

# Late Tertiary Planktonic Foraminifera from Southern Taiwan

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## ABSTRACT

The stratigraphic distribution and coiling patterns of 42 species and subspecies of planktonic Foraminifera were studied.

Six zones are newly proposed based upon the foraminiferal assemblages from the Hunghuatzu, Kueitangchi, Napalin and Chishan sections. These zones are correlated with those of the Caribbean region and the Philippines. Their order in upward sequence is: *Globorotalia fohsi robusta* Zone, *Globorotalia mayeri-Globoquadrina dehiscens advena* Zone, *Globigerina nepenthes-Pulleniatina obliquiloculata* Zone, *Sphaeroidinellopsis seminulina* Zone, *Globigerinoides quadrilobatus fistulosus* Zone and *Globorotalia inflata-Globorotalia truncatulinoides* Zone. Discussions are given on the zones based on the vertical ranges, characteristic coiling pattern, and joint occurrence of the diagnostic planktonic foraminiferal species.

The rock units in the area studied correspond to the Sankyo Group and Miaoli Group in northern Taiwan, and range in age from the Middle Miocene to Pleistocene. The Middle Miocene to Pliocene planktonic Foraminifera of Taiwan form an important tie for correlation between the tropical and temperate regions of the western Pacific region.

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## INTRODUCTION

The planktonic foraminiferal zones proposed by Bolli (1957) for the Trinidad Tertiary were accepted and followed by many micropaleontologists of the world who made correlation of their local biostratigraphic zones with the Trinidad zones. Bolli's zones are accepted in general as a standard for intercontinental correlation within the equatorial and subequatorial regions.

Previous foraminiferal studies have been concentrated to the planktonic forms of the Miocene or older deposits. However, presently there is an increasing tendency to study the stratigraphy and paleontology of the Upper Miocene, Pliocene, and Pleistocene planktonic Foraminifera, although much remains unpublished.

In Taiwan, since 1955 studies have been made, stratigraphically and paleontologically on the planktonic Foraminifera, chiefly of the Tertiary rocks. It has been found that the planktonic foraminiferal zones established in the Caribbean region can also be applied to Taiwan, although the fossil yield is sometimes not abundant.

Although some of the Caribbean planktonic foraminiferal zones have been recognized in western Taiwan (Chang, 1962), their actual upper and lower limits are mostly obscured by the repeated intercalation of thick paralic sediments.

In the attempt to search for additional evidence for the establishment of zones and the determination of the exact ranges of the planktonic Foraminifera in Taiwan, the writer concentrated on the stratigraphy and micropaleontology of southern Taiwan, where the marine deposits are thick and well developed.

The writer was fortunate to select four continuous sections in southern Taiwan for the study of the Late Cenozoic planktonic Foraminifera. The total thickness of the marine sediments in southern Taiwan is about ten thousand meters and these range in age from the Middle Miocene Sanmin Shale to the Pleistocene *Elephas-Stegodon* horizon. From the almost continuous four sections, called the Hunguatzu-, Kueitangchi-, Napalin-, and the Chishan sections, closely spaced samples were collected for study of the planktonic Foraminifera.

This article is the first of a systematic study of the Late Cenozoic planktonic Foraminifera in Taiwan, and is based upon the samples collected from the four sections mentioned above. The foraminiferal assemblages were analysed for the purpose of establishment of planktonic foraminiferal zones in the younger Tertiary in southern Taiwan, to clarify the stratigraphic relation of the Cenozoic rocks between northern and southern Taiwan and to contribute to the biostratigraphy of the western Pacific region.

#### ACKNOWLEDGEMENTS

The writer expresses his sincere gratitude to the undermentioned persons for their encouragement and help in many ways: Professors Kiyoshi Asano, Jun-Ichi Iwai, Kotora Hatai, Drs. Taro Kanaya, Nobu Kitamura, Tamio Kotaka and Yokichi Takayanagi of the Institute of Geology and Paleontology, Faculty of Science, Tohoku University.

Professor Ting-Ying H. Ma of the Department of Geology, National Taiwan University, China aided the writer for visiting the Institute of Geology and Paleontology, Tohoku University, Sendai, Japan for research. The writer is also indebted to the following persons for their support in various ways; Professor V. C. Juan of the Department of Geology, National Taiwan University, Mr. Te-Mei Wu, Vice President of Chinese Petroleum Corporation, Mr. C. Y. Meng, Chief Geologist of Chinese Petroleum Corporation, Mr. Stanley S. L. Chang, Chief of Geological Department, Taiwan Petroleum Exploration Division, CPC. The Chinese Petroleum Corporation for the free permission to take the materials to Japan for study. Dr. L. S. Chang of the Geological Survey of Taiwan for his valuable advice on the biostratigraphy of Taiwan, and Dr. T. P. Yen of the same office for his kind suggestions and encouragement. And, the National Council on Science Development for financial support.

#### REVIEW OF THE GEOLOGY

The Neogene System in western Taiwan is distributed in a belt extending nearly parallel to the axis of the island. It is, on the whole, composed of sediments which were deposited within a single sedimentary basin. The Neogene strata are folded, fractured into imbricated fault blocks and also brought into direct contact with various formations of the Paleogene on the east by a series of longitudinal reverse faults. The general

trend of the strata seems to indicate that the shoreline on the western side of the ancient land was nearly parallel to that of the present island. As a result, thick Tertiary strata are well developed in many continuous sections of the geosynclinal and marginal deposits.

The first work on the geology of Taiwan was published by Ishii (1897) in his Explanatory Text of the Map of the Geology and Mineral Resources of Taiwan (Formosa) in the scale of 1:800,000. He classified the Neogene deposits into two parts of northern and southern regions, of which the former is mainly composed of sandstone and shale associated with many coal seams whereas the latter is monotonously composed of sandy shale occasionally intercalated with sandstone and coralline limestone. Hence the northern Tertiary was considered to be of shallow water or subterrestrial origin and the southern of relatively deeper marine origin, though one grades gradually into the other.

The first comparatively detail work in southern Taiwan was by Iizuka (Oinouye, *et al.*, 1928). Among the stratigraphic units proposed the Upper Arisan, Byoritsu and Shokkozan Formations of Neogene age, in ascending order, were stated to be distributed throughout the island.

The first local geological survey was conducted by Torii, Yoshida, Rokkaku and Makiyama during 1932 to 1964 for the purpose of petroleum exploitation. Their works were in detail and accompanied with maps. They, based upon lithological characters, proposed the Mokusaku (or Kanshirei), Koteiko (or Unsui) and Kityo (or Zentaiho) Formations in ascending order for the rocks distributed in the areas where mapping was undertaken.

After the World War II, basic geological and paleontological works were progressed by the Geological Survey of Taiwan and the Taiwan Petroleum Exploration Division, CPC.

#### REVIEW OF PREVIOUS WORKS ON THE FORAMINIFERA

The first descriptions of the Foraminifera of Taiwan were by Newton and Holland, based upon the collections made by Koto. This work was published in the Journal of the Geological Society of Tokyo, vol. 7, no. 81, 1900. This work was succeeded by those of Yabe and Hanzawa, Hayasaka, Tan, Asano, Ishizaki, and Nakamura. Especially, Yabe and Hanzawa (1928, 1930) described several kinds of foraminiferous rocks from the Tertiary of Taiwan.

Since the World War II, the Geological Survey of Taiwan and the Chinese Petroleum Corporation have made extensive use of the Foraminifera. But, in general, the majority of the studies were concentrated on the benthonic Foraminifera. Since 1958, efforts have been directed towards research on the planktonic Foraminifera because of their importance in correlation.

The first systematic work on the Tertiary planktonic Foraminifera from Taiwan was published by L. S. Chang (1959), who studied many foraminiferal samples from various areas in western Taiwan. In 1963, he attempted a correlation between the Taiwan and Caribbean planktonic foraminiferal zones, and found that most of the species diagnostic for the zones in the Caribbean region also occur in the Neogene deposits of western Taiwan, and that the order of their appearance is also similar.

Although there are a few reports on the Foraminifera from southern Taiwan (Oinomikado and Huang, 1957a and 1957b; Huang, 1960b), nothing has been published on the planktonic foraminiferal fauna and their zoning in the Late Cenozoic sequence in southern Taiwan.

#### MATERIAL

The samples used for the biostratigraphic studies were all collected systematically at

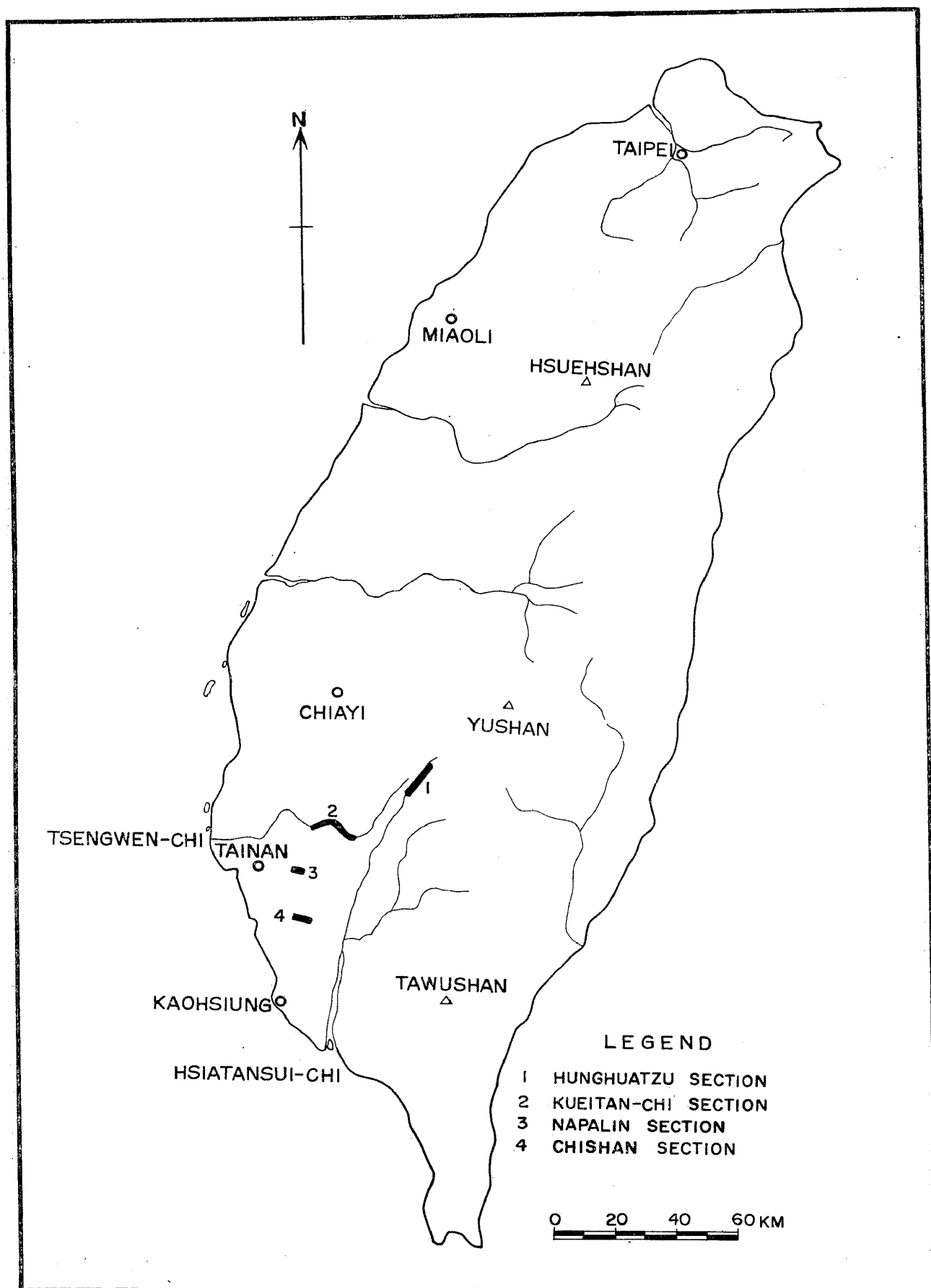


Fig. 1. Map of Taiwan showing the localities of the measured sections.

regular stratigraphic intervals from four geological sections in southern Taiwan (Fig. 1). The localities from where the samples were collected are shown in the sample locality map (Figs. 2-5). The geological age of the samples studied range from the Middle Miocene to the Pleistocene as inferred from the paleontological evidence of the foraminifers. The total thickness of the sediments is calculated to be approximately ten thousand meters.

Two hundred cubic centimeters of each of the samples was crushed into fragments with a rock crusher. The crushed material was placed in a jar, water was added and then left to stand for two or three days, after which the jars were rotated on a roller-mill for one or two hours. After disintegration, the samples were washed through a 60-mesh and 150-mesh sieves with water, and the residues on the sieves were dried in an oven. The Foraminifera were picked-up from the dried residues by the wetted tip of a thin bamboo stick under the binocular microscope.

Most of the samples yielded an abundant and diversified fauna of planktonic Foraminifera except those from the Changchikeng Formation and the Liushuan Formation. The Foraminifera are generally well-preserved in the samples of Pliocene and Pleistocene age, but usually ill-preserved from those of the Miocene deposits. They are generally filled with calcite to become discolored to a brown color and sometimes they are only partially observable due to adherence of the matrix or because of being deformed. For such reasons an accurate quantitative analysis of the foraminifers was not done. The stratigraphic distribution of each species and subspecies is shown in the range chart of the late Tertiary sediments of southern Taiwan (Chart 1).

Accordingly the analysis is concentrated to the vertical distribution of the foraminifers and to the change of the coiling patterns of the species and subspecies.

All the species are deposited in the Paleontological Laboratory of the Chinese Petroleum Corporation, China.

#### LOCATION OF SECTIONS AND GENERAL STRATIGRAPHY

The four surface sections already mentioned above are briefly described below and shown in Fig. 1 and Chart 1. The general stratigraphy of each of the four sections is also given.

I. The Hunghuatzu section is located about 15 km northeast of Chiahsien, Kaohsiung Hsien, and about 20 km northeast of the Chishan section. The dominantly marine sediments measured, about 3900 m in thickness, range from the Middle Miocene Sanmin Shale to the Upper Miocene Peiliao Shale (lower than the type formation, and probably equivalent to the Yenshuikeng Shale of the type locality) and are exposed along the Nantzuhsien-chi upstream from the axial part of the Hunghuatzu anticline. A series of 328 samples were collected from this section.

General Stratigraphy—The stratigraphic subdivision proposed by Chung (1962) for the Upper Cenozoic marine sequence in the Hunghuatzu anticline east of Kaohsiung is adopted. Since detailed descriptions of each formation are found in Chung's paper, duplication is here avoided. The stratigraphic sequence of the section is shown in the Table 1.

Based upon the results of paleontologic research and lithologic evidence the stratigraphic correlation between the Chutouchi and the Hunghuatzu sections is as shown in Table 2.

II. The Kueitanchi section is located near the Chutouchi oil-field, Tainan Hsien, where a sequence of shale and sandstone of about 3,500m in thickness is exposed along the Kueitanchi on the west flank of the Chutouchi anticline. A series of 184 samples were collected from this section and another supplementary section along the Niuchouchi which is along the southern border of the oil-field. The Kueitanchi section consists of two

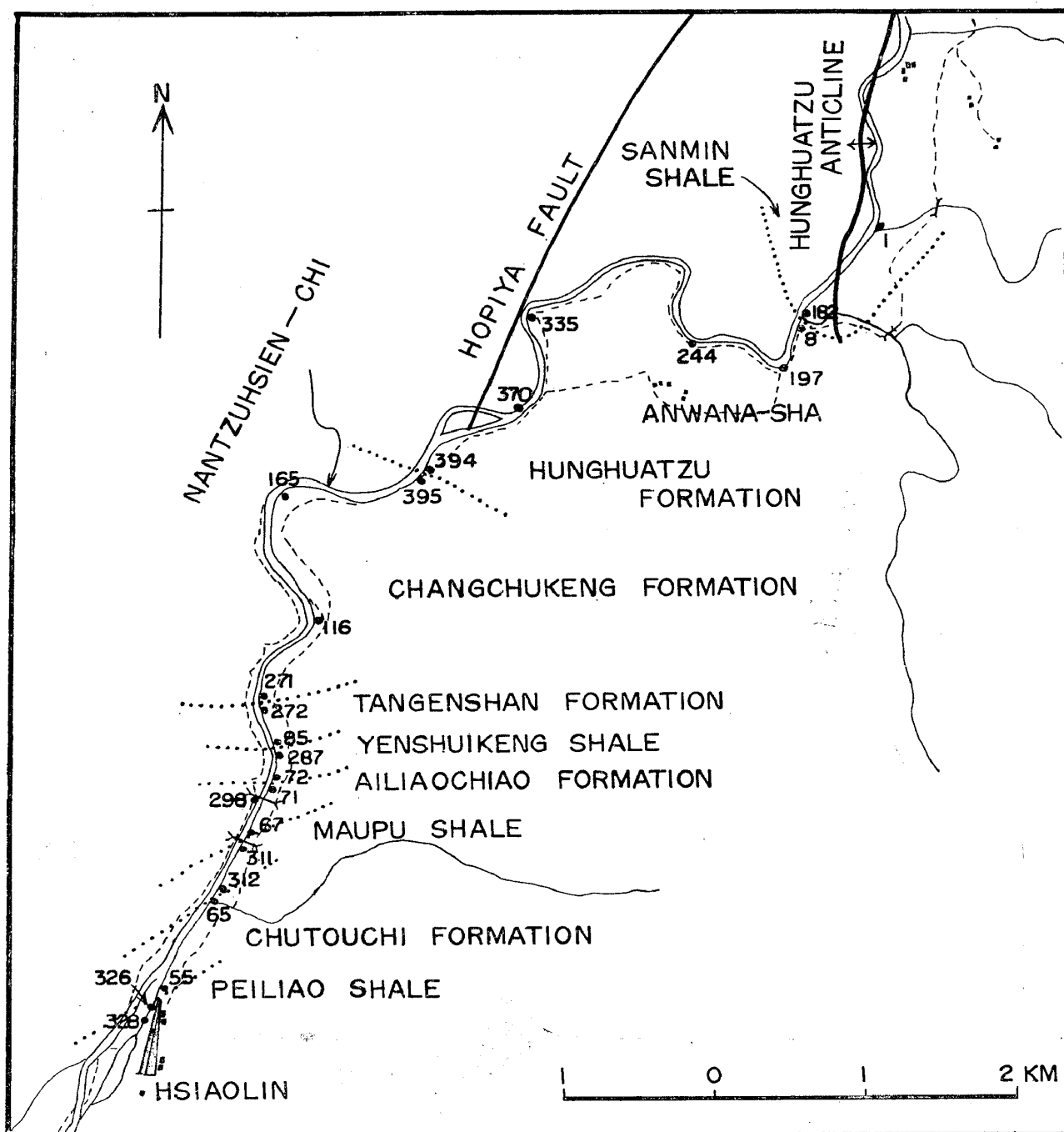


Fig. 2. Map showing localities of samples from the Hunghuatzu section of Nantzuhsien-chi, Kaoshung, Taiwan.

separated sections and covers a continuous sequence of sediments ranging from the Miocene Tangenshan Formation to the Pliocene Yuchin Shale.

General Stratigraphy — The stratigraphic classification of the Kueitanchi section now adopted by the Geological Department of the Taiwan Petroleum Exploration Division, CPC is given in Table 3.

III. The Napalin section is located at about 4 km east of Hsinhua, and about 14 km east of Tainan City, where an approximately 1960 m thick, continuous sequence of Pliocene-Pleistocene marine sediments are exposed on the southeast border of the Napalin

Table 1. Stratigraphic sequence of the Hunghuatzu section (after Chung, 1962).

Name of formation	Thickness (in meters)	Lithology
Peiliao Shale	+70	Dark gray shale intercalated with thin muddy sandstone.
Chutouchi	218	Gray, massive, muddy sandstone. Sandy shale in lower part, alternation of dark gray sandy shale and gray muddy sandstone.
Maupu Shale	164	Dark gray shale intercalated with thin muddy sandstone beds.
Ailiaochiao	272	Gray massive, muddy sandstone. Gray fine grained muddy sandstone with Foraminifera at base.
Yenshuikeng Shale	212	Dark gray shale intercalated with sandy shale and gray muddy sandstone.
Tangenshan Sandstone	264	Predominantly gray massive, muddy sandstone intercalated with three beds of dark gray sandy shale.
Changchihkeng	1305	Predominantly gray fine grained muddy sandstone and dark gray shale or sandy shale in alternation with thick micaceous, calcareous in part. And with two <i>Ostrea</i> beds in upper part. One <i>Operculina</i> bed at middle part and one <i>Ditrupe</i> bed at lower part.
Hunghuatzu	1206	Thin alternation of sandstone and shale with gray thick bedded sandstone, intercalated with dark gray shale.
Sanmin Shale	+800	Predominantly black gray compact shale intercalated with gray calcareous muddy sandstone and lenticular thin carbonaceous layers at lower part.

Table 2. Stratigraphic relation between the Chutouchi and Hunghuatzu anticlines.

Chutouchi Anticline (Chang and Chung, 1957)	Hunghuatzu Anticline (Chung, 1960)
Peiliao Shale Chutouchi Formation Maupu Shale Ailiaochiao Formation	
Yenshuikeng Shale	Peiliao Shale
Tangenshan Formation	Chutouchi Formation Maupu Shale Ailiaochiao Formation
Changchikeng Formation	Yenshuikeng Shale Tangenshan Sandstone Changchikeng Formation
	Hunghuatzu Formation
	Sanmin Shale

anticline. A series of 61 samples were collected from this surface section.

General Stratigraphy — The three undermentioned formations in Table 4, of the Napalin section are now in use by the Geological Department of the Taiwan Petroleum Exploration Division, CPC.

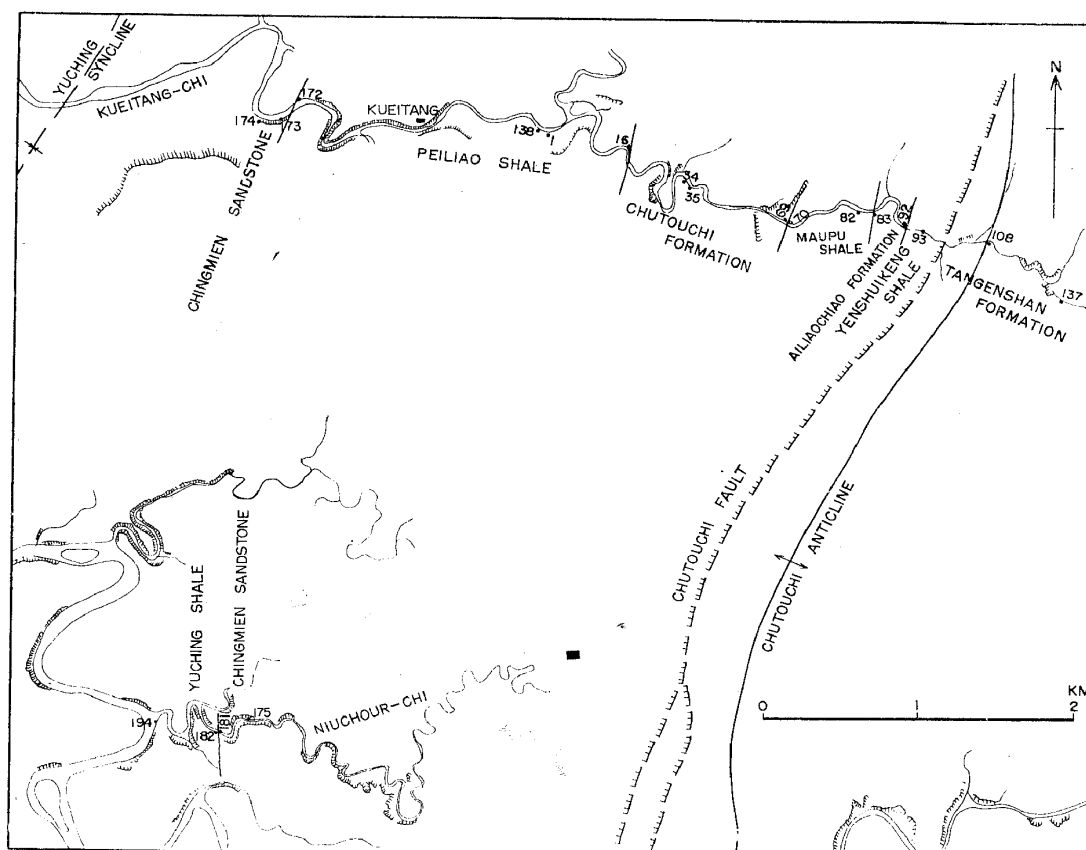


Fig. 3. Map showing localities of samples from the Kueitangchi section of Kueitangchi, Tainan, Taiwan.

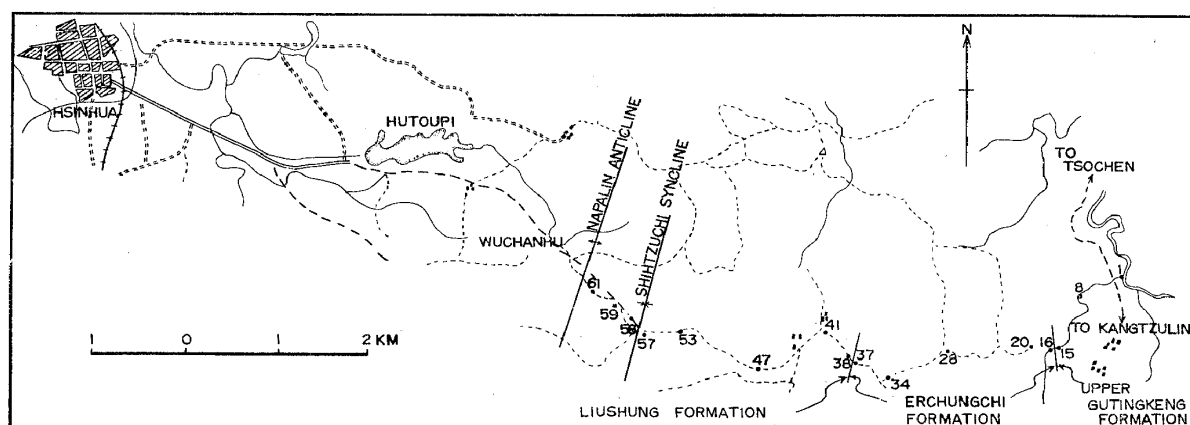


Fig. 4. Map showing localities of samples from the Napalin section, Tainan, Taiwan.

Hayasaka (1942) reported on the occurrence of many mammalian fossils from the Kityo Formation (=Liushung Formation) and many of them were collected by Kokubun and Kaneko. These for the purpose of reference are listed below:

- Elephas* cf. *trogotherii* Pohlig (similar to *E. namadicus*)
- Elephas indicus buski* Matsumoto
- Stegodon* cf. *sinensis* Owen
- Bibos geson* Matsumoto
- Cervus* (*Sika*) *taioanus* Blyth
- Cervus* (*Deperetia*) *kazusensis* (Matsumoto)



Table 3. Stratigraphic sequence of the Kueitanchi section.

Name of formation and thickness (in meters)	Lithology	Previous stratigraphic subdivision (Rokkaku & Makiyama, 1934)
Yuchin Shale (+200)	Bluish gray mudstone.	Unsui Formation
Chingmen Sandstone (130)	Yellowish gray or gray, medium to fine grained, loose sandstone with thin layers of bluish gray mudstone.	
Peiliao Shale (1200)	Gray or bluish gray sandy shale with occasional thin muddy sandstone and calcareous muddy sandstone beds with <i>Operculina</i> , of which one is in the upper part and the other is in the middle part of this shale.	
Chutouchi (750)	Gray fine to medium grained muddy sandstone with several gray sandy shale beds.	
Maupu Shale (350)	Dark gray shale interbedded with gray muddy sandstone and fine grained sandstone.	Kansirei Formation
Ailiaochiao (230)	Thin-bedded alternation of finely laminated shales and siltstone with occasional thin sandstone beds about 10 cm thick.	
Yenshuikeng Shale (170)	Dark gray shale with many thin sandstone beds averaging about 10–20 cm especially in the lower part.	
Tangenshan (+500)	Massive hard gray sandstone with dark gray shale.	
Anticlinal Axis		

Table 4. Stratigraphic sequence of the Napalin section.

Name of formation and thickness (in meters)	Lithology	Previous stratigraphic subdivision (Torii, 1932)
Liushung (+706)	Yellowish brown thick sandstone beds with dark gray mudstone. ( <i>Elephas-Stegodon</i> fauna).	Kityo Formation
Erhchungchi (855)	Gray sandstone and bluish gray mudstone in alternation, the sandstone is rather dominant in the lower part.	
Upper Gutingkeng (+400)	Dark gray shale with thin sandstone and sandy shale beds.	

*Cervus* sp. (aff. *Cervus* sp. of Schlosser)

*Tragocerus?* sp. (aff. *T. gregarius* Schlosser)

The details of the mammalian remains found *in situ* at Usenko, Daikobi, Sinka-gun, were given by Kaneko (1941). This horizon is stratigraphically equivalent to the uppermost part of the Napalin section and the locality of the fossil mammals is close to the western margin of the Napalin section. Mammalian remains are found sparsely in the conglomeratic sandstone which pebbles are of bluish gray soft shale. About 30 species of brackish water molluscs were collected by Kaneko in association with fragmentary specimens of a ramus and an antler of *Sika taiouana*.

IV. The Chishan section is located in the Chishan district and about 20 km southeast of Tainan City. A series of 350 samples were collected from an unbroken sequence of nearly 3,500 m thick marine sediments on the west flank of the Siaokunshui anticline, ranging from the Pliocene lower Gutingkeng Formation through the Pleistocene Liushuang Formation.

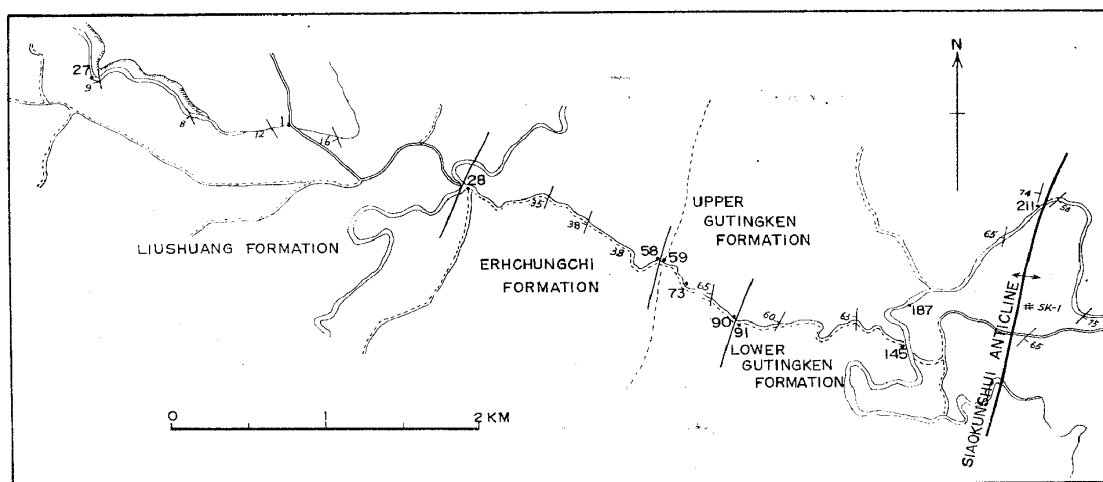


Fig. 5. Map showing localities of samples from the Chishan section, Kaoshung, Taiwan.

Table 5. Stratigraphic sequence of the Chishan section.

Name of formation and thickness [(in meters)]	Lithology	Previous stratigraphic subdivision (Torii, 1932)
Liushuang (+510)	Bluish gray mudstone with brown loose sandstone. Three <i>Ostrea gigas</i> beds at the base.	Kityo Formation
Erchungchi (680)	Yellowish brown medium grained sandstone member (410). Molluscan fossils scattered throughout the member.	
	Bluish gray shale (40) intercalated with thin loose sandstone beds.	
	Grayish brown muddy sandstone (230). Two thin pebbly beds with molluscan fragments at the base.	
Upper Gutingkeng (500)	Bedded sandy shale with occasional thin sandstone beds: distinguished from the more sandy and bedded facies, passes gradually downward into massive mudstone.	Koteiko Formation
Lower Gutingkeng (+1,590)	Massive mudstone with very rare, thin beds of sandy mudstone.	

General Stratigraphy — The Chishan section, consisting of several thousands of meters thick marine sediments, is subdivided into six lithologic units. The stratigraphic subdivision proposed by Leo W. Stach, is summarized in Table 5.

## PLANKTONIC FORAMINIFERAL ZONES

An analysis of the planktonic Foraminifera from the four sections resulted in the establishment of zones.

The Late Cenozoic formations of southern Taiwan may be biostratigraphically subdivided, by the assemblages of genera and species, and characteristic coiling pattern of the shells, into the following six planktonic foraminiferal zones and two poor zones.

8. 2nd poor fauna Zone (= *Elephas-Stegodon* fauna)
7. *Globorotalia inflata*-*Globorotalia truncatulinoides* Zone
6. *Globigerinoides quadrilobatus fistulosus* Zone
5. *Sphaeroidinellopsis seminulina* Zone
4. *Globigerina nepenthes*-*Pulleniatina obliquiloculata* Zone
3. 1st poor fauna Zone
2. *Globorotalia mayeri*-*Globoquadrina dehiscens advena* Zone
1. *Globorotalia fohsi robusta* Zone

Most of the species diagnostic for the zones established in the Caribbean region and the Philippines are also found in the present area of Taiwan, and their order of appearance and/or extinction are similar.

From the similarity in the appearances, extinction and coiling patterns of the various species which are correlative with the Caribbean region and the Philippines, the zonal boundaries in southern Taiwan can be defined with reference to one or two species or subspecies and the characteristic coiling pattern of the foraminifers.

The zonation adopted in the present article principally follows those of Bolli (1957), Blow (1959), and Bandy (1964). The boundaries of the zones are shown in Chart 1 and the planktonic Foraminifera yielded from the four sections are given in the same chart.

The zones mentioned above are described briefly in ascending order as follows:

1. *Globorotalia fohsi robusta* Zone.

This zone is characterized by the restricted occurrence of the marker species *Globorotalia fohsi robusta* in association with *Globorotalia menardii praemenardii*. The planktonic fauna is rather small and comprises 20 species and subspecies, some of which become extinct at different intervals within the overlying zones. The top of the zone is defined by the extinction of *Globorotalia fohsi robusta* and *G. menardii praemenardii*. *Globorotalia menardii menardii* and *Globigerina nepenthes* make their first appearance at the upper part of this zone. *Orbulina universa*, *Globorotalia mayeri* and *Globoquadrina venezuelana* are present in all of the assemblages.

The base of the zone is not recognized in the Hunghuatzu section, because the base of the Sanmin Shale is not exposed.

The specimens of *Globorotalia fohsi robusta* resemble the ones reported by Bandy (Jenkins, 1965) from the Philippines. The specimens questionably referred to *G. fohsi robusta* are forms transitional between that subspecies and *G. menardii menardii*. They have thicker test with less pronounced sutures compared with the typical *G. menardii menardii*.

2. *Globorotalia mayeri*-*Globoquadrina dehiscens advena* Zone.

This zone spans the uppermost part of the Sanmin Shale and the Hunghuatzu Formation in the section of the Hunghuatzu anticline. This zone is characterized by the continuous presence of *Globorotalia mayeri* and *Globoquadrina dehiscens advena* after the extinction of *Globorotalia fohsi robusta* and *G. menardii praemenardii*. A significant feature is an abrupt change in the coiling direction (from strictly sinistral to exclusively dextral) of *G. mayeri* at the base of the zone.

This zone is rather poor in planktonic Foraminifera and the specimens are ill preserved. The top of the zone is defined by the extinction of *Globorotalia mayeri* and *Globoquadrina dehiscens advena*.

### 3. 1st poor fauna Zone.

This arbitrary zone occupies the lower half of the Changchikeng Formation and rarely yields planktonic Foraminifera, probably due in part to the environmental control. However, some samples from isolated localities yielded fairly rich planktonic assemblages composed of *Globorotalia menardii menardii*, *Globigerina nepenthes*, *Orbulina universa*, *Globoquadrina dehiscens*, *Gq. venezuelana*, and *Gq. altispira* besides others.

The upper limit of this zone is defined by the first appearance of *Pulleniatina obliquiloculata*, and the lower limit just above the horizon of extinction of *Globorotalia mayeri* and *Globoquadrina dehiscens advena*.

### 4. *Globigerina nepenthes*-*Pulleniatina obliquiloculata* Zone.

This zone is distinguished by the continuation of *Globigerina nepenthes* which coexists with *Pulleniatina obliquiloculata* and the absence of *Globorotalia menardii*. The top of the zone is defined by the extinction of *Globigerina nepenthes*. *Pulleniatina obliquiloculata* first appears in the lowest part of the zone and shows sinistral coiling. *Globigerina dutertrei* and *Globorotalia menardii miocenica* also appear at the upper part of this zone. The planktonic fauna becomes abundant at the upper part and continues into the youngest zones. *Sphaeroidinella dehiscens* first appears in the uppermost part of this zone and continues into the youngest zone. *Globorotalia menardii menardii* becomes more abundant in the topmost part of this zone.

### 5. *Sphaeroidinellopsis seminulina* Zone.

This zone is characterized by the coexistence of *Sphaeroidinellopsis seminulina* and dextrally coiled specimens of *Pulleniatina obliquiloculata*, and the continuing presence of *Sphaeroidinellopsis seminulina*, *S. seminulina kochi*, and *Sphaeroidinella dehiscens*. *Globorotalia menardii menardii* is often abundant. *Globorotalia menardii multicamerata*, *Globigerinoides quadrilobatus fistulosus* and *Sphaeroidinella dehiscens* occur for the first time within this zone. A significant feature is the abrupt change in the coiling direction (from sinistral to dextral) of *Pulleniatina obliquiloculata* in the lower part of the zone and the dextral coiling direction of *Globorotalia menardii menardii* in the upper part of the zone. The top of this zone is defined by the extinction of *Globoquadrina altispira*, *Gq. dehiscens*, *Sphaeroidinellopsis seminulina* group and some other characteristic Miocene species.

### 6. *Globigerinoides quadrilobatus fistulosus* Zone.

This zone is characterized by the continuation of *Globigerinoides quadrilobatus fistulosus* and the absence of the *Sphaeroidinellopsis seminulina* group and other diagnostic Miocene species. *Globigerinoides quadrilobatus fistulosus* may have developed from a gerontic phase of *Globigerinoides quadrilobatus sacculifer*. *Globigerinoides quadrilobatus sacculifer* becomes abundant and typical in the upper part of the underlying zone. A significant feature is the abrupt change in the coiling direction of *Pulleniatina obliquiloculata* (from dextral to sinistral) and of *Globorotalia menardii menardii* (from dextral to sinistral) at the base of this zone.

The top of this zone is defined by the first appearance of *Globorotalia crassaformis*, *G. inflata* and *G. truncatulinoides*, after the extinction of *Globigerinoides quadrilobatus fistulosus*.

The foraminiferal assemblage of this zone is characterized by *Globigerinoides quadrilobatus fistulosus*.

### 7. *Globorotalia inflata*-*Globorotalia truncatulinoides* Zone.

This zone is characterized by *Globorotalia crassaformis*, *G. inflata*, *G. truncatulinoides*, and *Globigerinoides elongatus* which first appear at the base of the zone and are restricted to it.

It is difficult to define the top of the zone in the sections (the Chishan and Napalin sections) probably because of the environmental change. At present, the top of this zone

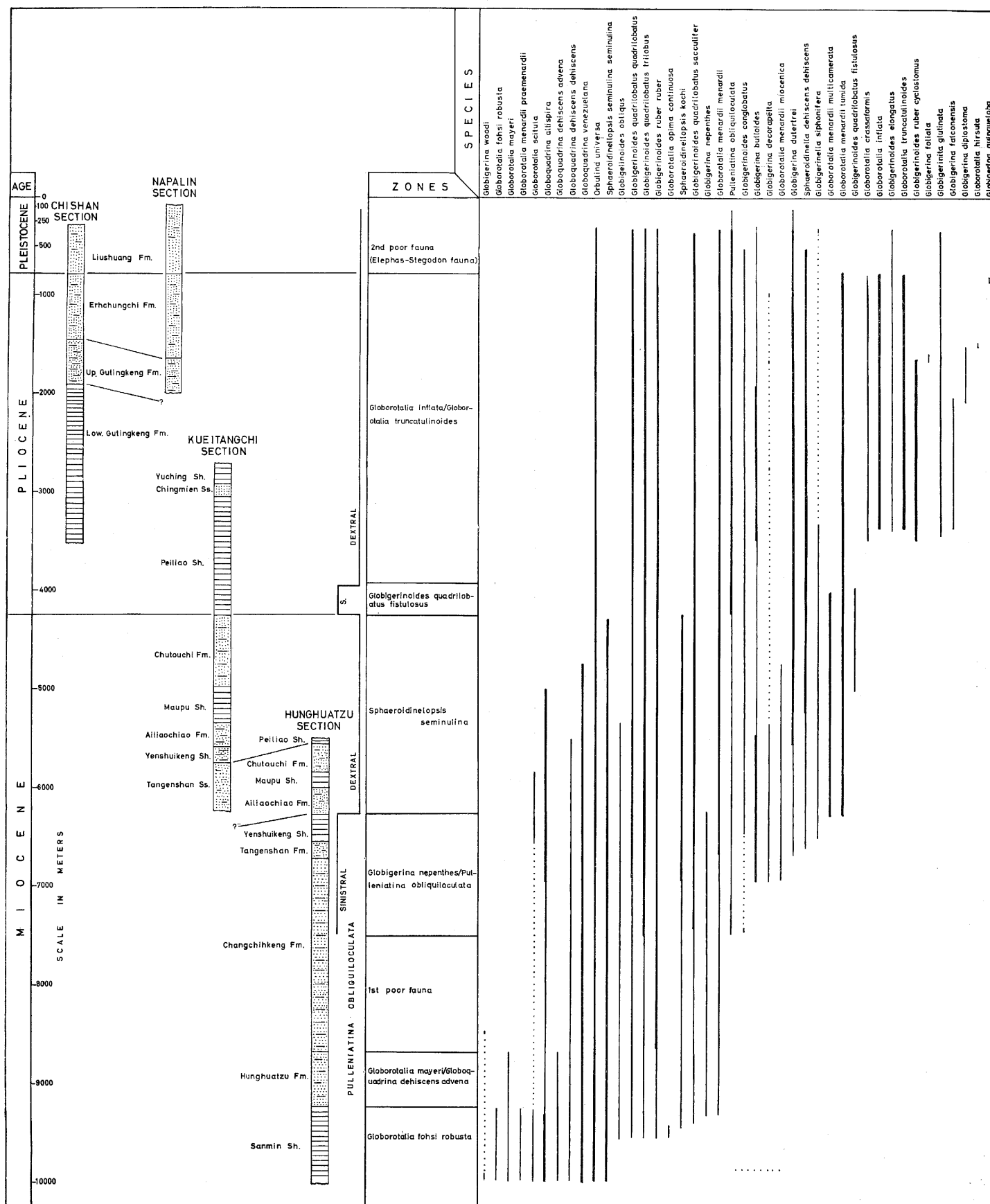


Chart 1. The zonal succession and distribution of planktonic Foraminifera within the Late Cenozoic of the four sections in southern Taiwan.

is distinguished by the abruptly decreased abundance or disappearance of most of the planktonic Foraminifera. And, the upper limit of this zone is tentatively regarded as corresponding to the upper boundary of the Erhchungchi Formation.

An interesting feature of the zone is the abrupt change in the coiling direction of *Globorotalia menardii menardii* (from sinistral to dextral) in the upper part of the Erhchungchi Formation.

8. 2nd poor fauna Zone. (= *Elephas-Stegodon* fauna)

This zone is very poor in fossil Foraminifera and moreover, is frequently lacking in planktonic Foraminifera. It is characterized by the *Elephas-Stegodon* fauna. The base of this zone is defined by the extinction of *Globorotalia inflata* and *G. truncatulinoides*.

This zone is almost equivalent to the Liushuang Formation. The top of the zone is not exposed in the sections studied, and the formation is almost barren in fossil Foraminifera, therefore it is difficult to define it at present.

### COILING PATTERNS AND STRATIGRAPHIC RANGES

Many foraminiferologists have paid attention to the coiling pattern of some planktonic Foraminifera through the geological column because of its value in age determination or in regional and inter-regional correlation.

Bolli (1950, 1951, and 1957) used the changes in coiling direction ratios of certain species of planktonic Foraminifera as stratigraphic markers in the Tertiary sequence of Trinidad. Subsequently some paleontologists followed this method (Akers, 1955; Nagappa, 1957; and Jenkins, 1960).

Recently, Bandy (1963a, 1963b, and 1964) and Bolli (1964) made notable contributions on the coiling pattern of certain planktonic species of Foraminifera in the formations of the Late Cenozoic age. They have shown that the coiling just mentioned is useful and aids in accurate correlation. Jenkins (1965), however, once mentioned the possibility of a pitfall in use of only the changes in coiling ratios for correlations. However, such change is characteristic and is found in *Globorotalia menardii menardii* and *Pulleniatina obliquiloculata* in the Miocene-Pliocene rocks of Venezuela, Philippines, Java, Japan (Asano and Takayanagi, 1965) and Taiwan (this article). This shows that the coiling ratios of certain species of planktonic Foraminifera are useful for correlations.

The use of the stratigraphic ranges of certain diagnostic planktonic Foraminifera for age determination and correlation is well known and in practice today. However, not all the initial appearances and extinctions have equal value as time markers, because such may be influenced by the changing ecological conditions, affecting the survival of some species (Table 6). For instance most of the planktonic Foraminifera become extinct at the top of the *Globorotalia inflata*-*Globorotalia truncatulinoides* Zone of southern Taiwan.

Some of the interesting species are discussed below and the other species from the southern Taiwan sections are shown in Table 6 and Chart 1.

*Pulleniatina obliquiloculata* (Parker and Jones) is one of the more interesting species for stratigraphic correlation. The four known distinct zones of coiling directions during its stratigraphic range are also found in the present sections. This species first appears in the lower part of the *Globigerina nepenthes*-*Pulleniatina obliquiloculata* Zone; all are coiled sinistrally throughout this zone and associated with *Globigerina nepenthes* Todd. After the extinction of *G. nepenthes*, *Pulleniatina obliquiloculata* changes to dextral coiling.

At the basal part of the Peiliao Shale, this species is coiled sinistrally. This coiling apparently corresponds with the second sinistral coiling phase of Bandy, which according to him, marks the base of the Pliocene (Bandy, 1963a, 1963b, and 1964). Bolli (1964) found the same patterns of coiling in Java and Venezuela, and Asano and Takayanagi (1965) reported a similar occurrence in Japan. As mentioned above, this characteristic coiling of *P.*



*fohsi robusta* in the topmost Burdigalian. Its occurrence in Taiwan coincides with that of *Globorotalia menardii tumida* in Bodjonegoro-1 in Java (Bolli, 1964). It shows almost exclusively dextral coiling throughout the species range in southern Taiwan.

*Globorotalia menardii menardii* (d'Orbigny) in the Kueitangchi section, shows the same pattern of coiling as the specimens of the Philippines. This species shows random coiling in the Hunghuatzu section and in the middle part of the *Sphaeroidinellopsis seminulina* Zone of the Kueitangchi section it tends to dextral coiling. With the appearance of the second horizon of sinistral coiling of *Pulleniatina obliquiloculata* at the base of the Pliocene, there is an abrupt switch to sinistral coiling and this direction persists throughout its ranges in the sections studied. At the upper part of the Erchungchi Formation, this species changes to dextral coiling again. The characteristic coiling pattern of *Globorotalia menardii menardii* during its Upper Miocene-Lower Pliocene range is probably of significance as also shown by the coiling pattern of *Pulleniatina obliquiloculata* in the early part of its range.

In northern Taiwan, *Globorotalia menardii menardii* occurs sporadically only throughout the Sankyo Group, and sometimes it appears in great abundance in the upper half (Chang, 1962). In the Miocene of northern Taiwan, the *menardii-tumida* group indicates the Sankyo Group and its equivalents.

From the studies on the coiling ratios of the *menardii-tumida* group, it is found that, *G. menardii menardii* and *G. menardii tumida* should be taxonomically held separate, because the coiling patterns differ as already mentioned above.

*Globigerina dutertrei* d'Orbigny in the southern Taiwan sections shows dextral coiling throughout its observed ranges and first appears in the uppermost part of the *Globigerina nepenthes* Zone. This first occurrence is similar to that in Bodjonegoro-1 recorded by Bolli (1964).

*Globoquadrina altispira* Cushman and Jarvis, *Globorotalia menardii miocenica* Palmer, and *G. menardii multicamerata* Cushman and Jarvis were described from the Miocene of Jamaica. Although, Haque has observed *Globoquadrina altispira* in the Miocene and Pliocene of the Mekran coastal region of Pakistan (Akers and Dorman, 1964) its details have not been described. Pessagno (1964) reported some Recent specimens of *Globorotalia menardii miocenica* from the Atlantic Ocean and from the coastal and offshore regions of Louisiana; it is considered to be a guide fossil for the Lower Pliocene. However, up to the present, these two species have not been reported from formations younger than the Miocene in the western Pacific region. In the southern Taiwan sections, *Globoquadrina altispira* is restricted to the Miocene formations; *Globorotalia menardii miocenica* is found only in the *Globigerina nepenthes* Zone and *Sphaeroidinellopsis seminulina* Zone; and *Globorotalia menardii multicamerata* appears in the *Sphaeroidinellopsis seminulina* Zone and ranges up into the overlying younger horizons.

In southern Taiwan, *Globorotalia truncatulinoides* (d'Orbigny) first appears after the second stage of sinistral coiling of *Pulleniatina obliquiloculata* and does not occur as in the Philippines at the base of the Pliocene (Bandy, 1963a, and 1963b). The observed range of *Globorotalia tosaensis* Takayanagi and Saito, a related species, is similar to that of this species in southern Taiwan.

Both species mentioned above show dextral coiling throughout their ranges. *Globorotalia tosaensis* has never been found in the Miocene formations of Taiwan but was reported from the Pliocene formations of eastern Taiwan (Huang, 1964, pl. 1, fig. 13). *Globorotalia tosaensis* Takayanagi and Saito, 1963, has been reported from the Pliocene or younger formations outside of the type locality.

The two planktonic species which have not been recorded from sediments as old as the Miocene are *Globorotalia inflata* and *G. truncatulinoides*. These two species have been



reported from the Italian Pliocene.

*Sphaeroidinella dehiscens dehiscens* (Parker and Jones), is a species commonly found in the recent tropical and subtropical seas. This species in southern Taiwan first appears in the *Sphaeroidinellopsis seminulina* Zone. The early occurrence of this species is also recorded in Japan in the *Globorotalia menardii menardii*-*Globigerina nepenthes* Zone by Takayangai and Saito (1962), and Asano and Takayanagi (1965). Such an occurrence has also been reported by Bandy (1963a and 1963b) from the Philippines. Todd (1957, p. 279, table 3, pl. 79, fig. 8) reported the species from the Donni Sandstone Member of the Tagpochau Limestone on Saipan. This is the record of its oldest occurrence, if the Donni Sandstone is really correlative with the Aquitanian Tagpochau Limestone.

In Taiwan, *Sphaeroidinella dehiscens dehiscens* is common in the Sankyo Group, especially in the Shihliufeng Sandy Shale.

### CORRELATION AND AGE

Based on the zones already described, an attempt is made to correlate them with those which have been established outside this region. Using planktonic Foraminifera, Bolli (1957) has divided the Cipero Formation of Trinidad into 13 planktonic foraminiferal zones, Blow (1959) applied the scheme to a Venezuela sequence and recently Bandy (1963a and 1963b) in his study of the Philippines Tertiary rocks was able to correlate his zones with those established by Bolli. This direct correlation was made possible by use of the planktonic foraminiferal populations.

The correlations are based on the synchronicity of initial occurrences and extinctions, close affinity of faunal associations, aspect of coiling patterns and stratigraphic ranges of several planktonic species common to the areas in question.

For the present study the recent paper of Bandy (1964) was taken as an important reference, mainly because of its being the first systematic study in the tropical western Pacific region.

A suggested correlation of the southern Taiwan planktonic foraminiferal zones with those established by Bolli (1957) in Trinidad, by Blow (1959) in Venezuela, by Bandy (1963a, 1963b, and 1964) in Philippines, and by Saito (1963) in Japan are discussed and shown in Table 7.

The six most useful species for close stratigraphic assignment in the Miocene are *Globorotalia fohsi robusta*, *G. menardii praemenardii*, *G. menardii menardii*, *G. mayeri*,

Table 7. A proposed correlation of the biostratigraphic zones established in southern Taiwan with those proposed by Bolli in Trinidad, by Blow in Venezuela, by Saito in the Miocene of Japan, and by Bandy in the Philippines.

BOLLI, 1957	BLOW, 1959	BANDY, 1964	HUANG	SAITO, 1963
			2nd poor fauna	
		<i>Globorotalia crassaformis</i>	<i>Globorotalia inflata</i> / <i>Globorotalia truncatulinoides</i>	
	<i>Globigerina bulloides</i>	<i>Globorotalia puncticulata</i>	<i>Globigerinoides quadrilobatus fistulosus</i>	
<i>Globorotalia menardii</i>	<i>Sphaeroidinella seminulina</i>	<i>Globaquadrina dehiscens</i> / <i>Sphaeroidinellopsis seminulina subdehiscens</i>	<i>Sphaeroidinellopsis seminulina</i>	<i>Sphaeroidinella seminulina</i>
	<i>Globorotalia menardii menardii</i> / <i>Globigerina nepenthes</i>	<i>Globigerina nepenthes</i>	<i>Globigerina nepenthes</i> / <i>Pulleniatina obliquiloculata</i>	<i>Globorotalia menardii menardii</i> / <i>Globigerina nepenthes</i>
<i>Globorotalia mayeri</i>	<i>Globorotalia mayeri</i> / <i>Globigerina nepenthes</i>	<i>Globorotalia mayeri</i> / <i>Globaquadrina altispira altispira</i>	1st poor fauna	<i>Globorotalia mayeri</i> / <i>Globigerina nepenthes</i>
	<i>Globorotalia mayeri</i> / <i>Globorotalia linguensis</i>	<i>Globaquadrina dehiscens advena</i>	<i>Globorotalia mayeri</i> / <i>Globaquadrina dehiscens advena</i>	
<i>Globorotalia fohsi robusta</i>	<i>Globorotalia fohsi robusta</i>	<i>Globorotalia fohsi robusta</i>	<i>Globorotalia fohsi robusta</i>	<i>Globorotalia bykovae</i>

*Globigerina nepenthes*, and *Sphaeroidinellopsis seminulina*. And useful species are such as *Globoquadrina dehiscens advena*, *G. altispira altispira* and *G. altispira globosa* as already suggested by Bandy (1964). The upper limit of these species tentatively indicate, according to Bandy, the Helvetian, Tortonian, and Pontian or Uppermost Miocene respectively.

The first appearance of *Globorotalia menardii menardii* in a continuously deposited sequence of open sea sediments has been suggested by Bandy (1964) as constituting an important datum plane within the Late Tertiary.

As stated above, *Globorotalia menardii menardii* first appears in Trinidad at a level higher than the first appearance of *Orbulina universa*; that is, rarely in the uppermost part of the *Globorotalia fohsi* Zone (s.l.) and more abundantly in the *Globorotalia mayeri* and *G. menardii* Zone of the Upper Miocene. This species seems to be a good guide among the planktonic Foraminifera available to define the lower limit of the Hunghuatzu Formation in age.

In the Pozón Formation, Blow (1959, chart 3) records the extinction of *Globorotalia menardii praemenardii* almost with *Globorotalia fohsi robusta* just before the *Globorotalia mayeri* Zone. Bandy (1964) also records that both species become extinct at the end of the Burdigalian *Globorotalia fohsi* Zone. Thus, it can be accepted that these extinction levels are contemporaneous and have important significance. Although *Globorotalia fohsi robusta* from southern Taiwan is not a typical form its extinction is simultaneous with *Globorotalia menardii praemenardii*. The time of extinction of the latter species is generally recognized as equal to that of *Globorotalia fohsi* (s. l.), at the top of the Burdigalian. And, better still, *Globorotalia menardii menardii* first appears within the uppermost part of the Sanmin Shale. In the Hunghuatzu section, the Sanmin Shale is correlated with the upper part of the *Globorotalia fohsi robusta* Zone of Blow, as indicated by the association of the species mentioned above. The writer tentatively places the Helvetian-Burdigalian boundary at the top of the *Globorotalia fohsi robusta* Zone in southern Taiwan.

The extinction of *Globoquadrina dehiscens advena* is considered by Bandy (1963a and 1964) as useful to define the top of the Helvetian. The planktonic fauna of the Hunghuatzu Formation is rather impoverished in the section. *Globoquadrina dehiscens advena* occurs sporadically within the formation and becomes extinct at its uppermost part. Although the possibility exists that the upper limit of this species is influenced to some extent by facies change of the superjacent formation. The writer now tentatively places the upper boundary of the Helvetian at the top of the *Globorotalia mayeri*-*Globoquadrina dehiscens advena* Zone in the Hunghuatzu section of southern Taiwan. The Hunghuatzu Formation is correlated with the *Globorotalia mayeri*-*Globorotalia linguaensis* Subzone of Blow, and the *Globoquadrina dehiscens advena* Zone of Bandy. According to Bandy (1964) the extinction of *Globorotalia mayeri* marks the top of the Tortonian. Accidentally, in southern Taiwan, this species becomes extinct at the same time as *Globoquadrina dehiscens advena* in the section studied but such may not be its true range.

Bandy (1963a and 1963b) pointed out that the Tortonian-Sarmatian boundary is marked by the upper limit of *Globoquadrina altispira altispira* in the Philippines section, and that *Globoquadrina altispira globosa* survives up to the Pontian or uppermost Miocene. But the specimens of *G. altispira globosa* in southern Taiwan because of their poor preservation, is hard to distinguish from *G. altispira altispira*. Thus the stratigraphic distribution of these species can not be determined in the present study.

The writer tentatively places the Tortonian-Sarmatian boundary at the base of the *Globigerina nepenthes*-*Pulleniatina obliquiloculata* Zone in the Hunghuatzu section. The lower limit of this zone may not correspond to the upper limit of Bandy's *Globorotalia mayeri*-*Globoquadrina altispira altispira* Zone of the Philippines because of the subjacent zone

lacking diagnostic species in the former locality for such correlation.

The first poor fauna Zone is recognized in the lower part of the Changchihkeng Formation, and in it the planktonic foraminiferal species are only very sparingly present. There are no planktonic species diagnostic for zoning or age assignment.

*Globigerina nepenthes* is another well-known species in the Caribbean region. In Trinidad *G. nepenthes* occurs in the *Globorotalia mayeri* and *G. menardii* Zone of the Upper Miocene and its stratigraphic range is rather restricted. This species was originally described by Todd from the Miocene Donni Sandstone Member of Saipan, Mariana Islands in 1957. The geologic and geographic distribution of this species has been discussed by Saito (1962). However, Jenkins (1964, text-fig. 1) observed *Globigerina nepenthes* as ranging through the Upper Miocene to the Lower Opoitian in New Zealand. Except for the above record this species has not been recorded as occurring above the Miocene in the western Pacific region. And its initial appearance was earlier than in the Caribbean region. The time of extinction of this species is useful for correlation. Therefore, it provides additional evidence for the correlation of the upper Changchihkeng Formation (the Hunghuatzu section includes the so-called Tangenshan Formation and the Yenshuikeng Shale) with the *Globorotalia menardii menardii*-*Globigerina nepenthes* Zone of Bolli and the Sarmatian *Globigerina nepenthes* Zone of Bandy.

*Globorotalia menardii menardii* and *G. menardii tumida* become richer in the upper part of the *Globigerina nepenthes* Zone and there on upwards they resemble the occurrence of those species in northern Taiwan (Chang, 1963).

These Miocene species are conspicuously absent in the *Globigerina bulloides* Zone in the Caribbean area (Bolli, 1957; Blow, 1959). The *Sphaeroidinellopsis seminulina* Zone of southern Taiwan without *Globigerina nepenthes* is correlative with the Caribbean *Sphaeroidinellopsis seminulina* Zone and the Philippine *Globoquadrina dehiscens*-*Sphaeroidinella seminulina subdehiscens* Zone.

The planktonic foraminiferal fauna of the Chutouchi Formation and its subjacent formation are distinctly Miocene in character, containing many of the species common in the Middle Miocene. The foraminiferal evidence to define the Miocene-Pliocene boundary is not particularly clear-cut, and depends heavily on the extinction of Miocene species and initial appearance of Pliocene species. However, the change of the coiling pattern in certain planktonic species may be our greatest hope for correlation.

According to Bandy, the first abundant appearance of *Sphaeroidinella dehiscens dehiscens* in geologic time is important (the *Sphaeroidinella dehiscens* datum). In the southern Taiwan sections, the writer has not observed any horizon of numerical "bursts" of *Sphaeroidinella dehiscens dehiscens*. The occurrence of this species shows a gradual increase from the upper part of the *Sphaeroidinellopsis seminulina* Zone in southern Taiwan. Thus the writer finds it difficult to accept the *Sphaeroidinella dehiscens* datum as the Miocene-Pliocene boundary in this article.

The writer now suggests that the Miocene-Pliocene boundary should be defined by the extinction of the *Sphaeroidinellopsis seminulina* group and the base of Bandy's second sinistral coiling of *Pulleniatina obliquiloculata*. And the name of *Sphaeroidinella dehiscens* datum is liable to cause misunderstanding, and so should be reconsidered.

In the southern Taiwan sections (the Chishan section and Napalin section), after the extinction of *Sphaeroidinellopsis seminulina seminulina* and other characteristic Miocene species the strata become defined by the species which are known to be common in the Pliocene or younger sediments (*Globorotalia inflata*, *G. truncatulinoides*, etc.).

According to Blow (1959), the *Globigerina bulloides* Zone is poor in planktonic foraminiferal assemblages and only some isolated samples show fairly rich planktonic foraminiferal assemblages. Occasional specimens of *Sphaeroidinella dehiscens subdehiscens*

occur, but no species of the *Sphaeroidinellopsis seminulina* group have been observed. However, *S. dehiscens subdehiscens* is generally recognized to range into the lowest part of the Pliocene (Bandy, 1964, text-fig. 6).

Thus the *Globigerinoides quadrilobatus fistulosus* Zone is tentatively considered as equivalent to the lower part of the *Globigerina bulloides* Zone of the Caribbean region (Bolli, 1957; Blow, 1959) and to the *Globorotalia puncticulata* Zone of the Philippines (Bandy, 1963a, 1963b, and 1964).

Consequently, the writer considers that the *Globorotalia inflata*-*Globorotalia truncatulinoides* Zone is the Middle to Upper Pliocene in age.

The sections in southern Taiwan are not suitable for studying the Pliocene-Pleistocene boundary, because the foraminiferal fauna shows a tendency towards impoverishment.

At present there is little microfaunal evidence to indicate a change in environment at the base of the Upper Guttingkeng Formation; the overlying Lihhsuang Formation represents a littoral facies. For that reason, the Pliocene-Pleistocene boundary based on the planktonic Foraminifera alone is difficult. Of course, the Pliocene-Pleistocene boundary can be roughly determined at present on other paleontological and lithological data. In this article, the boundary is tentatively placed at the top of the *Globorotalia inflata*-*Globorotalia truncatulinoides* Zone in the sections studied in southern Taiwan.

The 2nd poor fauna Zone which yielded the *Elephas-Stegodon* fauna may belong to the Lower Pleistocene in age.

The planktonic Foraminifera bearing formations recognized in southwest Japan, the Ryukyu Islands, and Taiwan are checked against the published foraminiferal data and the opinions are briefly discussed as follows.

Since there only a few studies on the Late Cenozoic planktonic foraminiferal fauna of southwestern Japan detailed discussions are difficult. For instance *Globigerina nepenthes* from the Nobori Formation in Shikoku, as Bolli (1964) pointed out, cannot be included in the typical *G. nepenthes*, besides it occurs with *Globorotalia tosaensis* (= *G. truncatulinoides*). The writer had a chance to study the specimens of *Globigerina nepenthes* from the Nobori Formation by the courtesy of Dr. Takayanagi during an investigation of the Foraminifera from the Somachi Formation. Small specimens of *Globoquadrina altispira*, *Gq. altispira globosa*, and *Gq. venezuelana* were identified and illustrated from the Nobori Formation of Shikoku by Takayanagi and Saito (1962, pl. 25, figs. 7-9). These species have not been reported from formations younger than the Miocene in the western Pacific regions. Therefore the stratigraphic position of the Nobori Formation in terms of correlation is a problem, that should be reserved for further study.

Although McTavish (1966) considered the Nobori Formation to be a probable equivalent of his *Globigerina dutertrei* fauna, in Table 6 (page 16) he correlated the Nobori Formation to the Nanko Sandstone of Taiwan, and this procedure may have been a typographical error. This error is evident from the significant difference of the planktonic foraminiferal fauna between those formations and their fauna had been described in detail by those authors (Chang, 1959, 1962; Takayanagi and Saito, 1963) and discussed by some students (Bolli, 1964; Huang, 1966). Based upon an analysis of the planktonic foraminiferal fauna and stratigraphic succession the Nobori Formation should be placed in a position younger than the Nanko Sandstone.

The foraminiferal sequence of the Miyazaki Group in Kyushu was studied by H. Natori (MS), and from his information, the writer suggests that the major part of the Miyazaki Group can be correlated with the Hunghuatzu Formation to the Peiliao Shale in southern Taiwan.

In Taiwan, Chang described the stratigraphy and Foraminifera of western Taiwan in two papers (1959, and 1962), and based upon the planktonic foraminiferal zones he

Table 8. Correlation table of the Late Cenozoic formations of southern and northern Taiwan, based on the planktonic Foraminifera.

Southern Taiwan					Chang, 1952	
Age	Napalin and Chishan	Kueitangchi	Hunghuatzu	Planktonic Foraminiferal Zones	Caribbean Planktonic Foraminiferal Zones	Formation
Pleistocene	Liushuang Formation			2nd poor fauna (Elephas-Stegodon fauna)		Tokazan Formation
Pliocene	Erhchungchi Formation Up. Gutingkeng Fm.	Yuching Shale Chingmien Sandstone Peilliao Shale		Globorotalia inflata/Globorotalia truncatulinoides	Globigerina bulloides	Miaoli Group
	Low. Gutingkeng Fm.			Globigerinoides quadrilobatus fistulosus		Tewo Siltstone
Miocene		Chutouchi Formation Maupu Shale Ailiaochiao Fm. Yenshuikeng Shale Tangenshan Sandstone	Peilliao Shale Chutouchi Formation Maupu Shale Ailiaochiao Fm.	Sphaeroidinellopsis seminulina	Sphaeroidinellopsis seminulina	Shihlu Feng Sd. Sh.
			Yenshuikeng Shale Tangenshan Formation	Globigerina nepenthes/Pulleniatina obliquiloculata	Globorotalia menardii menardii/Globigerina nepenthes	Kantosan (Taipho) Ss.
		(Changchihkeng Fm.)	Changchihkeng Fm.	1st poor fauna	Globorotalia mayeri/Globigerina nepenthes	
			Hunghuatzu Formation	Globorotalia mayeri/Globobulimina dehiscens advena	Globorotalia mayeri/Globorotalia liguensis	Wutu Formation (Up. Coal M.)
			Sanmin Shale	Globorotalia fohsi robusta	Globorotalia fohsi robusta	

recognized and made correlation of them with the Caribbean planktonic foraminiferal zones (Table 7). The position of the strata barren of planktonic Foraminifera has been identified by their stratigraphical relationship with the beds containing the planktonic faunas. The correlation between the Tertiary rocks of southern and northern Taiwan is shown in Table 8.

Chang considered that *Globorotalia fohsi fohsi* represents the Kuanyinshan Sandstone Member of the Nanko Sandstone and may also represent the lower part of the Wutu Formation. Therefore, the Sanmin Shale with *Globorotalia menardii praemenardii* and *G. fohsi robusta* may be correlated with the lower part of the Wutu Formation.

Chang (1963, 1964, and 1965), working with surface samples, published on the biostratigraphy of the benthonic and planktonic Foraminifera from the Hengchun Peninsula, Taiwan. He recognized five planktonic foraminiferal zones and compared the upper three zones with those of the *Globorotalia fohsi robusta* Zone to the *Sphaeroidinellopsis seminulina* Zone in the sections studied in southern Taiwan.

The age assignment, although Jenkins described and discussed the planktonic Foraminifera from the type Aquitanian-Burdigalian of France in two papers (1964, and 1966), and based upon the occurrence of some diagnostic planktonic species he proposed a new chronological stage boundary in the planktonic foraminiferal zones of Trinidad. But the writer tentatively follows the old idea in this article.

NOTE ON *GLOBIGERINOIDES QUADRILOBATUS FISTULOSUS* (SCHUBERT)

There are many records and discussions on *Globigerinoides quadrilobatus fistulosus*, among which Belford (1962), Todd (1964), and Banner and Blow (1965) discussed the taxonomic problem in detail. Although the fistulose character in *G. q. sacculifer* seems to have no taxonomic value, it may have important paleoecological significance.

*Globigerinoides quadrilobatus fistulosus* was first described by Schubert (1910) from Sandwich Island, New Guinea, and subsequently it has been recorded from various parts of the world. The known records of this subspecies are shown in Chart 1. Most of the known occurrences are from the equatorial belt between 15°S and 30°N latitude, with the exception of the occurrence in western Europe, the distribution is between about 30°N to 45°N latitude.

Cushman *et al.* (1954, p. 369, pl. 91, fig. 13) reported this subspecies from the Recent deposits of the Guyot samples, from a core at Bikini 1176 meters in depth and as suggested by Bramlette *et al.* (1959), it may have been reworked from a Pliocene formation just as some of the Eniwetok Atoll samples. Hamilton and Rex (1959, p. 792, pl. 254, fig. 14) described this form from the *Globigerina* Ooze of Sylvania Guyot at 880 fathoms depth near the Bikini Atoll, Marshall Island. Bramlette *et al.* based on the distinct assemblages of coccoliths, including discoaster and related forms which occurred in association with the subspecies suggested that it may serve to date the early Pliocene.

Microfossils from the Tertiary occurring on the bottom surface of the Ocean and reworked from "outcrops" are more common than formerly recognized. That foraminifer has never been reported from planktonic tows and is presumably extinct. It is here suggested that all the recorded *G. quadrilobatus fistulosus* may be extinct and do not appear in either the Pleistocene or Recent deposits. If the occurrence in the Guyot samples is the result of reworking from some Tertiary strata then it might be useful in dating the younger Tertiary.

Although many opinions have been expressed on the stratigraphic distribution of this subspecies the writer agrees with Todd (1964) that this subspecies probably came into existence sporadically in the Upper Miocene, blossomed out briefly in the Pliocene, and died out rapidly, probably before the end of the Pliocene.

The tendency of the geographic distribution of the subspecies closely resembles the distribution of the four subspecies of *Globorotalia fohsi* (s. l.) as already expressed by Jenkins (1965).

In the southwestern Pacific region, the distribution of this subspecies coincides with the distribution of *Calcarina* and *Baculogypsina* reported by Todd (1960). Namely the distribution of this subspecies is controlled by the temperature of the sea water. The idea of dispersal of this subspecies based on a comparison between its distribution (Fig. 6) and the current patterns in the present Oceans is arbitrary.

Jenkins (1965) published an interesting map of the distribution of the four subspecies of *Globorotalia fohsi* (s. l.), and discussed the geographic distribution of the planktonic Foraminifera. It seems that the distribution of some of the species were probably effected by latitudinal distribution and current patterns of the Oceans. Based on the distribution and present day current patterns of the Oceans the dispersal of the foraminifers may be ecologically controlled by the warm current patterns and/or perhaps it floated at a different level. Whatever be the case, it is assumed that the oceanic circulation at the time *fistulosus* developed may have been similar to that of today in both the Pacific Ocean and Atlantic Ocean, and is responsible for the distribution of the subspecies.

It is assumed that the geographic distribution of the subspecies was due to the equatorial waters that carried it from the southern Pacific *via*, the Coral Sea northwards to

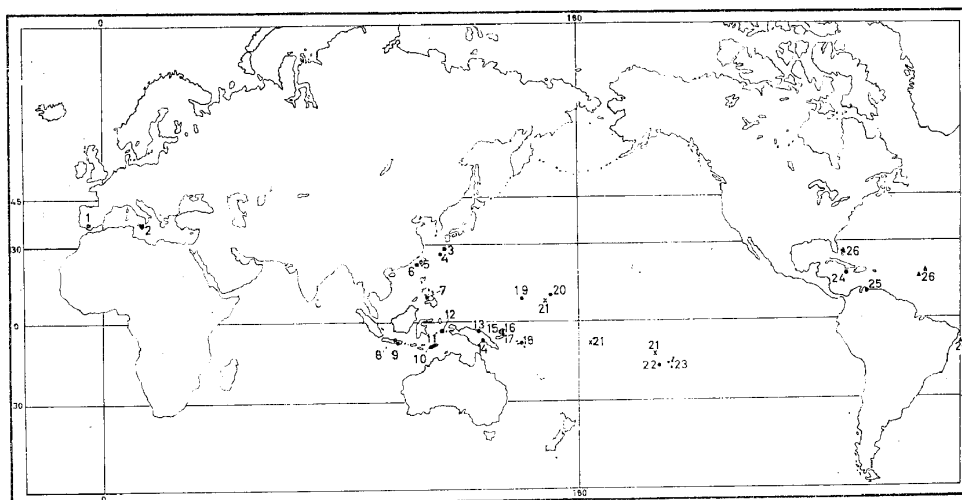


Fig. 6. Distribution map of *Globigerinoides quadrilobatus fistulosus* (Schubert).

1, Colom (1947); 2, Jenkins (1964); 3, Huang (1966); 4, Hanzawa (1925); 5, Huang (1960); 6, Huang (in this paper); 7, Bandy (1963); 8, Boomgaart (1949); 9, Sluis and Vletter (1942); 10, Fischen (1927); 11, Rocha and Ubaldo (1964); 12, Valk (1945); 13, 14, Belford (1962); 15, 16, 17, Schubert (1910, 1911); 18, McTavish (1966); 19, Cushman, Todd, and Post (1954); 20, Todd (1964); 21, Riedel and Funnel (1964); 22, Hamilton and Rex (1959); 23, Todd (1964); 24, 25, Cushman and Jarvis (1930); 26, Ericson, Ewing, and Wollin (1963).

New Guinea, Philippines, Taiwan, and Ryukyu to southwest Japan. In the Atlantic Ocean, the North equatorial current carried the subspecies populations from the Caribbean Sea northward along the Gulf of Mexico to the western coast of Europe. Therefore the distribution in the Atlantic Ocean is remote from the equatorial belt compared with that in the Pacific Ocean.

#### SUMMARY

1. A total of 42 species and subspecies of planktonic Foraminifera representing 10 genera were obtained from the four sections studied in southern Taiwan.
2. The majority of the planktonic species survive to the Pliocene and Recent, and only a few are of stratigraphic value.
3. The stratigraphic distribution of these species are shown in the range chart.
4. All the planktonic foraminiferal assemblages examined from each formation of the Late Cenozoic in southern Taiwan are composed entirely of warm-water forms. Some are distributed to middle latitudes.
5. Six tentative planktonic foraminiferal zones are proposed for southern Taiwan.
6. The planktonic foraminiferal zones recognized in the Caribbean Tertiary and other tropical or subtropical regions are also represented in the sections studied in southern Taiwan.
7. The incomplete zoning in the Changchihkeng Formation and the Liushung Formation was due to the impoverished planktonic fauna. Therefore a restudy is needed to determine the geological ages of those formations.
8. This is the first record of the *Globorotalia fohsi robusta* Zone in Taiwan.
9. The stratigraphic correlation between the Chutouchi anticline and the Hunghuatzu anticline is justified.
10. The formations from the Sanmin Shale up to the Liushung Formation in southern Taiwan are correlative to the Sankyo Group, Miaoli Group and the Tokazan Formation in northern Taiwan.

## REFERENCE LIST OF PLANKTONIC SPECIES

All of the planktonic species and subspecies of Foraminifera discriminated from the sections in southern Taiwan are listed on Chart 1. The well-known species and subspecies are not figured, but the common ones, those of stratigraphic interest, doubtful taxonomic position, and characteristic are illustrated. The references and list of the planktonic foraminiferal species identified in this study are listed below:

*Globigerina bulloides* d'Orbigny, 1826, Ann. Sci. Nat., ser. 1, t. 7, p. 277. — Banner and Blow, 1960, Cushman Found. Foram. Res., Contr., v. 11, pt. 3, p. 25, pl. 7, fig. 4 (lectotype).

*Globigerina decoraperta* Takayanagi and Saito=*Globigerina druryi* Akers *decoraperta* Takayanagi and Saito, 1962, Tohoku Univ., Sci. Rep., 2nd ser. (Geol.), Spec. Vol. No. 5, p. 85, pl. 28, fig. 10; pl. 25, fig. 2.

*Globigerina diplostoma* Ruess, 1850, K. Akad. Wiss. Wien, Math.-Naturw. Kl., Denkschr., Bd. 1, p. 373, pl. 47, figs. 9, 10; pl. 48, fig. 1 (*fide* Ellis and Messina, 1940 *et seq.*).

*Globigerina dutertrei* d'Orbigny, 1839, in de la Sagra, Hist. Phys. Pol. Nat. Cuba, p. 84, pl. 4, figs. 19–21. — Banner and Blow, 1960, Cushman Found. Foram. Res., Contr., v. 11, pt. 3, p. 11, pl. 2, fig. 1 (lectotype). No specimens of this species with umbilical teeth were observed from southern Taiwan. Therefore the generic name of *Globigerina* is used for this species.

*Globigerina falconensis* Blow, 1959, Am. Pal., Bull., v. 39, no. 178, p. 177, pl. 9, figs. 40–41.

*Globigerina foliata* Bolli, 1957, U.S. Nat. Mus., Bull. 215, p. 111, pl. 24, figs. 1a-c.

*Globigerina nepenthes* Todd, 1957, U.S. Geol. Surv. Prof. Paper, 280-H, p. 301, pl. 78, figs. 7a-b.

*Globigerina quinqueloba* Natland, 1938, Scripps Inst. Oceanog., Tech. ser., v. 4, no. 5, p. 149, pl. 6, fig. 7.

*Globigerina woodi* Jenkins, 1960, Micropal., v. 6, no. 4, p. 352, pl. 2, figs. 2a-c.

*Globigerinella siphonifera* (d'Orbigny)=*Globigerina siphonifera* d'Orbigny, 1839, in de la Sagra, Hist. Phys. Pol. Nat. Cuba, p. 83, pl. 4, figs. 15–18. — Banner and Blow, 1960, Micropal., v. 6, no. 1, p. 22, text-figs. 2 (lectotype), 3. *Globigerinella aequilateralis* (Brady) is a junior synonym of this species.

*Globigerinita glutinata* (Egger)=*Globigerina glutinata* Egger, 1893, Abh. K. Bayer. Akad. Wiss. München, Cl. 2, Bd. 18, Abt. 2, p. 317, pl. 13, figs. 19–21 (*fide* Ellis and Messina, 1940 *et seq.*).

*Globigerinoides conglobatus* (Brady)=*Globigerina conglobata* Brady, 1879, Jour. Micro. Sci., Quart., n. s., v. 19, p. 286. — Banner and Blow, 1960, Cushman Found. Foram. Res., Contr., v. 11, pl. 3, p. 6, pl. 4, fig. 4 (lectotype).

*Globigerinoides elongatus* (d'Orbigny)=*Globigerina elongata* d'Orbigny, 1826, Ann. Sci. Nat., ser. 1, t. 7, p. 277 (no figure). — Banner and Blow, 1960, Cushman Found. Foram. Res., Contr., v. 11, pt. 3, p. 12–13, pl. 3, figs. 10a-c (lectotype).

*Globigerinoides obliquus* Bolli, 1957, U.S. Nat. Mus., Bull. 215, p. 113, pl. 25, figs. 9a-10c, text-fig. 21 (5a-c).

*Globigerinoides quadrilobatus fistulosus* (Schubert)=*Globigerina fistulosa* Schubert, 1910, Geol. Reichsanst. Verk., Wien, no. 14, p. 324, fig. 2 (*fide* Ellis and Messina, 1940 *et seq.*). In this paper *G. quadrilobatus fistulosus* is used for the typical form, the *hystricocus* form of Belford and the "var. *recumbens*" of Rumbler.

*Globigerinoides quadrilobatus quadrilobatus* (d'Orbigny) = *Globigerina quadrilobata* d'Orbigny, 1846, Paris, Gide et Compe, p. 164, pl. 9, figs. 7–10 (*fide* Ellis and Messina, 1940 *et seq.*).

*Globigerinoides quadrilobatus sacculifer* (Brady)=*Globigerina sacculifera* Brady, 1877, Geol. Mag., London, n.s., decade 2, v. 4, no. 12, p. 535. — Banner and Blow, 1960, Cushman Found. Foram. Res. Contr., v. 11, pt. 3, p. 21, pl. 4, figs. 1 (lectotype), 2. In this paper *G. sacculifer* is used for the typical form and includes *G. irregularis* LeRoy.

*Globigerinoides quadrilobatus trilobus* (Reuss)=*Globigerina triloba* Reuss, 1850, K. Akad. Wiss. Wien, Math.-Naturw. Kl., Denkschr., Bd. 1, p. 374, pl. 47, figs. 11a-c (*fide* Ellis and Messina, 1940 *et seq.*). In this paper, this subspecies includes the typical form and also *G. immaturus* LeRoy.

*Globigerinoides ruber cyclostomus* (Galloway and Wissler)=*Globigerina cyclostoma* Galloway and Wissler, 1927, Jour. Pal., v. 1, no. 1, p. 42, pl. 7, figs. 8–9. This subspecies is closely related to *G. ruber* (s. s.), thus, it is here treated as a subspecies of *G. ruber*.

*Globigerinoides ruber ruber* (d'Orbigny)=*Globigerina ruber* d'Orbigny, 1839, in de la Sagra, Hist.



Phys. Pol. Nat. Cuba, p. 82-83 (plates published separately, v. 8, pl. 4, figs. 12-13. — Banner and Blow, 1960, Cushman Found. Foram. Res., Contr., v. 11, pt. 3, p. 19, pl. 3, fig. 8 (lectotype).

*Globigerinoides* spp. All the indetermined species are placed under this name in this study.

*Globoquadrina altispira* (Cushman and Jarvis) = *Globigerina altispira* Cushman and Jarvis, 1936, Cushman Lab. Foram. Res., Contr., v. 12, p. 5, pl. 1, figs. 13-14. In this paper *Gq. altispira* is not separated into taxons, because the specimens are not suitable for a fine cut classification.

*Globoquadrina dehiscens advena* Bermudez = *Globoquadrina quadraria advena* Bermudez, 1949, Cushman Lab. Foram. Res., Spec. Publ., no. 25, p. 287, pl. 22, figs. 36-38.

*Globoquadrina dehiscens dehiscens* (Champan, Parr and Collins) = *Globorotalia dehiscens* Chapman, Parr, and Collins, 1934, Linn. Soc. London, Jour. Zool., v. 38, no. 262, p. 596, pl. 11, figs. 36a-c (*fide* Ellis and Messina, 1940 *et seq.*).

*Globoquadrina venezuelana* (Hedberg) = *Globigerina venezuelana* Hedberg, 1937, Jour. Pal., v. 11, no. 6, p. 681, pl. 92, figs. 7a-b.

*Globorotalia crassaformis* (Galloway and Wissler) = *Globigerina crassaformis* Galloway and Wissler, 1927, Jour. Pal., v. 1, p. 41, pl. 7, fig. 12.

*Globorotalia fohsi robusta* Bolli, 1950, Cushman Found. Foram. Res., Contr., v. 1, pts. 3-4, p. 89, pl. 15, figs. 3a-c. According to the descriptions of Jenkins (1965), the specimens of this species from southern Taiwan closely resemble the Philippines form.

*Globorotalia hirsuta* (d'Orbigny) = *Rotalina hirsuta* d'Orbigny, 1839, in Berker-Webb and Berthelot, Hist. Nat. Iles Canaries, t. 2, pt. 2, p. 131, pl. 1, figs. 37-39 (*fide* Ellis and Messina, 1940 *et seq.*).

*Globorotalia inflata* (d'Orbigny) = *Globigerina inflata* d'Orbigny, 1839, in Berker-Webb and Berthelot, Hist. Nat. Iles Canaries, t. 2, pt. 2, p. 134, pl. 2, figs. 7-9 (*fide* Ellis and Messina, 1940 *et seq.*). *Globorotalia nipponica* and *G. trigonula* are placed in the synonymy of this specific name in this paper.

*Globorotalia mayeri* Cushman and Ellisor, 1939, Cushman Lab. Foram. Res., Contr., v. 15, p. 11, pl. 2, figs. 4a-c.

*Globorotalia menardii menardii* (d'Orbigny) = *Rotalia* ("Rotalie") *menardii* d'Orbigny, 1826, Ann. Sci. Nat., ser. 1, t. 7, p. 273, Modèle no. 10.

*Globorotalia menardii miocenica* Palmer, 1945, Am. Pal., Bull., v. 29, no. 115, p. 70-71, pl. 1, figs. 10a-c.

*Globorotalia menardii multicamerata* Cushman and Jarvis, 1930, Jour. Pal., v. 4, no. 4, p. 367, pl. 34, fig. 8. Although this species is closely related to *G. fijiensis*, but as shown in Cushman's description, this subspecies is characteristic in its distinct lobing of the chambers in the later part of the whorl.

*Globorotalia menardii praemenardii* Cushman and Stainforth = *Globorotalia praemenardii* Cushman and Stainforth, 1945, Cushman Lab. Foram. Res., Spec. Publ., no. 14, p. 70, pl. 13, fig. 14.

*Globorotalia menardii tumida* (Brady) = *Pulvinulina menardii tumida* Brady, 1877, Geol. Mag., n. ser., dec. 2, v. 4, no. 12, p. 535.

*Globorotalia opima continuosa* Blow, 1959, Am. Pal., Bull., v. 39, no. 178, p. 218-219, pl. 19, figs. 125a-c.

*Globorotalia scitula* (Brady) = *Pulvinulina scitula* Brady, 1882, Roy. Soc. Edinburgh, Proc., v. 11, (1880-1882), no. 111, p. 716-717 (no figure). — Banner and Blow, 1960, Cushman Found. Foram. Res., Contr., v. 11, p. 27, pl. 5, figs. 5a-c (lectotype).

*Globorotalia truncatulinoides* (d'Orbigny) = *Rotalia truncatulinoides* d'Orbigny, 1839, in Barker-Webb and Berthelot, Hist. Nat. Iles Canaries, t. 2, pt. 2, p. 132, pl. 2, figs. 25-27 (*fide* Ellis and Messina, 1940 *et seq.*). In this paper *G. truncatulinoides* is used for the typical form and includes *G. tosaensis*.

*Orbulina universa* d'Orbigny, 1839, in de la Sagra, Hist. Phys. Pol. Nat. Cuba, p. 3, pl. 1, fig. 1 (*fide* Ellis and Messina, 1940 *et seq.*).

*Pulleniatina obliquiloculata* (Parker and Jones) = *Pullenia sphaeroides* (d'Orbigny) var. *obliquiloculata* Parker and Jones, 1865, Roy. Soc. London, Phil. Trans., v. 155, p. 365, 368, pl. 19, figs. 4a-b. — Banner and Blow, 1960, Cushman Found. Foram. Res., Contr., v. 11, pt. 3, p. 25, pl. 7, fig. 4 (lectotype).

*Sphaeroidinella dehiscens dehiscens* (Parker and Jones) = *Sphaeroidina bulloides* d'Orbigny var. *dehiscens* Parker and Jones, 1865, Roy. Soc. London, Phil. Trans., v. 155, p. 369, pl. 19, fig. 5 (*fide* Ellis and Messina, 1940 *et seq.*). In this paper, *S. dehiscens* is used for the modern form with or without the cortex as mentioned by Bé (1965). *S. dehiscens immatura* (Cushman) is considered to be an earlier chronospecies in the *S. dehiscens* evolutionary series and is included in this species.

*Sphaeroidinellopsis seminulina kochi* (Caudri) = *Globigerina kochi* Caudri, 1934, "Tertiary deposits of Soemba", p. 144, (*fide* Ellis and Messina, 1940 *et seq.*). *Sphaeroidinellopsis grimsdalei* (Keijzer) and *S. multiloba* LeRoy are junior synonyms of this species.

*Sphaeroidinellopsis seminulina seminulina* (Schwager) = *Globigerina seminulina* Schwager, 1866, Novara Exped., 1857–1859, Geol. Theil, Bd. 2, Abth. 2, p. 256, pl. 7, fig. 112. — Banner and Blow, 1960, Cushman Found. Foram. Res., Contr., v. 11, pt. 3, p. 24, pl. 7, figs. 2a-b (neotype). In this paper, this species includes the normal adults, *S. seminulina subdehiscens* is possibly a juvenile or morphological variant of *S. seminulina*. Thus, it is here treated as a subspecies of *S. seminulina seminulina*.

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Ailiaochiao 隘寮脚  
 Changchihkeng 長枝坑  
 Chiahsien 甲仙  
 Chiayi 嘉義  
 Chingmien 鏡面  
 Chishan 旗山  
 Chutouchi 竹頭崎  
 Erchungchi 二重溪  
 Gutingkeng 古亭坑  
 Hsiatansui-chi 下淡水溪  
 Hsichih 汐止  
 Hsuehshan 雪山

Hunghuatzu 紅花子  
 Kaohsiung Hsien 高雄縣  
 Kuanyinshan 觀音山  
 Kueitangchi 龜田溪  
 Liushung 六双  
 Maupu 茅埔  
 Miaoli 苗栗  
 Nantzuhsien-chi 楠梓仙溪  
 Napalin 荳荪林  
 Niuchouchi 牛稠溪  
 Peiliao 北寮  
 Sanmin 三民

Shihliufeng 十六份  
 Siaokunshui 小滾水  
 Tainan 台南  
 Taipei 台北  
 Tangenshan 糖恩山  
 Tawo 大窩  
 Tawushan 大武山  
 Tsengwen-chi 曾文溪  
 Wutu 五堵  
 Yenshuikeng 鹽水坑  
 Yuching 玉井

### Plate 15

Figs. 1a-c. *Globorotalia mayeri* Cushman and Ellisor.

1a, Umbilical view; 1b, side view; 1c, spiral view.  $\times 40$ . From sample HH-5, the Sanmin Shale of the Hunghuatzu section.

Figs. 2a, b. *Globorotalia opima continuosa* Blow.

2a, Umbilical view; 2b, side view.  $\times 40$ . From sample HH-21, the Sanmin Shale of the Hunghuatzu section.

Figs. 3a, b. *Globorotalia truncatulinoides* (d'Orbigny).

3a, Spiral view; 3b, side view.  $\times 40$ . From sample CK-101, the Lower Gutingkeng Formation of the Chishan section.

Fig. 4. *Globorotalia scitula* (Brady).

4, Spiral view.  $\times 40$ . From sample HH-179, the Sanmin Shale of the Hunghuatzu section.

Figs. 5a, b. *Globorotalia truncatulinoides* (d'Orbigny).

5a, Spiral view; 5b, side view.  $\times 40$ . From sample CK-101, the Lower Gutingkeng Formation of the Chishan section.

Fig. 6. *Globorotalia inflata* (d'Orbigny).

6, Umbilical view.  $\times 40$ . From sample CK-101, the Lower Gutingkeng Formation of the Chishan section.

Figs. 7, 8, 10a, b. *Globorotalia inflata* (d'Orbigny).

7, 8, 10a, Umbilical view; 10b, side view.  $\times 60$ .

From sample CK-199, The Lower Gutingkeng Formation of the Chishan section.

Figs. 9a-c. *Globorotalia truncatulinoides* (d'Orbigny).

9a, Spiral view; 9b, side view; 9c, umbilical view.  $\times 60$ .

From sample CK-121, the Lower Gutingkeng Formation of the Chishan section.

Figs. 11a, b. *Pulleniatina obliquiloculata* (Parker and Jones).

11a, Spiral view; 11b, side view.  $\times 60$ . From sample CK-140, the Lower Gutingkeng Formation of the Chishan section.

Figs. 12a, b. *Globorotalia menardii menardii* (d'Orbigny).

12a, Umbilical view; 12b, spiral view.  $\times 40$ . From sample KT-184, the Yuching Shale of the Kueitangchi section.

Figs. 13a-c. *Globorotalia fohsi robusta* Bolli.

13a, Umbilical view; 13b, spiral view; 13c, side view.  $\times 46$ . From sample HH-54, the Sanmin Shale of the Hunghuatzu section.

Fig. 14. *Globorotalia menardii multicamerata* Cushman and Jarvis.

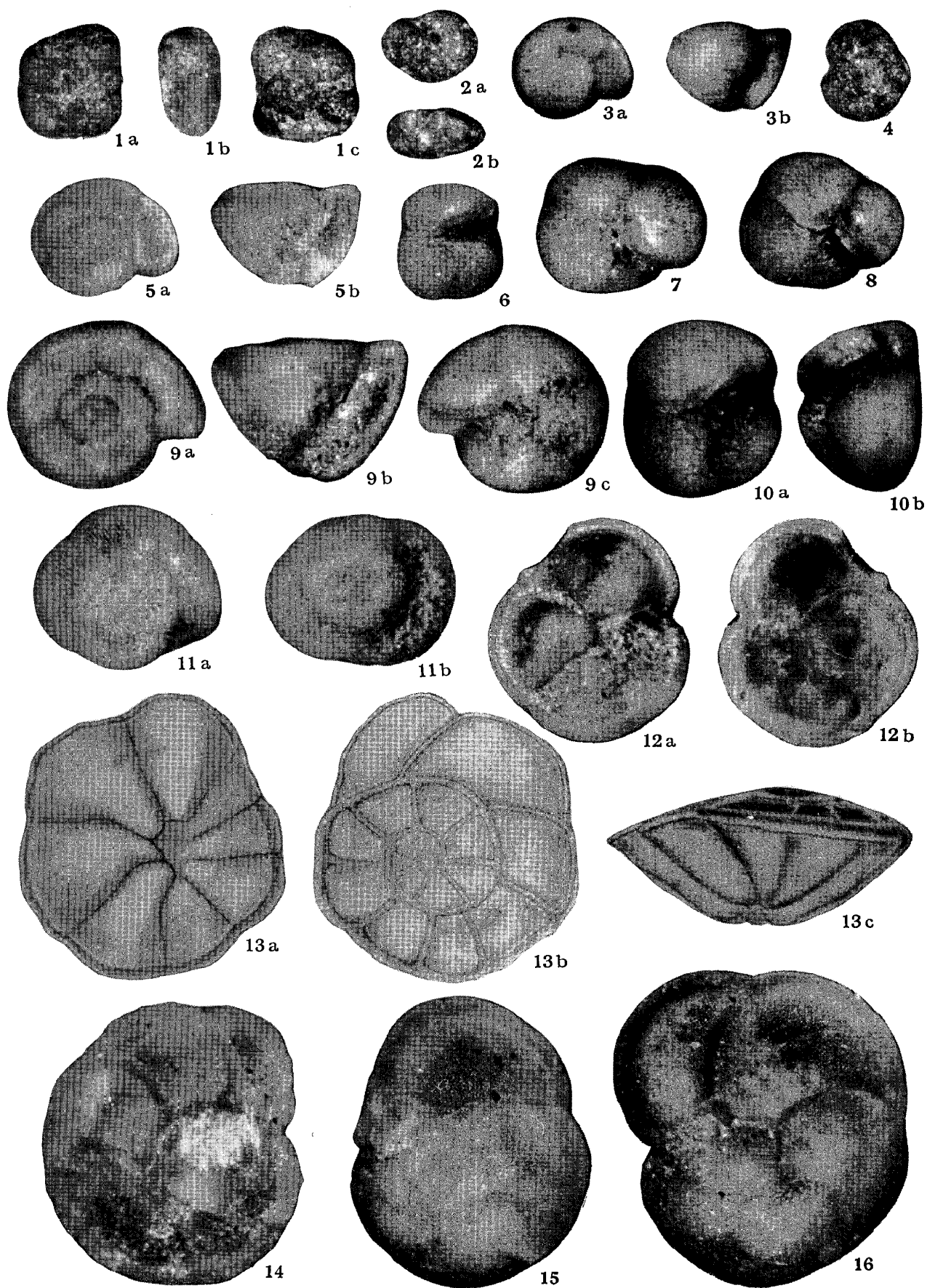
14, Spiral view.  $\times 60$ . From sample CC-33, the Erchungchi Formation of the Chishan section.

Fig. 15. *Globorotalia menardii tumida* (Brady).

15, Spiral view.  $\times 60$ . From sample CK-199, the Lower Gutingkeng Formation of the Chishan section.

Fig. 16. *Globorotalia menardii tumida* (Brady).

16, Spiral view.  $\times 60$ . From sample CK-101, the Lower Gutingkeng Formation of the Chishan section.





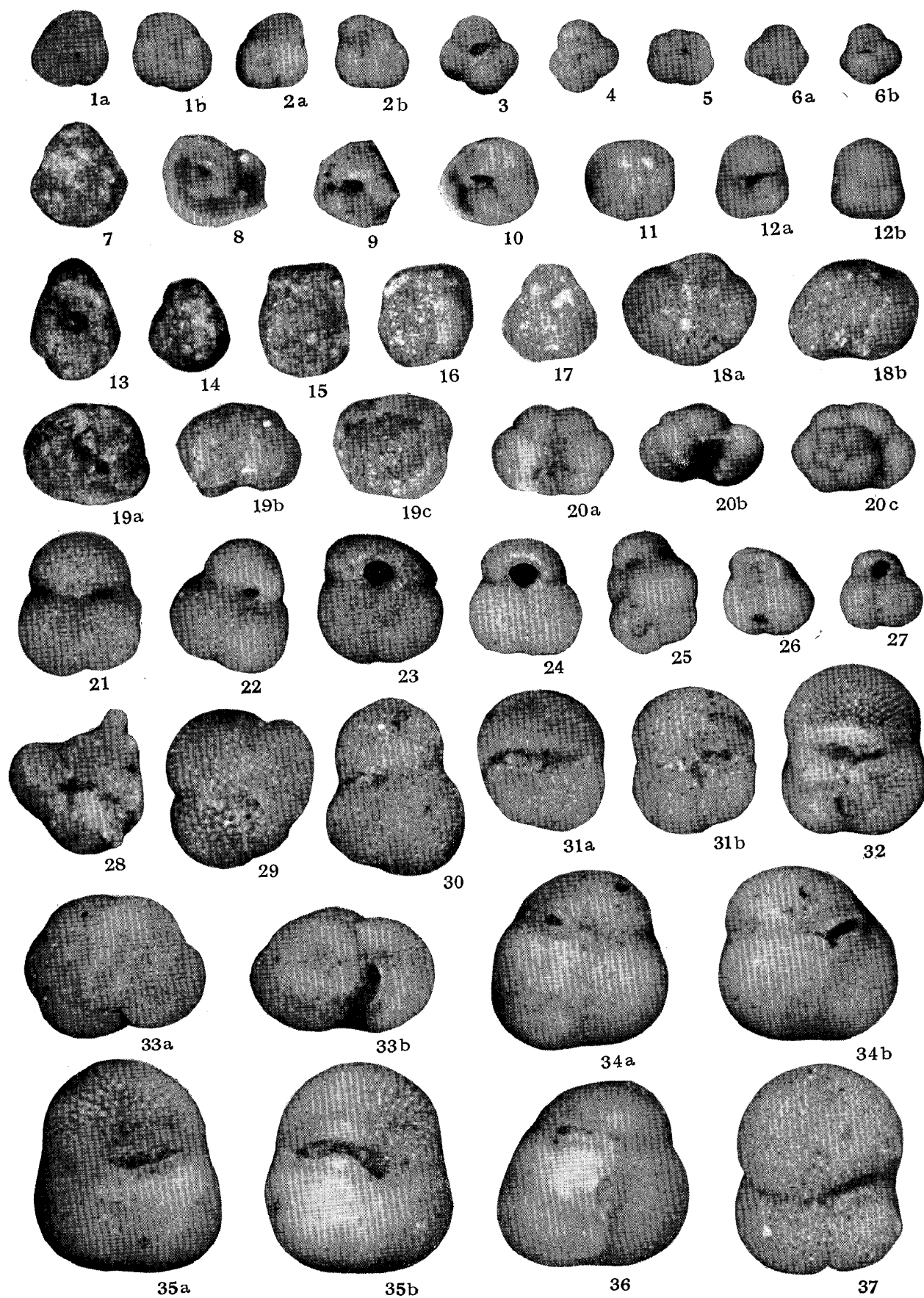


Plate 16

- Figs. 1a-2b. *Globigerinoides elongatus* (d'Orbigny).  
1a, 2b, Umbilical view; 1b, 2a, spiral view.  $\times 40$ .  
From sample CK-101, the Lower Gutingkeng Formation of the Chishan section.
- Fig. 3. *Globigerina bulloides* d'Orbigny.  
3, Umbilical view.  $\times 40$ . From sample CC-33, the Erchungchi Formation of the Chishan section.
- Fig. 4. *Globigerina falconensis* Blow.  
4, Umbilical view.  $\times 40$ . From sample CK-101, the Lower Gutingkeng Formation of the Chishan section.
- Fig. 5. *Globigerina diplostoma* Reuss.  
5, Umbilical view.  $\times 40$ . From sample CK-121, the Lower Gutingkeng Formation of the Chishan section.
- Figs. 6a, b. *Globigerinita glutinata* (Egger).  
6a, Spiral view; 6b, umbilical view.  $\times 40$ . From sample CK-101, the Lower Gutingkeng Formation of the Chishan section.
- Fig. 7. *Globigerina nepenthes* Todd.  
7, Umbilical view.  $\times 40$ . From sample HH-73, the Yenshuikeng Shale of the Hunghuatzu section.
- Figs. 8-11. *Pulleniatina obliquiloculata* (Parker and Jones).  
8, 9, 10, Disected specimens, showing the earlier ontogenetic stage; 11, side view.  $\times 40$ .  
From sample CK-121, the Lower Gutingkeng Formation of the Chishan section.
- Figs. 12a, b. *Sphaeroidinella dehiscent dehiscent* (Parker and Jones).  
12a, Umbilical view; 12b, spiral view.  $\times 40$ . From sample CK-196, the Lower Gutingkeng Formation of the Chishan section.
- Figs. 13, 14. *Globigerina nepenthes* Todd.  
13, 14, Umbilical view.  $\times 40$ . From sample HH-95, the Tangenshan Sandstone of the Hunghuatzu section.
- Fig. 15. *Globoquadrina dehiscent advena* Bermudez.  
15, Side view.  $\times 40$ . From sample HH-340, the Changchihkeng Formation of the Hung-huatzu section.
- Fig. 16. *Globoquadrina dehiscent advena* Bermudez.  
16, Spiral view.  $\times 40$ . From sample HH-185, the Sanmin Shale of the Hunghuatzu section.
- Fig. 17. *Globigerinoides obliquus* Bolli.  
17, Umbilical view.  $\times 40$ . From sample HH-327, the Peiliao Shale of the Hunghuatzu section.
- Figs. 18a, b. *Globoquadrina venezuelana* (Hedberg).  
18a, Umbilical view; 18b, side view.  $\times 40$ . From sample HH-78, the Yenshuikeng Shale of the Hunghuatzu section.
- Figs. 19a-c. *Globoquadrina altispira* (Cushman and Jarvis).  
19a, Umbilical view; 19b, side view; 19c, spiral view.  $\times 40$ . From sample HH-338, the Changchihkeng Formation of the Hunguatzu section.
- Figs. 20a-c. *Globigerina dutertrei* d'Orbigny.  
20a, Umbilical view; 20b, side view; 20c, spiral view.  $\times 40$ . From sample KT-184, the Yuching Shale of the Kueitangchi section.
- Fig. 21. *Globigerinoides quadrilobatus quadrilobatus* (d'Orbigny).  
21, Umbilical view.  $\times 60$ . From sample CK-199, the Lower Gutingkeng Formation of the Chishan section.
- Fig. 22. *Globigerinoides quadrilobatus sacculifer* (Brady).  
22, Umbilical view, *G. irregularis* form.  $\times 40$ . From sample CK-101, the Lower Gutingkeng Formation of the Chishan section.
- Fig. 23. *Globigerinoides ruber cyclostomus* (Galloway and Wissler).  
23, Umbilical view.  $\times 60$ . From sample CK-111, the Lower Gutingkeng Formation of the Chishan section.
- Fig. 24. *Globigerina ruber ruber* (d'Orbigny).  
24, Umbilical view.  $\times 60$ . From sample CK-111, the Lower Gutingkeng Formation of the Chishan section.



- Fig. 25. *Globigerinoides ruber ruber* (d'Orbigny).  
25, *G. helicina* form.  $\times 40$ . From sample CK-101, the Lower Gutingkeng Formation of the Chishan section.
- Fig. 26. *Globigerinoides elongatus* (d'Orbigny).  
26, Umbilical view.  $\times 40$ . From sample CK-101, the Lower Gutingkeng Formation of the Chishan section.
- Fig. 27. *Globigerinoides ruber ruber* (d'Orbigny).  
27, Umbilical view.  $\times 40$ . From sample CK-199, the Lower Gutingkeng Formation of the Chishan section.
- Fig. 28. *Globigerinoides quadrilobatus fistulosus* (Schubert).  
28, Spiral view.  $\times 40$ . From sample KT-8, the Peiliao Shale of the Kueitangchi section.
- Fig. 29. *Globigerinoides quadrilobatus sacculifer* (Brady).  
29, Umbilical view.  $\times 60$ . From sample CK-121, the Lower Gutingkeng Formation of the Chishan section.
- Fig. 30. *Globigerinoides quadrilobatus trilobus* (Reuss).  
30, Umbilical view, *G. immaturus* form.  $\times 60$ .  
From sample CK-111, the Lower Gutingkeng Formation of the Chishan section.
- Figs. 31a-32. *Sphaeroidinella dehiscentis dehiscentis* (Parker and Jones).  
31a, Umbilical view; 31b, spiral view; specimen without the cortex; 32, spiral view, with the cortex.  $\times 40$ . From sample CK-92, the Lower Gutingkeng Formation of the Chishan section.
- Figs. 33a, b. *Globigerina dutertrei* d'Orbigny.  
33a, Spiral view; 33b, side view.  $\times 60$ . From sample CK-111, the Lower Gutingkeng Formation of the Chishan section.
- Figs. 34a, b, 36. *Sphaeroidinella dehiscentis dehiscentis* (Parker and Jones).  
34a, 36, Spiral view; 34b, umbilical view.  $\times 60$ . From sample CK-199, the Lower Gutingkeng Formation of the Chishan section.
- Figs. 35a, b. *Sphaeroidinella dehiscentis dehiscentis* (Parker and Jones).  
35a, Spiral view; 35b, umbilical view.  $\times 60$ . From sample CK-140, the Lower Gutingkeng Formation of the Chishan section.
- Fig. 37. *Globigerinoides quadrilobatus trilobus* (Reuss).  
37, Umbilical view.  $\times 60$ . From sample CK-140, the Lower Gutingkeng Formation of the Chishan section.