

ABSTRACT

About 4000 rock samples from the upper Cenozoic sequence of western Taiwan previously examined in the micropaleontology laboratory have been restudied for the purpose of determining the stratigraphic ranges of the various species of the "Rotalia" group of foraminifera. Twenty species, three subspecies and one variety representing four genera have been distinguished, and seven of them are the first reported occurrence in Taiwan.

"Rotalia" group from the upper Cenozoic of Taiwan

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INTRODUCTION

In recent years, the writer has observed the value of the various species of the "Rotalia" group of foraminifera for understanding the stratigraphy of the upper Cenozoic of western Taiwan. The purpose of this study is to determine the stratigraphic ranges and show the significance of the species of this "Rotalia" group in the biostratigraphic sequence, and to give a systematic account of the genera *Ammonia*, *Asterorotalia*, *Pararotalia* and *Pseudorotalia* in western Taiwan.

Twenty species, three subspecies and one variety of the "Rotalia" group have been recognized in the samples from the upper Cenozoic sequence of western Taiwan. All of them have been reported previously either as living or fossil forms from tropical and subtropical Pacific regions, but seven of them are the first reported occurrence in Taiwan. The stratigraphic ranges of these twenty-four taxa are shown in the accompanying chart.

All the specimens are deposited in the Micropaleontology Laboratory, Geological Division, Taiwan Petroleum Exploration Office, Chinese Petroleum Corporation, Miaoli, Taiwan.

SOURCES OF MATERIAL

The upper Cenozoic sequence is well exposed in western Taiwan. During the last few years, a program of systematic and detailed micropaleontological study of surface and subsurface sections of the upper Cenozoic sequence was carried out by the Taiwan Petroleum Exploration Office of the Chinese Petroleum Corporation. The foraminifera obtained from the rock samples collected from these surface and subsurface sections, distributed over a distance of about 300 kilometers from north to south, were used for the present study. The locations of the surface and subsurface sections are shown in text-figure 1.

STRATIGRAPHIC DISTRIBUTION

The stratigraphic ranges of the twenty-four taxa of the "Rotalia" group in western Taiwan are summarized in a chart (text-figure 2). The ranges are based mainly on the results of the present study but partly on the occurrences of the fossils recorded in scientific literature.

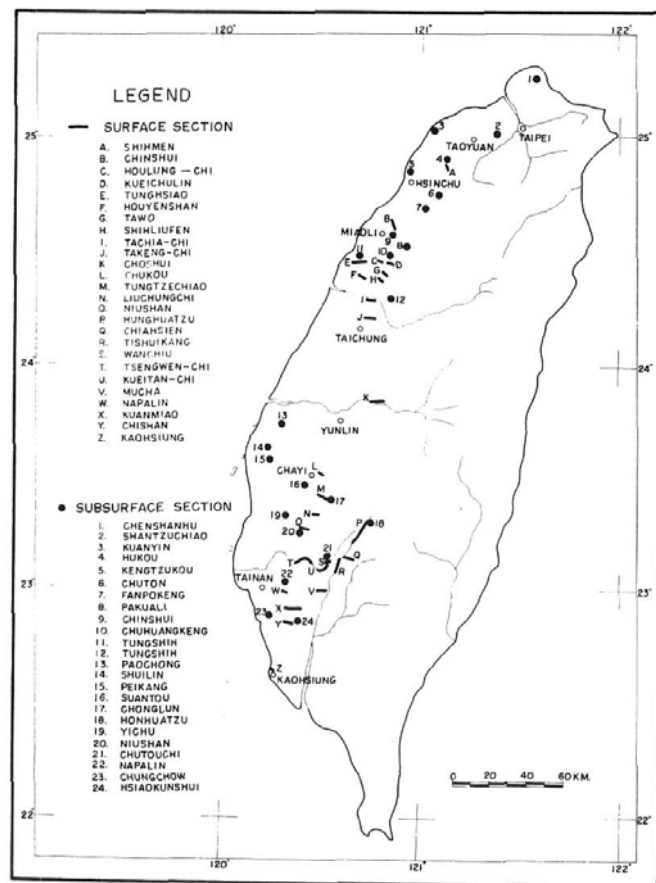
The stratigraphic distribution of the "Rotalia" group in Taiwan is characterized by the rapid introduction and succession of new and more highly developed forms in the upper Cenozoic sequence. All species commonly occur in formations higher than the Talu Shale Member of the Nankang Sandstone except for a few species of the *Ammonia beccarii* gens. Thus there is a sudden faunal change after the Talu deposition.

Pseudorotalia yabei appears in the uppermost part of the Nankang Sandstone and continues as a relatively common form in the Upper Miocene and Pliocene. It is especially abundant and widespread in the Sanhsia (Sankyo) and Miaoli Groups.

Asterorotalia subtrispinosa first appears in the upper sandstone member of the Nankang Sandstone and is very common in the uppermost Hsichih Group, the middle Sanhsia Group and the lower Miaoli Group. It exhibits a diminishing frequency in younger formations and becomes extinct before the deposition of the Toukoshan Formation.

Asterorotalia trispinosa appears in the lowermost part of the Toukoshan Formation and closely follows *Asterorotalia subtrispinosa* in biostratigraphic sequence. Its first appearance marks one of the horizons useful for stratigraphic correlations in western Taiwan.

Pseudorotalia schroeteriana tikutoensis, very short in range, is a relatively rare form and is found only in the lowest part of the Miaoli Group, but it is very rare in southern Taiwan.



TEXT-FIGURE 1

MAP OF TAIWAN SHOWING LOCATION OF SAMPLES

Ammonia equatoriana is confined to the Mucha (Mokusa-ku) Formation of southern Taiwan (equivalent to the upper Kueichulin Formation, Chinshui Shale and lower Cholan Formation of northern Taiwan). It is frequently found and occasionally common in this formation. However, it has never been found in northern Taiwan up to now.

Ammonia annectens is very common in the Toukoshan and younger formations of western Taiwan, but in the Peikang subsurface section it may occur as early as the Miocene.

Pararotalia ozawai is relatively rare, and is known only from the Toukoshan Formation of western Taiwan. It appears for the first time in the Erchungchi Formation in southern Taiwan and in the Toukoshan Formation in northern Taiwan.

Ammonia beccarii, *Ammonia japonica*, *Ammonia takanabensis*, *Ammonia ketienziensis*, *Pseudorotalia gaimardii*, *Pseudorotalia indopacifica* and *Pseudorotalia schroeteriana schroeteriana* are widespread, being very common in the Upper Miocene and the Pliocene formations of western Taiwan.

Asterorotalia multispinosa appears in the uppermost Nanchuang Formation and continues as a common form through the Chinshui Shale to the Cholan Formation. It is known only from northern Taiwan.

Pararotalia taiwanica appears in the upper Nankang Sandstone in the Kuanyin well KY-1 and continues as a relatively rare form through the Chinshui Shale. Thereafter, it becomes common and widespread, especially in the upper Cholan Formation.

Ammonia nipponica occurs frequently in the Nanchuang Formation and the Kueichulin Formation.

Ammonia hozanensis occurs in the Chinshui Shale, continues as a relatively rare form through the Cholan Formation, and becomes rare in the Toukoshan Formation. Sometimes it may also occur in the Miocene in the coastal plain area of Peikang.

Ammonia ketienziensis angulata, *Ammonia inflata*, *Ammonia beccarii koeboeensis* and *Ammonia sikokuensis* are all relatively rare forms. The latter two occur in the Pliocene and Pleistocene but have little stratigraphic value.

Ammonia indica, *Ammonia hozanensis*, *Ammonia japonica* and *Ammonia beccarii* var. are the only species known from the Talu Shale Member of the Nankang Sandstone and older formations.

Some species show different stratigraphic distributions between the foothill regions and the coastal plain areas of Kuanyin and Peikang, perhaps due to ecologic control.

SYSTEMATIC PALEONTOLOGY

From the results of the present study the writer concludes that the species of the "Rotalia" group from the upper Cenozoic of western Taiwan regarded by earlier workers as *Rotalia* or *Streblus* should be referred to *Ammonia*, *Asterorotalia*, *Pararotalia* and *Pseudorotalia*.

The grouping of these four genera into a family or families within a superfamily, such as the *Rotaliidea*, would be too much a matter of conjecture, and is not attempted here.

Synonymy lists are restricted to the original description and to report of a species or subspecies from the Taiwan region.

Genus AMMONIA Brönnich, 1771

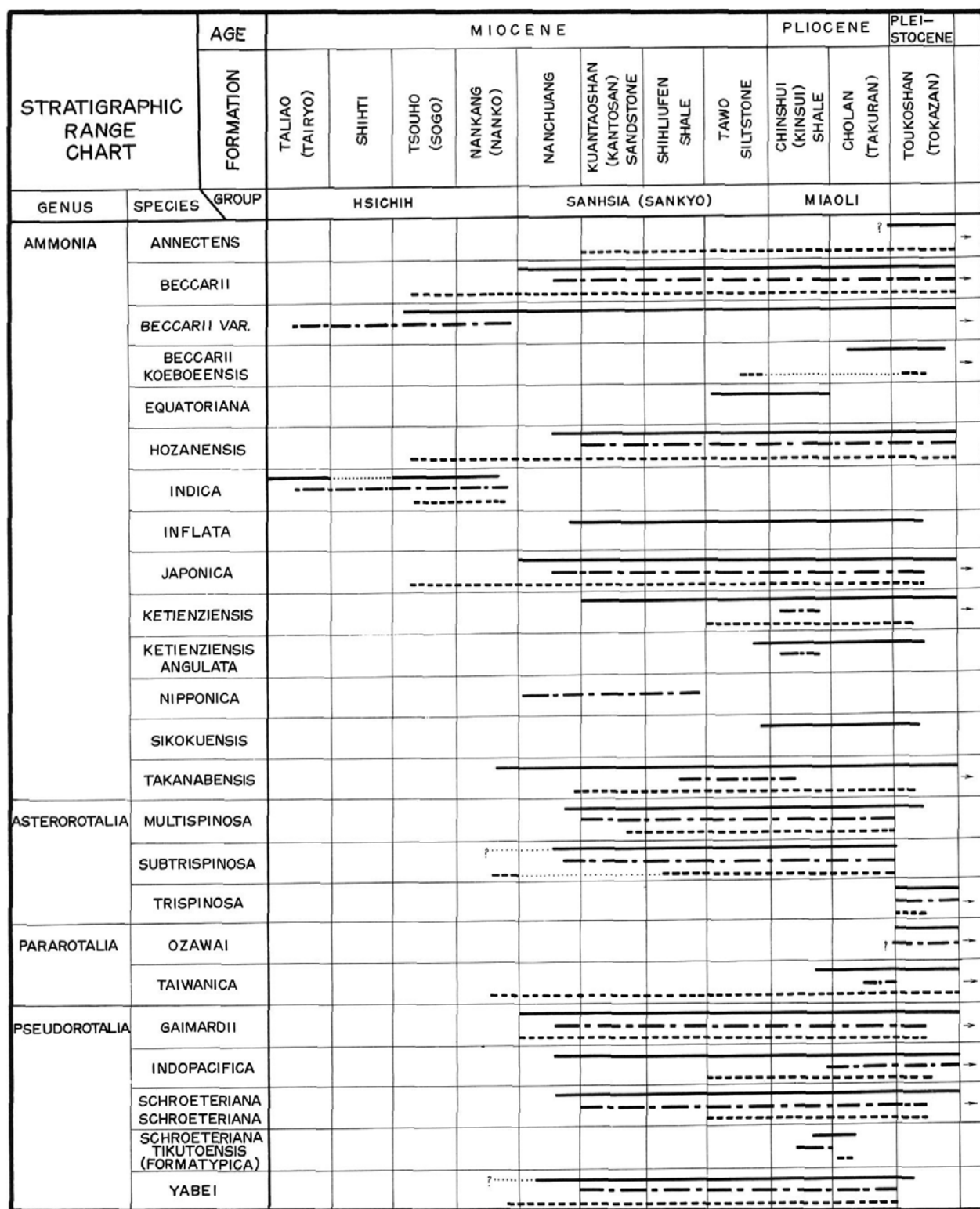
Ammonia annectens (Parker and Jones)

Plate 2, figure 3; plate 3, figures 1-2; text-figure 3

Rotalia beccarii (Linnaeus) var. *annectens* PARKER and JONES, 1865, Roy. Soc. London, Philos. Trans., vol. 155, pp. 387, 422, pl. 19, fig. 11.

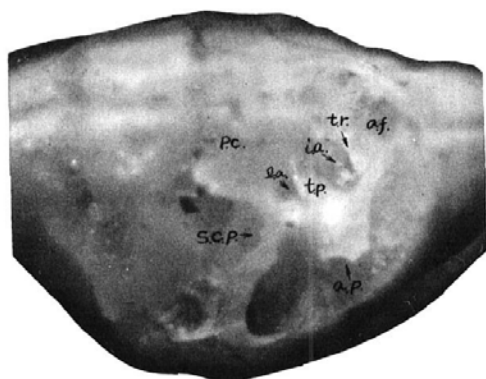
Streblus annectens (Parker and Jones). - ISHIZAKI, 1940, Taiwan Tigaku Kizi, vol. 11, no. 2, p. 58, pl. 3, figs. 12-13.

"ROTALIA" GROUP OF TAIWAN



LEGEND : — THE FOOTHILLS REGION OF WESTERN TAIWAN
 - - - THE COSTAL PLAIN REGION OF NORTHERN TAIWAN (KUANYIN AREA)
 . . . THE COSTAL PLAIN REGION OF SOUTHERN TAIWAN (PEIKANG AREA)

TEXT-FIGURE 2
 STRATIGRAPHIC RANGE CHART



TEXT-FIGURE 3

A photograph showing internal aspects of a specimen of *Ammonia annectens* (Parker and Jones).

- a.f. aperture face;
- a.p. angular process;
- i.a. interiomarginal cameral aperture;
- l.a. labial aperture;
- p.c. previous coil;
- t.p. toothplate;
- t.r. thickened apertural "rim";
- s.c.p. spiral communication passage.

The internal structure of *Ammonia annectens* (text-figure 3) is briefly described as follows. The chamber aperture is converted into an intercameral foramen after a subsequent chamber is built, thus providing communication between the two chambers. The intercameral foramen is situated at the interior margin of the intercameral septum and is of elliptical shape in this species. The so-called "labial aperture" is almost comma-shaped in outline and is an opening below the intercameral foramen which provides a passageway from the chamber through the angular process to the outside. A communication lumen provides a passageway from one angular process to another. This communication passage is coiled on the outer surface of the spiral wall of the previous whorl parallel to the coiling direction of the test and below the labial apertures. The well-developed toothplate bends above the labial aperture and its inner side continues up to meet the spiral wall of the previous whorl. The intercameral septum is secondarily doubled by the septal flap, leaving an intraseptal space between them which opens at the ventromarginal part but thins out toward the ventral and dorsal sides. In *Ammonia annectens* the labial aperture is present only in the interiomarginal position, no umbilical labial aperture being formed. The labial aperture remains open apparently throughout the life of the individual.

In the Peikang subsurface section of the Taiwan coastal plain, this species has been very rarely recorded from the Miocene, but in the foothills region it occurs only in the Late Pliocene and Pleistocene deposits.

Dimensions of figured specimen: Diameter 0.66 mm., thickness 0.46 mm.

Ammonia beccarii (Linné)

Plate 2, figure 6

Nautilus beccarii LINNÉ, 1758, Syst. Nat., ed. 10, vol. 1, p. 710.
Streblus beccarii (Linné). – ISHIZAKI, 1943, Taiwan Tigaku Kizi, vol. 14, nos. 3–4, p. 53, pl. 1, fig. 6.

Rotalia beccarii (Linné) var. A, HUANG, 1961, Formosan Sci., vol. 15, no. 2, p. 68, figs. 1–12.

The Taiwan specimens show a wide variation in number of chambers. Frequent in the Upper Miocene to Pleistocene deposits all over Taiwan.

Dimensions of figured specimen: Diameter 0.41 mm., thickness 0.15 mm.

Ammonia beccarii (Linné) var.

Plate 1, figure 11

Rotalia beccarii (Linné) var. – HUANG, 1961, Geol. Soc. China, Proc., no. 4, p. 87, pl. 4, figs. 1–3, 19–20.

Test free, small, with 7 to 8 chambers in the adult whorl; periphery rounded, slightly lobulate; sutures on dorsal side distinct, slightly oblique, limbate, but in last whorl slightly depressed; sutures on the ventral side curved and depressed; sometimes with small umbilical plug, but occasionally without it.

Dimensions of figured specimen: Diameter 0.46 mm., thickness 0.30 mm.

Remarks: This variety is rare in the Nankang and Tsouho Formations, where it occurs with *Ammonia indica*, but is very rare throughout the Pliocene and Pleistocene to Recent. It is easily distinguished from *Ammonia hozanensis* by its small umbilical plug and depressed oblique sutures on the dorsal side.

Occurrence of hypotypes: The figured specimen is from the Pliocene upper Gutingkeng Formation, Loc. KSS-105 at Shoushan, near the city of Kaohsiung.

Ammonia beccarii koeboeensis (LeRoy)

Plate 2, figure 5

Rotalia beccarii (Linné) var. *koeboeensis* LEROY, 1939, Natuurk. Tijdschr. Nederl.-Indie, vol. 99, no. 6, p. 255, pl. 6, figs. 13–15.

This subspecies differs from *Ammonia beccarii* (Linné) s. s. chiefly by being more convex. It is commonly encountered in the Pliocene formations and sometimes occurs in the Upper Miocene and Pleistocene formations of western Taiwan. Brady's *Rotalia beccarii*, plate 107, figure 2 (1884) is a variety larger than that described by LeRoy. The Taiwan specimens closely resemble Brady's figure. The Taiwan specimens of this subspecies are similar to the figure of LeRoy's Indonesian form (1939) but differ from it somewhat in the test, the dorsal side being highly elevated with a rounded apex, and the sutures being irregularly thickened on the dorsal side.

Dimensions of figured specimen: Diameter 0.61 mm., thickness 0.40 mm.

"ROTALIA" GROUP OF TAIWAN

Ammonia equatoriana (LeRoy)

Plate 1, figure 3

Rotalia equatoriana LeROY, 1941, Colorado School of Mines Quarterly, vol. 36, no. 1, p. 40, pl. 1, figs. 8-10.

The Taiwan specimens correspond closely to this species as figured by LeRoy from Loc. E-2, near P. Badjo, Sangkoelirang Bay area, east Borneo. This species is frequently found in the Upper Miocene to Lower Pliocene formations of southern Taiwan, but is scarce in northern Taiwan and unknown in the Pliocene and Pleistocene deposits of western Taiwan.

Dimensions of figured specimen: Diameter 0.36 mm., thickness 0.24 mm.

Ammonia hozanensis (Nakamura)

Plate 1, figure 4

Rotalia hozanensis NAKAMURA, 1937, Jap. Jour. Geol. Geogr., vol. 14, nos. 2-3, p. 141, pl. 12, fig. 4.

This species differs from *Ammonia japonica* in its low spiral in apertural view, and in the small number of chambers in the last whorl. It is common in the Pliocene and Pleistocene deposits, and is found also in the Miocene deposits of Taiwan.

Dimensions of figured specimen: Diameter 0.74 mm., thickness 0.40 mm.

Ammonia indica (LeRoy)

Plate 2, figure 7

Rotalia indica LeROY, 1939, Natuurk. Tijdschr. Nederl.-Indie, vol. 99, no. 6, p. 257, pl. 2, figs. 17-19.

Streblus indicus (LeRoy). - CHANG, 1960, Bull. Geol. Survey Taiwan, no. 12, pl. 14, fig. 7.

This species is well developed in the upper part of the Telisa Formation and in the Transitional zone in Sumatra, as reported by LeRoy. It is also known from the Talu Shale Member of the Nankang Sandstone and from older formations of western Taiwan. Commonly, it occurs with *Ammonia beccarii* var. in the Miocene formations.

Dimensions of figured specimen: Diameter 0.62 mm., thickness 0.32 mm.

Ammonia inflata (Seguenza)

Plate 1, figure 8

Rosalina inflata SEGUENZA, 1862, Accad. Gioenia Sci. Nat. Catania, Atti, ser. 2, vol. 18, p. 106, pl. 1, figs. 6a-c.

Streblus tosaensis Ishizaki, 1948, Acta Geol. Taiwanica, vol. 2, no. 1, p. 56, pl. 1, figs. 6a-c.

This species differs from *Ammonia japonica* in the strongly limbate sutures on the dorsal side and in its more globular test form.

It occurs rarely in the upper Cenozoic samples, but is never found in beds older than the Kueichulin Formation of western Taiwan.

Dimensions of figured specimen: Diameter 0.42 mm., thickness 0.34 mm.

Ammonia japonica (Hada)

Plate 1, figure 10

Rotalia japonica HADA, 1931, Tōhoku Univ., Sci. Rep., ser. 4, vol. 6, no. 1, p. 137, text-fig. 93.

This species is frequently found in the Kueichulin Formation and younger formations, is common in the Pliocene formations and rare in the Nanchuang Formation, and first appears in the Tsouho Formation. It is easily distinguished from *Ammonia hozanensis* by the shape of the chamber in apertural view.

Dimensions of figured specimen: Diameter 0.42 mm., thickness 0.30 mm.

Ammonia ketienziensis (Ishizaki)

Plate 1, figure 13

Streblus ketienziensis ISHIZAKI, 1943, Taiwan Tigaku Kizi, vol. 14, nos. 3-4, pp. 59-60, pl. 1, fig. 5; 1948, Acta Geol. Taiwanica, vol. 2, no. 1, pp. 59-60, pl. 1, fig. 2.

This species is common from the Miocene to the Recent, and is especially developed in the Pliocene formations of southern Taiwan. No specimens such as Asano's figure (1951) shows are present, but those found agree closely with Ishizaki's illustration (1943b) of the Lower Pliocene *Ammonia ketienziensis*.

Dimensions of figured specimen: Diameter 0.57 mm., thickness 0.34 mm.

Ammonia ketienziensis angulata (Kuwano)

Plate 1, figure 6

Rotalia ketienziensis angulata KUWANO, 1950, Geol. Soc. Japan, Jour., vol. 56, no. 657, p. 312, text-fig. 1.

Some Taiwan specimens referred to this subspecies are only a little more highly elevated on the dorsal side than the type, but many are so highly elevated that they might belong to a different species. In the foothills region, the subspecies is fairly common from the Upper Miocene to the Pleistocene of southern Taiwan, but rare in the north. In the coastal plain, it is found only in the Kuanyin subsurface section. The plano-convex form is commonly found in Taiwan. This species is very similar to Asano's figure (1951) but differs in that the sutures are nearly radial on the dorsal side and the test is of plano-convex form.

Dimensions of figured specimen: Diameter 0.40 mm., thickness 0.22 mm.

Ammonia nipponica (Asano)

Plate 2, figure 1

Rotalia nipponica ASANO, 1936, Geol. Soc. Japan, Jour., vol. 43, no. 515, p. 614, pl. 31, fig. 2.

Rotalia cf. *nipponica* ASANO. - CHANG, 1957, Symp. Petroleum Geol. Taiwan (1956), pl. 15-3.

This species is somewhat similar in appearance to the Miocene form of *Pseudorotalia yabei* but has fewer chambers per whorl, much finer pores on the dorsal side, and thin plates covering the inner portions of the ventral fissures.

The two forms occur in approximately the same horizons in western Taiwan. A few typical specimens of *A. nipponica* were found in the Shanchenshan section, and

it may be regarded as a good diagnostic species for the Upper Miocene of western Taiwan.

Dimensions of figured specimens: Diameter 0.76 mm., thickness 0.40 mm.

Ammonia sikokuensis (Ishizaki)

Plate 1, figure 1

Streblus sikokuensis ISHIZAKI, 1948, Acta Geol. Taiwanica, vol. 2, no. 1, pp. 61-62, pl. 1, fig. 1.

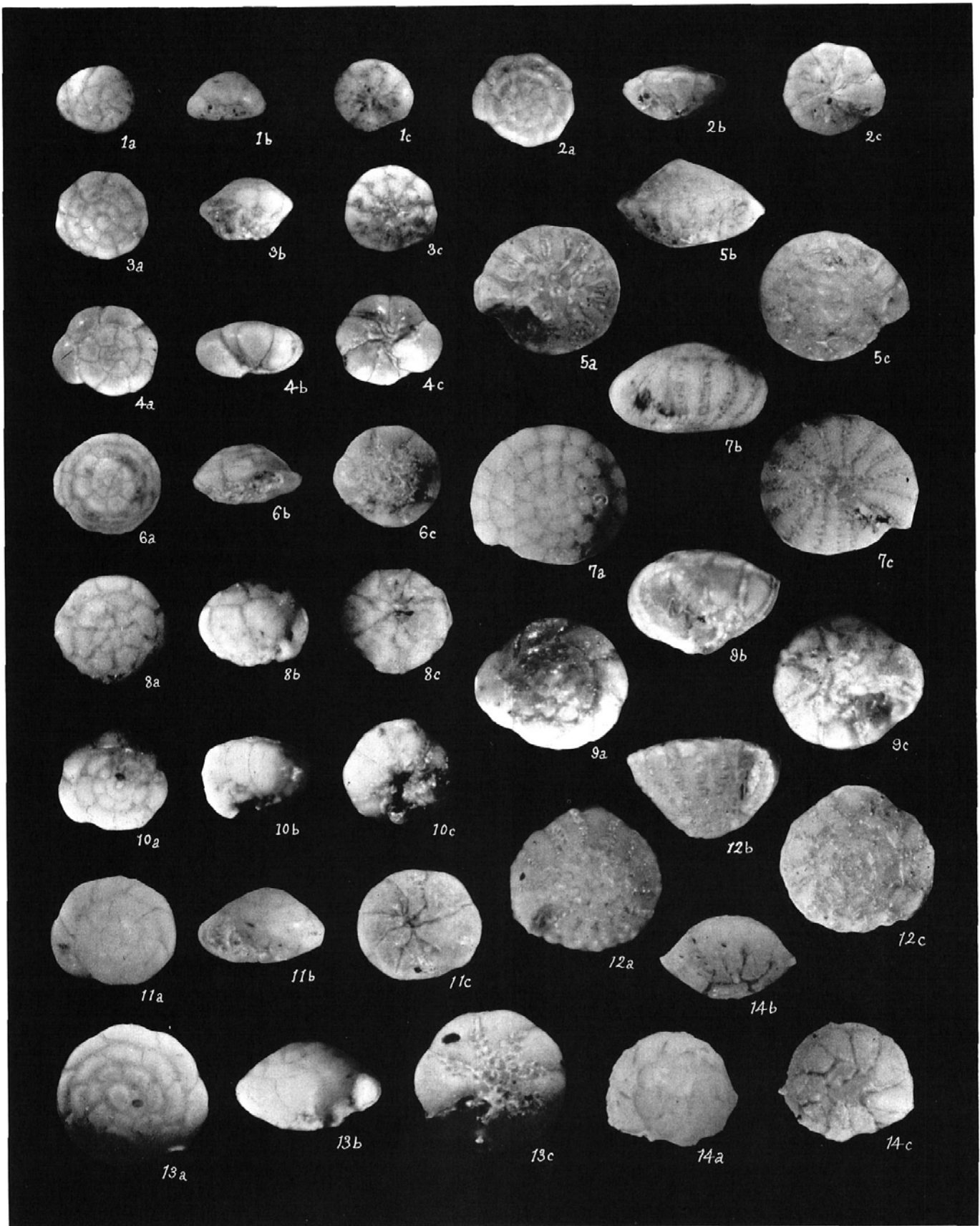
This species is rare from the Upper Miocene to the Lower Pleistocene formations of western Taiwan.

Dimensions of figured specimen: Diameter 0.30 mm., thickness 0.19 mm.

PLATE 1

All figures $\times 50$, unless otherwise noted

- 1 *Ammonia sikokuensis* (Ishizaki)
From the Yanmei Formation in the Hukou Well R-1, 218.13 m.
- 2 *Ammonia takanabensis* (Ishizaki)
From the upper Gutingkeng Formation at Loc. Cc-64 in the Chishan section.
- 3 *Ammonia equatoriana* (LeRoy)
From the lower Gutingkeng Formation at Loc. Ck-338 in the Chishan section.
- 4 *Ammonia hozanensis* (Nakamura)
From the Toukoshan Formation at Loc. Tu-39 in the Tunghsiao section.
- 5 *Pseudorotalia yabei* (Ishizaki)
From the Cholan Formation at Loc. Hm-56 in the Houlung-chi section; $\times 20$.
- 6 *Ammonia ketienziensis angulata* (Kuwano)
From the lower Gutingkeng Formation at Loc. Ck-405 in the Chishan section.
- 7 *Pseudorotalia indopacifica* (Thalmann)
From the Cholan Formation at Loc. Cst-30, Hsinkang, Houlung Chen, Miaoli Hsien.
- 8 *Ammonia inflata* (Seguenza)
From the Nanchuang Formation in the Kengtzukou Well KT-1, 2168-2175 m.
- 9 *Pseudorotalia gaimardii* (d'Orbigny)
From the upper Gutingkeng Formation in the Chishan section at Loc. Cc-71.
- 10 *Ammonia japonica* (Hada)
From the Nanchuang Formation at Loc. Scs-17 in the Sanchenshan section.
- 11 *Ammonia beccarii* (Linné) var.
From the upper Gutingkeng Formation at Loc. Kss-105, Shoushan, Kaohsiung City.
- 12 *Pseudorotalia schroeteriana schroeteriana* (Parker and Jones)
From the Cholan Formation in the Kuanyin Well KY-1, 952 m.
- 13 *Ammonia ketienziensis* (Ishizaki)
From the upper Gutingkeng Formation at Loc. Kss-70, Niushoupu, Kangshan Chen, Kaohsiung Hsien.
- 14 *Pararotalia ozawai* (Asano)
From the Erhchungchi Formation at Loc. Kss-38, Antzuping, Tienliao Hsiang, Kaohsiung Hsien.



Ammonia takanabensis (Ishizaki)

Plate 1, figure 2

Streblus takanabensis ISHIZAKI, 1948, Acta Geol. Taiwanica, vol. 2, no. 1, p. 57, pl. 1, fig. 5.*Streblus nakamurai* ISHIZAKI, 1948, Acta Geol. Taiwanica, vol. 2, no. 1, p. 62, pl. 1, fig. 4.

This species is common in the Upper Miocene, Pliocene and Pleistocene deposits of western Taiwan.

Dimensions of figured specimen: Diameter 0.38 mm., thickness 0.22 mm.

Genus PARAROTALIA Le Calvez, 1949

Pararotalia ozawai (Asano)

Plate 1, figure 14

Rotalia ozawai ASANO, 1941, Illus. Cat. Jap. Tert. Smaller Foram., pt. 14, p. 15, figs. 115-117.This species differs from *Pararotalia taiwanica* in the spiny projections on the periphery. It frequently occurs in the Pleistocene Toukoshan Formation of western Taiwan. *Pararotalia ozawai*, both living and fossil, has been reported as found locally in the East China and

South China Seas by Polski (1959) and Waller (1950), and as most abundant between 151 and 400 feet in depth.

Dimensions of figured specimens: Diameter 0.50 mm., thickness 0.32 mm.*Pararotalia taiwanica* (Nakamura)

Plate 2, figure 2

Rotalia taiwanica NAKAMURA, 1942, Coll. Essays Geol. Pal. by the late M. Nakamura, p. 84, pl. 4, fig. 6.The species was compared with *Pararotalia ozawai* from the Yangmei (Yobai) Formation of the Hukou structure and Formations A and B of the Chishan area. It differs from *Pararotalia ozawai* only in that it is without spiny projections on the periphery. It is frequently found in association with *Pararotalia ozawai* in the Toukoshan Formation. The two forms seem to intergrade and might possibly be considered to represent the same species except for the fact that *Pararotalia ozawai* has short radial spines on the periphery of the chamber walls. A reinvestigation of the lineage between them is necessary. *Pararotalia taiwanica* is frequent in the Pliocene

PLATE 2

All figures $\times 50$, unless otherwise noted

- 1 *Ammonia nipponica* (Asano)
From the Nanchuang Formation at Loc. SCS-19 in the Sanchenshan section.
- 2 *Pararotalia taiwanica* (Nakamura)
From the Cholan Formation at Loc. HM-116 in the Houlung-chi section.
- 3 *Ammonia annectens* (Parker and Jones)
From the Toukoshan Formation at Loc. HC-106 in the Houlung-chi section.
- 4 *Asterorotalia multispinosa* (Nakamura)
From the equivalent of the Cholan Formation in the Peikang Well PK-1, 859 m.
- 5 *Ammonia beccarii koeboeensis* (LeRoy)
From an unnamed Pleistocene formation at Loc. CC-21 in the Chishan section.
- 6 *Ammonia beccarii* (Linné)
From the Cholan Formation at Loc. HM-71 in the Houlung-chi section.
- 7 *Ammonia indica* (LeRoy)
From the Tsouho Formation in the Kuanyin Well KY-1, 2005 m.
- 8 *Asterorotalia subtrispinosa* (Ishizaki)
From the equivalent of the Cholan Formation in the Peikang Well PK-1, 859 m.
- 9 *Pseudorotalia schroeteriana tikotoensis* (Nakamura)
From the Chinshui Shale at Loc. HC-1 in the Houlung-chi section; $\times 20$.
- 10 *Asterorotalia trispinosa* (Thalmann)
From the Toukoshan Formation in the Peikang Well PK-3, 604 m.



formations of western Taiwan and rare from the Pleistocene to the Recent. A more highly developed form of this species occurs commonly in the Cholan Formation.

Dimensions of figured specimen: Diameter 0.70 mm., thickness 0.43 mm.

Genus *ASTEROROTALIA* Hofker, 1951

Asterorotalia multispinosa (Nakamura)
Plate 2, figure 4

Rotalia multispinosa NAKAMURA, 1942, Coll. Essays Geol. Pal. by the late M. Nakamura, p. 84, pl. 4, fig. 5.

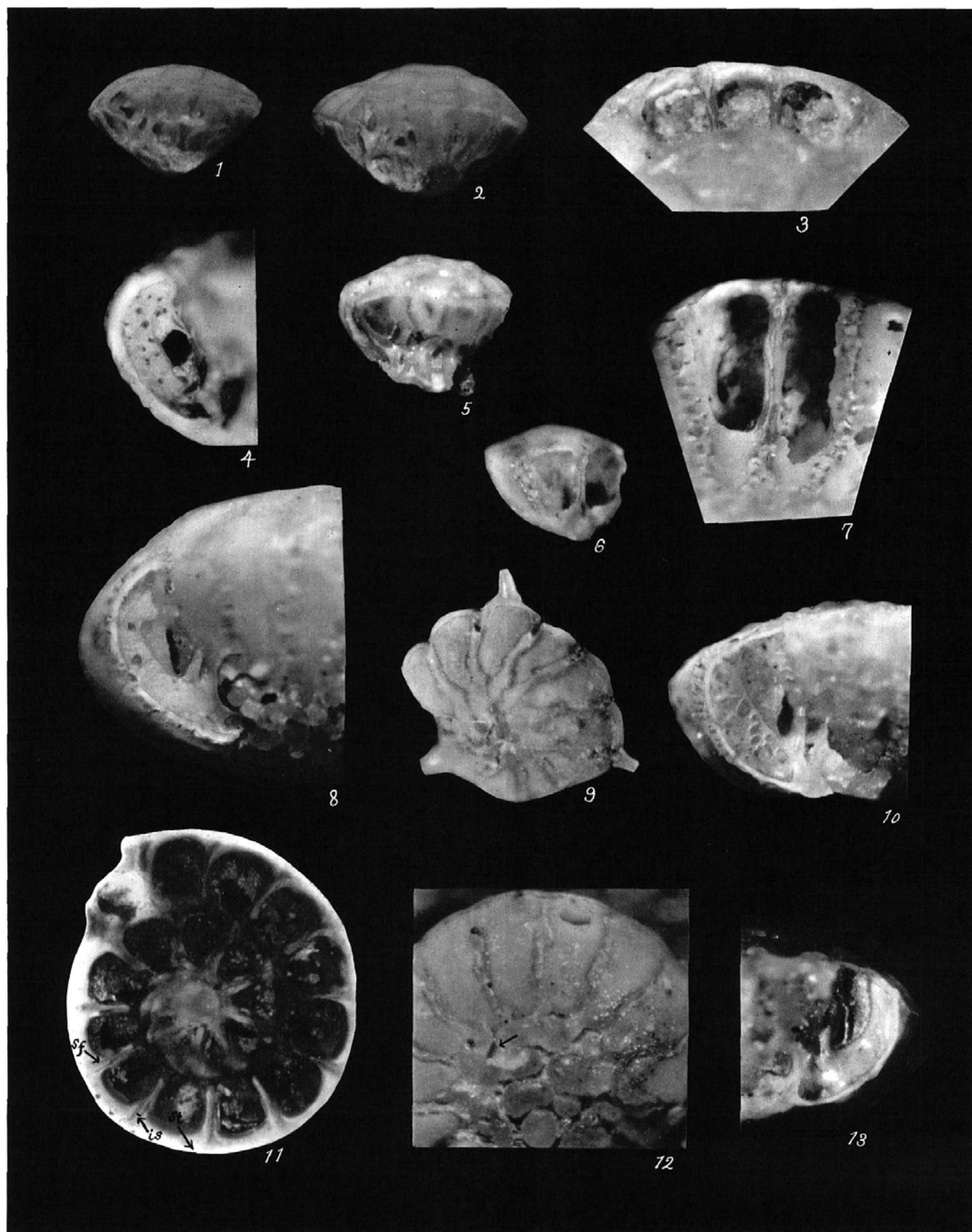
According to Hofker's definition (1951), this species belongs to the genus *Asterorotalia*. It is similar to *Asterorotalia trispinosa* and *Asterorotalia subtrispinosa* from western Taiwan, but its peripheral outline is more rounded, with many more, shorter spines. The ventral side resembles those of *Asterorotalia trispinosa* and *Asterorotalia subtrispinosa*, which in turn closely resemble that shown by Hofker's figure 343 (1951), depicting *Asterorotalia pulchella*, (d'Orbigny), the type species. It is common from the Upper Miocene Kueichulin Formation to the Pliocene Cholan Formation of western Taiwan.

Dimensions of figured specimen: Diameter 0.60 mm., thickness 0.36 mm.

PLATE 3

All figures $\times 50$

- 1-2 *Ammonia annectens* (Parker and Jones)
Internal aspect of dissected chambers, showing the septal flap and intraseptal space, toothplates, and labial apertures. From the equivalent of the Cholan Formation in the Suantou Well SU-1, 790-800 m.
- 3 *Pseudorotalia yabei* (Ishizaki)
Internal aspect of dissected chambers, showing the septal flap and intraseptal space. From the Kueichulin Formation in the Kuanyin Well KY-1, 1001 m.
- 4 *Pseudorotalia indopacifica* (Thalmann)
Internal aspect of dissected chambers, showing the intercameral foramina, toothplates, labial apertures and "intraseptal pores". From the Cholan Formation at Loc. Cst-28, Hsinkang, Houlung Chen, Miaoli Hsien.
- 5-6 *Pseudorotalia gaimardii* (d'Orbigny)
Internal aspect of dissected chambers, showing the septal flap and intraseptal space, intercameral foramen, toothplates, and labial apertures. From the Kueichulin Formation in the Kuanyin Well KY-1, 1100 m.
- 7-8 *Pseudorotalia schroeteriana tikutoensis* (Nakamura)
Internal aspect of dissected chambers of specimens from the Kueichulin Formation in the Kuanyin Well KY-1, 1002.50 m.; 7, dissection showing the septal flap and the intraseptal space; 8, dissection showing the intercameral foramina, toothplates, labial apertures and "intraseptal pores".
- 9 *Asterorotalia trispinosa* (Thalmann)
Ventral side of specimen, showing protoforamina, sutural plate and the additional chamberlets. From an unnamed Pleistocene formation at Loc. Cc-26 in the Chishan section.
- 10, 13 *Pseudorotalia yabei* (Ishizaki)
Internal aspect of dissected chambers, showing the intercameral foramen, toothplates, and labial apertures. From the Cholan Formation in the Kuanyin Well KY-1, 851 m.
- 11 *Pseudorotalia yabei* (Ishizaki)
Horizontal section; sf, septal flap; is, intraseptal space; st, fibrous spiral wall. From the Chinshui Shale, Loc. CHH-2, Peipu, Peipu Hsiang, Hsinchu Hsien.
- 12 *Pseudorotalia yabei* (Ishizaki)
Showing labial opening (arrow) on umbilical area. From the Cholan Formation in the Kuanyin Well KY-1, 851 m.



Asterorotalia subtrispinosa (Ishizaki)

Plate 2, figure 8

Streblus subtrispinosus Ishizaki, 1941, Taiwan Tigaku Kizi, vol. 12, no. 4, pp. 63-66, pl. 6, figs. 1-4.

Rotalia trispinosa (Thalmann). — NAKAMURA, 1942, Coll. Essays Geol. Pal. by the late M. Nakamura, p. 100, pl. 14, figs. 4-5.

Asterorotalia subtrispinosa closely resembles *Asterorotalia trispinosa*, but its peripheral outline is subtriangular in form, and it has shorter spines, a thicker test, and curved sutures on the dorsal side. Very rarely it has an extra short spine at the center of the outer edge of one chamber like the spines on many chambers of *Asterorotalia multispinosa*. This species differs from *Asterorotalia trispinosa* in the ratio of its diameter to its thickness, in its dorsal and ventral sides not being parallel in transverse view, and in having curved dorsal sutures. It is known only from the Upper Miocene to Pliocene of western Taiwan and vanishes at a horizon at the top of the Cholan Formation.

Dimensions of figured specimen: Diameter (without spines) 0.70 mm., thickness 0.38 mm.

Asterorotalia trispinosa (Thalmann)

Plate 2, figure 10, plate 3, figure 9

Rotalia trispinosa THALMANN, 1933, Eclog. Geol. Helv., vol. 26, no. 2, pp. 249-250.

Streblus trispinosa (Thalmann). — ISHIZAKI, 1943, Taiwan Tigaku Kizi, vol. 14, nos. 3-4, p. 57, pl. 2, fig. 4.

Asterorotalia trispinosa is a useful stratigraphic index species, at the base of its range, throughout western Taiwan.

Asterorotalia trispinosa is characterized by its typical triangular outline, with three long spines, the comparatively small thickness and the almost straight dorsal sutures nearly perpendicular to the periphery. The three spines are placed on the three corners stretching out from the sutures on the dorsal side, and are much longer than those of *Asterorotalia subtrispinosa*.

This characteristic Indo-Pacific shallow-water form is quite common in the Malayan region, and is found in the Toukoshan Formation of western Taiwan.

Dimensions of figured specimen: Diameter (without spines) 0.62 mm., thickness 0.21 mm.

Genus *Pseudorotalia* Reiss and Merling, 1958

Although Reiss and Merling considered the range of the genus *Pseudorotalia* to be from the Pliocene to the Recent, it begins in the Miocene in Taiwan.

Pseudorotalia gaimardii (d'Orbigny)

Plate 1, figure 9; plate 3, figures 5-6

Rotalia (Turbinulina) gaimardii D'ORBIGNY, 1826, Ann. Sci. Nat., vol. 7, p. 275, no. 46 (*nom. nud.*). — FORNASINI, 1906, R. Accad. Sci. Ist. Bologna, Mem. Sci. Nat., ser. 6, vol. 3, pp. 67, 70, pl. 4, fig. 1.

Streblus papillosus (Brady). — ISHIZAKI, 1943, Taiwan Tigaku Kizi, vol. 14, nos. 3-4, pp. 57-58, pl. 2, fig. 1.

This Indo-Pacific form is common from the Upper Miocene to Pleistocene deposits of Taiwan and particularly abundant in the lower Gutingkeng Formation of southern Taiwan.

A detailed description of it is available in "Foraminifera from the Yurakucho Formation (Holocene) Tokyo City" by Ujiie (Tokyo Kyoiku Daigaku, Sci. Rep., sec. C, in press). Similar structure is found in the Taiwan specimens.

Dimensions of figured specimen: Diameter 0.58 mm., thickness 0.40 mm.

Pseudorotalia indopacifica (Thalmann)

Plate 1, figure 7; plate 3, figure 4

Rotalia indopacifica THALMANN, 1935, Eclog. Geol. Helv., vol. 28, no. 2, pp. 605-606 [= *R. schroeteriana* Cushman (not Parker and Jones or Brady), 1921, U. S. Nat. Mus., Bull. 100, vol. 4, p. 347, pl. 73, fig. 1].

Streblus indopacificus (Thalmann). — ISHIZAKI, 1940, Taiwan Tigaku Kizi, vol. 11, no. 2, p. 54, pl. 3, fig. 1; pl. 4, figs. 1-6.

Rotalia sp. NAKAMURA, 1942, Coll. Essay Geol. Pal. by the late M. Nakamura, pl. 15, fig. 3; pl. 16, fig. 2.

This widely distributed, shallow-water, Indo-Pacific form commonly occurs in the Miocene to Pleistocene formations of western Taiwan.

Pseudorotalia indopacifica is a species restricted to the Taiwan fauna in the Recent sea by Polski (1959). This species is like *Pseudorotalia schroeteriana schroeteriana* in inner structure, as confirmed in every particular by the writer, but the outer forms are different. The writer has examined well-preserved specimens of *Pseudorotalia schroeteriana schroeteriana* and *Pseudorotalia indopacifica*, and has found all the specimens of both species having the "intraseptal pores" (see plate 3, figures 4, 8). These "pores" are secondarily formed, being only present on the septal flap of well-preserved specimens. They are probably used for the passage of the protoplasm into the intraseptal spaces and then to the exterior.

Dimensions of figured specimen: Diameter 0.60 mm., thickness 0.34 mm.

Pseudorotalia schroeteriana schroeteriana

(Parker and Jones)

Plate 1, figure 12

Rotalia schroeteriana PARKER and JONES, 1862, in CARPENTER, Intr. Foram., p. 213, pl. 13, figs. 7-9.

"ROTALIA" GROUP OF TAIWAN

Rotalia conoides THALMANN, 1934, *Eclogae Geol. Helv.*, vol. 27, no. 2, p. 432, fig. 2. — NAKAMURA, 1942, *Coll. Essays. Geol. Pal.* by the late M. Nakamura, pl. 15, figs. 1–2.
Streblus schroeterianus (Parker and Jones). — ISHIZAKI, 1940, *Taiwan Tigaku Kizi*, vol. 11, no. 2, p. 56, pl. 3, figs. 5, 9; pl. 4, figs. 7–8.

This subspecies is very easily distinguished from *Pseudorotalia indopacifica* by its conical shape in apertural view, and is commonly found in the Upper Miocene to Pleistocene formations of Taiwan, especially in the Chinshui Shale. This is the most abundant tropical form of moderately shallow-water origin, and is often found in the Miocene to Pleistocene deposits of western Taiwan.

Dimensions of figured specimen: Diameter 1.30 mm., thickness 0.90 mm.

Pseudorotalia schroeteriana tikutoensis (Nakamura)
Plate 2, figure 9; plate 3, figures 7–8

Rotalia tikutoensis NAKAMURA, 1937, *Jap. Jour. Geol. Geogr.*, vol. 14, nos. 2–3, p. 141, pl. 12, fig. 7.

This subspecies has internal partitions, and therefore it should belong to this genus. Ishizaki reduced Nakamura's species to a subspecies of *Pseudorotalia schroeteriana*. According to the writer's observation of its occurrence, this opinion may be acceptable. *Pseudorotalia schroeteriana tikutoensis*, forma typica, is a useful index fossil, being known only from the Chinshui Shale and the base of the Cholan Formation. It is persistent and common only in the muddy facies, and has therefore been very rarely found in southern Taiwan. This subspecies is probably a most highly developed form of *Pseudorotalia schroeteriana schroeteriana* as Ishizaki observed. Perforated with rounded apertures on both sides, this form differs from *Pseudorotalia schroeteriana schroeteriana* in its relatively small thickness and larger umbilicus, and from *Pseudorotalia indopacifica* in that the diameter of the large umbilicus is nearly half that of the test and in that the dorsal and ventral sides are nearly parallel in transverse view. The outer form of this subspecies is shaped like a tambourine.

Dimensions of figured specimen: Diameter 2.65 mm., thickness 1.20 mm.

Pseudorotalia yabei (Ishizaki)
Plate 1, figure 5; plate 3, figures 3, 10–12

Streblus sp. ISHIZAKI, 1940, *Taiwan Tigaku Kizi*, vol. 11, no. 2, p. 55, pl. 3, figs. 7–8; pl. 4, fig. 20.

Rotalia sp. NAKAMURA, 1942, *Coll. Essays Geol. Pal.* by the late M. Nakamura, pl. 16, fig. 1.

Streblus yabei ISHIZAKI, 1943, *Taiwan Tigaku Kizi*, vol. 14, nos. 3–4, p. 53, pl. 1, figs. 2–3; 1948, *Acta Geol. Taiwanica*, vol. 2, no. 1, p. 63, pl. 1, fig. 3.

This species seems to appear for the first time in the upper sandstone member of the Nankang Sandstone and to continue as a relatively common form through the Upper Miocene and Pliocene. The lower limit of the range of this species has not been established definitely but is probably close to the base of the upper sandstone

member of the Nankang Sandstone of the Hsichih Group. It is especially abundant and widespread in the Sanhsia and Miaoli Groups.

This species has septal flaps, intraseptal passages and umbilical cavities, separated by pierced plates.

Although Ishizaki very carefully studied all of the species of *Streblus* in Taiwan, he never reported *Pseudorotalia yabei* as having a septal band and fissures remnant on both dorsal and ventral sides, probably because the remnant fissure structure is very hard to observe on the poorly preserved specimens, as Ishizaki remarked in regard to *Streblus tikutoensis* (1943b).

In general, older and more fossilized specimens tend to have simple walls without pores. The writer frequently observed that the Miocene species are like this.

Dimensions of figured specimen: Diameter 0.40 mm., thickness 0.80 mm.

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