamber ... μ	30x150	40x120	40x120	30x70	
Distance across both chambers ... μ	120	120	130	130	
Number of operculine chambers	2	1	1		
Number of whorls	2.5	2.5	3		
Surface diameter of axial plug ... μ				450	400

Remarks.—Whipple (in Hoffmeister, 1932, p. 83, pl. 20 fig. 9) illustrated the central part of a *Heterostegina* without identifying this specimen as to species. Cole (in Cole and Bridge, 1953, p. 24), in naming specimens from Saipan Island as *Heterostegina saipanensis,* wrote: "The median section resembles one illustrated by Whipple (1932, p. 83, pl. 20, fig. 9) from the Eocene of Eua, Tonga." Study of the specimens in the present collection proves that the specimens in the upper Eocene of Eua, Tonga, are indeed the same as the Saipan Island specimens.

Genus SPIROCLYPEUS Douvillé, 1905

Spiroclypeus vermicularis Tan

Plate 2, figures 6–12

1937. *Spiroclypeus vermicularis* Tan, De Ingenieur in Nederlandsche-Indië—IV Mijnb. en Geol., v. 4, no. 10, p. 187–190, pl. 1, figs. 7, 8; pl. 2, figs. 6–10; pl. 3, figs. 13–23; pl. 4, figs. 11–18.
1953. *Spiroclypeus* sp. Cole, U.S. Geol. Survey Prof. Paper 253, p. 18, pl. 14, fig. 7.
1957. *Spiroclypeus vermicularis* Tan. Cole, U.S. Geol. Survey Prof. Paper 280–I, p. 333, pl. 102, figs. 12–14.
1957. *Spiroclypeus vermicularis* Tan. Cole, U.S. Geol. Survey Prof. Paper 260–V, p. 764, pl. 238, figs. 1–6, 8–10, 11, 12.
1960. *Spiroclypeus vermicularis* Tan. Cole, U.S. Geol. Survey Prof. Paper 374–A, p. A4, A5, pl. 1, figs. 10–14.
1963. *Spiroclypeus vermicularis* Tan. Cole, U.S. Geol. Survey Prof. Paper 403–E, p. E3, E11.
1965. *Spiroclypeus vermicularis* Tan. Adams, Geol. Soc. London Quart. Jour., v. 121, p. 295, pl. 23, figs. *u–w*, *aa*.

The test is small and has an eccentric evenly biconvex umbonal area which is bordered particularly on the distal margin by a thin flat rim. Some specimens have prominent umbonal bosses (pl. 2, fig. 6) and small papillae scattered over the remainder of the umbonal area. Other specimens lack the umbonal bosses but have small papillae over the entire umbonal area.

Measurements of the internal features follow.

Measurements of sections of Spiroclypeus vermicularis *Tan*

	Specimen shown on pl. 2—						
	Fig. 10	Fig. 11	Fig. 12	Fig. 8	Fig. 7	Fig. 6	Fig. 9
Height mm	2.2	2.4	2.8	2.4	1.45	2.85	2.0
Width mm	2.1	2.1	2.3				
Thickness mm				.65	.62	1.0	.7
Embryonic chambers:							
Diameters of initial chamber μ	130x140	110x100	110x120				100x120
Diameters of second chamber μ	60x160	70x180	70x190				70x80
Distance across both chambers μ	220	200	200	130			200
Number of operculine chambers	1	1	1				
Number of volutions	2	2.125	2.5				
Lateral chambers:							
Length μ				50	30–100	50–120	50–160
Height μ				10	10	10–20	10
Number on each side of center				3	4	4	4
Thickness of spiral sheet μ				50	40–60	30–100	50–60
Diameter of pillars μ				50–200	30–100	100–350	60–120

Remarks.—Although *Spiroclypeus vermicularis* n external view resembles certain specimens of *Heterostegina saipanenis* Cole, the two species can normally be separated by the numerous small papillae on the surface of *S. vermicularis* and the absence of these on the surface of *H. saipanensis.*

The types are from Tertiary *b* (upper Eocene) sediments at Koetai, East Borneo. This species is widely distributed in the Indo-Pacific area; it has been reported from Saipan Island, Guam Island, Eniwetok Atoll drill hole F–1, Viti Levu, Fiji, and Sarawak.

The material from Eua, Tonga, contained only a few specimens of this species. Although these specimens are typical, they are small. The infrequent occurrence and the small size of the specimens suggests that the ecological situation was not optimum for their development.

Family DISCOCYCLINIDAE
Genus DISCOCYCLINA Gümbel, 1870
Subgenus DISCOCYCLINA Gümbel, 1870

Discocyclina (Discocyclina) sp.

Plate 2, figure 18

Remarks.—The specimen illustrated as figure 18, plate 2, has a diameter of 1.3 mm and so far as could be ascertained seems to be a representative of the genus *Discocyclina s. s.* This was the only specimen of this kind found.

The embryonic chambers are unusual as there are three nearly globular, concentric chambers. The innermost chamber has an internal diameter of about 100 μ and a wall about 10 μ thick. This inner chamber is encircled by a slightly larger chamber that has a slightly thicker wall. The distance between these two chambers is about 10 μ. These two chambers are enclosed by a larger chamber that has an internal diameter of about 200 μ and a wall about 20 μ thick. The distance between the outermost chamber wall and the outer wall of the middle chamber is about 30 μ. This interval appears to be subdivided into small rectangular chambers.

The equatorial chambers are arranged around the embryonic chambers in fairly regular concentric rows. These chambers are either rectangular or faintly hexagonal in shape.

The development of the embryonic apparatus indicates that this is an abnormal specimen. Generally it is impossible even with a single normal specimen to identify such a specimen specifically.

Genus ASTEROCYCLINA Gümbel, 1870

Three species of *Asterocyclina* are recognized. These species are readily recognized in equatorial section by the marked differences in the embryonic apparatuses (pl. 2, figs. 13, 24, 25) and in vertical section by the arrangement of the lateral chambers. Although many specimens were sectioned, it is impossible to arrange these specimens in a continuous gradational series as could be done with the variable sequence of specimens assigned to *Pellatispira madaraszi* (Hantken).

Asterocyclina matanzensis Cole

Plate 2, figures 14, 24; plate 3, figures 1–3, 7; plate 4, figures 2–4, 6, 8–10, 12

1932. *Discocyclina* (*Asterocyclina*) *stellata* (d'Archiac). Whipple, *in* Hoffmeister, Bernice P. Bishop Mus. Bull. 96, p. 84, 85, pl. 21, figs. 1, 2; pl. 22, figs. 6, 7 (not *Calcarina stellata* d'Archiac, 1846).
1957. *Asterocyclina matanzensis* Cole, U.S. Geol. Survey Prof. Paper 280–I, p. 350, pl. 117, figs. 6–10; pl. 118, figs. 9–18.
1959. *Asterocyclina matanzensis* Cole. Cole, U.S. Geol. Survey Prof. Paper 260–V, p. 777, 778, pl. 249, figs. 1–17 [imprint date 1957].
1960. *Asterocyclina matanzensis* Cole. Cole, U.S. Geol. Survey Prof. Paper 374–A, p. A6, pl. 1, figs. 4–9.
1963. *Asterocyclina matanzensis* Cole. Cole, U.S. Geol. Survey Prof. Paper 403–E, p. E3.
1965. *Asterocyclina matanzensis* Cole. Samanta, Cushman Found. Foram. Research Contr., v. 16. pt. 1, p. 23–25, pl. 1, figs. 1–12.
1967. *Asterocyclina matanzensis* Cole. Cole, Bulls. Am. Paleontology, v. 52, no. 233, p. 9, pl. 1, fig. 17; pl. 2, fig. 7.

External views of two specimens are illustrated (pl. 4, figs. 3, 4). The specimen illustrated as figure 4, plate 4, is similar to the specimens illustrated by Whipple (in Hoffmeister, 1932, pl. 21, figs. 2, 3). Whipple's specimens have diameters slightly over 3 mm. This specimen (pl. 4, fig. 4) has a diameter of about 3.2 mm and an unbonate area having a diameter of about 2.0 mm. One specimen (pl. 4, fig. 3) has long slender tapering rays, the longest of which is 1.7 mm, extending from a nearly globular central area that has a diameter of about 1.9 mm. A more general description of the shape of the test follows.

The test is composed of an umbonal area which may be nearly globular (pl. 3, fig. 2) and surrounded by a narrow rim or by long slender rays (pl. 4, fig. 3). Other specimens (pl. 4, figs. 4, 9) have a more compressed umbonal area which merges into four or five wide compressed rays. The umbonal area and the rays in most of the specimens are covered by small papillae.

The embryonic apparatus consists of a nearly circular initial chamber which is slightly embraced by the larger second chamber (pl. 3, fig. 1, 3; pl. 4, figs. 8, 10, 12). Two distinct periembryonic chambers are located at each end of the dividing wall between the embryonic chambers. The two periembryonic chambers are separated from each other by two or more normal equatorial chambers which border the initial embryonic chamber between the principal embryonic chambers. The second embryonic chamber has on its margin three to five or more, distinct periembryonic chambers which are only slightly smaller than the two principal embryonic chambers (pl. 4, fig. 10). Certain of these periembryonic chambers are in contact; others are separated by one or more normal equatorial chambers.

Measurements of equatorial sections follow.

Measurements of equatorial sections of Asterocyclina matanzensis *Cole*

	Specimen shown on—			
	Pl. 3		Pl. 4	
	Fig. 1	Fig. 3	Fig. 8	Fig. 12
Diameter mm	3.75	2.85	2.3	3.6
Embryonic chambers:				
Diameters of initial chamber μ	90x100	80x100	90x110	100x130
Diameters of second chamber μ	100x190	90x185	90x200	120x210
Distance across both chambers μ	200	190	200	230
Thickness of outer wall μ	10	8	10	10
Equatorial chambers:				
In rays:				
Radial diameter μ	30–60	30–50	30–40	30–50
Tangential diameter μ	25–30	20–30	10–20	20–30
In interrays:				
Radial diameter μ	25–30	30–50	20–30	20–30
Tangential diameter μ	20–25	15–20	10–20	15–20

The lateral chambers are arranged in regular tiers. The openings of the lateral chambers are low, and the thickness of the intervening floors and roofs is about equal to the height of the lateral chamber cavity. Slender pillars are irregularly scattered throughout the umbonate part of vertical sections.

Measurements of vertical sections follow.

Measurements of vertical sections of Asterocyclina matanzensis *Cole*

	Specimen shown on—				
	Pl. 3		Pl. 4		
	Fig. 2	Fig. 7	Fig. 2	Fig. 9	Fig. 6
Diameter of umbo mm	1.6	2.25	1.3	1.3	2.85
Width of rim or rays mm	.5	-------	.35	.5	-------
Thickness mm	2.0	1.14	.65	.75	1.5
Embryonic chambers:					
Length μ	90	170	130	120	80
Height μ	80	90	50	80	60
Thickness of outer wall μ	10	10	10	10	15
Equatorial layer:					
Height at center μ	30	40	40	30	30
Height at periphery μ	50	80	30	90	50
Lateral chambers:					
Number	37	25	14	14	36
Length μ	40–100	60–80	50–70	40–60	70–80
Height μ	10–20	10–15	10	10	10
Thickness of roofs and floors μ	10	10	10	10	10
Surface diameter of pillars μ	40–100	60–90	50	30–50	50

Occurrence elsewhere.—Saipan Island (Cole, 1957a, p. 350); Eniwetok Atoll drill holes (Cole, 1957b, p. 777); Guam Island (Cole, 1963, p. E3); Viti Levu, Fiji (Cole, 1960a, p. A6); Assam (Samanta, 1965, p. 23).

Remarks.—Whipple (in Hoffmeister, 1932, p. 84) assigned similar specimens from Eua, Tonga, to *Discocyclina* (*Asterocyclina*) *stellata* (d'Archiac). The illustrations, measurements, and description given by Whipple demonstrate conclusively that the specimens he identified as *Asterocyclina stellata* are the same as those which are identified here as *A. matanzensis.*

Concerning certain specimens Whipple (in Hoffmeister, 1932, p. 85) wrote: "At the proximal end of each ray there are two or three elongate equatorial chambers, this number increases toward the periphery producing a fan-like arrangement of the chambers within the ray." This unusual arrangement is shown excellently in the specimen illustrated as figure 6, plate 4. This same phenomenon is found in certain specimens (Cole, 1957a, pl. 118, fig. 17) from Saipan Island, the type locality of *A. matanzensis.*

Cole (1967, p. 9) stated previously that *A. matanzensis* has a "general resemblence" to *A. stellata* (d'Archiac) (Neumann, 1958, pl. 30, figs. 1–7) from the Lutetian and Bartonian of France. The lateral chambers of *A. stellata* have more open cavities than do those of *A. matanzensis*, and the ring of periembryonic chambers on the border of the second embryonic chamber in *A. stellata* is more complete and has more chambers than in *A. matanzensis.*

Relatively few adequate photographs of thin sections of *A. stellata* have been published. As additional illustrations become available, it may be possible to demonstrate satisfactorily that *A. matanzensis* is a junior synonym of *A. stellata* (d'Archiac). For the present, *A. matanzensis* is retained as a valid species, closely related to *A. stellata.*

Asterocyclina penuria Cole

Plate 2, figures 16, 17, 25; plate 4, figures 1, 5, 7, 11, 13, 14

1957. *Asterocyclina penuria* Cole, U.S. Geol. Survey Prof. Paper 280–I, p. 350, 351, pl. 116, figs. 1–10 [references and discussion]. [Nom. nov. for *Orthophragmina pentagonalis* Deprat, 1905, preoccupied by *Asterodiscus pentagonalis* Schäfhault, 1863.]
1957. *Discocyclina* (*Discocyclina*) *dispansa* Hanzawa, not *Lycophris dispansus* Sowerby, 1840, Geol. Soc. America Mem. 66, p. 83, 84, pl. 13, figs. 1, 3, 4; pl. 14, figs. 2, 3, 8, 9.
1958. *Asterodiscus cuvillieri* Neumann, Soc. Géol. France Mém. 83 (new ser.), v. 37, pt. 2–3, p. 119–121, pl. 21, figs. 1–8; pl. 32, fig. 5; text fig. 40.
1959. *Asterocyclina penuria* Cole. Cole, U.S. Geol. Survey Prof. Paper 260–V, p. 778–780, pl. 246, figs. 1–11; pl. 247, figs. 1–15; pl. 248, figs. 8, 12–17 [imprint date 1957].
1959. *Asterocyclina penuria* Cole. Cole, Cushman Found. Foram. Research Contr., v. 10, pt. 1, p. 12–14, pl. 1, figs. 1–4, 6–11; pl. 2, figs. 1–9; pl. 3, figs. 1–4.
1963. *Asterocyclina penuria* Cole. Cole, U.S. Geol. Survey Prof. Paper 403–E, p. E3.

The test has diameters of 2.3 to 7.0 mm and thicknesses of 1.2 to 2.7 mm. Specimens are usually strongly umbonate (pl. 4, figs. 5, 13), and the inflated central area is bordered by a narrow flange. Other specimens (pl. 4, fig. 11) are compressed and lenticular. The central area does not show any rays. If rays are present, they are weakly developed on the bordering rim. Thus, it is often impossible to recognize that specimens are *Asterocyclina* until they are sectioned.

The embryonic apparatus consists of two large embryonic chambers in which the larger second chamber slightly embraces the initial chamber. The embryonic chambers are surrounded completely by large periembryonic chambers. The initial embryonic chamber is bordered by two elongate periembryonic chambers (pl. 4, figs. 7, 14; pl. 2, figs. 16, 25). In some specimens (pl. 4, fig. 14) the second embryonic chamber is surrounded by a ring of about nine rudely rectangular chambers. Other specimens (pl. 2, fig. 25) have the second embryonic chamber bounded by two periembryonic chambers which are similar to those bordering the initial embryonic chamber.

Measurements of equatorial sections follow.

Measurements of equatorial sections of Asterocyclina penuria *Cole*

	Specimen shown on				
	Pl. 4			Pl. 2	
	Fig. 1	Fig. 7	Fig. 14	Fig. 25	Fig. 16
Diameter mm	4.8	6.95	4.2	5.2	2.3
Embryonic chambers:					
Diameters of initial chamber μ	230x300	200x350	240x340	200x300	230x300
Diameters of second chamber μ	180x440	230x470	220x500	180x390	200x420
Distance across both chambers μ	430	450	470	390	430
Thickness of outer wall μ	10	10	10	10	10
Equatorial chambers:					
In rays:					
Radial diameter μ	40–100	60–100	80–120	40–80	60–100
Tangential diameter μ	20–30	20–40	15–20	20	30–40
In interrays:					
Radial diameter μ	30–40	40–60	40–50	60–100	30–50
Tangential diameter μ	20–30	20–30	20–30	20	20–35

Normally, there are four rays developed in which the equatorial chambers are radially elongate. These rays are distinct in the zone adjacent to the embryonic apparatus but commonly are less distinct in the peripheral zone.

The lateral chambers are abundant, arranged in regular tiers, and have low openings between rather thick floors and roofs. Distinct pillars are irregularly scattered throughout the vertical sections, the greatest concentration being in the umbonal area.

Measurements of vertical sections follow.

Measurements of vertical sections of Asterocyclina penuria *Cole*

	Specimen shown on pl. 4—		
	Fig. 5	Fig. 11	Fig. 13
Diameter mm	4.45	3.5+	4.85+
Thickness mm	2.7	1.37	2.57
Embryonic chambers:			
Length μ	360	440	450
Height μ	260	250	260
Thickness of outer wall μ	10	10	10
Equatorial layer:			
Height at center μ	50	60	80
Height at periphery μ	30	70	80
Lateral chambers:			
Number	31	19	38
Length μ	100–140	80–100	100–140
Height μ	20–30	10–20	10–20
Thickness of floors and roofs μ	15–20	20	10–20
Surface diameter of thickened areas between the lateral chambers μ	70–150	150–200	50–180

Occurrence elsewhere.—New Caledonia (Deprat, 1905, p. 507); Soemba (Caudri, 1934, p. 97); Saipan Island (Cole, 1957a, p. 350); Eniwetok Atoll drill hole (Cole, 1957b, p. 778); Guam (Cole, 1963, p. E3); seamount near Tuamotu Islands (Cole, 1959, p. 12); France (Neumann, 1958, p. 119, as *Asterodiscus cuvillieri*); Greece (Aubouin and Neumann, 1959, p. 48, as *Asterodiscus cuvillieri*).

Remarks.—This species is characterized by its distinctive embryonic apparatus and by the abundant, long, appressed lateral chambers arranged in regular tiers between irregularly scattered, pronounced pillars.

This species was described by Deprat (1905, p. 507) as *Orthophragmina pentagonalis* and was based upon specimens from New Caledonia. As the specific name *O. pentagonalis* had been used by Schäfhault in 1863 for a different European species, Cole (1957a, p. 350) proposed the specific name *Asterocyclina penuria.*

Caudri (1934, p. 97) identified specimens from Soemba, which are without question *A. penuria,* as *A.* aff. *pentagonalis* Deprat. Van der Weijden (1940, p. 38) assigned European specimens from the upper Lutetian and Auversian to *Discocyclina* (*Isodiscodina*) *pentagonalis* (Deprat).

Neumann (1958, p. 119) described *Asterodiscus cuvillieri* as a new species from the upper Lutetian, Auversian, and Bartonian of Europe. She included in this new species the European specimens which van der Weijden had assigned to *Asterocyclina pentagonalis* (Deprat) (= *A. penuria* Cole). Later, Aubouin and Neumann (1959, p. 48) identified specimens from the upper Eocene and the upper Lutetian of Greece as *Asterodiscus cuvillieri* Neumann (= *Asterocyclina penuria* Cole).

The European specimens to which Neumann (1958) assigned the name *Asterodiscus cuvillieri* are identical externally and internally to the Indo-Pacific specimens which Cole (1957a) named *Asterocyclina penuria*; thus, *Asterodiscus cuvillieri* is a junior synonym of *Asterocyclina penuria.*

Whipple (in Hoffmeister, 1932, p. 84, pl. 22, figs. 1, 2) briefly discussed and illustrated specimens from several stations in Eua, Tonga, as *Discocyclina* (*Discocyclina*) sp. His equatorial section (1932, pl. 22, fig. 1) shows rays of the kind which are characteristic of *Asterocyclina penuria,* and his vertical section (1932, pl. 22, fig. 2) has abundant aligned lateral chambers between irregularly developed pillars similar to those of *A. penuria.* Unfortunately, the embryonic chambers in these illustrations do not show. However, the other internal stuctures are so similar to those of *A. penuria* that one may correlate Whipple's *Discocyclina* (*Discocyclina*) sp. with *A. penuria.*

Asterocyclina praecipua Cole

Plate 2, figure 13; plate 5, figures 1–21

1959. *Asterocyclina praecipua* Cole, U.S. Geol. Survey Prof. Paper 260–V, p. 780, pl. 245, figs. 11, 12, 16, 18–20 [imprint date 1957].

1963. *Asterocyclina praecipua* Cole. Cole, U.S. Geol. Survey Prof. Paper 403–E, p. E24, pl. 9, figs. 12, 13, 18.

Three external shapes are exhibited by specimens assigned to this species. Certain specimens are subcircular and have low rays, which are observed only on the margin of the test. In equatorial sections, such specimens normally possess five rays (pl. 5, fig. 20), and in vertical section (pl. 5, figs. 4, 21), the tests are compressed lenticular. Other specimens (pl. 5, figs. 11, 19) are quadrate and have four short, bluntly rounded rays. These specimens in vertical section (pl. 5, figs. 1, 2, 12, 13) are inflated and lenticular. Specimens of another group have four elongate rays (pl. 5, figs. 5, 9). In vertical section (pl. 5, figs. 6–8), a small infated umbonal area, from which the elongate rays project, is observed. The surface of all these specimens is covered by small distinct papillae.

The small bilocular embryonic chambers in many of these specimens were destroyed. However, several satisfactory sections (pl. 5, figs. 17, 18) were obtained. The periembryonic chambers are small and abundant and form a complete encircling ring around the embryonic chambers.

Measurements of some equatorial sections follow.

Measurements of equatorial sections of Asterocyclina praecipua *Cole*

	Specimen shown on pl. 5—				
	Fig. 19	Fig. 20	Fig. 11	Fig. 9	Fig. 5
Diameter mm	2.1	1.6	1.75	3.65+	2.6
Embryonic chambers:					
Diameters of initial chamber μ	60x100	55x70			
Diameters of second chamber μ	70x120	40x90			
Distance across both chambers μ	140	100	130	110	100
Thickness of outer wall μ	5	5		5	5
Equatorial chambers:					
In interray areas:					
Radial diameter μ	15–40	20–40	20–30	30–40	20–40
Tangential diameter μ	15–20	20	20–40	20	20
In rays:					
Radial diameter μ	50–65	50	40–100	100–120	40–100
Tangential diameter μ	20–25	20	20–30	20–30	10–20

The lateral chambers are somewhat regularly aligned in tiers. The floors and roofs of these chambers are about equal in thickness to the chamber cavity. Heavy distinct pillars are irregularly scattered throughout the vertical sections. Measurements of some vertical sections follow.

Measurements of vertical sections of Asterocyclina praecipua *Cole*

	Specimen shown on pl. 5—					
	Fig. 1	Fig. 13	Fig. 12	Fig. 7	Fig. 8	Fig. 21
Diameter ... mm	1.7	1.8+	1.9+	4.45	2.9+	1.67
Thickness ... mm	.75	.9	1.0	.85	.8	.45
Embryonic chambers:						
Length ... μ	140	110	150	90+	-------	90+
Height ... μ	90	90	110	40+	-------	80
Thickness of outer wall ... μ	10	8	5	-------	-------	5
Equatorial layer:						
Height at center ... μ	30	25	40	20	30	15
Height at periphery ... μ	40	100	50	80	60	30
Lateral chambers:						
Number	17	18	18	22	17	10
Length ... μ	50–70	60–80	50–70	60–70	40–60	40–70
Height ... μ	10–20	10	10	10	10	10
Thickness of floors and roofs ... μ	10–20	10	10	10	10	10
Surface diameter of pillars ... μ	100–180	50–100	80–100	40–100	60–120	50–100

Remarks.—The types are from Eniwetok Atoll drill hole F–1 in core 12 (4,316–4,341 ft). This species is characterized by the small bilocular embryonic chambers, the thick roofs and floors of the lateral chambers, and the many heavy pillars. Specimens in the collection from Eua, Tonga, have a greater diversity of external shape than the types, but the internal structures of all these specimens are similar.

A few microspheric specimens (pl. 5, figs. 10, 15, 16) were found. These specimens closely resemble microspheric specimens from Guam (Cole, 1963, pl. 9, fig. 18), which were assigned to this species.

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PLATES 1–5

PLATE 1

FIGURES 1–13. *Pellatispira madaraszi* (Hantken) (p. B6).

1–6, 8–12. Transverse sections.

1. Thin, compressed specimen; compare with figure 13, plate 2 of Boussac (1906); × 20; USNM 651045.
2. Specimen having slightly inflated umbonal area and large pillars; × 20; USNM 651046.

3, 4. Specimens having strongly inflated central areas; "*P. rutteni*" kind; compare with figures 57 and 59 of Umbgrove (1928); × 20; USNM 651047, 651048.

5. Highly inflated specimen having two sets of embryonic chambers; × 20; USNM 651049.
6. Evenly biconvex specimen; "*P. orbitoidea*" kind; compare with figure 36–38 of Umbgrove (1928); × 20; USNM 651050.
8. Compressed, lenticular specimen, intermediate in shape between figures 1 and 2, this plate; × 20; USNM 651052.
9. Subglobular specimen; "*P. inflata*" kind; compare with figures 54 and 56 of Umbgrove (1928); × 20; USNM 651053.
10. Specimen which has internal structures of both *Pellatispira madaraszi* (central area) and "*P. fulgeria*" (top and bottom); × 20; USNM 651054.
11. Typical "*P. fulgeria*"; compare with figure 5, plate 20, of Whipple, in Hoffmeister, 1932, and with *Biplanispira absurda*, figures 2–15, of Umbgrove (1938); × 20; USNM 651055.
12. Slightly thicker and larger specimen than figure 11, this plate; × 12.5; USNM 651056.

7, 13. Median sections.

7. Typical median section; × 20; USNM 651051.
13. Median section of the "*P. fulgeria*" kind; note the expanded marginal cord and the development of secondary chamberlets beyond the zone of the primary spiral; × 12.5; USNM 651057.

PELLATISPIRA

PLATE 2

FIGURES 1–5. *Camerina pacifica* (Whipple) (p. B3).

1, 2. Median sections, centered, × 20, of megalospheric specimens; USNM 651058, 651059.

3. Median section, not centered, × 20, of a megalospheric specimen; USNM 651060.

4. Median section, centered, × 20, of a microspheric specimen; USNM 651061.

5. Transverse section, × 20, of a megalospheric specimen; USNM 651062.

6–12. *Spiroclypeus vermicularis* Tan (p. B10).

6. Transverse section, × 20, of a probable microspheric specimen; USNM 651063.

7–9. Transverse sections, × 20, of megalospheric specimens; USNM 651064–651066.

10, 12. Median sections, × 20, of megalospheric specimens; USNM 651067, 651069.

11. Part of a median section, × 40, of a megalospheric specimen to illustrate the embryonic chambers; USNM 651068.

13. *Asterocyclina praecipua* Cole (p. B13).

Central part of an equatorial section, × 40, of a megalospheric specimen for comparison of the embryonic apparatus with those of *A. matanzensis* (fig. 24, this plate) and *A. penuria* (fig. 25, this plate); see figure 18, plate 5, for enlargement; USNM 651070.

14, 24. *Asterocyclina matanzensis* Cole (p. B11).

14. Transverse section, × 20; USNM 651071.

24. Part of an equatorial section, × 40, of a megalospheric specimen; see explanation of figure 13, this plate; USNM 651081.

15. *Heterostegina saipanensis* Cole (p. B9).

Transverse section, × 20; introduced for comparison with similar sections of *Spiroclypeus vermicularis*, figures 7–9, this plate; USNM 651072.

16, 17, 25. *Asterocyclina penuria* Cole (p. B12).

16. Equatorial section, × 20, of a small specimen similar in size and external appearance to certain specimens of *A. matanzensis*; USNM 651073.

17. Vertical section, × 20, of a companion specimen to figure 16; USNM 651074.

25. Part of an equatorial section, × 40, of a megalospheric specimen; see explanation of figure 13, this plate; USNM 651082.

18. *Discocyclina* (*Discocyclina*) sp. (p. B10)

Part of an equatorial section, × 40, to illustrate the embryonic apparatus and equatorial chambers; USNM 651075.

19–23. *Pellatispira madaraszi* (Hantken) (p. B6).

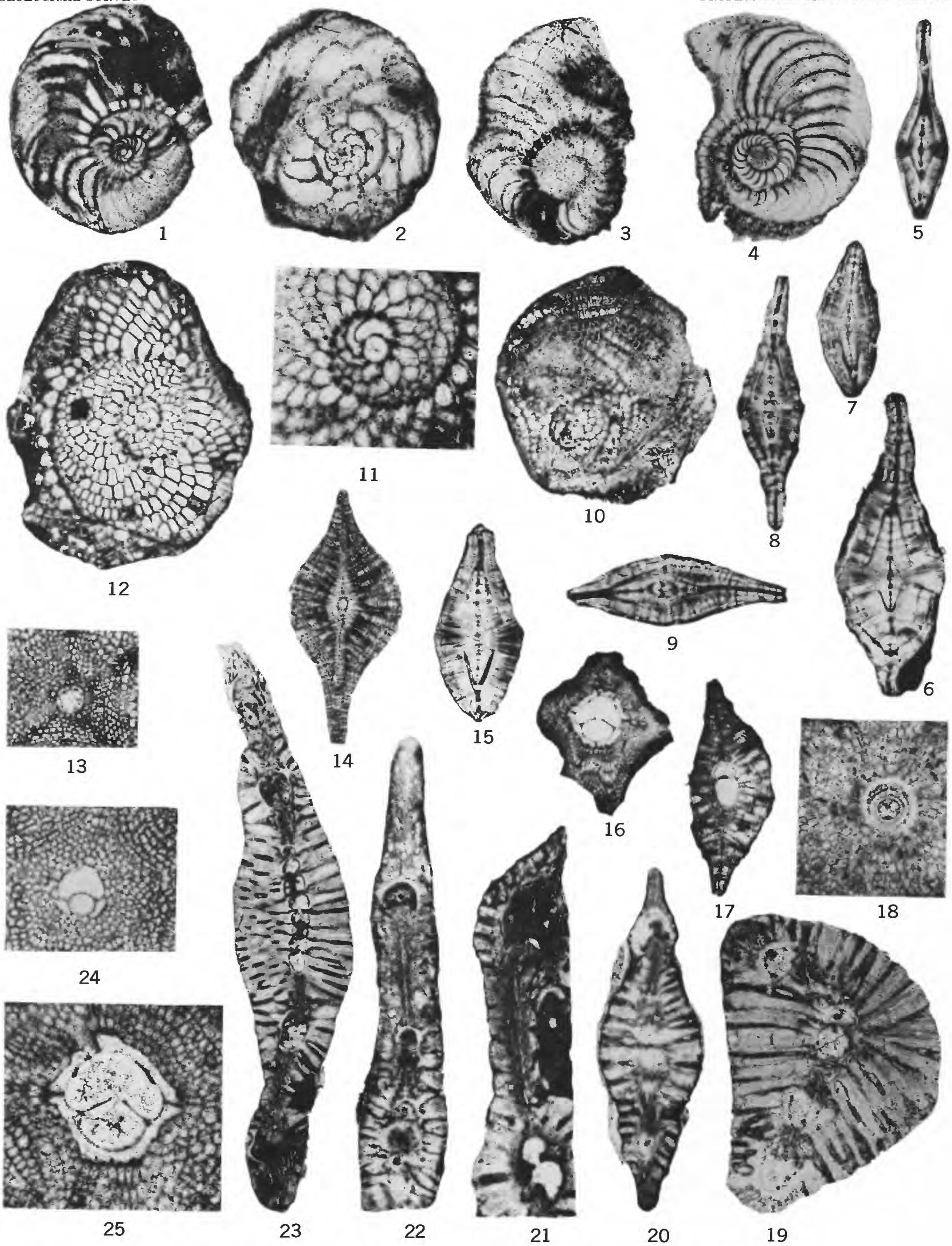
19. Transverse section, × 20, of an inflated, selliform specimen to be compared with specimens from Saipan Island (Cole, 1957a, pl. 97, fig. 10); USNM 651076.

20. Compressed specimen, × 20; USNM 651077.

21. Part of a transverse section, × 20, of a microspheric specimen to illustrate the development of the marginal cord; USNM 651078.

22. Part of a transverse section, × 20, of a large, thin, megalospheric specimen; USNM 651079.

23. Transverse section, × 12.5, of a probable microspheric specimen; USNM 651080.



CAMERINA, SPIROCLYPEUS, ASTEROCYCLINA, HETEROSTEGINA, DISCOCYCLINA, AND *PELLATISPIRA*

PLATE 3

FIGURES 1–3, 7. *Asterocyclina matanzensis* Cole (p. B11).

1. Equatorial section, × 20, of a specimen having a subglobular central area and elongate rays; see plate 4, figure 10, for enlargement of the embryonic apparatus; USNM 651083.
2. Vertical section, × 20, of a specimen having a narrow rim from which bluntly rounded rays protrude; USNM 651084.
3. Equatorial section, × 20, of a specimen having an evenly lenticular central area which merges with five bluntly rounded rays; USNM 651085.
7. Vertical section, × 20, of a specimen similar to the one from which the equatorial section, figure 3, was made; USNM 651089.

4–6, 8, 9, 12. *Heterostegina saipanensis* Cole (p. B9).

4, 5. Transverse sections, × 20; USNM 651086, 651087.

6. Part of a median section, × 40, of a specimen having one camerinid chamber after the embryonic chambers; USNM 651088.

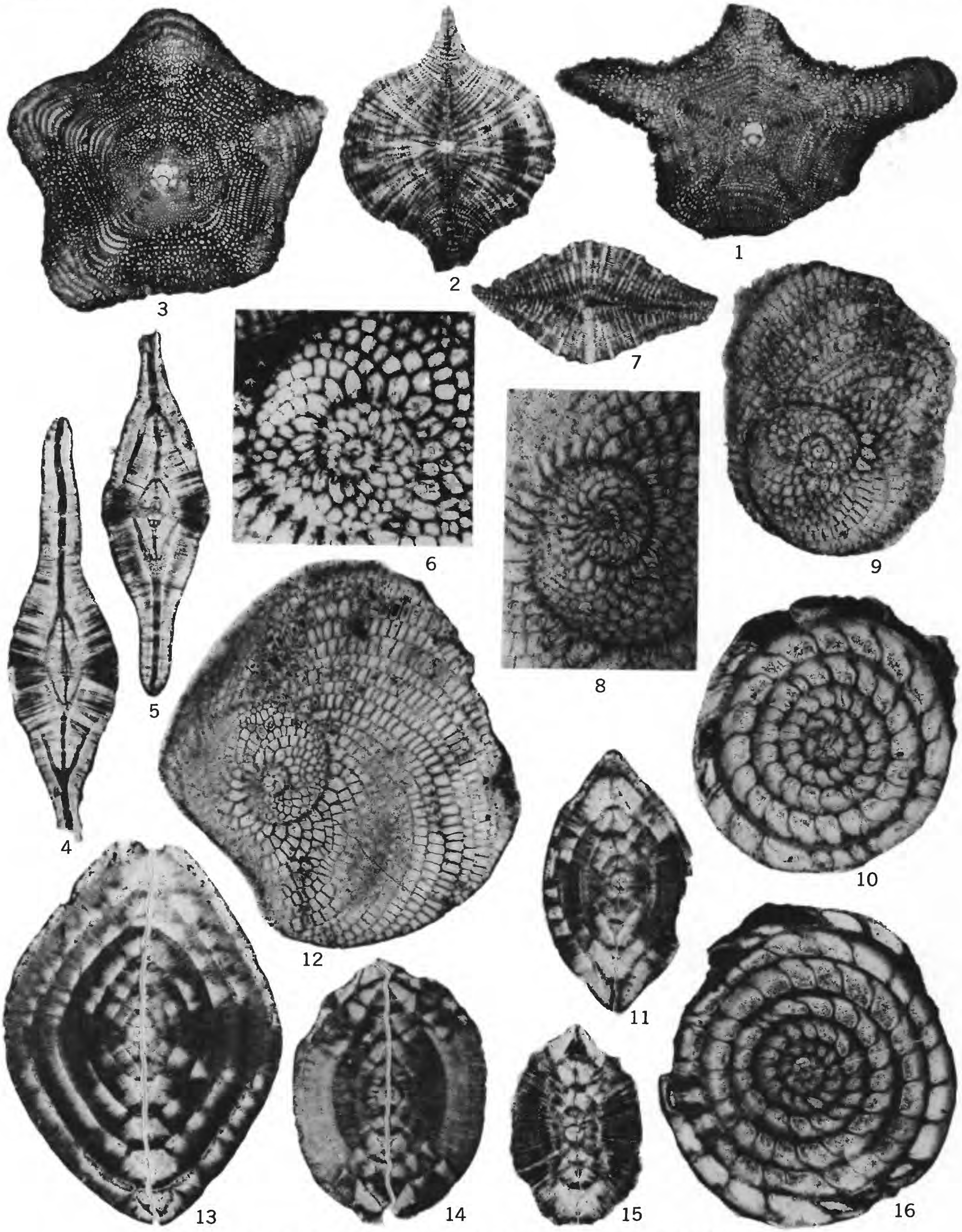
8. Part of a median section, × 40, of a microspheric specimen; USNM 651090.

9, 12. Median sections, × 20, of megalospheric specimens; USNM 651091, 651094.

10, 11, 13–16. *Camerina pengaronensis* (Verbeek) (p. B4).

10, 16. Median sections, × 20; USNM 651092, 651098.

11, 13–15. Transverse sections, × 20; USNM 651093, 651095–651097.



ASTEROCYCLINA, *HETEROSTEGINA*, AND *CAMERINA*

PLATE 4

FIGURES 1, 5, 7, 11, 13, 14. *Asterocyclina penuria* Cole (p. B12).

1. Equatorial section, × 12.5, to illustrate the rayed pattern of the equatorial chambers; USNM 651099.
5. Vertical section, × 20, of an inflated specimen; USNM 651103.
7. Part of an equatorial section, × 20; USNM 651105.
11. Vertical section, × 20, of a compressed specimen; USNM 651108.
13. Vertical section, × 12.5; USNM 651110.
14. Part of an exactly centered equatorial section, × 40, to illustrate the embryonic, periembryonic, and equatorial chambers; USNM 651111.

2–4 6, 8–10, 12. *Asterocyclina matanzensis* Cole (p. B11).

2, 9. Vertical sections, × 40, of small specimens; USNM 651100, 651107.

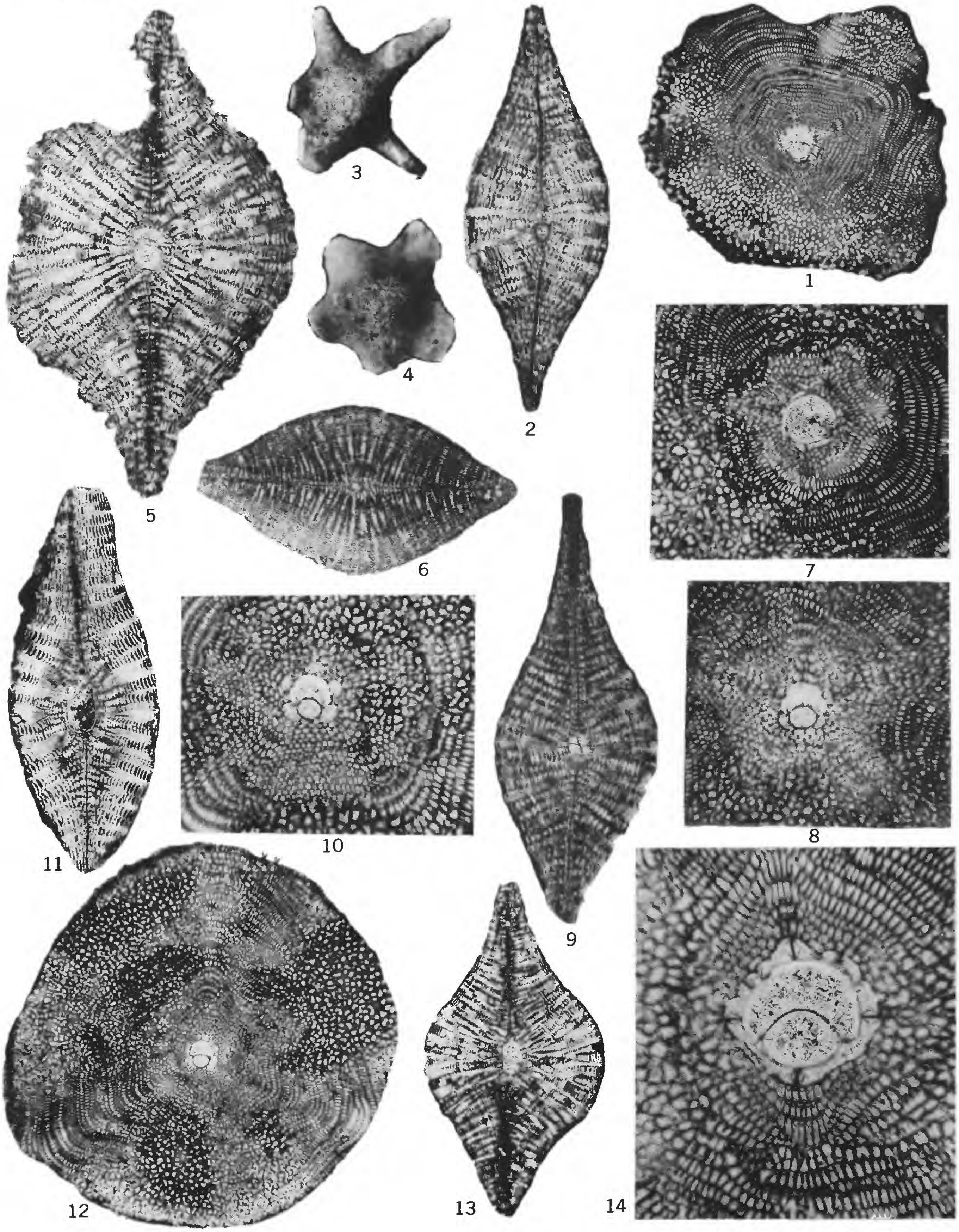
3. External view, × 8, of a specimen having a subglobular central area and distinct, elongate rays; USNM 651101.

4. External view, × 8, of a compressed specimen having short, bluntly rounded rays; USNM 651102.

6. Vertical section, × 20, of an inflated specimen having numerous lateral chambers; USNM 651104.

8, 10. Parts of equatorial sections, × 40, to illustrate slight differences in size of the periembryonic chambers; USNM 651106, 651085.

12. Equatorial section, × 20; USNM 651109.



ASTEROCYCLINA

PLATE 5

FIGURES 1–21. *Asterocyclina praecipua* Cole (p. B13).

1–4, 6–8, 10, 12, 13, 16, 21. Vertical sections. Figures 1–3, 13, 21, × 40; figures 4, 6–8, 10, 12, 16, × 20.

1, 2, 4, 12, 13. Inflated, biconvex, megalospheric specimens having four short, bluntly rounded rays; USNM 651112, 651113, 651115, 651123, 651124.

3, 21. Moderately inflated megalospheric specimens having many strong pillars and moderately extended rays; USNM 651114, 651129.

6–8. Megalospheric specimens having a distinct umbonal area and four extended rays; USNM 651117–651119.

10, 16. Microspheric specimens having a subglobular central area, strong pillars, and a narrow rim; USNM 651121, 651127.

5, 9, 11, 15, 19, 20. Equatorial sections. All figures × 20, except figure 20, × 40.

5, 9. Megalospheric specimens having tests similar to the specimens illustrated as figures 6–8, this plate; USNM 651116, 651120.

11, 19, 20. Megalospheric specimens having tests similar to the specimens illustrated as figures 1–4, 12, 13, 21, this plate; USNM 651122, 651125, 651128.

15. Microspheric specimen having a test similar to the specimens illustrated as figures 10 and 16, this plate; USNM 651126.

14, 17, 18. Central parts of equatorial sections of megalospheric specimens. Figure 14, × 40; figures 17, 18, × 210.

14, 17. Embryonic and periembryonic chambers of the specimen illustrated as figure 19, this plate.

18. Embryonic and periembryonic chambers of another megalospheric specimen; see figure 13, plate 2.

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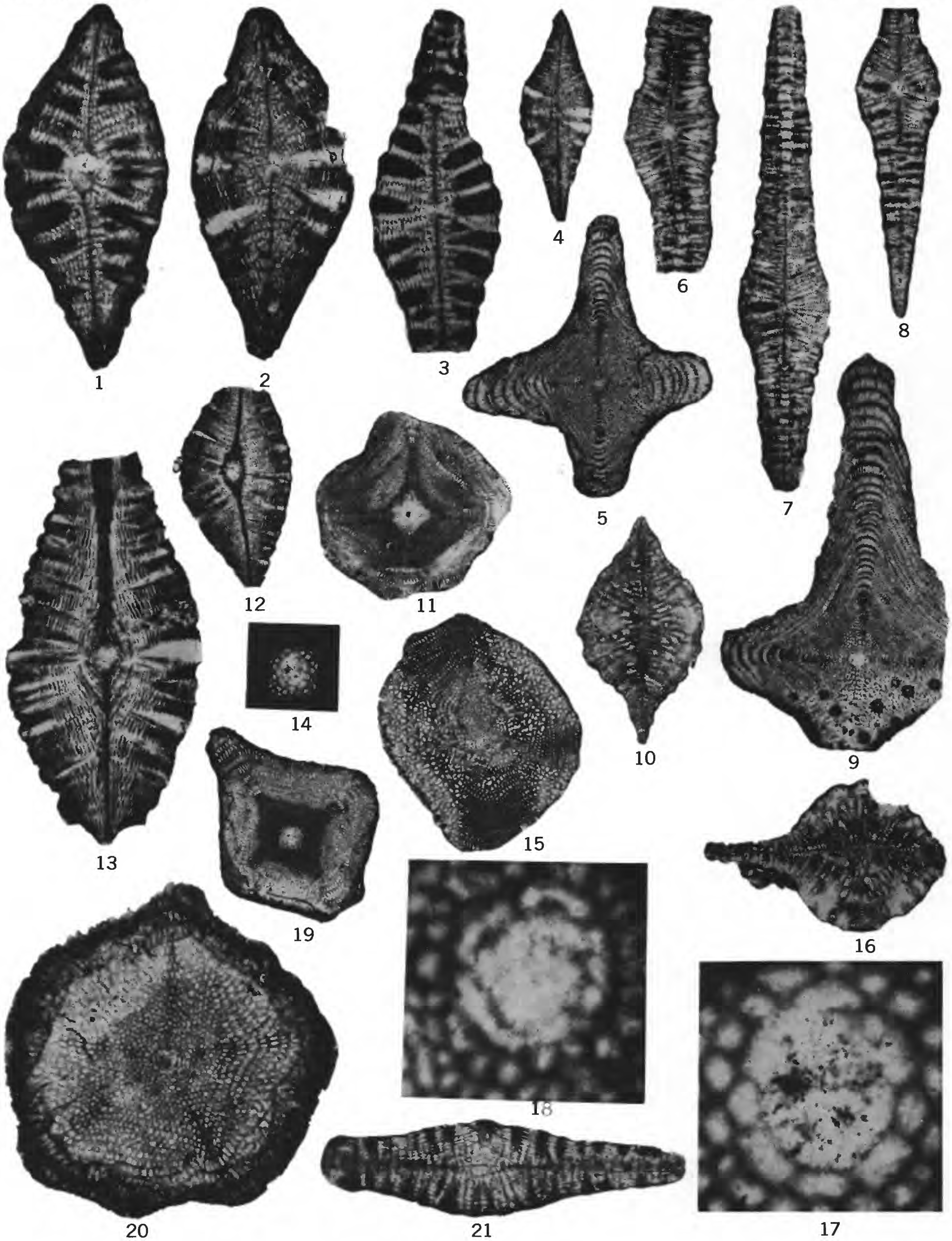

ASTEROCYCLINA