

Foraminiferal biofacies of the Taiwan Strait, ROC

TUNYOW HUANG

Chinese Petroleum Corporation
Taipei, Taiwan, R O C

(manuscript received June 8, 1982
accepted December 2, 1982)

KEY WORDS — Foraminifera, Biofacies, Paleoecology, Taiwan Strait, E-Asia.

ABSTRACT — The Taiwan Strait is about 500 km long and 150 km wide, with water depths ranging down to 150 m. The bathymetry of the area studied and the Penghu Islands, the Taiwan Bank, the Taichung Bank, the Penghu Basin, the Matsu Basin, the Penghu Channel, and the Chilung Channel are recognizable in the area.

Three major currents occurs in the area; the Kuroshio Current, the China Coastal Stream, and drift due to monsoon in the South China Sea. Oceanographic observations, sediment, and other features in the strait of the different seasons are described.

Ninety sediment samples were taken in the Taiwan Strait to study distribution of the planktonic and the benthonic foraminifers. More than 400 species of the benthonic foraminifers and 27 species of the planktonic foraminifers were found in the strait and were used for the analyses.

The high density of the foraminifers is in the Matsu Basin and near the edge of the shelf off the coast of northern and southern Taiwan.

The distribution of planktonic foraminifers is controlled by the topography and the current action and the high density in the Penghu Channel and the Chilung Channel areas. The cool-water species are abundant in the north half of the strait and warm-water species are abundant in the south half.

Six foraminiferal facies were determined: (1) the near-shore facies (less than 40 m), characterized by predominant *Pararotalia ozawai* and *P. taiwanica* in the assemblage, with reworked worn specimens common; (2) the offshore facies along the west side of near-shore facies (40-100 m), characterized by mixed occurrences of the near-shore and basin facies with *Textularia conica* abundant in the assemblages; (3) the basin facies (60-100 m) in the central portion of the strait and along the west side of the offshore facies, characterized by the dominant occurrence of *Bolivina robusta pacifica*; (4) the bank facies in the area near the Taiwan Bank (20-150 m), characterized by the dominance of *Cibicides pseudoungerianus* and *Cibicides sintikuensis* together with *Pararotalia* and miliolids; (5) the Chilung Channel facies (50-150 m) near the Chilung Channel, characterized by the *Cibicides pseudoungerianus* - *Asterorotalia inflata* assemblage; and (6) the Penghu Channel facies (100-200 m) in the Penghu Channel, characterized by an association of rather deep water forms, including *Bolivina*, *Bulimina*, *Cassidulina*, *Gyroidina*, *Hanzawaia*, *Siphogenerina*, and *Uvigerina*.

For an attention for faunal diversity, four different index are measured. The result correlated well with the facies distribution and topography of the strait.

RIASSUNTO — [Biofacies dello Stretto di Taiwan sulla base dei Foraminiferi]— Lo Stretto di Taiwan è lungo circa 500 km e largo 150 km, con profondità che raggiungono i 150 m. È stata studiata la batimetria dell'area, con le Isole Penghu, il Banco di Taiwan, il Banco di Taichung, il Bacino di Penghu, il Bacino di Matsu, il Canale di Penghu ed il Canale di Chilung.

Nell'area esistono tre correnti marine principali: la Corrente Kuroshio, la Corrente Costiera Cinese e la corrente di deriva dovuta al monzone nel Mar Cinese Meridionale. Vengono riportate le osservazioni oceanografiche, lo studio dei sedimenti ed altri caratteri dello Stretto nelle diverse stagioni.

Sono stati prelevati novanta campioni di sedimenti nello Stretto di Taiwan allo scopo di studiare la distribuzione dei foraminiferi planctonici e bentonici. Sono state riconosciute oltre 400 specie di foraminiferi bentonici e 27 specie di foraminiferi planctonici; tutte sono state utilizzate per l'analisi delle facies.

Vi è un'alta densità di foraminiferi nel Bacino di Matsu e presso il ciglio della piattaforma continentale delle parti settentrionale e meridionale dell'Isola di Taiwan.

La distribuzione dei foraminiferi planctonici è condizionata dalla topografia e dall'azione delle correnti, con alta densità di distribuzione nel Canale di Penghu e nel Canale di Chilung. Le specie di acque fredde abbondano nella metà settentrionale dello Stretto, mentre in quella meridionale prevalgono le specie di acque calde.

Sono state distinte sei facies sulla base dei foraminiferi: (1) la facies costiera (sopra i 40 m), caratterizzata dalla prevalenza di *Pararotalia ozawai* e *P. taiwanica*, con molti esemplari rimaneggiati ed usurati; (2) la facies esterna (40-100 m), sul lato occidentale di quella costiera, con miscela di specie costiere e di bacino, con abbondanza di *Textularia conica*; (3) la facies di bacino (60-100 m), nella parte centrale dello Stretto e lungo il lato occidentale della facies esterna, caratterizzata dalla prevalenza di *Bolivina robusta pacifica*; (4) la facies di banco, nell'area del Banco di Taiwan (20-150 m), caratterizzata dall'abbondanza di *Cibicides pseudoungerianus* e *Cibicides sintikuensis*, assieme a *Pararotalia* e miliolidi; (5) la facies del Canale di Chilung (50-150 m),

con l'associazione *Cibicides pseudoungerianus* - *Asterorotalia inflata* e infine (6) la facies del Canale di Penghu, con specie di acque piuttosto profonde, fra cui varie *Bolivina*, *Bulimina*, *Cassidulina*, *Gyroidina*, *Hanzawaia*, *Siphogenerina* e *Uvigerina*.

Per distinguere le diversità faunistiche sono stati misurati quattro diversi indici. I risultati si adeguano bene alla situazione topografica e alla distribuzione di facies dello Stretto.

INTRODUCTION

Studies to determine the distribution patterns in Recent foraminifers (planktonic plus benthic types) in the marine environment of the world have been carried out by many authors.

The Taiwan Strait is an ideal area for the analysis of the distribution patterns and the variability of the species diversity of the marginal sea because of the presence of warm- and cool-water masses, and fresh water injection in the strait.

The objective of this study is to compare the foraminiferal population, to establish faunal assemblages, to compare their distribution with various environments, to attempt zonation by the non-specific faunal characteristics and to make a systematic study of the foraminifers in the sediments of the marginal sea, the Taiwan Strait, Taiwan, Republic of China and compare the distribution with the distribution occurring in other part of the world, and their relation to paleoecology.

Ninety sediment samples collected in the strait (between 22°N and 26°N, and 118°E and 122°E) during the period 1965-1968 were analyzed to determine the distribution of the foraminifers in the sediments of the strait.

One of the main objectives of the many studies of modern faunas now being made in the interpretation of fossil faunas and sediments from environmental criteria, as ancient shelf deposits have long been of interest to the oil industry as potential petroleum reservoirs. Some of the physical factors of the various environments in the strait were studied to determine which of these factors might control the distribution of the foraminifers. This was done in an effort to establish some parameters for recognizing and understanding similar environments in the Cenozoic sedimentary column of Taiwan.

PREVIOUS WORK

A huge sums of literature has accumulated in recent concerning the distribution, ecology, and morphologic variation of recent foraminifers. The waters of the Pacific and Atlantic Oceans have been scanned most thoroughly.

Previous studies on the benthic foraminifers of the Taiwan Strait and adjacent areas may be divided into two parts: those which are primarily taxonomic and those which emphasize distribution patterns and ecologic conditions. The first category includes papers on

new and interesting species of the strait and adjacent areas by the author (1970a, and b), and Polski and Waller (1958); the second includes those of Polski (1959), Waller (1960), Waller and Polski (1959), and the author (1971). Polski and Waller's studies are the first to attempt a quantitative analysis of the distribution of benthic foraminifers in bottom sediments from the Taiwan Strait and other Asiatic shelf area. The author studied the horizontal variation and distribution of benthic foraminifers, and the trends of the foraminiferal assemblages in the sediments are described and the biofacies and faunal distribution are analysed.

The earliest contributions on the planktonic foraminifers on the Taiwan Strait and other Asiatic shelf was also carried out by Waller and Polski (1959), who showed broad distribution patterns of planktonic foraminifers in 300 surface sediment samples from the Asiatic coast, presenting the distribution of faunal groups relating to temperatural ranges and latitude.

Cheng and Cheng (1964), studying the living planktonic foraminifers from the northern South China Sea, observed seasonal variations in some planktonic foraminifers and found that the factor of salinity has a great influence upon the planktonic foraminifers.

The sediments of the area has been described partially by Niino and Emery (1961), and Emery and others (1969). The oceanography of the strait and adjacent has been described in reports by some authors (Chu, 1963, 1971; CSK Rept., 1966-1970; and Emery, *et al.*, 1969).

METHODS OF STUDY

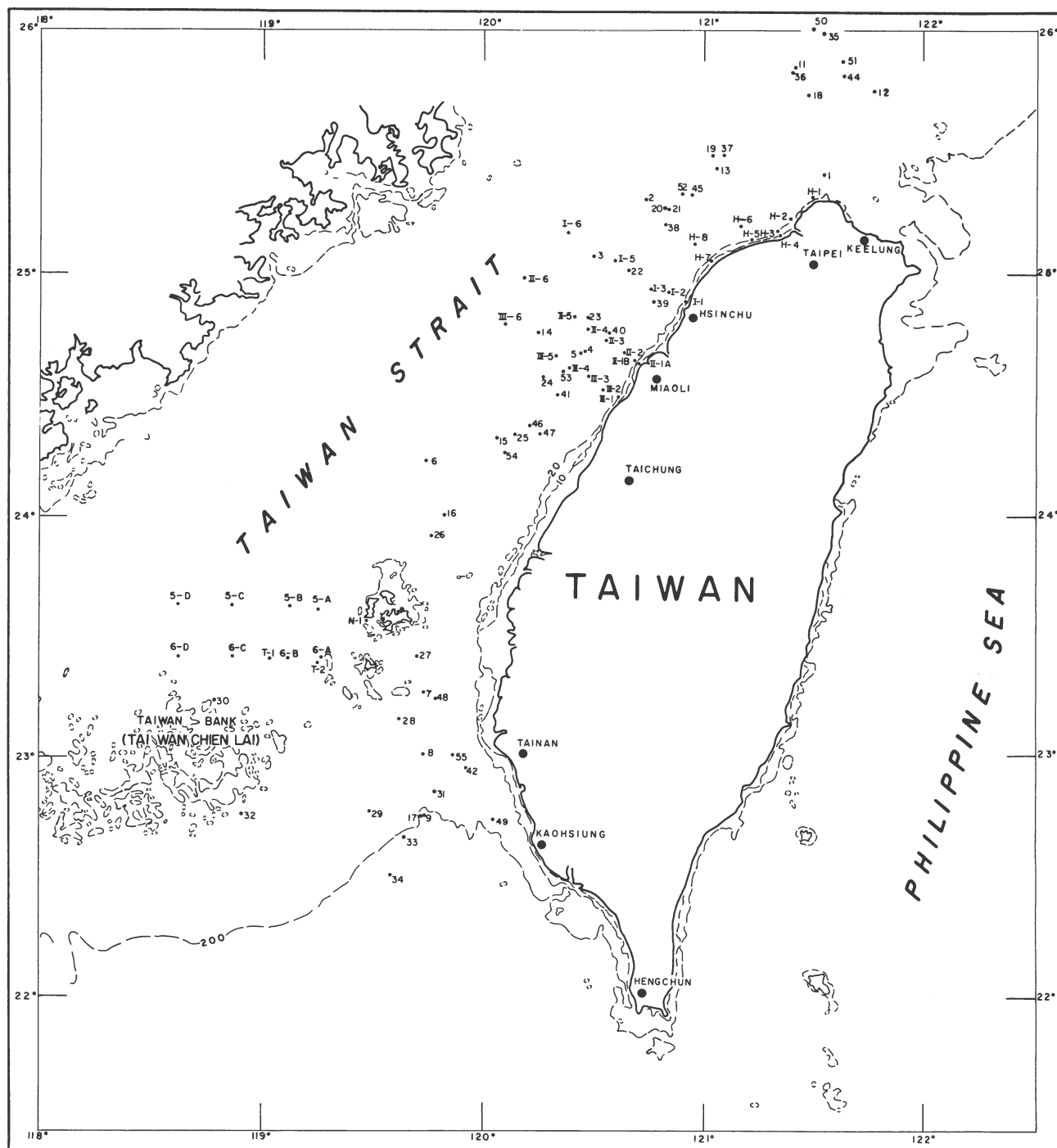
The locations of the ninety surface sediment samples collected in the Taiwan Strait from water depths ranging from 3 to 200 m are shown in text-fig. 1.

Most of the samples were collected by the Research Vessel Yong Ming as part of CSK projects conducted from 1965 to 1968 during eight cruises over the seas adjacent to Taiwan. In addition, several samples were collected by the author from areas west of Hsinchu and north of the Taiwan Bank along east-west lines to supplement the data from the roughly north-south trends of the CSK traverses, as part of CCOP (1) project in Taiwan Strait; this was done from the

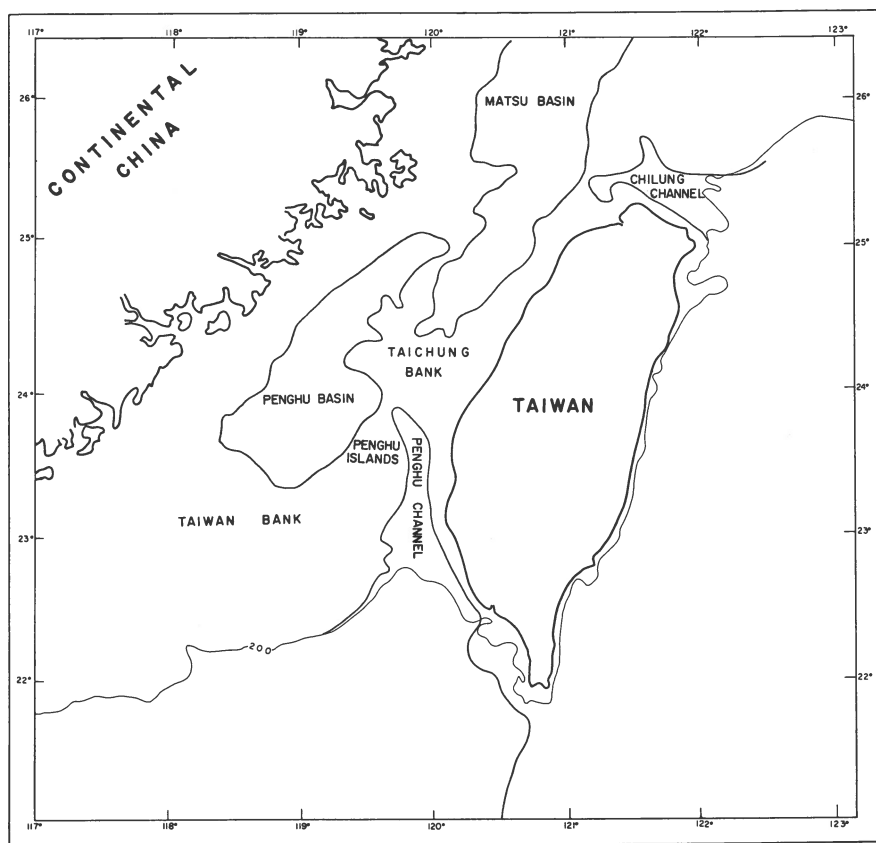
(1) Committee for Co-ordination of Joint Prospecting for Mineral Resources in Asia Offshore Areas; sponsored by the United Nations, ECAFE.

Taiwan Fisheries Research Institute's R/V HAI HSIEN under contract with the Chinese Petroleum Corporation. The area surveyed extends seaward for about 60 km from the shore of western Taiwan and includes the northern part of the Taiwan Bank, west of the Penghu Island. This study is based on 90 surfa-

ce sediment samples collected between 22°N and 26°N, and 118°E and 122°E (text-fig. 1). Of these, 18 are short gravity cores and 72 are snapper samples with a special tool (Boltovskoy, 1965, fig. 1). Thus, there was no sorting of sediments as is usual for drag samples.



Text-fig. 1 - Locations of sampling stations.



Text-fig. 2 - Outline of main topographic features of Taiwan Strait.

Foraminifers were examined only from the upper 2 cm of each core, but the snapper samples were possibly obtained from slightly deeper layers of the sea floor. The samples for study were not treated for preservation at the time of collection and, consequently, the live-to-dead ratios could not be determined. However, according to a study by Bandy *et al.* (1964) and Boltovskoy (1959), the dominant biofacies pattern would reflect in general the occurrence of the living populations. The total specimens including both the living and dead were treated in the same sense as the fossil foraminifers in strata. In other words, the analyses of the samples was undertaken in a manner similar to a thanatocoenosis. According to Fagerstrom (1964), fossil assemblages consist of individuals that were members of many ancient communities. Therefore, this treatise may be more useful for to assess the paleoenvironment.

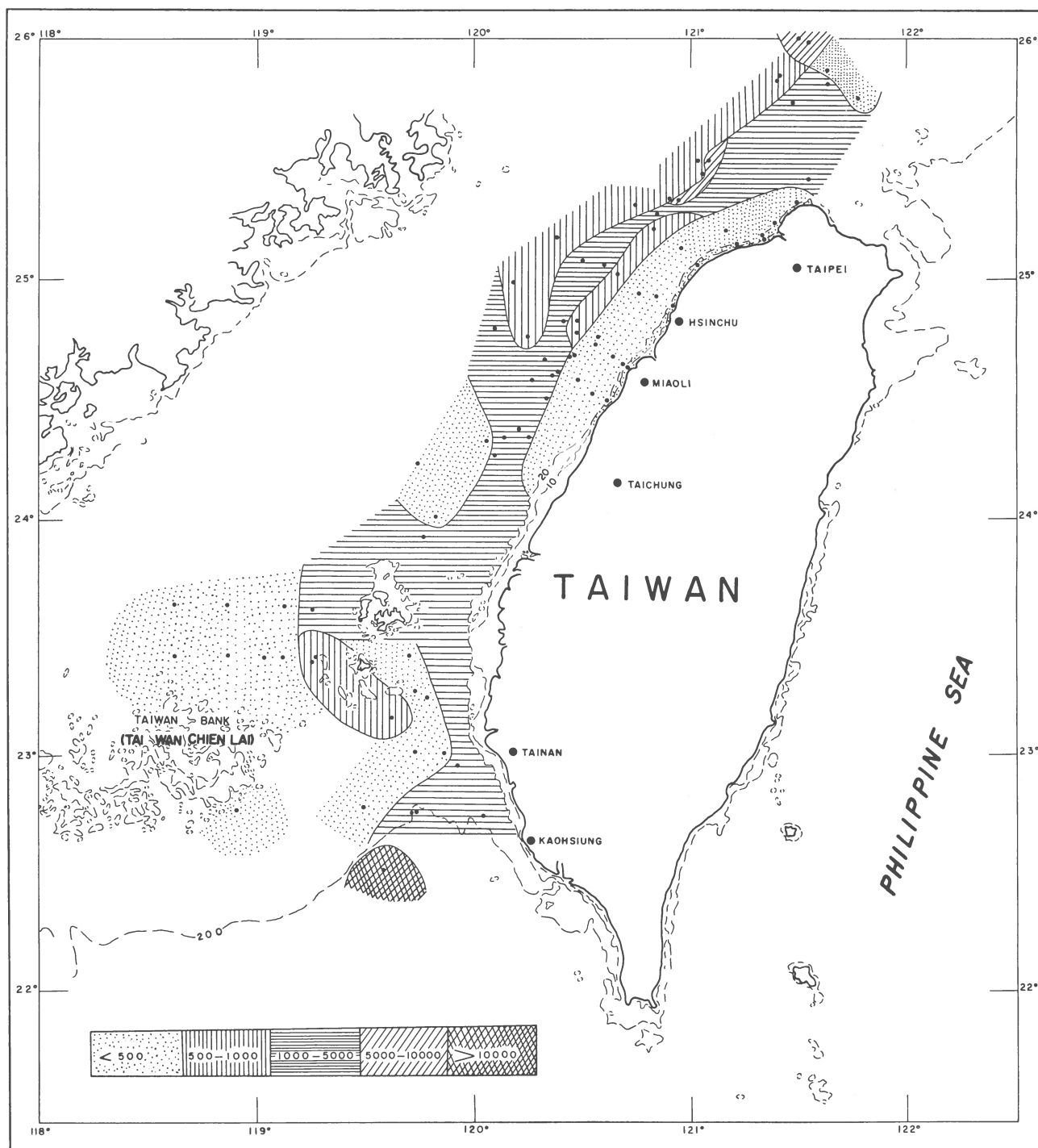
The dry samples (50 g) were weighed and washed on 200-mesh standard screen (0.074 mm openings). Samples with a large faunal population were split to a convenient size with a Phleger splitter. The foraminifers were picked out from the residues with the wetted tip of a thin bamboo stick under a binocular microscope and the picked foraminifers were then all counted. Frequency counts of the samples, multivariate

analysis and some diversity calculation were used as the basis for this study.

CHARACTERISTIC OF THE STRAIT

Taiwan Strait, lying along the middle portion of the eastern Asiatic shelf, between latitudes 26°00'N and 22°00'N and longitudes 117°00'E and 122°00'E, is about 500 km long and about 150 km wide. Most of the strait is a shallow submerged platform with a maximum water depth of about 150 m and an average depth of slightly less than 50 m. The strait may be considered as a marginal semi-enclosed sea (Menard, 1967; Hedberg, 1970). The continental slope steepens off eastern Taiwan and is cut by a considerable number of canyons (Yabe and Tayama, 1928 and 1939; Ma, 1967). It is very rocky and parts of it rise as banks or even as islands.

The bathymetry of the area: some of the topographic highs extend above sea level to form islands, whereas others rise almost to sea level, forming shallow banks, most of which are flat-topped; two of these banks are covered by only 10 m of water. An important structural trend (Text-figs. 2, 3) is represented by the Taiwan Bank, the Penghu Islands, and the



Text-fig. 3 - Total planktonic foraminifers in 50 gr of sediment.

Taichung Bank, which form a ridge trending northeast-southwest in the middle of the strait which divides it into two parts.

The shallowest area in the strait is the Taiwan Bank (Text-fig. 2), situated southwest of the Penghu Islands; this shallow oval bank is about 90 km wide

and about 210 km long and its axis trends east-west. The Taichung Bank (Text-fig. 2) is a small bank northeast of the Penghu Islands, and west of Taichung.

The Penghu Channel (Text-fig. 2) between the Penghu Islands and the west coast of southern Taiwan is the most remarkable bathymetric feature in Taiwan

Strait; it increases in depth southwards from less than 50 m at its northern end offshore from the Taichung area. The Chilung Channel (Text-fig. 2) begins in the northeastern part of Taiwan Strait and increases in depth from about 80 m offshore from the Kuanyin area northeastwards along the coast of northern Taiwan but changes its direction suddenly off Fukuichiao and continues to become deeper towards the east (Text-fig. 2).

In this paper, the term « basin » is used for a more or less closed depression on the shelf which is deeper than its surroundings; the lowest point on its rim is termed the sill and the higher parts may be shallow banks or even islands. Based on the bathymetric map, a depression northwest of the Penghu Islands, with its deepest portion at about 80 m in depth, is named by the author as the Penghu Basin (Text-fig. 2), and another north of the Taichung Bank, with its deepest portion about 100 m in depth, is named the Matsu Basin (Text-fig. 2).

The shore line along the lowland areas of western Taiwan consists of Recent alluvium and Quaternary paralic sediments. Many islands are found in the Taiwan Strait and most of them are composed of volcanic rocks intercalated in Pleistocene marine sediments (Lin, *et al.*, 1957). An exception is Liuchiushu, situated 13 km south-west of Tungkan (at the mouth of the Hsiatanshui-chi) and 30 km south-east of Kaohsiung; it has a foundation of massive bluish grey mudstone which is unconformably covered by reef limestones (Huang, 1960) and the islet is surrounded by cliffs of coral reef limestone and living coral reefs.

CLIMATE

The climate of Taiwan is warm and favourable for plant growth. The island receives more rainfall than any part of the mainland (Elliot, *et al.*, 1971).

The air temperature of the Taiwan Strait is under the effect of the continent. It is high in summer and low in winter. Penghu has an average value of 28.1°C in July and of 15.9°C in January and February. The annual range reaches 12.0°C.

The wind in the strait is generally NNE, but north in June and July and SSW in August. The wind in winter is very strong, the mean velocity reaching 9.1 m/sec in December, and there are 20.8 days of storm with a mean velocity of more than 15 m/sec. The wind velocity is weak in summer except when typhoons come. The high velocity of wind is a factor that is related to water motion. Consequently, all the types of water motion may directly or indirectly affect the foraminifers in the strait.

OCEANOGRAPHY

The Taiwan Strait can be classified as a tropical-subtropical marginal semi-enclosed sea.

1. CURRENTS

The currents are important to this study insofar as they effect salinity and temperature distribution.

The most well known and most up-to-date surface current maps of the Taiwan Strait and adjacent seas were published by the U.S. Naval Hydrographic Office (1964) and Naval Hydrographic Office of China (1962).

Three major currents occur in the area; the Kuroshio Current, the China Coastal Stream, and drift due to monsoon in the South China Sea.

The dominant current in the area is the Kuroshio Current which flows over the outer part of the shelf east of Taiwan. The Kuroshio Current is a water mass of high temperature, salinity, and transparency that comes from the equatorial regions, running northeast off Taiwan and the Ryukyu Islands and then close to the coast of Japan as far as latitude 35°N. The Kuroshio waters favour the deposition of calcareous shell and algal debris which is absent or rare in the areas affected by near-shore currents.

During the summer months the current is strongest as the trade wind belt is shifted northwards (Niino and Emery, 1961; CSK Rept., 1966-1970) and this causes a stronger deflection of water to pass up the continental coast. The current between Taiwan and the Ryukyu Islands is 150 miles in width (Nannichi, 1963; Uda, 1963); it reaches to a depth of about 700 m, and the maximum velocity is 1-1.5 knots (Sverdrup, 1965). A current with such a velocity would certainly play an important role in the transportation of planktonic organisms.

A branch of the Kuroshio Current enters the South China Sea through the Bashi Channel. It joins the surface drift which is produced by the prevailing northeast wind of the monsoon in winter to flow in the southwest direction. But, in summer time, as the southeast wind is the prevailing in the South China Sea, the branch of the Kuroshio is diverted by the surface drift due to the southwest monsoon and flows northeastward in the Taiwan Strait to flow out and join the mainflow of the Kuroshio in the East China Sea.

Water of low temperature, low salinity, and low transparency is carried southward along the mainland China coast by a well defined countercurrent that is best developed during the winter season when the Kuroshio Current is weakest. In winter time, the northeast wind is prevalent, and the coastal current flows through the strait to the South China Sea. But

in summer time, when the southwest monsoon is prevailing, this current is difficult to enter the strait.

The surface drift due to the monsoon in the South China Sea changes its course in different seasons. It flows in the southwest direction in winter and flows in the northeast direction in summer.

On the photograph taken by Astronauts Young and Collins, NASA, on July 20, 1966, two upwelling areas are clearly shown. The first is a fishing region since old time in an area west off the Tainan coastal plain; the second was first observed by these two astronauts in an area off the coast at Taitung.

The zones of upwelling area distinguished by the deepening of the thermocline, the decrease in temperature, and the increase in the concentration of phosphate at the depth of 100 m (Oceanographic Data Report of CSK, no. 1-4, 1966-1970). Off the southwestern coast of Taiwan, the phenomenon of upwelling, from Tungshang to Tainan is not as clearly marked as off the southeast coast.

2. TEMPERATURE

Geographically half of the strait belongs to the subtropical zone and half to the tropics. However, climatologically the whole strait is influenced greatly by both the continent and the ocean. The monsoon effects prevail in the sea of the strait.

The high temperature Kuroshio Current comes from the tropical area and the China Coastal Stream has its origin in the North China Sea so that sea water in the strait is warmer in summer and cooler in winter. The variation of temperature from the coast of the mainland to the offshore area is quite large. In February, 12°C near Amoy and 23°C near the southern tip of Taiwan. In August, the surface temperature distribution in the waters of the Taiwan Strait is simple, with only one isotherm of 28°C crossing the island into the strait in a direction from northeast to the southwest.

All the temperature records are within the range suitable for the development of tropical and temperate water foraminiferal representatives.

According to the data taken by the R/V YANG MING in December 1962 to January 1963, the temperature is 17°C in the offshore area to the northwest of Taiwan while it is 25°C in the area to the southeast of Taiwan.

The mean value of the temperature for the months April and May, according to data collected on the cruises during the years 1966 to 1970, is lowest in the East China Sea to the north of Taiwan, being 24°C.

For September and October, according to the mean values for these years 1962 to 1969, the lowest temperature is 25°C in the Taiwan Strait and the highest

temperature is 28°C on both sides of the southern part of the island.

3. SALINITY

The salinity distribution in the Taiwan Strait is influenced by the different flows of the currents and by the precipitation and river runoff in this area, but the seasonal variation of salinity is not so great as of the temperature. The salinity in the Taiwan Strait is around 34.00‰, but along the coast of the mainland it can be lowered down to below 33.00‰.

According to the data taken by the R/V YANG MING, in December 1962 and January 1963, the salinity is 33.80‰ in the strait and 34.60‰ in the Pacific Ocean.

The mean value of the salinity for the month April and May, according to data collected on the cruises during the years 1966 to 1970, is lowest in the area offshore of southwestern Taiwan, being 34.10‰.

For September and October, the mean value of the lowest salinity for the years 1962 to 1969, is still found in the offshore area to the southwest of Taiwan, being 33.80‰.

The salinity of China Coastal Stream is low usually between 31-33‰. It can be very low in estuaries during the rain season. Influenced by precipitation and isolation the surface layer belonging to the China Coastal Stream is even lower in salinity.

A paper by Emery, *et al.* (1969, figs. 4, 5, 6, 7, and 8), provides useful oceanographic reference data for the biofacies analysis of the Taiwan Strait.

4. OXYGEN CONTENT

The distribution of dissolved oxygen in sea water is influenced by temperature, current flow, and biological activities. The maximum oxygen concentration in the sea is approximately 9 ml/l.

The distribution of O₂ for the months April and May, according to the mean values determined on the cruises during the years 1966 to 1970, and for the months September and October for the years 1962 to 1969, shows that the value of O₂ content is high (4.6 ml/l) in the northern half of the strait and low (4.3 ml/l) in the southern half. Thus there was an adequate supply, and there is no reason to believe that lack of oxygen was an important controlling factor.

5. pH VALUES

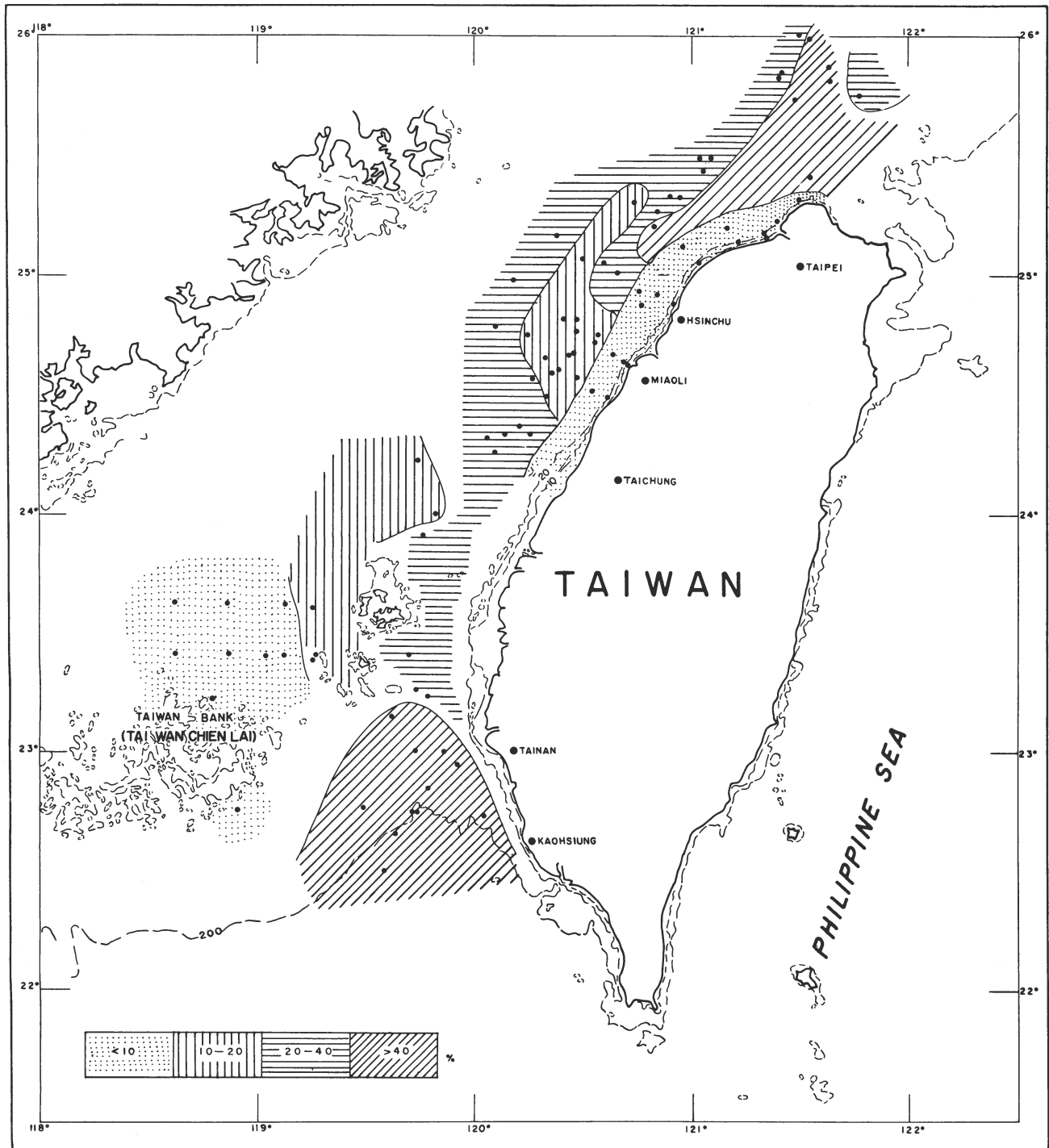
The distribution of pH values in the surface water of the strait is simple, ranging from 8.25 to 8.35 was

well within the limits tolerated by the majority of organisms, and therefore this factor is thought not to be important.

SEDIMENTS

The chief sources of the detrital sediments in the Taiwan Strait are the island of Taiwan and the main-

land, from which sediments are contributed from both land masses by streams, waves and wind. The streams, which contribute the bulk of the sediments, obtain most of their load from the areas of western Taiwan; their courses are short, with steep gradients and small drainage basins or catchment areas, and the headwaters of most of the major streams are located high in the Central Range.



Text-fig. 4 - Frequency of planktonic foraminifera in total populations.

The sediments of the Taiwan Strait have been reported on by Niino and Emery (1961), Emery, *et al.* (1969), and Wageman, *et al.* (1970). According to Emery, *et al.* (1969), and Wageman, *et al.* (1970), the sediments of the strait exhibit a simple pattern of silt and clay on the inner half near the mainland and sand on the other half near Taiwan. The sand on the half of the strait nearest Taiwan are calcareous and iron-stained; this is typical of relict sediments that have remained unburied on most continental shelves of the world (Emery, 1968).

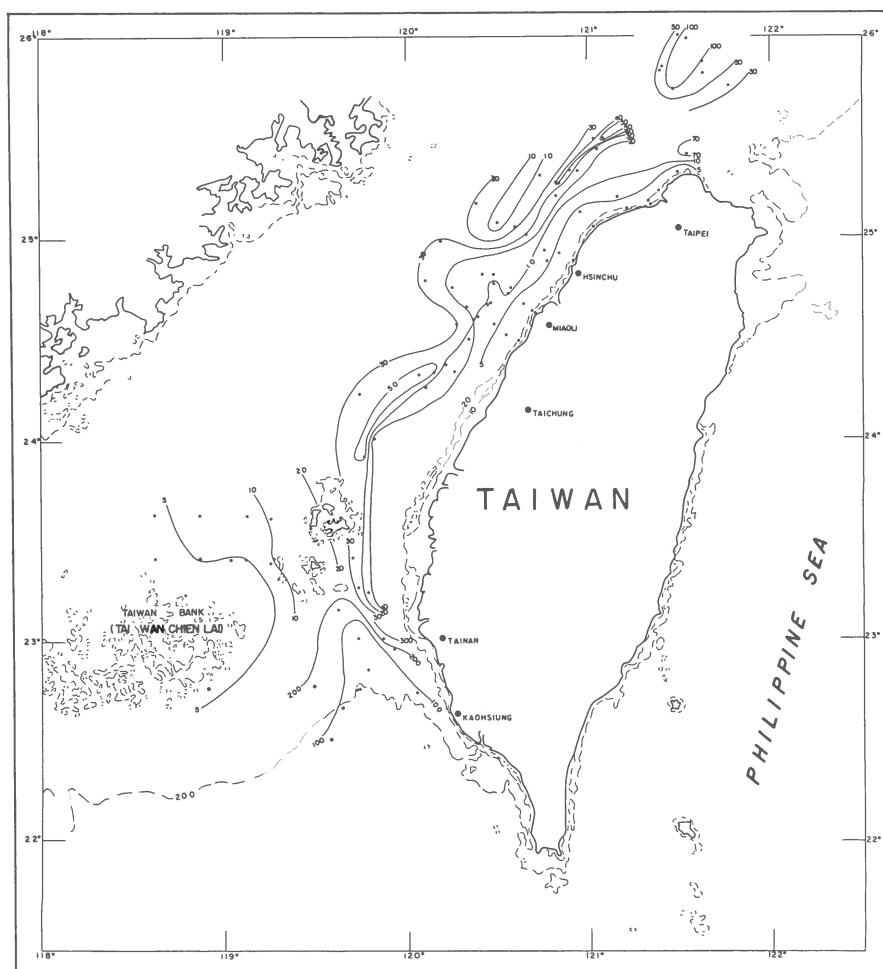
The sediments from the rivers usually contribute bulk the deposition along the coast especially in the typhoons season, but some one, as the Tanshui River in the north and the Hsiatanshui River in the south, never caused any accumulation of sediments on the coast because the sediments are conspicuously moved away by the strong currents. Thus, the coastal zone of western Taiwan is affected by the high marine agencies.

FORAMINIFERAL FACIES

Foraminiferal facies are based mainly on the benthonic foraminifers. The distribution of the foraminifers in the surface sediments of the Taiwan Strait is separated into two parts as planktonic foraminifers and benthonic foraminifers for the discussion in the following chapters. Because, the planktonic foraminifers are significant tracers of water masses and the benthonic foraminifers are a good environmental indices.

1. PLANKTONIC FORAMINIFERS

The planktonic foraminifers of the Taiwan Strait constitute a shallow water tropical-subtropical assemblage. Twenty-seven species and subspecies have been recognized. But only two species (*Globigerina borealis* and *G. bulloides*) are cool-water species. Generally, most of the species in the strait sediments are the smaller sized and thin shelled.



Text-fig. 5 - Planktonic/benthonic foraminiferal ratios.

The distribution of planktonic foraminifers in the sediments of the Taiwan Strait is significantly modified by the terms of all physical, chemical, and biological variables that may effect the growth of the species. Foremost among these factors modifying the distribution of planktonic foraminifers is the large volume of fresh water introduced into the sea off western Taiwan by many rivers. During the rainy season, the amount of fresh water flowing into the sea is greatly increased with a marked decrease in the salinity. As planktonic foraminifers are stenohaline, the area of low salinities is reflected in low planktonic numbers in the sediments of the near shore zone, with poor specimens of fossils or subfossils common. This distribution illustrates the utility of plots of planktonic foraminiferal numbers as indicators of euryhaline conditions and as current tracers.

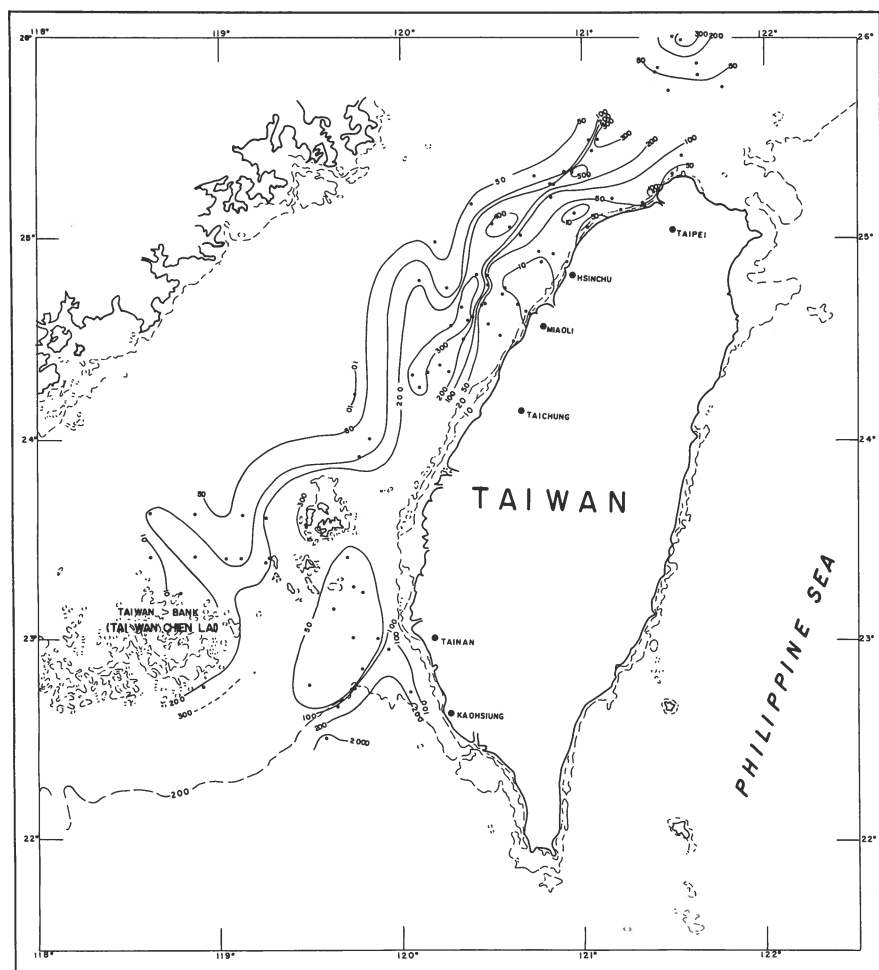
The distribution of high planktonic foraminiferal numbers on the middle portion of the strait is a reflection of the slow rates of deposition, and is also dependent upon the topographic low.

The percentages and numbers of planktonic foraminifers are closely related to submarine topography

and current action (Text-figs. 3, 4). High percentages of planktonic foraminifers are present in the Penghu Channel and the Chilung Channel areas (Text-fig. 4). Low percentages of planktonic foraminifers are present north of the Taiwan Bank, sometimes less than 2 per cent, perhaps because the Taiwan Bank obstructs the current in its flow from south to north across the bank (Text-fig. 4).

It may be worth mentioning that the distributions of the low percentages and low numbers of specimens of the planktonic foraminiferal portion of the strait correspond approximately to the areas of high concentrations of suspended sediment, more than 10 mg/l (Emery, *et al.*, 1969, fig. 8). and high percentages of yellow portion in water (Emery, *et al.*, 1969, fig. 6) in the near-shore zone of western Taiwan.

Planktonic-benthonic foraminiferal ratios are variable in the strait (Text-fig 5), although a trend toward high values exists at the outer edge of the shelf (Penghu Channel and Chilung Channel portion) and in the low topographic portions. The high ratio portions are subject to the great influence from the Kuroshio Current and the Coastal Stream. An even more



Text-fig. 6 - Total foraminifers in per gram of dry sediment.

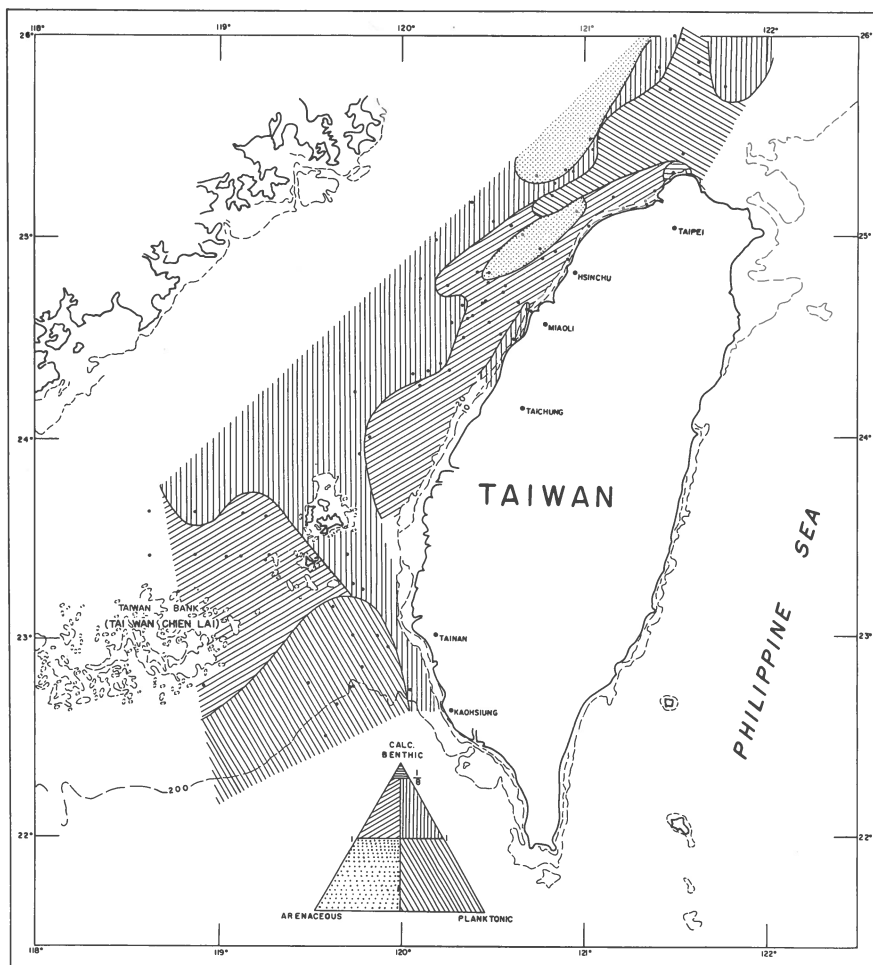
significant trend is illustrated in the analysis of planktonic foraminifers in unit sediments (Text-fig. 3), which shows that the near-shore and bank areas are generally characterized by values of less than 10 specimens per gram and the channel and basin areas by an increase to between 20 and 200 (Text-fig. 6).

In general, the planktonic population, which is very closely related to the submarine topography and distribution of water masses or currents, contributes greatly to the high foraminiferal number in both the channel areas and the depressions in the central part of the strait (Text-fig. 2); this is due to the influence of the branches of the Kuroshio current which carry planktonic forms through the Penghu Channel and the Chilung Channel into the portion of the strait nearest to Taiwan.

Multivariate analysis (trigon plot) is used to illustrate the interrelationship among the planktonic, calcareous benthonic, and arenaceous foraminiferal groups (Text-fig. 7). This shows that: (1) planktonic specimens are the more important element near the edge of the shelf and are the dominant group in the both channel portions; (2) calcareous benthonic for-

aminifers are more abundant than the other categories over almost the entire strait; (3) arenaceous specimens are more important than the planktonic specimens over most of the strait area.

Multivariate analyses (Text-fig. 8) of three component system of selected dominant planktonic foraminiferal species or species group are used for recognition of the water masses or currents movement. The multivariate analyses of a three component system involve *Globigerina bulloides*, *Neogloboquadrina dutertrei humerosa*, and *Globigerinoides trilobus-sacculifer* (because *G. sacculifer* and *G. trilobus* are in similar isotopic temperature, and presumably grow at similar depth (Hecht and Savin, 1971)), which are dominant faunal constituents of the Taiwan Strait area. Based on recent information of the distribution of planktonic foraminifers in the oceans, these three species were chosen for multivariate analysis. The first species occurs in abundance in cold-temperate water; the second species is common in intermediate depth, temperate-warm water; and both species of the third component are characteristic shallow tropical species. Multivariate analysis of the planktonic foraminiferal



Text-fig. 7 - Multivariate analysis of calcareous benthonic-planktonic-arenaceous foraminiferal relationships.

populations of these three components shows a dominance of *Globigerina bulloides* in the Matsu Basin, a dominance of *Neogloboquadrina dutertrei humerosa* in north of the Chilung Channel, and a dominance of *Globigerinoides trilobus-sacculifer* over the Taichung Bank and in the southern part of the strait (Text-fig. 8).

Based on this analysis, the distribution patterns of warm and cool fauna on the floor of the strait is quit similar to that of the current or water masses in the area.

Current indicator

Distribution of planktonic foraminiferal tests in marine sediments generally reflect their living patterns within given water masses. As a result of this, the distribution of planktonic foraminiferal tests in fossil marine sediments are being used increasingly for paleo-oceanographic reconstructions.

The organisms that are used to separate different water masses are called biologic indicators. It is quite understandable that the best current indicators belong

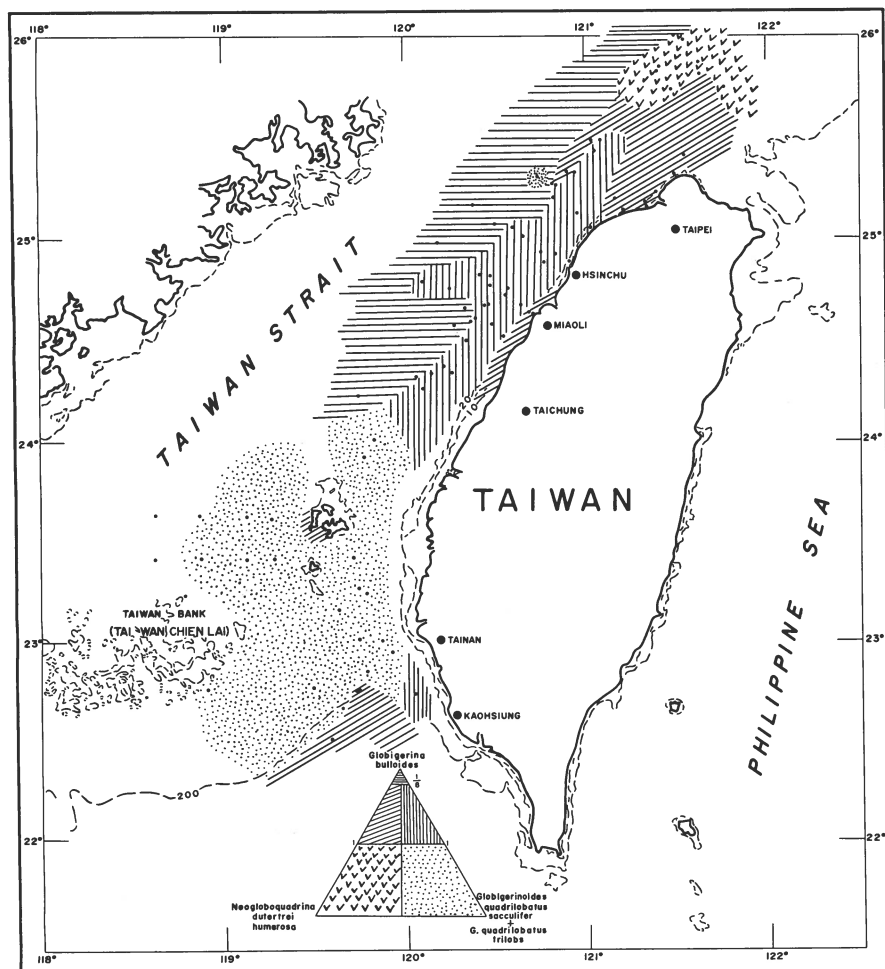
to the planktonic, because they have no movement of their own and are closely confined to the water where they live. The foraminiferal indicators are used for the first time to determine the limits of ocean currents by Boltovskoy (1959).

Planktonic foraminifers are known to be sensitive to ecological changes, numerous, and widely distributed throughout the world. It is therefore logical to expect that their distribution would depend on the distribution of different water masses, that among them species could be found that can serve as good biological indicators, and some attempt should have been made to define ocean currents with their help.

And Boltovskoy (1959) has observed that good correspondence in distribution is found between the faunas living in the water and the dead assemblages in the bottom surface sediments.

On this reason, the analysis of the distribution of the planktonic foraminifers in the surface sediments of the Taiwan Strait is used to recognize the character of water movements in the strait (Text-fig. 8).

The distribution of *Globorotalia cultrata menardii* indicates that the Kuroshio Current extends up to lati-



Text-fig. 8 - Relationship of *Globigerina bulloides*, *Neogloboquadrina humerosa* and *Globigerinoides sacculifer* (including *G. trilobus*) as a three-component trigon system.

tude 38°N (Asano, 1957) along the east coast of Japan, and that it turns to the east and becomes mixed with waters of other origins. The branches of the Kuroshio Current extend into the Taiwan Strait from north and south.

The distribution of *Globigerina bulloides* indicates that the cool water masses come from the north by its presence in large quantity in the northern half of the strait and in smaller quantity in the southern half. The topographic high of the Taichung Bank, Penghu Islands, and Taiwan Bank in the middle portion of the strait undoubtedly have great influence upon the planktonic foraminiferal distribution.

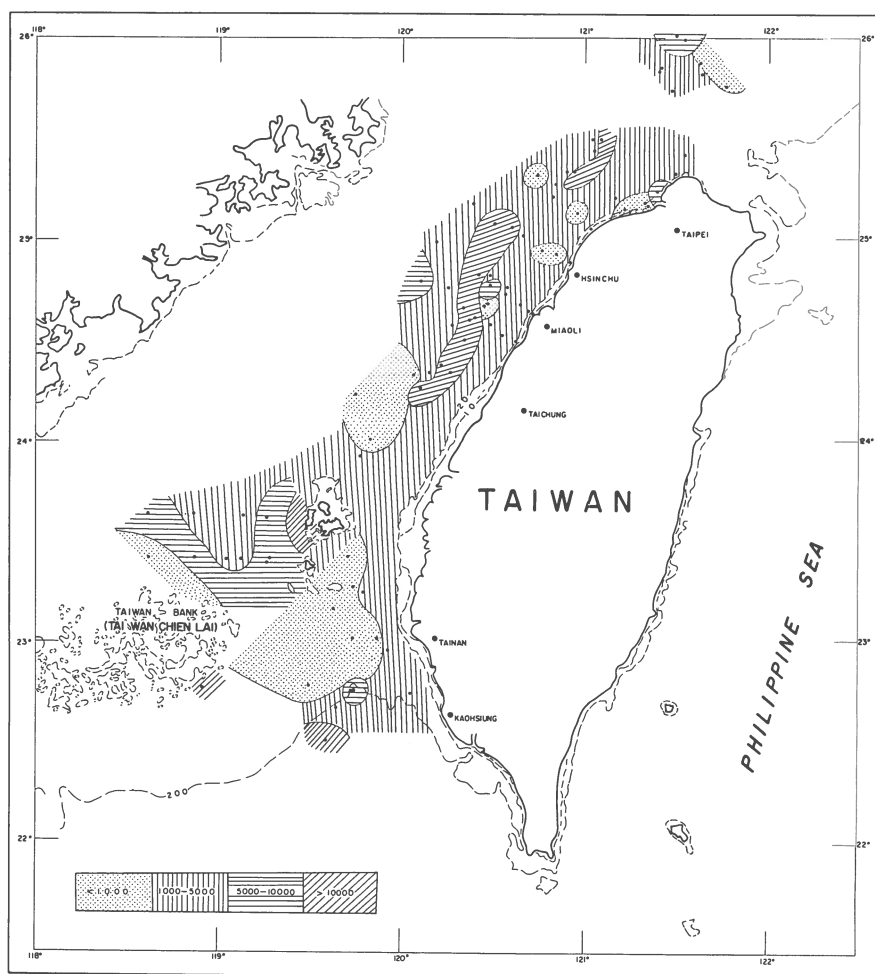
Globorotalia menardii tumida is a foraminifer not present in the strait water. Thus makes it much more logical to assume that the specimens of this species are not brought into the strait by the Kuroshio Current in the winter time, since this species was found only in the winter material of the Atlantic Ocean by Boltovskoy (1968).

Although *Globigerina borealis* (= *G. pachyderma*) is generally considered to be a characteristic high-latitude species, it is interesting to note that the studies

of Ericson (1959), Bandy (1960), and others on the coiling characteristics of this species have made it possible to divide the Recent populations of *G. borealis* into two categories: one the sinistrally-coiled, cool-water type and the other the dextrally-coiled, warm-water type, the former confined to high latitudes and the latter abounding in temperate waters of mid-latitudes but sometimes extending to low latitudes. In the sample from the Taiwan Strait, all the specimens of *G. borealis* are dextrally coiled and in this respect fit the latter category. Additional evidence for their being warm-water types is furnished by their test wall invariably thinner and lacking the characteristic calcareous thickening considered typical of cool-water forms. Thinner-test population of *G. borealis*, reflecting the effect of warmer temperatures, have also been often noted by other workers (Parker, 1962; Saito, 1963).

Thus the occurrence of dextrally-coiled *G. borealis* in association with *G. bulloides* in significant numbers indicates the existence of mid-latitude faunal elements in the assemblage under review.

It is, however, logical postulate also, in the present



Text-fig. 9 - Total benthonic foraminifera in 50 gr of dry sediment.

case, that the cool-water elements may have been introduced into the area by a current off the coast of the continent flowing south from the mid-latitudes, carrying with it elements of the northern cool-water fauna.

2. BENTHONIC FORAMINIFERS

Use of benthonic foraminifers as environmental indices has already proved to be of great value in reconstructing paleoenvironments. Some of the more recent advances consist of more quantitative evaluations of general distribution patterns and their reliability.

The quantitative and qualitative analysis on the benthonic foraminifers collected from the Taiwan Strait are discussed in this section.

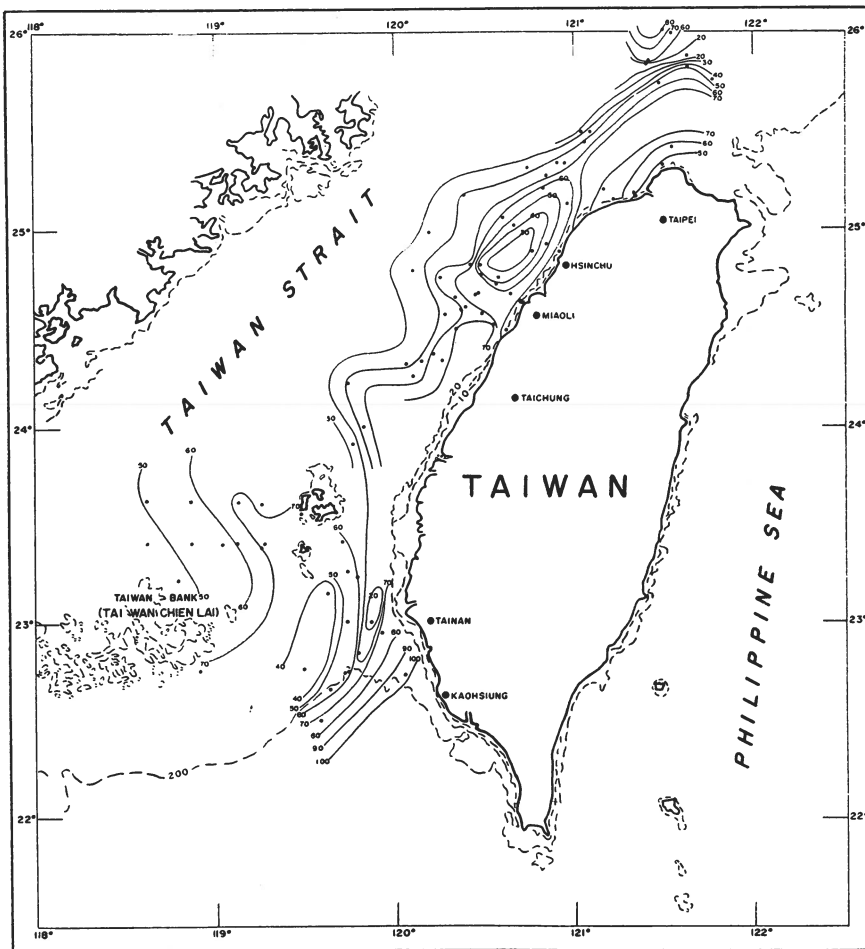
A. Foraminiferal number

The total foraminiferal abundance, including both live and dead specimens in the samples, was used in

this study. Foraminiferal abundance in the Taiwan Strait is less than 200 specimens per gram over extensive areas, but the values are higher in the Matsu Basin and the Penghu Channel areas (Text-fig. 2). The isopleth for 50 specimens per gram falls approximately along the near-shore area of western Taiwan except in near the mouth of the Tanshui River (Text-fig. 6).

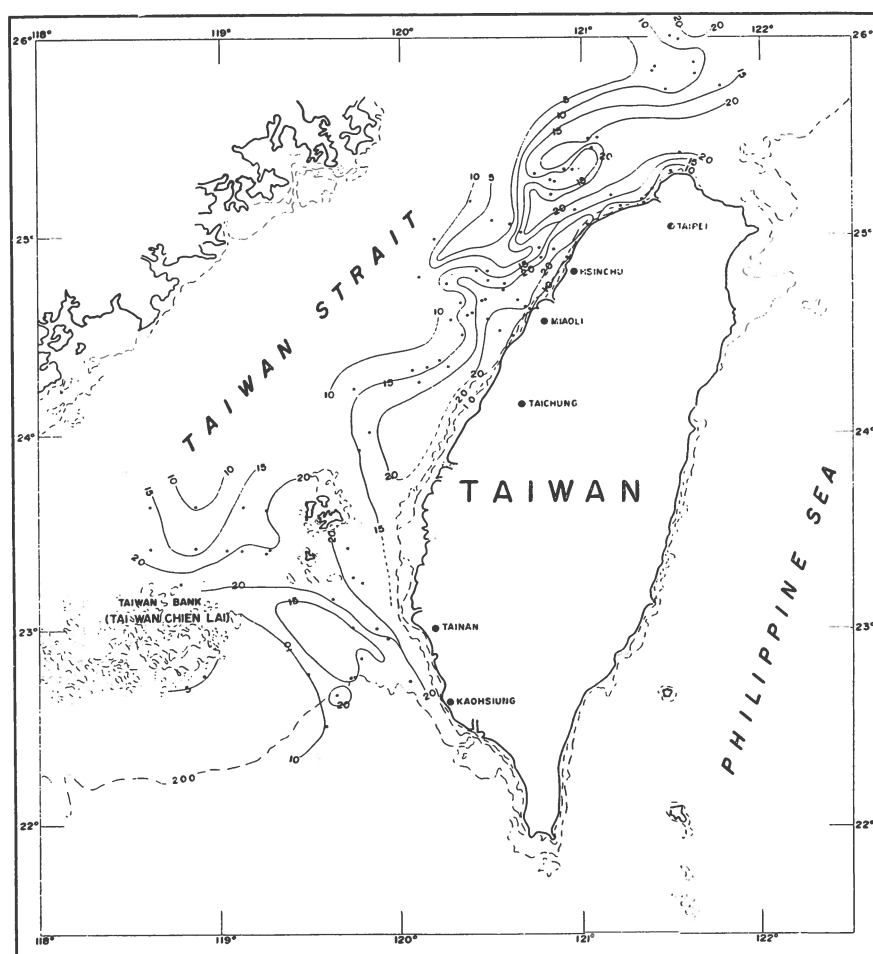
The low value of the shallow near-shore areas can be attributed to the outflow of fresh river water, which is not conducive to the proliferation of foraminifers, and the rapid sedimentation (John, *et al.*, 1970) which dilutes the concentration of foraminiferal tests. The highest values, just beyond the break in slope west of Kaohsiung (St. No. 34), are on the side of the southern slope where it is met by the branch of the Kuroshio Current which brings in many planktonic foraminifers from the south (Text-fig. 3).

Off the west coast of Central America the foraminiferal number increases out of the upper part of the continental slope and then decreases in deeper water (Bandy and Arnal, 1957). In the Taiwan Strait, the variation of the foraminiferal number is generally the similar as else where in the north half of the strait,



Text-fig. 10 - Geographic distribution of number of species in Taiwan Strait.

From the consideration made on a quantitative research by application of Simpson's Method (Text-fig. 11), Motomura's Low (Text-fig. 12), and Walton's Method (Text-fig. 13), however, in general the areal distribution pattern of these diversity index are closely similar to each other. In general, the southern half of the strait is simple, except the Penghu Channel por-



Text-fig. 11 - Diversity distribution of the Taiwan Strait.

tion, but in the northern half is more complicated in composition. Therefore, the existence may be expected of two independent communities one particular to the shallow flat bottom area and the other to the shallow with depressional bottom area.

D. Relict specimens

Displacement of faunas has resulted in considerable mixing of assemblages in the strait, especially in the near-shore shallow waters where specimens are reworked from older beds and deposited in the sea and in the Matsu Basin where the specimens are displaced from the surrounding shallow rim portion into center of the basin.

Some group of species may be reworked from the older strata and transported into the near shore zone (Huang, 1961a and b) and the distribution of the species diversity affected by it.

The displaced specimens are easily distinguished by the state of preservation as the external surface is dull, chamber cavities are infilled and brown in colour, and test is deformed; these poorly preserved specimens

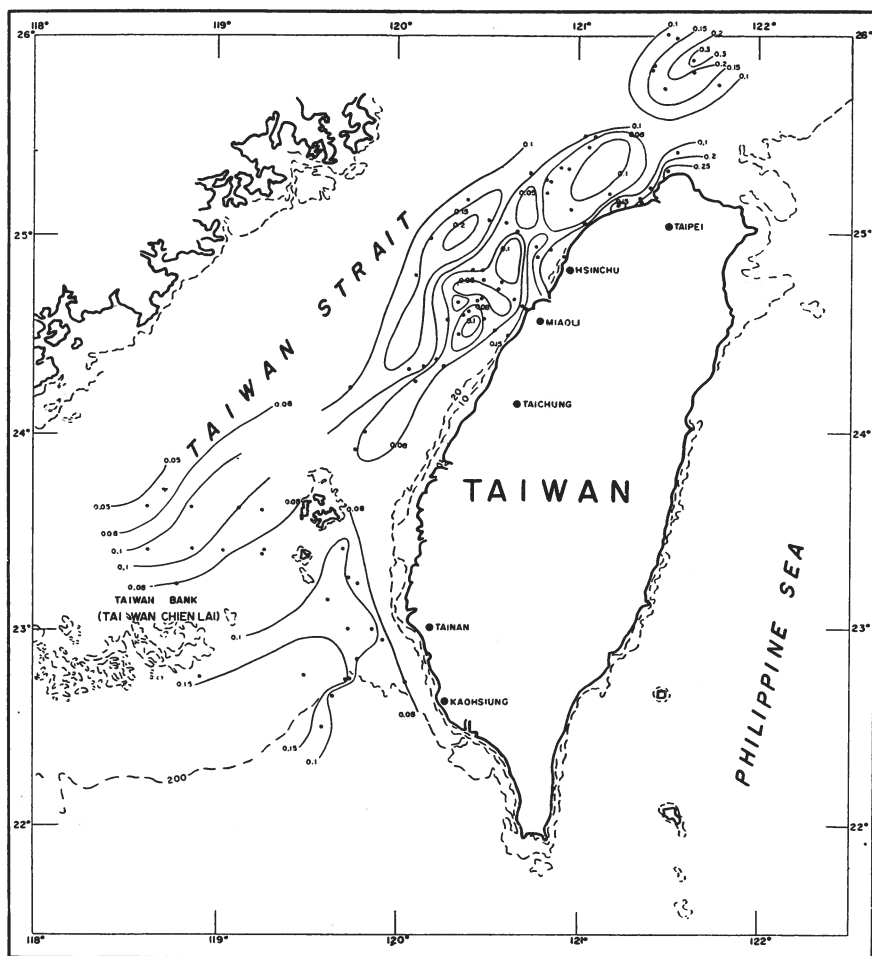
may include both reworked fossils and dead transported tests.

E. Planktonic-benthonic ratio

The abundance of planktonic foraminiferal tests in bottom sediments reflects their rate of productivity in the overlying water column as well as the rate of sedimentation on the sea floor. In the Taiwan Strait deposits are characterized by values of 20 planktonic specimens per gram is less in the most of the bottom samples whereas planktonic number abruptly increases to 30 and 200 at depressed portions and channels (Text-figs. 5, 7).

F. Distribution of the major groups

A method of foraminiferal analysis which has proved to be interesting and significant is determining the relationship among the major groups designated as hyaline (calcareous perforate), arenaceous, and por-



Text-fig. 12 - Distribution of the value *a* in Motomura's Low.

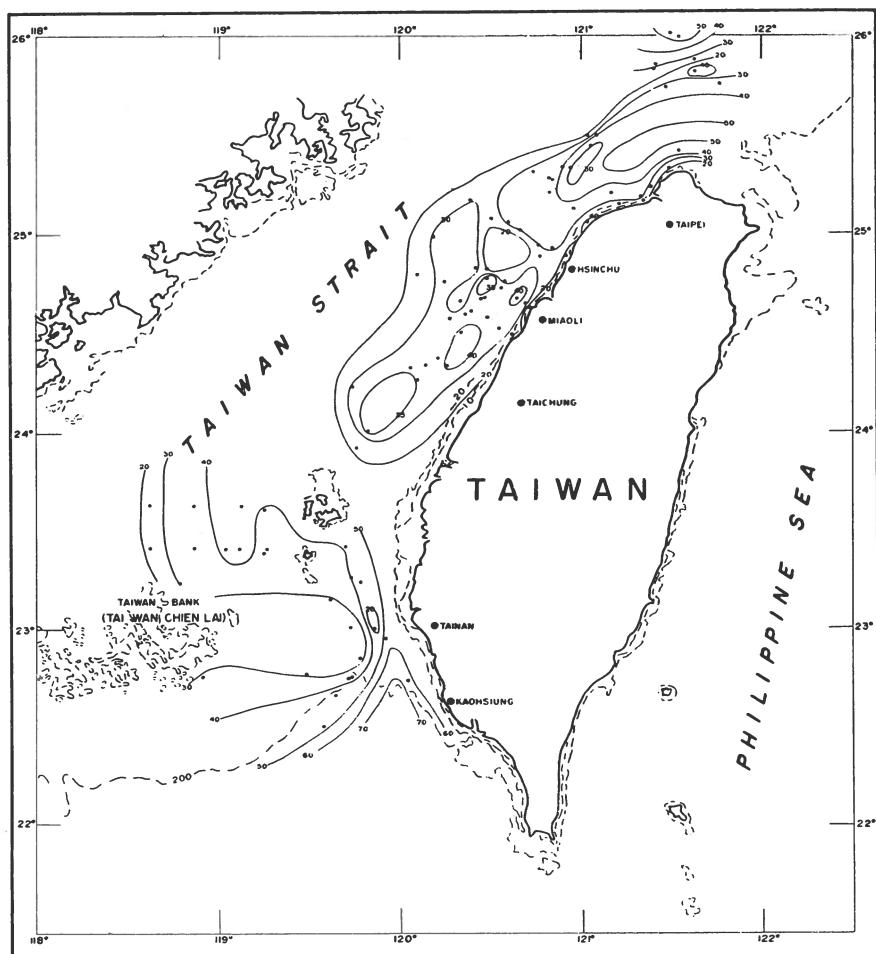
cellaneous (Text-fig. 14). Although hyaline types are usually dominant over the other groups, porcellaneous foraminifers are common in the near-shore zone and the bank area, but are generally relatively insignificant in the strait, whereas arenaceous types are the most important group in the topographic depressions such as the Matsu Basin. The relative abundance distributions of the three major groups (Text-figs. 15, 16, 17) of benthonic foraminifers in the strait is clearly correlated with the submarine topography.

The highest proportion of arenaceous forms is in the basin and channel portions (Text-fig. 15). The porcellaneous forms are less than 5 per cent in Penghu Channel and the Matsu Basin areas, and more than 20 per cent in the near-shore zone of northern Taiwan (Text-fig. 16). The relative abundance of the calcareous perforate forms is more than 60 per cent in the near-shore zone and the central portion of the strait and 40-60 per cent in the area between (Text-fig. 17).

In conclusion, the distribution of the benthonic foraminifers are greatly influence by the submarine topography and water masses in the strait.

G. Distribution of the dominant species

The distribution patterns of the selected species and species group show trends useful for analysis of some of the principal species. *Pararotalia ozawai* and *P. taiwanica* are occurred abundantly in the near-shore zone of northern Taiwan and over the shallow water area around the Penghu Islands. *Asterorotalia inflata* is abundantly just off the Miaoli coast, in the Matsu Basin and off the north coast of Taiwan. *Ammonia takanabensis* is abundant in the Matsu Basin, and are in the area between the Taiwan Bank and the Penghu Islands. *Hanzawaia hoppoensis* is widespread among the faunas in the strait and it increases away from shore towards the central portion of the strait and towards the shelf edge. *Discorbis chinensis* is dominant in the shallower areas offshore from northern Taiwan, over the Taichung Bank and around the Penghu Islands. *Cibicides pseudoungerianus* is very similar to that of *Discorbis chinensis*. *Textularia* is most dominant in the topographically depressed areas in the strait: the Matsu Basin, Taichung Basin, and



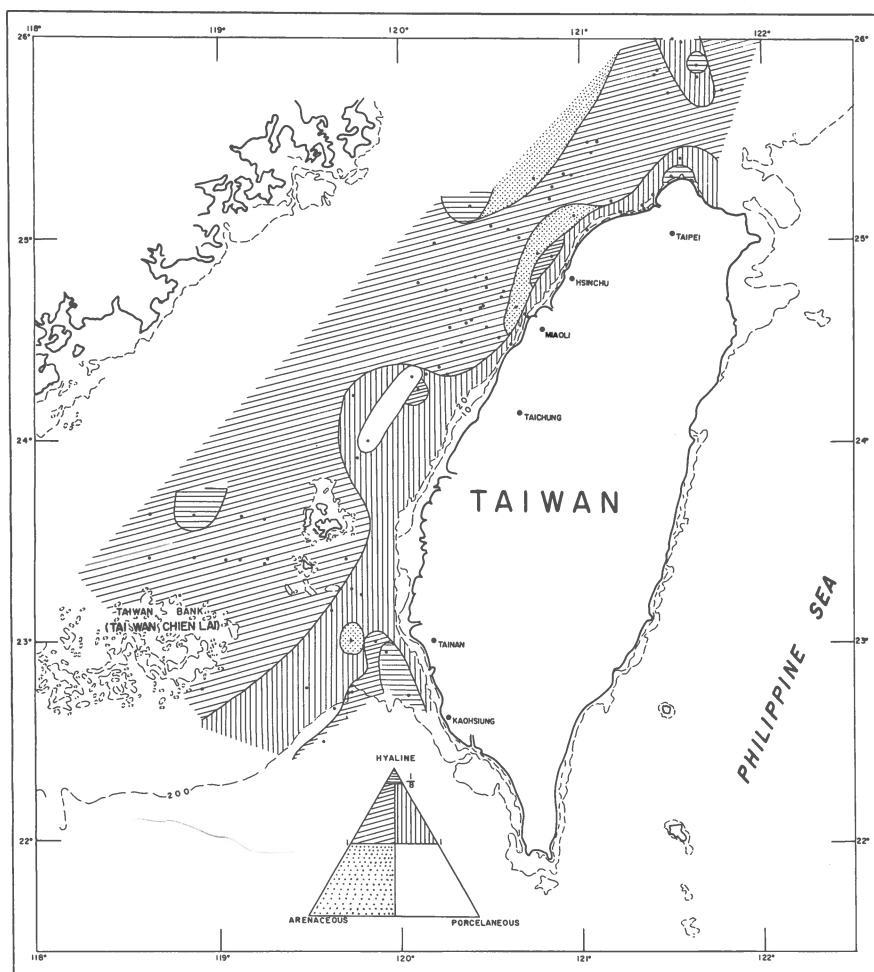
Text-fig. 13 - Geographic distribution of variability values (V) in Taiwan Strait.

Penghu Channel. *Siphonaperta formosana* is widely distributed in the strait but not very abundantly and it is relatively more common in the Matsu Basin. *Quinqueloculina vulgaris* is common in the strait. *Bolivina robusta pacifica* is widely distributed in the strait but is only dominant in the Matsu Basin and the Penghu Channel and also in a small area near the mouth of the Houlung-chi. Buliminidae are most dominant in the Matsu Basin and the Penghu Channel. The relative frequency distribution of this group increases in percentage with increasing depth of water and distance from shore. *Amphistegina* spp. and *Operculina* spp. are frequent in the near shore zone off the Hsinchu-Miaoli area and near the Taiwan Bank area but all not over 4 per cent. The cold or deep water species, *Hyalinea balthica* and *Pullenia bulloides* are found in the Matsu Basin and the Penghu Channel portion and absent in the Taiwan Bank-Penghu Islands area. The percentages of the both species are also lower than 10 per cent.

H. Faunal trends

Recently, communality has become increasingly accepted as a reliable criterion for the quantitative representation of faunal composition or comparison and the quantitative faunal analyses of Taiwan Strait will be treated on this basis (Ujiie, 1962). Six foraminiferal faunas are recognized from the strait based on the abundancy occurrences of the total foraminifers (Text-fig. 18).

In these faunal groupings, the species in the assemblage of each sample were arranged in order of abundancy occurrence and, of those comprising the cumulative 50 per cent of the assemblage the most abundant of them are taken into account to determine the order of the dominant species in the samples (Tab. 1). The characteristics of the six facies, in which minor subfacies are recognized in facies 2, 3, and 4, are described below.



Text-fig. 14 - Multivariate analysis of hyaline-arenaceous-porcellaneous group of benthonic foraminifers.

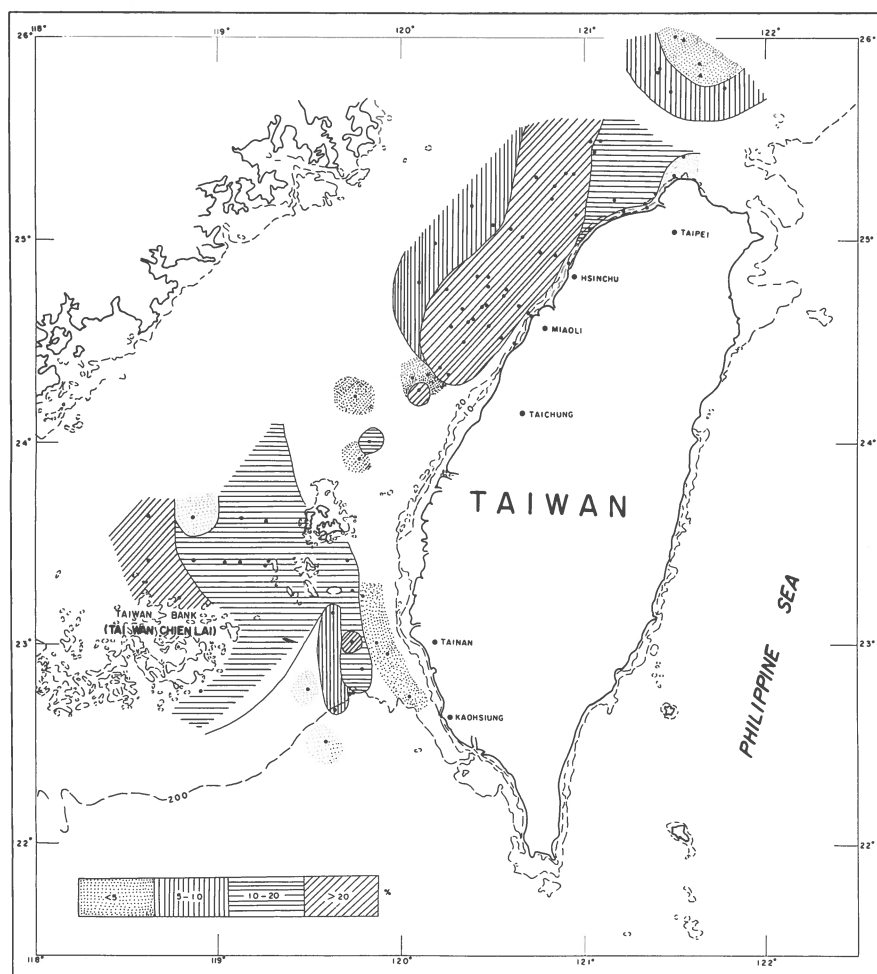
Facies 1 (near-shore facies): This facies is in the shallow near-shore areas off western Taiwan. It is characterized by the predominance of *Pararotalia oza-wai* and *P. taiwanica* in the assemblages at depths shallower than 40 m. The number of species comprising 50 per cent of each assemblage varies from 2 to 8. Buliminids are generally very rare in this facies (less than 5 per cent) except in the area off the mouth of the Houlung-chi station (II-1b). The total number of species varies greatly from 10 to 75. This facies is also characterized by the low numbers of the total benthonic foraminifers in sediment units and the planktonic/benthonic foraminiferal ratios are less than 5. Associated species with significant frequencies are *Discorbis chinensis*, *Cibicides pseudoungerianus*, and *Quinqueloculina seminulina*. Planktonic foraminifers are very rare in this facies but reworked specimens, including fossils derived from Cenozoic sediments, are common.

Facies 2 (offshore facies): This facies, along the western side of the near-shore facies, which corresponds to the east rim of the Matsu Basin and the Taichung Bank environment, is characterized by the

high frequencies of arenaceous forms in the assemblages, but no particular species can be regarded as characteristic as far as dominance is concerned. The water depths range from 40 to 100 m and the number of species comprising 50 per cent of each assemblage is 4 to 10. The distribution of the number of species in this facies varies between 30 to 71 but the range of 40 to 60 is most common. The planktonic/benthonic foraminiferal ratios range between 10 and 40 for most of this facies. *Amphistegina* and *Operculina* are frequently found in it, and *Hyalinea balthica* occurs rarely. The facies is subdivided into four subfacies according to the composition of the dominant forms.

Subfacies 2a, found in the area northwest of Hsin-chu, is characterized by the dominance of *Textularia conica*. Associated species with significant frequencies are *Discorbis chinensis* and *Textularia foliacea oceanica*.

Subfacies 2b is found only in a small area north of subfacies 2a; it is distinguished by the dominance of *Bolivina robusta pacifica* and *Discorbis chinensis* and a rather high frequency of Textulariid forms, while *Hyalinea balthica* is very rarely present.



Text-fig. 15 - Distribution of arenaceous forms in per cent of total benthonic population.

Subfacies 2c, to the south of subfacies 2a, is characterized by the dominance of *Asterorotalia inflata* and *Quinqueloculina seminulina*.

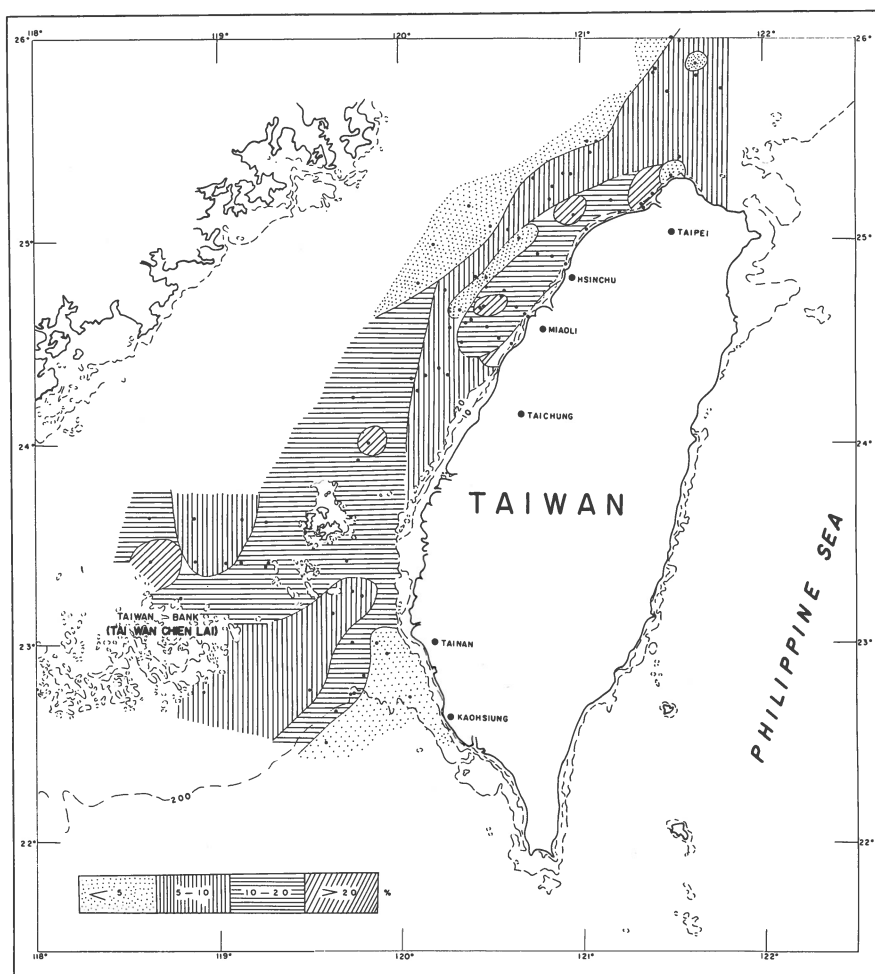
Subfacies 2d, to the west of subfacies 2c, is characterized by the dominance of *Discorbis chinensis* and *Ammonia takanabensis*, together with *Siphonaperta formosaensis* and Textulariids. *D. chinensis* is most dominant in all the assemblages.

Facies 3 (basin facies): This is situated in the central portion of the strait, corresponding to the Matsu Basin and part of the Penghu Basin at water depths ranging from 60 to 100 m. It is characterized by the dominant occurrence of *Bolivina robusta pacifica*, while *Hanzawaia hoppoensis*, *Ammonia takanabensis*, and *Florilus japonicum* are next in abundance. *Hyalinea balthica*, which is a typical cold water inhabitant, occurs rarely in the assemblages. The number of species comprising 50 per cent of each assemblage is from 3 to 6 except for sample 3, where *B. robusta pacifica* alone comprises 50 per cent of the assemblage. The planktonic/benthonic foraminiferal ratios range from 20 to 30 and the foraminiferal number is less than 100

per gram of dry sediment. The number of species is rather uniform and ranges between 42 and 60. Planktonic foraminifers are common and comprise more than 15 per cent of the assemblage. This facies includes two subfacies.

Subfacies 3a is situated at the northern part of the central portion of the strait and is characterized by the *Bolivina robusta pacifica* assemblage, while subfacies 3b is north of the Penghu Island and is characterized by the *Bolivina robusta pacifica* - *Florilus japonicum* assemblage.

Facies 4 (bank facies): This facies, in the area between the Taiwan Bank and the Penghu Islands, is characterized by the dominance of *Cibicides pseudo-ungerianus* and *C. sintikuensis* at depths between 20 and 150 m. Associated species with significant frequencies are *Pararotalia taiwanica*, *Hanzawaia hoppoensis*, and miliolids, while *Amphistegina* and *Operculina* are also frequently found. The number of species comprising 50 per cent of each assemblage varies widely, from 27 to 75. This facies is characterized by the low numbers of the total planktonic foraminifers



Text-fig. 16 - Distribution of porcellaneous foraminifers in per cent of total benthonic population.

per unit of sediment, less than 50 specimens and the planktonic/benthonic foraminiferal ratio are also lower, less than 20. This facies is similar to the near-shore facies but easily distinguished from the near-shore facies by the low frequency of Textulariids. This facies includes three subfacies.

Subfacies 4a, along the northeast edge and slope of the Taiwan Bank, is characterized by the dominance of *Cibicides pseudoungerianus* and *C. sintikuensis*.

Subfacies 4b, situated to the north of subfacies 4a and west of the Penghu Islands, is characterized by the dominance of *Cibicides pseudoungerianus* and *C. sintikuensis*.

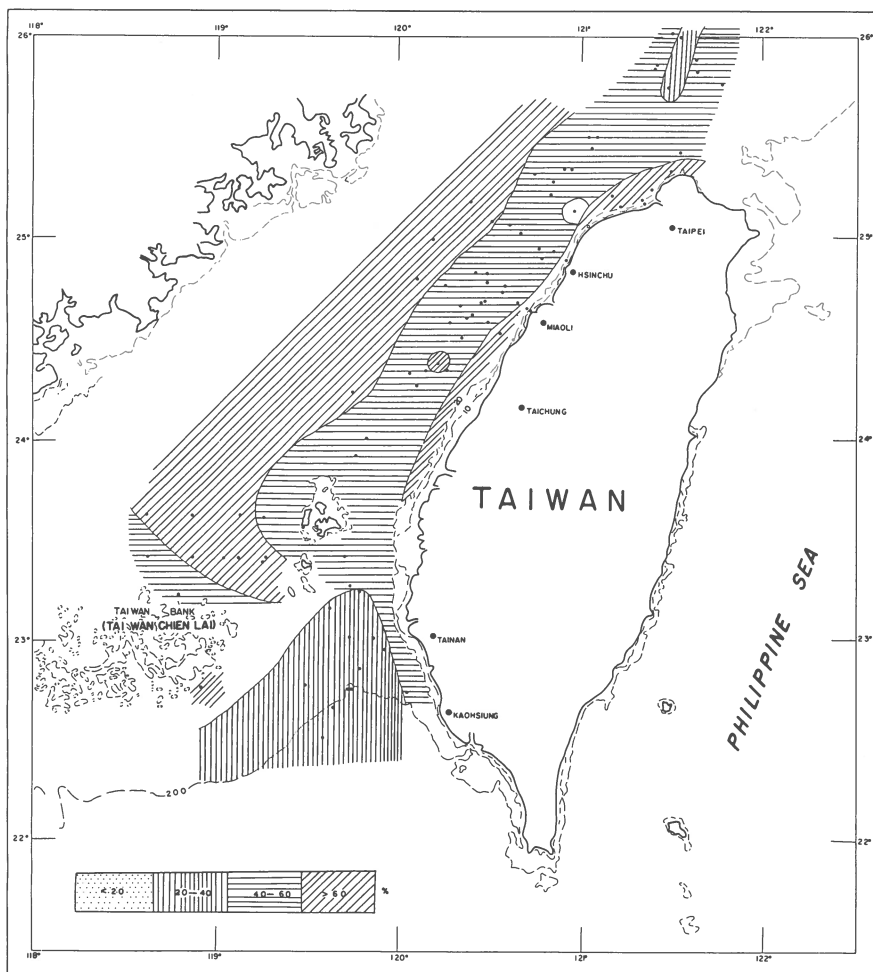
Subfacies 4c lies to the southeast of subfacies 4a but no particular species can be regarded as the most dominant. Associated species with significant frequencies are *Bigenerina irregularis*, *Ammonia beccarii*, *Quinqueloculina lamarckiana*, *Heterolepa praecincta*, *Florilus japonicum* and *Asterorotalia inflata*.

Facies 5 (Chilung Channel facies): This facies, north of the Chilung Channel, is characterized by the

dominant occurrence of *Cibicides pseudoungerianus* and *Asterorotalia inflata* at depths of 50 to 150 m. The number of species is highly variable, from 15 to 80, and the foraminiferal ratios are highly variable, from 30 to more than 300. Associated species with significant frequencies are *Hanzawaia hoppoensis*, *Cibicides sintikuensis*, *Heterolepa praecincta*, and *Bolivina robusta pacifica*.

This facies is similar to the bank facies but it differs in the *Amphistegina* and *Operculina* are lacking and the frequency of *Hyalinea balthica* and *Pullenia bulloides* is very low.

Facies 6 (Penghu Channel facies): This facies found in the Penghu Channel at depths ranging from 100 to 200 m, is characterized by mixed occurrences of shallow water and rather deep water species. Most of the dominant species belong to the Buliminacea, including *Bolivina robusta*, *Bolivina robusta pacifica*, *Uvigerina auferiana* and *Siphogenerina raphanus*. Other associated species with significant frequencies are *Gyroidina neosoldanii*, *Melonis barleeanus*, *Discorbis taiwanensis*, *Elphidium advenum*, and *Ammonia*



Text-fig. 17 - Distribution of calcareous foraminifers in per cent of total benthonic population.

spp. The number of species comprising 50 per cent of each assemblage ranges from 5 to 10. The total benthonic foraminifers is over 1,000 per unit of sediment and the total planktonic foraminifers is also over 1,000. The planktonic/benthonic foraminiferal ratios range from 100 to 300. Planktonic foraminifers are very abundant in this facies, more than 40 per cent.

CONCLUSIONS

1. More than 400 species constitute the total benthonic foraminiferal assemblages in the Taiwan Strait. Most of the species of foraminifers found there are common in the Indo-Pacific region.

2. Twenty-seven planktonic species have been found in the sediments, and the most of them are common in the tropical to subtropical water. Only two species (*Globigerina borealis* and *G. bulloides*) are from the middle latitude.

3. The strait fauna is characterized by the many fossil specimens in the sediments. The value of fossil specimens are decreasing in the number away from the

shore zone. The relative abundance of the fossil specimens of foraminifers may be used to interpret the paleoenvironment.

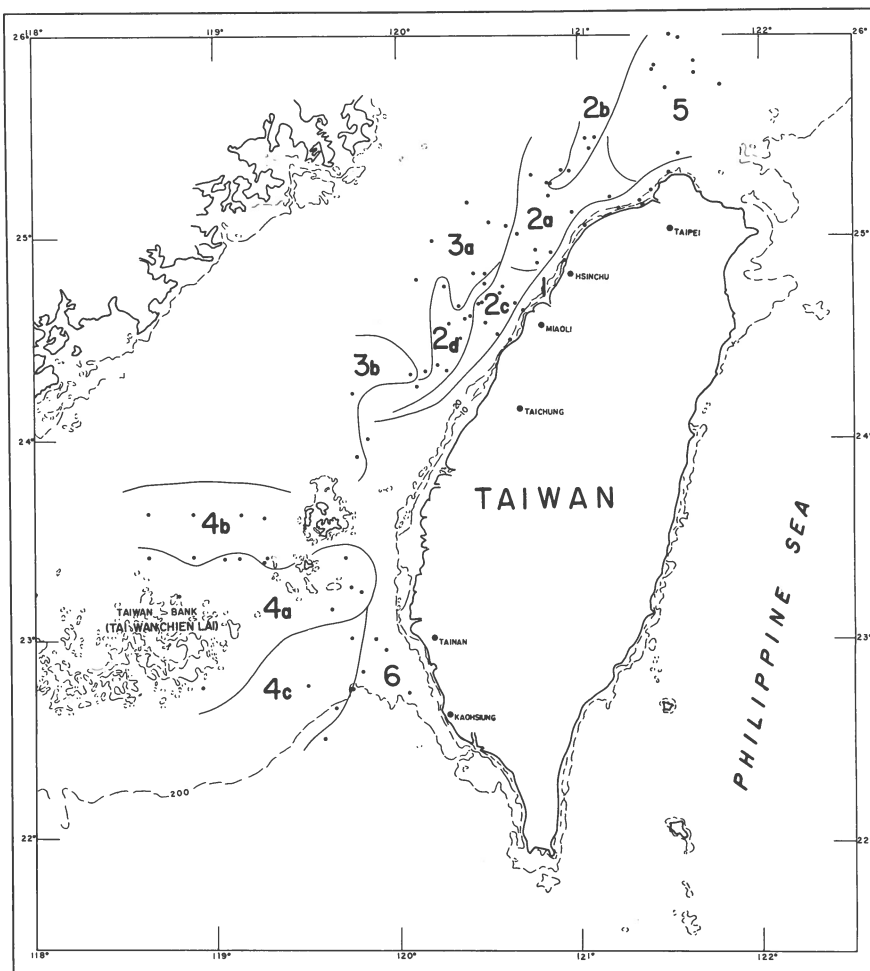
4. The faunal gradation is related to the distribution of the water masses comprising the cold current along the mainland coast, the Kuroshio Current, and the upwelling water, and the topography of the strait.

5. The Taichung Bank, Penghu Islands, and Taiwan Bank apparently exert a strong influence on the density and distribution pattern of the species on both the benthonic and planktonic foraminifers.

6. Based on the distribution of the planktonic foraminifers, the water masses exerting the most influence are the Kuroshio Current and the China Coastal Stream.

7. The cool water species of planktonic foraminifers are dominant in the north half of the strait and the warm water species are dominant in the south half.

8. The planktonic assemblage in the strait is characterized by the very rare occurrence of *Orbulina universa* and absence of *Globorotalia menardii tumida*.



Text-fig. 18 - Distribution of the foraminiferal facies and subfacies in Taiwan Strait.

Faunal group	Station	Name and order of species comprising 50% of assemblage	Number of species	Faunal group	Station	Name and order of species comprising 50% of assemblage	Number of species
1	H-1	Pr ₃ -Di ₁	2	3a	II-6	Bo ₂ -Ha-A ₃	3
	H-2	Pr ₃ -Ci ₂ -T ₁ -Ha-Q ₂ -Sp	6		III-5	Bo ₂ -Ha-A ₃	3
	H-5	Pr ₃ -Q ₃	2		III-6	Bo ₂ -Ar-A ₃	3
	I-1	Pr ₃ -Di ₁ -Ci ₂ -Pr ₁	4		25	Bo ₂ -Ha-A ₃ -Fs-El-Ar	6
	III-1	Pr ₃ -Tr-Pr ₃ -Q ₃ -Ml-A ₁	6		II-5	Di ₁ -Bo ₂ -A ₃ -T ₃ -Sn	5
	H-3	Ci ₂ -Pr ₃ -Q ₈ -T ₁ -Pe	5		14	Di ₁ -T ₃ -T ₁ -A ₃ -El-Ha	6
	H-7	Ci ₂ -Pr ₃ -Di ₁ -T ₁ -Ha-El-A ₄ -T ₃	8		23	Ha-Bo ₂ -A ₂ -T ₃	4
	H-4	Q ₈ -P ₃	2		46	A ₃ -Bo ₂ -El-A ₉ -T ₃ -Di ₁	6
	II-1a	Pr ₄ -Q ₈ -Ci ₂ -Ha-Ce-Sp	6	3b	15	Bo ₂ -Fl-Uv-Di ₁ -Fs	5
	II-1b	Bo ₂ -Ar-Di ₁ -Ha-Pr ₄ -El-Pr ₁ -Ci ₂	8		6	Bo ₂ -Le-Fl-Q ₈ -Di ₁	5
2a	I-2	T ₁ -As ₂ -El-Ps ₁ -Q ₈ -Ha-T ₄ -Pe	8		26	Fl-Bo ₂ -A ₁ -A ₂ -Di ₁ -Fs	6
	I-3	T ₁ -A ₄ -Ha-Ar-Sz-A ₁	6	4a	6-B	Ci ₂ -Pr ₄ -Ci ₃ -T ₄ -Pe-T ₁ -Ha	7
	I-4	T ₁ -T ₃ -Di ₁ -Ha-A ₃	5		27	Ci ₂ -T ₁ -Di ₁ -Ci ₃ -Pr ₄ -Ha-El	7
	2	T ₁ -T ₃ -A ₁ -A ₃ -Ha-Ac	6		7	Ci ₂ -Pr ₄ -Ar-T ₁ -Pe-Q ₄ -Ro-Bo ₂ -T ₂	9
	52	T ₁ -Di ₁ -Ha-T ₃ -Ci ₁ -Ci ₂	6		48	Ci ₂ -Pr ₄ -Q ₈ -El-A ₁ -T ₄ -T ₁	7
	22	T ₄ -A ₂ -Bo ₂ -Di ₁ -T ₁ -Ha-Sn-El	8		32	Pr ₄ -Ci ₃	2
	H-8	T ₃ -T ₁ -T ₆ -T ₃ -Sm-Tr	6		30	De-Ps ₃ -Ci ₂ -Pr ₃ -Pe-Q ₄ -Di ₃ -T ₄ -Ci ₁	9
	39	Ha-T ₅ -A ₄ -Ci ₂ -T ₃ -T ₄ -Q ₁ -Di ₁	8		28	El-A ₁ -Q ₁ -Ha-T ₁ -Pr ₄ -T ₄	7
	20	Di ₁ -T ₁ -A ₃ -Sn-T ₃ -Fs-Ci ₂ -Sl	8	4b	5-B	Ci ₂ -Ci ₃ -Ha-T ₅ -T ₁ -Di ₁	6
	38	Di ₁ -T ₁ -T ₅ -Ha-T ₃ -Ci ₂	6		5-B	Ci ₃ -Ci ₂ -Ha-Di ₁	4
	H-6	Ci ₂ -Di ₁ -T ₁ -Ha-A ₄ -Q ₈ -Ci ₁	7		6-A	Ci ₂ -Ci ₃ -Di ₁ -Di ₁ -Pe-T ₁ -T ₅ -Ci ₁	8
2b	19	Bo ₂ -T ₁ -T ₁ -Ar-A ₂ -Ha-Di ₁	7		6-C	Ci ₂ -Ci ₃ -Ha-T ₅ -A ₄ -T ₁	6
	45	Bo ₂ -Di ₁ -A ₃ -T ₁ -Sn	5		5-A	As ₂ -Ci ₃ -Ci ₂ -T ₅ -Ci ₁	5
	21	Bo ₂ -Di ₁ -T ₁ -Sl	4		5-D	Ha-El-Ci ₂ -Bo ₂ -Sn-Ar-Fs-T ₃	8
	37	A ₃ -Bo ₂ -T ₄ -Ar-Di ₁ -T ₁ -Ci ₂ -Sn	8		6-D	De-Ps ₃ -As ₁ -Q ₇ -Ps ₂ -Sm	6
	13	Di ₁ -Ci ₂ -Ha-Bo ₂ -T ₆	5	4c	17	Bi-Ci ₂ -He	3
2c	II-3	Ar-Ha-Ce ₂ -T ₁ -Q ₈ -Sn-A ₃ -Pd-Ft	10		8	Q ₁ -Bi-Ft-Ci ₂ -P ₁	5
	III-3	Ar-Ha-T ₃ -Sn-Ae-El-Di ₁	7		33	Ci ₂ -He-Ha-El-Sn-Ar-Q ₅	7
	III-2	El-T ₃ -Di ₁ -Ar-Ha-A ₃	6		29	A ₁ -Fl-Ar-T ₄	4
	5	El-Ar-A ₃ -Di ₁ -Q ₈ -T ₁ -T ₃	7	5	1	Ci ₂ -Ar-El-Ha-Bo ₂ -Fl-He	7
	16	Ha-Q ₈ -Nn-A ₁ -A ₃ -T ₆ -T ₃ -El	8		18	Ci ₂ -Ar-T ₄	3
	40	T ₅ -Ha-Di ₁ -A ₄ -T ₁ -Ar	6		36	Ci ₂ -Ha-T ₄	3
	II-2	Sn-Ft-El-Ar-T ₃ -Ha-T ₄ -T ₁	8		11	Ci ₂ -Ar-Q ₈	3
	4	Q ₈ -A ₃ -El-T ₁ -Ha-Ar-Ft	7		35	Ci ₃ -Ha-A ₄ -Ar-T ₁ -T ₄ -Bo ₂ -Fl	8
2d	II-4	Di ₁ -T ₁ -Q ₈ -Ha-T ₃ -El	6		51	Ci ₂ -Ci ₃	2
	III-4	Di ₁ -A ₃ -El-Sn-T ₃	5		44	Ci ₂ -Bo ₂ -Ha-Ar	4
	53	Di ₁ -A ₃ -T ₃ -Sn-Ar-Bo ₂	6		50	Bo ₂ -Ci ₂ -Di ₁ -Ha-A ₃	5
	41	Di ₁ -T ₁ -A ₃ -Ha-Sn-T ₃	6		12	He-Ar-T ₄ -Ci ₂ -Ha-El	6
	47	Di ₁ -Sn-A ₃ -El-T ₃ -Ar	7	6	49	Bo ₁ -A ₃ -A ₁ -Bo ₂ -Uv-Di ₁ -Ci ₂	7
	54	Di ₁ -Sn-A ₃ -El-T ₃ -Ar-Bo ₂ -Ha	8		42	Bo ₂ -Uv-Sn-Fl-Mn-A ₁ -Ar-Di ₁ -Bu ₂ -A ₃	10
	24	T ₃ -Ha-A ₂ -Ar-El	5		34	Gy-Ha-Bo ₂ -Sn-Ci ₂ -Q ₁	6
3a	I-5	Bo ₂ -Ha-A ₃ -Di ₁ -T ₁ -Sn	6		55	Sg-Ci ₄ -He-Gy-Bo ₂	5
	3	Bo ₂	1		9	Di ₂ -Ep-Ca-Bo ₂ -Mn-Bu ₃ -Bu ₁ -Sr-Os-Br	10
	I-6	Bo ₂ -A ₃ -Hy-Ha	4		31	El-A ₁ -Mn-Ci ₂ -Pr ₄ -Ha	6

Abbreviation of the species names and the original references for dominant and important species

- A₁: *Ammonia* cf. *beccarii* (Linnaeus) = *Rotalia* cf. *beccarii* (Linnaeus), in Asano, 1951, Ills. Cat. Japan Ter. Smaller Foram., Pt. 14, p. 12, figs. 93-95.
A₂: *Ammonia ketienziensis* (Ishizaki) = *Streblus ketienziensis* Ishizaki, 1943, *Taiwan Tigaku Kizi*, v. 14, nos. 3-4, p. 59-60, pl. 1 (1 on the plate), figs. 5a-c.

- A₃: *Ammonia takanabensis* (Ishizaki) = *Streblus takanabensis* Ishizaki, 1948, *Acta Geol. Taiwanica*, v. 2, no. 1, p. 57, pl. 1, fig. 5.
A₄: *Ammonia tepida* (Cushman) = *Rotalia beccarii* (Linné) var. *tepida* Cushman, 1926, *Carnegie Inst. Washington*, publ. no. 344, p. 79, pl. 1.
As₁: *Amphistegina madagascariensis* d'Orbigny, 1826, *Ann. Sci. Nat. Paris*, ser. 1, v. 7, no. 5, p. 304.
As₂: *Amphistegina radiata papillosa* Said, 1949, *Cushman Lab. Foram. Res. Spec. Publ.*, XXVI, p. 39, pl. iv, fig. 12.

- Ac: *Amphicoryna simplex* (Boomgart) = *Nodogenerina scalaris* (Batsch) var. *simplex* Boomgart, 1949, Proefschrift (Thesis), Utrecht, p. 102, pl. viii, fig. 20.
- Ar: *Asterorotalia inflata* (Millet) = *Rotalia schroeteriana* Parker and Jones var. *inflata* Millett, 1904, *Journ. Roy. Micro. Soc.*, pt. 16, p. 504, pl. 10, fig. 5.
- Bi: *Bigenerina irregularis* Phleger and Parker, 1951, *Geol. Soc. Amer.*, Mem. 46, pt. 2, p. 4, pl. 1, figs. 16-21.
- Bo₁: *Bolivina robusta* Brady, 1881, *Quart. Jour. Micr. Sci.*, London, v. 21, p. 57; 1884, *Voy. Challenger, Rep. Zool.*, v. 9, p. 421, pl. 53, figs. 7-9.
- Bo₂: *Bolivina robusta pacifica* Boomgart, 1949, Proefschrift (Thesis) Utrecht Univ., p. 112, pl. xii, fig. 3.
- Br: *Brizalina hantkeniana* (Brady) = *Bolivina hantkeniana* Brady, 1881, *Quart. Jour. Micr. Sci.*, 21, p. 58.
- Bu₁: *Bulimina auriculata* Bailey, 1851, *Smithsonian Contr.*, 2, p. 12, figs. 25-27.
- Bu₂: *Bulimina marginata* d'Orbigny, 1826, *Ann. Sci. Nat. Paris*, ser. 1, v. 7, p. 269, pl. 12, figs. 10-12.
- Bu₃: *Bulimina* sp.
- Ca: *Cassidulina sagamiensis* Asano and Nakamura, 1937, *Jap. Jour. Geol. Geogr.*, v. 14, nos. 3-4, p. 147, pl. 14, figs. 5a-c.
- Ce₁: *Cellanthus craticulatus* (Fichtel and Moll) = *Nautilus craticulatus* Fichtel and Moll., 1798, *Test. Micr.*, p. 51, pl. 5, figs. h-k.
- Ce₂: *Cellanthus tikutoensis* (Nakamura) = *Elphidium tikutoensis* Nakamura, 1937, *Jap. Jour. Geol., Geogr.*, v. 14, p. 139-140, pl. 11, figs. 10a-b.
- Ci₁: *Cibicides lobatulus* (Walker and Jacob) = *Nautilus lobatulus* Walker and Jacob, 1798, *Adams' Essays*, p. 642, pl. 14, fig. 36.
- Ci₂: *Cibicides pseudoungerianus* (Cushman) = *Truncatulina pseudoungeriana* Cushman, 1922, *U.S. Geol. Surv. Prof. Paper*, 129-F, p. 97, pl. 20, fig. 9.
- Ci₃: *Cibicides sintikuensis* (Nakamura) = *Cibicides sintikuensis* Nakamura, 1937, *Jap. Jour. Geol. Geogr.*, v. 14, p. 142, pl. 12, figs. 9a-c.
- Ci₄: *Cibicides margaritiferus* (Brady) = *Truncatulina margaritifera* Brady, 1884, *Voy. Challenger, Rep. Zool.*, v. 9, p. pl. 96, fig. 2.
- De: *Dentastomina agglutinans* (d'Orbigny) = *Quinqueloculina agglutinans* d'Orbigny, 1839, «*Foraminifers*», p. 168, pl. 12, figs. 11-13.
- Di₁: *Discorbis chinensis* Huang, 1970, *Geol. Soc. China, Proc.*, no. 13, p. 112-113, pl. 1, figs. 8a-c.
- Di₂: *Discorbis taiwanensis* Huang, 1970, *Geol. Soc. China, Proc.*, no. 13, p. 113, pl. 1, figs. 7a-c.
- El: *Elphidium advenum* (Cushman) = *Polystomella advena* Cushman, 1922, *Carnegie Inst. Washington, Pub.* 311, p. 56, pl. 9, figs. 11, 12.
- Ep: *Epistominella exigua* (Brady) = *Pulvinulina exigua* Brady, 1884, *Voy. Challenger, Rep. Zool.*, v. 9, p. 696, pl. 103, figs. 13-14.
- Ft: *Flintina crassatina* (Brady) = *Miliolina crassatina* Brady, 1884, *Voy. Challenger, Rep. Zool.*, v. 9, p. 180, pl. 8, fig. 5.
- Fl: *Florilus japonicum* (Asano) = *Pseudononion japonicum* Asano, 1936, *Jour. Geol. Soc. Japan*, v. 43, no. 512, p. 347, figs. a-c.
- Fs: *Fursenkoina? tikutoensis* (Nakamura) = *Bolivina tikutoensis* Nakamura, 1937, *Jap. Jour. Geol. Geogr.*, v. 14, p. 140, pl. 12, figs. 3a-b.
- Gy: *Gyroidina neosoldani* Brotzen, 1936, *Sver. geol. Undersök. Avh.*, ser. C, no. 396, (Årsb. 30, no. 3). 158.
- Ha: *Hanzawaia hoppoensis* (Nakamura) = *Planulina hoppoensis* Nakamura, 1937, *Jap. Geol. Geogr.*, v. 14, p. 142, pl. 12, figs. 8a-c.
- He: *Heterolepa praecincta* (Karrer) = *Rotalia praecinctus* Karrer, 1868, *Sitz. Akad. Wiss. Wien.*, v. 58, p. 189, pl. 5, fig. 7.
- Hy: *Hyalinea balthica* (Schroeter) = *Nautilus balthicus* Schroeter, 1783, *Einleitung*, v. 1, p. 20, pl. 1, fig. 2.
- Le: *Lenticulina abensis* (Asano) = *Robulus abensis* Asano, 1936, *Jap. Jour. Geol. Geogr.*, v. 13, nos. 3-4, p. 327, pl. 5, fig. 10.
- ML: *Miliolinella oblonga* (Montagu) = *Vermiculum oblongum* Montagu, 1803, *Test Brit.*, p. 522, pl. 14, fig. 9.
- Mn: *Melonis barleeianum* (Williamson) = *Nonionina barleeana* Williamson, 1858, Recent Foraminifera of Great Britain, p. 32, pl. 3, figs. 68, 69.
- Nn: *Nonion japonicum* Asano, 1938, *Jour. Geol. Soc. Japan*, v. 45, no. 538, p. 593, pl. 15, figs. 1a-b, 2a-b.
- Os: *Oridosalis umbonatus* (Reuss) = *Rotalia umbonata* Reuss, 1851, *Zeitschr. dent. geol. Ges.*, 3, p. 75, pl. 5, figs. 35a-c.
- Pr₁: *Pararotalia? minuta* (Takayanagi) = *Rotalia? minuta* Takayanagi, 1955, *Toboku Univ., Inst. Geol. Pal., Contr.*, no. 45, p. 45, 52, text-figs. 29a-c.
- Pr₂: *Pararotalia? murrayi* (Heron-Allen and Earland) = *Rotalia murrayi* Heron-Allen and Earland, 1915, *Zool. Soc. London, Trans.*, XX, 721, liii, 27-34.
- Pr₃: *Pararotalia ozawai* (Asano) = *Rotalia ozawai* Asano, 1951, *Illst. Cat. Japan Tert. Small. Foram.*, pt. 14, p. 15, text-figs. 112-114.
- Pr₄: *Pararotalia taiwanica* (Nakamura) = *Rotalia taiwanica* Nakamura, 1937, *Jap. Jour. Geol. Geogr.*, v. 14, p. 141, pl. 12, figs. 6a-c.
- Pl: *Parrellina hispidulum* (Cushman) = *Elphidium hispidum* Cushman, 1936, *Cushman Lab. Foram. Res., Contr.*, 12, p. 83, pl. 14, fig. 13.
- Pe: *Poroeponides cribrorrepandus* Asano and Uchio, 1951, *Illst. Cat. Japan. Tert. Small. Foram.*, pt. 14, p. 18, text-figs. 134-135.
- Ps₁: *Pseudorotalia indopacifica* (Thalman) = *Rotalia indopacifica* Thalman, 1935, *Eclog. Geol. Helv.*, v. 28, no. 2, p. 605-606.
- Ps₂: *Pseudorotalia schroeteriana* (Carpenter, Parker and Jones) = *Rotalia schroeteriana* Parker and Jones, 1862, in Carpenter, *Intr. Foram.*, p. 213, pl. 13, fig. 7-9.
- Ps₃: *Pseudorotalia yabei* (Ishizaki) = *Streblus yabei* Ishizaki, 1943, *Taiwan Tigaku Kizi*, v. 14, nos. 3-4, p. 53, pl. 1, figs. 2-3.
- Pd: *Pseudoeponides nakazatoensis* (Kuwano) = *Epistomaria nakazatoensis* Kuwano, 1950, *Jour. Geol. Soc. Japan*, v. 56, no. 657, p. 316, text-figs. 4a-c.
- Q₁: *Quinqueloculina lamarckiana* d'Orbigny, 1839, «*Foraminifers*», p. 189, pl. 11, figs. 14, 15.
- Q₂: *Quinqueloculina pseudoreticulata* Parr, 1941, *Mining and Geol. Jour.*, II, 305, not figured, For: *Miliolina reticulata* Brady, 1884, *Rept. Voy. Challenger, Zool.*, v. 9, p. 177, pl. 9, figs. 2-3.
- Q₃: *Quinqueloculina bosciana* d'Orbigny, 1839, in de la Sagra, *Nist. Physiq. Pol. Nat. Cuba*, «*Foraminifers*», v. 8, p. 191, pl. 11, figs. 22-24.
- Q₄: *Quinqueloculina vulgaris* d'Orbigny, 1826, *Ann. Sci. Nat.*, Paris, 7, p. 302, no. 33.
- Q₅: *Quinqueloculina* aff. *subarenaria* Cushman, 1917, *U.S. Nat. Mus. Bull.*, 71, pt. 6, p. 44, pl. 10, figs. 1-2.

- Q₆: *Quinqueloculina* aff. *curta* Cushman = *Quinqueloculina disparalis* var. *curta* Cushman, 1917, U.S. Nat. Mus. Bull., 71, pt. 6, p. 49, pl. 14, figs. 2a-c., Text-fig. 30.
- Q₇: *Quinqueloculina* aff. *crassa subcuneata* Cushman, 1921, U.S. Nat. Mus. Bull., 100, v. 4, p. 423, pl. 89, figs. 4a-c.
- Q₈: *Quinqueloculina seminulina* (Linnaeus) = *Serpula seminulum* Linnaeus, 1767, Syst. Nat., 12 ed., p. 1267 no. 791.
- Ro: *Rotalidium annectenum* (Parker and Jones) = *Rotalia beccarii* (Linnaeus) var. *annectens* Parker and Jones, 1865, Roy. Soc. London, Philos. Trans., v. 155, p. 387, 422, pl. 19, fig. 11.
- Sm: *Sigmoidella bacomensis* Yabe and Asano, 1937, *Tohoku Imp. Univ., Sci. Repts.*, ser. 2, (Geol.), XIX, (1), 102, xviii, 8.
- Sg: *Siphogenerina raphanus* (Parker and Jones) = *Uvigerina* (Sagrina) *raphanus* Parker and Jones, 1865, Roy. Soc. London, Phil. Trans., v. 155, p. 364, pl. 18, figs. 16, 17.
- Sn: *Siphonaperta formosana* (Nakamura) = *Sigmoilina formosana* Nakamura, 1937, *Jap. Jour. Geol. Geogr.*, v. 14, p. 136, pl. 10, figs. 10a, b.
- Sr: *Sphaeroidina bulloides* d'Orbigny, 1826, *Ann. Sci. Nat. Paris*, ser. 1, v. 7, p. 267, Modeles no. 65.
- Sl: *Spiroloculina communis* Cushman and Todd, 1944, *Cushman Lab. Foram. Res., Spec. Publ.* no. 11, p. 63, pl. 9, figs. 4, 5, 7, 8.
- Sp: *Spiroplectamina* sp. (19).
- T₁: *Textularia conica* d'Orbigny, 1839, in de la Sagra, Nist. Physiq. Pol. Nat. Cuba, « Foraminifères », v. 8, p. 143, figs. 19-20.
- T₂: *Textularia kerimbaensis* Said, 1949, *Cushman Lab. Foram. Res., Spec. Publ.* no. 26, p. 6, pl. 1, fig. 8.
- T₃: *Textularia foliacea* Heron-Allen and Earland, 1915, *Zool. Soc. London, Trans.*, XX (1912-1915), pt. 17, 628, XIvii, 17-20.
- T₄: *Textularia foliacea oceanica* Cushman, 1932, U.S. Nat. Mus. Bull., no. 161, 8, i, 11-12.
- T₅: *Textularia gramen* d'Orbigny, 1846, *Foram. Fossiles* Vienne, p. 248, pl., 15, figs. 4-6.
- T₆: *Textularia sinikuensis* Nakamura, 1937, *Jap. Jour. Geol. Geogr.*, v. 14, p. 135, pl. 10, figs. 7a-b.
- Tr: *Triloculina trigonula* (Lamarck) = *Miliolites trigonula* Lamarck, 1804, *Ann. du Mus.*, 5, p. 351, no. 3.
- Uv: *Uvigerina auberiana* d'Orbigny, 1839, in de la Sagra, Hist. Phys. Pl. Nat. Cuba, « Foraminifères », v. 8, p. 106, pl. 2, figs. 23, 24.

Table 1. - Order of the abundance occurrence of the benthic foraminifers in each sample and their groups (as shown in Text-fig. 18).

9. Six foraminiferal facies occur in the Taiwan Strait; the near-shore facies, the offshore facies, the basin facies, the bank facies, and the channel facies.

10. The number of foraminiferal species and specimens become greater as the depth of water increases and the larger number are found in the topographic depression (include the basin and channel) and in near the shelf edge.

11. The planktonic number is an index to the movement of the current.

12. The percentage occurrence of arenaceous species increases and constitutes the highest percentages of the fauna (> 20%) in the Matsu Basin and the lowest in the upwelling area (Penghu Channel) off the Tainan-Kaohsiung area. The percentage occurrence of porcellaneous species also constitute the lowest percentage in the upwelling area.

13. Buliminidae and Anomalinidae are abundant in the Matsu Basin and the Penghu Channel areas. Textulariidae and Miliolids are abundant in the near shore zone off the Hsinchu-Miaoli area. The sessile species *Cibicides* and *Discorbis* are generally abundant in near the Taiwan Bank area.

14. *Hyalinea balthica* and *Pullenia bulloides* appears at the topographic depression of the strait but *Amphistegina* and *Operculina* are rare in the sediments of the strait.

ACKNOWLEDGMENTS

The author is indebted to the National Council on Science Development for appropriated funds enabling him to realize this project. Thanks are due to the Chinese Petroleum Corporation for the permission to publish this study.

REFERENCES

- ASANO, K., 1957, The Foraminifera from the Adjacent Seas of Japan, collected by the S. S. Soyo-maru, 1922-1930; pt. 3, Planktonic Species: Tohoku Univ., Sci. Rept., 2nd Ser. (Geol.), v. 28, pp. 1-26, pls. 1-2, fig. 1.
- BANDY, O. L., 1960, Geologic significance of coiling ratio in the foraminifer *Globigerina pachyderma*: *Journ. Paleont.*, v. 34 (4), pp. 671-681.
- , & ARNAL, R. E., 1957, Distribution of Recent Foraminifera off West Coast of Central America: *Bull. Amer. Assoc. Petrol. Geol.*, v. 41 (9), pp. 2037-2057.
- , & —, 1960, Concept of Foraminiferal Paleoecology: *Bull. Amer. Assoc. Petrol. Geol.*, v. 44 (12), pp. 1921-1932.
- , INGLE, J. C., Jr., & RESIG, J. M., 1964, Facies Trends, San Pedro Bay, California: *Bull. Geol. Soc. Amer.*, v. 75, pp. 403-424.
- BANNER, F. T., & BLOW, W. H., 1960, Some primary types of species belonging to the Superfamily *Globigerinaceae*: *Contrib. Cushman Found. Foram. Res.*, v. 11 (1), pp. 1-41.
- BÉ, A. W. H., 1960, Ecology of Recent planktonic foraminifera; Part 2-Bathymetric and seasonal distributions in the Sargasso Sea off Bermuda: *Micropaleont.*, v. 6 (4), pp. 373-392.
- BERGER, W. H., & PARKER, F. L., 1970, Diversity of planktonic Foraminifera in Deep-sea sediments: *Science*, v. 168, pp. 1345-1347.

- BLOW, W. H., 1969, Late Middle Eocene to Recent planktonic foraminiferal biostratigraphy: Internat. Conf. Plank. Microfossils, 1st (1967), Proc., v. 1, pp. 199-421, pls. 1-54, 43 figs.
- BOLTOVSKOY, E., 1959, Foraminifera as biological indicators in the study of ocean currents: Micropaleont., v. 5 (4), pp. 473-481.
- , 1962, Planktonic foraminifera as indicators of different water masses in the South Atlantic: Micropaleont., v. 8 (3), pp. 403-408.
- , 1965, Recoleccion de Foraminiferos en las y su preparacion: Centr. Investig. Biol. Marina, Inst. Nac. Tech. Industr., Contrib. Tecnica, no. 1, pp. 1-11.
- , 1968, Living planktonic foraminifera of the eastern part of the Tropical Atlantic: Rev. Micropaleont., v. 11 (2), pp. 85-98.
- BRADSHAW, J. S., 1959, Ecology of Living Planktonic Foraminifera in the North and Equatorial Pacific Ocean: Contrib. Cushman Found. Foramin. Res., v. 10 (2), pp. 25-64.
- CHEN, C. S., 1963, Taiwan, An Economic and Social Geography (v. 1): FW-Min Geograph. Inst. Econ. Developm., Taipei. Taiwan, Res. Rept. no. 96, pp. i-xiii, 1-653.
- CHENG, T., & CHENG, S., 1964, The planktonic Foraminifera of the northern South China Sea: Oceanol. Limmol. Sinica, v. 6 (1), pp. 38-77, pls. 1-6, text-figs. 1-10.
- CHINESE NATIONAL COMMITTEE ON OCEANIC RESEARCH, 1966-1970, Oceanographic Data Report of CSK: Academia Sinica, Nankang, Taiwan, no. 1-4.
- CHINESE PETROLEUM CORPORATION, 1970, Note on Sea Bottom Sampling in the offshore area of Taiwan, China: CCOP, Tech. Bull., v. 3, pp. 35-36.
- CHU, T. Y., 1963, The oceanographic of the surrounding waters of Taiwan: Rep. Inst. Fishery Biology Minist. Econ. Affairs S. National Taiwan Univ., v. 1 (4), pp. 29-44.
- , 1971, Environmental study of the surrounding waters of Taiwan: Sino-American Science Cooperation Colloquium on Ocean Resources, 28 April - 7 May, Taipei, v. 2, pp. 1-38.
- CIFELLI, R., 1961, *Globigerina incompta*, a new species of pelagic foraminifera from the North Atlantic: Contrib. Cushman Found. Foramin. Res., v. 12 (3), pl. 4, pp. 83-86.
- ELLIOT, W. P., EGAMI, R., & ROSSKNECHT, G., 1971, Rainfall at Sea: Nature, v. 229, pp. 108-109.
- EMERY, K. O., 1968, Relict Sediments on Continental Shelves of the World: Bull. Amer. Assoc. Petrol. Geol., v. 52, pp. 445-464.
- , et al., 1969, Geological Structure and Some Water Characteristics of the East China Sea and the Yellow Sea: CCOP, Tech. Bull., v. 2, pp. 3-43.
- ERICSON, D. B., 1959, Coiling direction of *G. pachyderma* as a climatic index: Science, v. 130, pp. 219-220.
- FAGERSTROM, J. A., 1964, Fossil Communities in Paleoecology: Their Recognition and Significance: Geol. Soc. America Bull., v. 75, pp. 1197-1216.
- FUNNELL, B. M., 1967, Foraminifera and Radiolaria as Depth Indicators in the Marine Environment: Marine Geol., v. 5 (5/6), pp. 333-347.
- GIBSON, L. B., 1966, Some unifying characteristics of species diversity: Contr. Cushman Found. Foramin. Res., v. 17 (4), pp. 117-124.
- HECHT, A. D., & SAVING, S. M., 1971, Oxygen - 18 Studies of Recent Planktonic Foraminifera: Science, v. 173, pp. 167-169.
- HEDBERG, H. D., 1970, Continental Margins from viewpoint of the Petroleum Geologist: Bull. Amer. Assoc. Petrol. Geol., v. 54 (1), pp. 3-43, 32 figs.
- HUANG, TUNYOW, 1960, The Foraminifera from the Liuchiu Mudstone of Linchiuhsu off the Southwestern Coast of Taiwan: Proc. Geol. Soc. China, v. 3, pp. 59-66, pls. 2, text-figs. 2, tab. 1.
- , 1961a, Smaller Foraminifera from the Beach Sands at Tanmenkang, Pachao-tao, Penghu: Proc. Geol. Soc. China, v. 4, pp. 83-90.
- , 1961b, Some Foraminifera from the River Sand at Tungchang, Ping-Tung, Taiwan: Formosan Science, v. 15 (2), pp. 67-69.
- , 1970a, New Foraminifera from the Taiwan Strait, Taiwan, China: Proc. Geol. Soc. China, v. 13, pp. 108-114, 1 pl.
- , 1970b, A New Species of *Planodiscorbis* from the Taiwan Strait, Taiwan, China: Petrol. Geol. Taiwan, v. 7, pp. 191-193, 1 fig.
- , 1971, Foraminiferal Trends in the Surface Sediments of Taiwan Strait: United Nations ECAFE, COOP Tech. Bull., v. 4, pp. 23-61.
- JONES, J. I., 1967, Significance of distribution of planktonic foraminifera in the Equatorial Atlantic Undercurrent: Micropaleontol., v. 13 (4), pp. 489-501.
- KENNETT, J. P., 1968a, *Globorotalia truncatulinoides* as a paleoceanographic index: Science, v. 159, pp. 1461-1463.
- , 1968b, Latitudinal variation in *Globigerina pachyderma* (Ehrenberg) in Surface Sediments of the Southwest Pacific Ocean: Micropaleont., v. 14 (3), pp. 305-318, pl. 1.
- , 1969, Distribution of planktonic Foraminifera in Surface Sediments Southeast of New Zealand: Internat. Conf. Plank. Microfossils, 1st (1967), Proc., v. 2, pp. 307-322.
- LIU, TSIEN-LUNG, 1967, The Fishing Ground Investigation of the Formosa Bank (Round herring and squid): Taiwan Fisheries Res. Inst., Res. Rept., v. 13, pp. 1-80.
- MA, T. Y. H., 1947, Submarine valleys around the southern part of Taiwan and their Geological Significance: Bull. Oceanographic Inst. Taiwan, v. 2, pp. 1-12.
- MURRAY, J. W., 1968, Living Foraminifera of Lagoon and estuaries: Micropaleont., v. 14 (4), pp. 435-455, text-figs. 1-20.
- NANNICHI, TOSIO, 1963, Physical oceanography: Kiinokuni Shoten, Tokyo, pp. 204 (in Japanese).
- NAVAL HYDROGRAPHIC OFFICE OF CHINA, 1962, Ocean currents in the vicinity of Taiwan: Publ. no. 13.
- , 1965, Yangtzu River Entrance to Hsiamen; no. 106, 1/1,000,000 at Lat. 30°.
- , 1966a, Eastern China Sea and Approaches to Southern part of Japan: No. 100, 1/2,500,000 at Lat. 35°.
- , 1966b, Mingchiang Entrance to Hongkong and Taiwan: no. 307, 1/1,000,000 at Lat. 30°.
- , 1966c, South China Sea: no. 471, 1/1,200,000 at Lat. 35°.
- NAVAL OCEANOGRAPHIC OFFICE OF U.S., 1964, Ocean currents in the vicinity of the Japanese Island and China Coast: The Secretary of the Navy, Washington, pub., no. 237, 2nd ed.
- NIINO, H. & EMERY, K. O., 1961, Sediments of shallow portions of East China Sea and South China Sea: Bull. Geol. Soc. Amer., v. 72, pp. 731-762, 21 figs.
- NIITSUMA, N., 1968, Analysis of the Benthonic Foraminiferal Community: Fossils, no. 16, pp. 25-33.
- ORR, W. N., 1967, Secondary Calcification in the Foraminiferal Genus *Globorotalia*: Science, v. 157, pp. 1554-1555.
- PARKER, F. L., 1962, Planktonic Foraminiferal Species in Pacific Sediments: Micropaleont., v. 8 (2), pp. 219-254.
- PHLEGER, F. B., 1951, Ecology of Foraminifera, Northwest Gulf of Mexico; pt. 1, Foraminifera Distribution: Geol. Soc. Amer. Mem. 46, pp. vii-ix, 1-88.

- POLSKI, W., 1959, Foraminiferal biofacies off the North Asiatic Coast: Jour. Paleont., v. 33 (4), pp. 569-587.
- , & WALLER H. O., 1958, Recent Occurrence of *Gumbelitra vivans* Cushman: Compass of Sigma Gamma Epsilon, v. 35 (4), pp. 226-229.
- SAITO, T., 1963: Miocene planktonic Foraminifera from Honshu, Japan: Tohoku Univ., Sci. Rept. 2nd Ser. (Geol.), v. 35 (2), pp. 123-209, pls. 53-56.
- SCHATT, W., 1935, Die Foraminiferen in dem Äquatorialen Teil des Atlantischen Ozeans: Deutsche Südpolar Exped., 11, v. 6, pp. 411-616.
- SEN GUPTA, B. K., 1971, The Benthonic Foraminifera of Tail of the Grand Banks: Micropaleont., v. 17 (1), pp. 69-98, pls. 1-2.
- SIMPSON, E. H., 1949, Measurement of diversity: Nature, v. 163, p. 688.
- SUDA, K., 1943, Kaiyo Kaku: Kokin Shoin, Tokyo, pp. 770 (in Japanese).
- UDA, M., 1963, The Sea: Iwanami Shoten, Tokyo, pp. 1-247 (in Japanese).
- UJIE, H., 1962, Introduction to statistical Foraminiferal Zonation: Jour. Geol. Soc. Japan, v. 68, pp. 431-450.
- WALLER, H. O., 1960, Foraminiferal Biofacies off the South China Coast: Jour. Paleont., v. 34 (6), pp. 1164-1182.
- , & POLSKI, W., 1959, Planktonic Foraminifera of the Asiatic Shelf: Contr. Cushman Found. Foram. Res., v. 10 (4), pp. 123-126, pl. 1.
- YABE, H., 1929, On some remarkable examples of drowned valleys found around Japanese Islands: Record of Oceanogr. Works in Japan, v. 11, pp. 11-5.
- , & TAYAMA, R., 1928, A cartographic study of the submarine relief of the Strait of Formosa: Rec. Oceanogr. Works in Japan, v. 1.

