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Distribution and Environment of Recent *Cycloclypeus*

Motoharu KOBA

Introduction

Recent or fossil coral reef complex consists of larger Foraminifera more than half in volume. *Cycloclypeus* is the most characteristic one of Foraminifera since younger Tertiary in Indo-Pacific oceanic region. First, it is the largest living foraminifer and its microspheric form attains 130 mm in diameter and very recognizable in the field, based on the author's observation in the Ryukyu limestone at Nagamine, Okierabu island, Ryukyu islands. Second, its vertical and areal distribution is very limited and accordingly it plays a key roll in palaeoecological reconstruction of coral reef.

The distribution of Recent *Cycloclypeus* have been discussed by Tan (1932), Grimsdale (1952), Yamazato *et al.* (1968), Ghose (1977) and others, far from satisfaction. In this paper, the author intends to examine the distribution of Recent *Cycloclypeus*, referring its environmental data oceanographic and biological.

1 Taxonomy and stratigraphy

The genus *Cycloclypeus* was established by Carpenter in 1856 on Recent specimens "dredged by Sir Edward Belcher from a considerable depth of water off the coast of Borneo" (Brady, 1884). The genus was divided into three subgenera, *i.e.*, *Cycloclypeus*, *Radiocycloclypeus* and *Katacycloclypeus* by Tan (1932).

The first appearance of the genus was as early as Eocene according to Tan (1932). Its first appearance horizon was Tertiary-*c* immediately above Tertiary-*a* and-*b* (Eocene) after Cole (1960), or Lattorfian (early Oligocene) after Hanzawa (1965). The subgenus *Cycloclypeus* is the longest in range among three subgenera extending from younger Tertiary to Recent (Cole, 1960). *Katacycloclypeus* ranges from Tertiary-upper *e* to Tertiary-upper *f* (Tertiary-*f* approximates middle Miocene.), and *Radiocycloclypeus* ranges only Tertiary-upper *f* (Cole, 1960), or *Katacycloclypeus* ranges from top *Eulepidina* to top Miogypsinidae, and *Radiocycloclypeus* ranges from a little before top Miogypsinidae to top *Lepidocyclina* (Mac Gillavry, 1962). As mentioned above, only one subgenus *Cycloclypeus* survived in Quaternary, and Recent *Cycloclypeus* means the subgenus name thereafter.

Recent *Cycloclypeus* consists of *Cycloclypeus carpenteri* Brady 1881 and *Cycloclypeus guembelianus* Brady 1881. There are two opinions in the division of *C. carpenteri* and *C. guembelianus*. One is that *C. guembelianus* corresponds with the megalospheric form, and *C. carpenteri* with the microspheric. The other is that both are sufficiently separable on the viewpoint of specific divergence. Students of the former are Chapman (1902), Cushman (1921), Yabe and Hanzawa (1925), Hofker (1927), Hanzawa (1951) and Cushman *et al.* (1954). They propose either of two names for both generations. Brady (1884), Tan (1932), Cole (1954) and Mac Gillavry (1962) are of the latter. Mac Gillavry (1962) asserted, "A derivation of *guembelianus* from *caprenteri* is practically certain."

The exact relationship of these two names is uncertain for the present author. The author aiming to summarize the distribution of Recent *Cycloclypeus*, follows the former opinion in this paper, because the data are obtained almost from the former students.

2 Areal distribution of Recent *Cycloclypeus* and oceanographical or biological environment

2.1. Areal distribution and environment

Recent *Cycloclypeus* is widely distributed in Indo-Pacific oceanic region. It is also reported from the Adriatic sea. Tan (1932) substantiated Silvestri's Recent forms (1907) from the Adriatic.

Fossil *Cycloclypeus* is also distributed commonly in Indo-Pacific Madagascar to the west, Fiji to the east, Taiwan and Ryukyu Is. to the north, New Zealand and Victoria to the south. Fossil *Cycloclypeus* cf. *carpenteri* and *Cycloclypeus* cf. *guemberianus* were described by Cosijn (1938) from Spain, Italy, and Austria but they are recognized different from the type of this species (Hanazawa, 1957).

Recent *Cycloclypeus* is for example reported in the Indian ocean from off Mauritius I. and in the South China sea, from the Macclesfield bank (Chapman, 1900). *Cycloclypeus*-sampled locations are shown in Fig. 1 and Table 1.

The genus inhabits some oceanic water masses, *i.e.* North, Southwest and Southeast Pacific Central water masses, while not found in the Northeast Pacific Central, Pacific Equatorial water masses. In the North Pacific Central water mass, it is sampled from the adjacent seas of Taiwan, Ryukyu Is., Philippine Is. and Bikini atoll; in the Southwest Pacific Central, from Lesser Sunda Is., Sulawesi I. and W. New Guinea, Solomon Is., Great Barrier Reef, Funafuti I., Fiji Is. and Tonga Is.; in the Southeast Pacific Central, from Tuamotu Is. (Figs. 1 & 2).

Viewing the habitat limitation in tropical or subtropical seas, its thermotropism is suggested. Recent *Cycloclypeus* is all sampled where the water temperature at 10 m depth is not less than 22.5°C in the coldest quarter of a year, and not less than 27.5°C in the warmest (Fig. 1). The water temperature at 10 m depth is thought to be less subject to diurnal changes than the surface temperature and

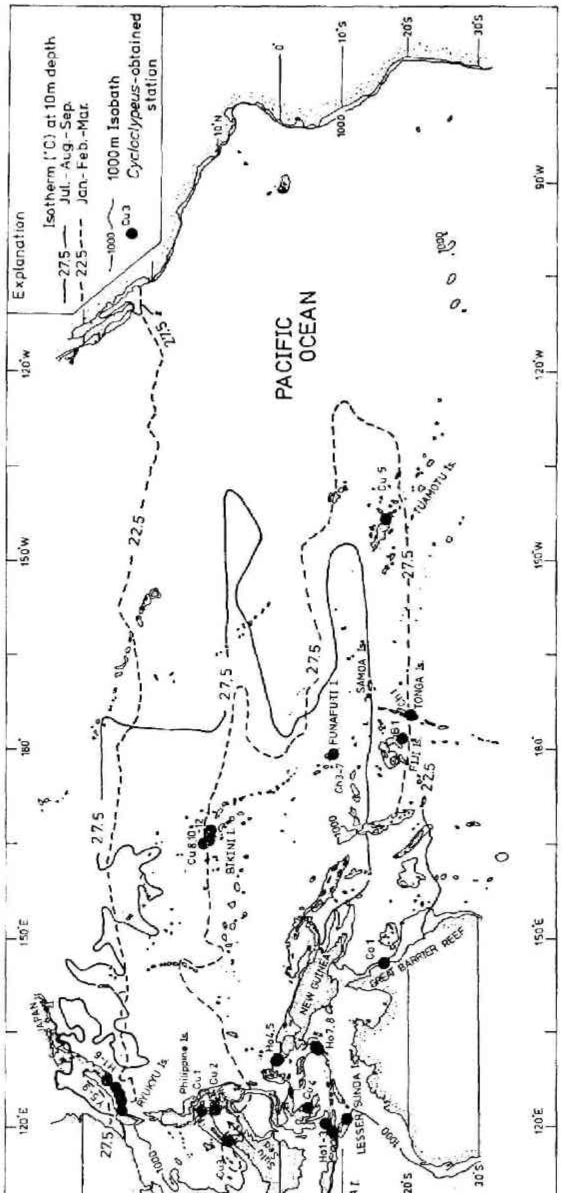

Fig. 1 Areal distribution of Recent *Cycloclypeus* in the Pacific ocean.
Data for quarterly 10-meter temperature depend on *Oceanographic Atlas of the Pacific Ocean* by Barkley (1968).

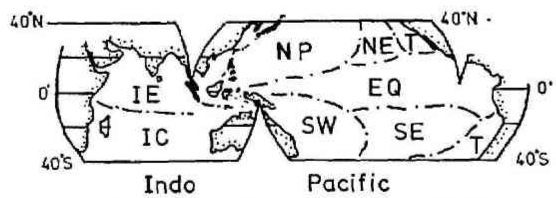

Fig. 2 Water masses in Indo-Pacific revised after Hidaka (1955).
NP: North Pacific Central. NE: Northeast Pacific Central EQ: Pacific Equatorial. SW: Southwest Pacific Central. SE: Southeast Pacific Central. IE: Indian Equatorial. IC: Indian Central. T: Transitional zone.

more representative of the water layer above the thermocline abundant in *Cycloclypeus*.

The relations of the habitation to salinity, dissolved oxygen concentration, inorganic phosphate-phosphorus at the sea surface were not fully elucidated. Such oceanographic factors are distributed usually in very wide range.

The lacking of *Cycloclypeus* in the Pacific Equatorial water mass enough warm for *Cycloclypeus*, is perhaps attributed to the shortage of habitable depth floor and primary oraganic production. There are hardly shallower oceanic floor than 1000-meter depth in this oceanic region (Fig. 2), and no space for the shallow benthic *Cycloclypeus* to inhabit. The Pacific Equatorial water mass, moreover, has the lowest productivity in the Pacific ocean, because the perpetual spring layer develops below the euphotic zone through the year in this oceanic region (Taniguchi, 1973).

Foraminiferal samples are dredged at more than 300 stations off East Indies by the Siboga Expedition (Hofker, 1927 and 1930), and *Cycloclypeus* is sampled only from the eastern part of the islands. This contrasting sampling may be related to the fact that the eastern part is affected by the Southwest Pacific Central water mass and the western part by the Indian Equatorial.

Around Ryukyu Is., Hanzawa (1948 and 1951) reported the genus dredged and Yamazato *et al.* (1968) observed it at the coral reef slopes on the deep-sea submarine ship "Yomiuri". Their data are mapped accompanied with the mean temperature at 100 m depth in Fig. 3. The habitation of *Cycloclypeus* mostly on reef bank or reef slope is confined by the 200 m isobath. It has not been found around Okinawa island,[1] and the vicinity of Kume island may be the northern limit of habitation. All the *Cycloclypeus* findings are enclosed by the isotherm of 23°C at 100 m depth except for H 4 off Taiwan. These facts also suggest the tropical habitation of the genus.

1) Hanzawa, S. (1935) reported, "I found it in bottom material dredged from the insular shelf east of Okinawa."

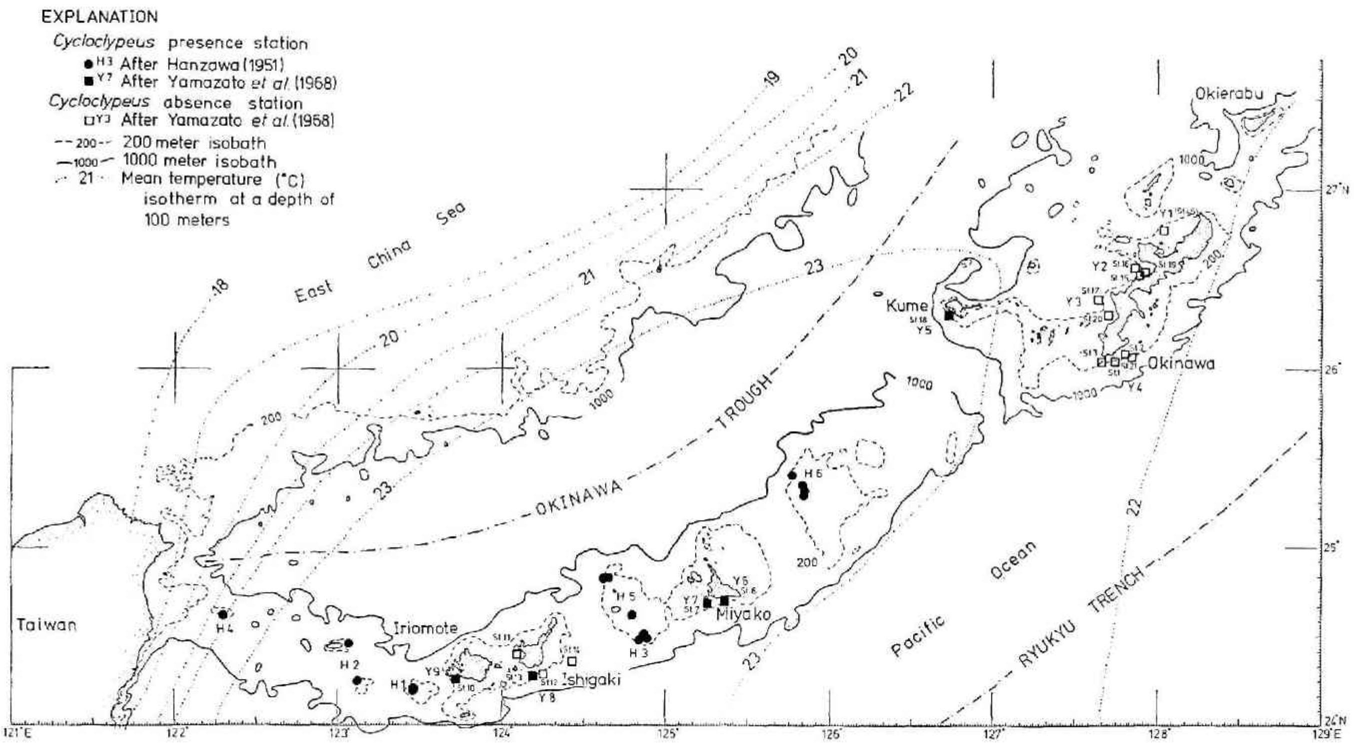

Fig. 3 Areal distribution of Recent *Cycloclypeus* in the adjacent sea of the Ryukyu islands. Mean temperature at a depth of 100 m is quoted from *Marine Environmental Atlas* compiled by the Japan Oceanographic Data Center (1975).

2.2. Habitat in coral reef

Cycloclypeus is found mainly on the outer slope of coral reef, on reef pass, under strait or on bank, but rarely in pelagic environment (Table 1). Many expeditions in pelagic environment have accumulated negative data concerning the habitation of *Cycloclypeus*.

Negative data are further reported from lagoons and bays. Chapman (1900, 1901 and 1902) studied in detail the distribution of Foraminifera around Funafuti, Ellice Is., and mentioned, "*Cycloclypeus* has never yet occurred in the lagoon dredgings, although nearby all the other genera of Foraminifera found at Funafuti have been found irrespectively inside the lagoon and on the other side of the reef." David, Halligan and Finckh (1904) state regarding *Cycloclypeus*, based on their dredging around Funafuti, "We obtained both live and dead specimens of this type on the ocean side of the reef, but in the lagoon its shells were extremely scarce and no live specimens of this genus were observed." (Grimsdale, 1952). Cushman *et al.* (1954) reported on a series of bottom foraminiferal samples from four atolls at the northwest of the Marshall islands, that *Cycloclypeus* was not dredged from any lagoon stations of Rongeric (15 stations), Rongelap (13 sts.), Bikini (58 sts.) and Eniwetok (48 sts.), but it was dredged at 1 of 4 outside stations of Rongelap atoll, at 10 of 18 of Bikini and at 2 of 21 on Sylvania guyot adjoining Bikini atoll. Yamazato *et al.* (1968) did not find it in Nago bay, Ishigaki island, Ryukyu Is., almost enclosed by barrier reef. The genus is not reported also in lagoon, reef flat or beach deposit from the Great Barrier Reef (Collins, 1958). *Cycloclypeus* never occurs at the inside lagoon of barrier or fringing reef as of atoll.

Then, *Cycloclypeus* looks to favour outer slope of coral reef, and to reject lagoon, bay or pelagic environment. Cushman *et al.* (1954) deduced from the data of Bikini and nearby atolls that the ecological factors affecting distribution and abundance of Foraminifera are depth and access to the open ocean. Such a deduction may be applied in part for this genus, not enough to interpret its habitational distribution. It is experimented by Arnold that ample oxygen and nutrient in moderately agitated water are generally effective for the growth of Foraminifera (1974). Yamazato *et al.* (1968) observed sand ripples and 50 cm/sec. subsurface current at 200 m depth around the habitations of *Cycloclypeus*. The present author frequently observed under microscope *Cycloclypeus* shells broken at various growth stages and recovered again as reported by Chapman (1900). There are different oceanographical and biological conditions between outer reef slope or margin and inner lagoon, such as temperature, salinity, CO_2 content, pH variation, dissolved oxygen, illumination, and nutrient. The following are noteworthy examples.

Smith and Pesret (1974) reported on Fanning island (4°N, 159°W), a small atoll in the Line islands, based on their study in July and August 1972, "Fanning lagoon is almost entirely surrounded by islands rather than by reefs. Despite being nearby landlocked, the lagoon supports abundant and diverse reef biota, apparently similar to that of less restricted lagoons. Therefore, the physiographic peculialities which make the lagoon convenient to study do not detract from the likelihood that we can use our results to draw conclusions about atoll lagoons in general." Inflowing water through the deepest reef pass of Fanning island was measured as samples of oceanic water and gave the following constant composition: salinity 34.8‰, total alkalinity 2.35 meq/1[1], pH 8.25, total CO_2 content 2.0 mmoles/1[2] and specific alkalinity[3] 0.122. The composition of lagoon water has wide range, for example, salinity from 29 to 34‰, but its mean was claculated as follows: Salinity 31.5‰, total alkalinity 1.9 meq/1, pII 8.1, total CO_2 content 1.7 mmoles /1 and specific alkalinity 0.108. These mean values in lagoon water are lower than those in ocean water, for the dilution effect of rainwater. Water temperatures are not different in both and average 29°C. Lagoon water has higher concentration of organic carbon (Kay, 1974), higher calcium carbonate load, more active turbidity and higher productivity. Guither (1974) reported on the same atoll that the heavy rainfall caused abrupt changes in salinity, turbidity and accumulations of dead mollusk shells. In consequence, lagoon water is quite changeable in composition and oceanic water constant.

Motoda (1940) brought an important result on water in Palao islands 7°N, 134°E), which have a vast lagoon in the west and south of the main island. He chose three stations: The Robugoru Passage of Iwayama bay as a bay, Palao Port as a lagoon and open sea off the barrier reef of Palao Port. He observed eleven times in the morning during the period from August 1935 to August 1936. Except for the remarkable difference of transparency among three stations, there were no notable differences in water temperature, oxygen content, pH value and specific gravity, though the latter two are slightly lower in inward order. Transparency and illumination are far higher at open sea than inside barrier reef. This difference should be related mainly to the amount and nature of silt and microorganisms. Both micro- and macroplankton are richer in quantity inside barrier reef than at open sea. Rainwater effected a slight decrease in specific gravity and pH value.

Richard (1977) investigated Tahiti and Lakeba in April 1975, and April 1976.

1) Milliequivalents per liter
2) millimoles per liter
3) total alkalinity/chlorinity

Tahiti island (17°S, 149°W) is completely enclosed by barrier reef, except two interruptions. He investigated at Faaa lagoon and Vairao lagoon, whose average depths are about 11 m and 25 m, maximum depths are about 32 m and 50 m, and maximum widths are about 2,000 m and 3,000 m respectively. Lakeba island (18°S, 178°W, Lau group; Fiji Is.) is almost surrounded by barrier. Its lagoon depth is more than 2–3 m, and its channel width more than 5,000 m. The circulation of lagoon water is similar at both islands. Ocean water enters lagoon by crossing over the barrier reef, and leaves lagoon through channels and passes. The productivity in Tahitian lagoon water decreases offshore, but is higher always than open sea water. It exceeds $1g \cdot C/m^2$. day at mid-lagoon stations. In Lakeba, it is equal or slightly higher than open sea water, but is lower than in Tahitian lagoons. Ricard explained the higher productivity of lagoon water by two reasons related to environmental influences. First, freshwater inflows carry into lagoons organic and mineral materials which increase phosphate and silicate content and fertilize lagoon water, particularly at river flood during the rainy season. Second, lagoon water is enriched with organic materials, mainly coral mucus and mollusc faeces by oceanic water crossing over coral barrier reef. This "reef pseudoplankton" enriches lagoon with organic matter, which can be utilized by zooplankton and other basic consumers.

The lagoons above-mentioned are inside barrier reef or atoll and relatively deep except a part of Lakeba. The next example is on fringing reef flat. Marsh (1977) surveyed two fringing reef flats, *i.e.* Tumon and Pago bays at Guam island (13°N, 144°E).

Tumon bay is on the leeward coast and about 600 m in width. The shallow reef flat consists of outer zone subaerially exposed at low spring tide and lower inner zone without such an exposure. There is a deeper moat 1 m in depth at low tide and 30 m in width adjacent to the shoreline at the western three fourths of the bay, in which are typical "birds' feet" deltas at most of storm drains that attest high sedimental inputs. Seepage of much groundwater into the bay results from Ghyben-Herzberg lens well developed in limestone bed of northern Guam. Water is driven primarily by surf action on reef margin and across the reef flat toward the moat, then it flows out through the channels at reef margin.

Pago bay is on the windward coast. A channel extends from the Pago river mouth and cuts the bay. Water is circulated by surf action in Pago bay as in Tumon bay. Long-shore current flows in the channel toward the Pago river mouth.

In Pago bay, nitrate is higher and phosphorus is lower in the channel than on reef margin. The higher nitrogen values suggest groundwater seepage into the channel or nitrogen-fixing organisms on reef flat and the lower phosphorus suggests the consumption by organisms on reef flat. In Tumon bay both nitrate and reactive phosphorus are markedly higher in the moat than on reef margin, probably because of groundwater seepage. Such a terrestrial input keeps both values higher on reef flat with sluggish water than reef flat with active circulation. The relative phosphorus and nitrate-nitrogen values on Guam fringing reef are higher than on Eniwetok reef.

From the above not so many examples, the environmental factors influencing lagoon water are deduced to some extent. Lagoon receives oceanic water, rainwater, groundwater and river water. Lagoon water is separated from ocean water depending on the continuity and height of surrounding reef. Lower reef permits the crossing over of ordinary tide and surf, which enriches lagoon water with organic matter or nourishes organisms on reef. The type of water circulation and the residence time are related to the features of coral reef. Rainfalls dilute lagoon water gradually or abruptly. The terrigenous effect is quite important. Groundwater or river water carries terrigenous materials into the lagoon of barrier or fringing reef, and lagoon water is fertilized by organic and mineral particles and its salinity is reduced. If the lagoon water is sluggish, the temperature and salinity are raised by tropical solar radiation.

Lagoon is full of varieties and lagoon water is variable in wide range. It may be concluded that *Cycloclypeus* cannot survive under such variable conditions as lagoon, which allow many other Foraminifera inhabit commonly.

3 Vertical distribution of Recent *Cycloclypeus* and oceanographical or biological environment

3.1. Previous studies

Cycloclypeus has been recognized as a depth indicator by some students. Based on samples at 16–200 fathom (30–366 m) depth on the seaward reef slope rock and at various depth on sand collected by David and Woolnough in 1897, and those at depths down to 240 fathom (440 m) on sand and reef rock around Funafuti collected by Halligan and Finckh in 1898, Chapman (1900 & 1902) inferred that *Cycloclypeus* sampled almost at depths down to 200 fathom (366 m) lives in 30–200 fathom depth (55–366 m), abounds in 50–200 fathom (92–366 m) and concentrates in 50–60 fathom (92–110 m). On Chapman's results concerning the distribution of Recent *Cycloclypeus*, Grimsdale (1952) reexamined occurrences of *Cycloclypeus* in the borings of Funafuti atoll and reconstructed the geohistory of the atoll.

Hanzawa (1948) examined 22 bottom materials collected at 45–340 m depth around the Ryukyu islands by the survey ship "Matsue", and identified the Foraminiferal assemblage composing the Ryukyu limestone with the Recent fauna examined. Considering the depth range of the predominant larger Foraminifera, *Alveolinella quoyi, Baculogypsinoides spinosus* and *Cycloclypeus carpenteri*, he concluded that the Pleistocene Ryukyu limestone was deposited in the neritic environment, not the littoral. If the neritic zone in his conclusion means the depth from 20 to 100 m, his generalization seems to be insufficient, for living coral reef generally ranges in wide depth from the sea surface to more than 100 m depth. Hanzawa (1951) found Recent *Cycloclypeus* at depths from 62 to 235 m around the Ryukyu islands. He (1957) reported furthermore the Cenozoic Foraminifera of Micronesia, when he regarded the geologic horizon containing *Cycloclypeus* as fore-reef detrital facies of Mariana limestone.

Yamazato *et al.* (1968) at the observation from the submarine ship divided the sea bottom down to 300 m surrounding the Ryukyu islands according to the depth into three: Coral reef slope down to 90/100, reef terrace between 90/100 m and 100/120 m, and slope at more than 100/120 m. The coral reef slope is subdivided into three. The upper subzone down to 20/50 m is coral reef cliff with irregular terracelets and built by hermatypic corals almost in 100%. The middle subzone between 50 and 70 m shows a reef structure similar to buttress zone at reef margin. The lower subzone between 70 and 90/100 m consists of sandy and gravelly gentle slope. *Cycloclypeus* is observed to be abundant in the lower subzone of coral reef slope and in the reef terrace at depths from 70 to 100 m. But Foraminifera Yamazato *et al.* regarded as *Cycloclypeus* may be microspheric one.

3.2. Vertical distribution

Data concerning the vertical distribution of *Cycloclypeus* is summarized in Table 1. *Cycloclypeus* samples have been dredged at depths from 32 (St. Ho 4) to 1,419 m (St. Ho 2). The shallowest one is numerous megalospheric and microspheric specimens obtained from Wuhoh bay, NW coast of Waigeu island, NW New Guinea. The deepest one is only one megalospheric specimen. Tan (1932) quoted Hofker (1927) found *Cycloclypeus* at 1,595 m depth, though the present author could not ascertain this description.

Megalospheric forms tend to live in wider depth range than microspheric ones. The former occur at depths between 32 and 1,419 m, but the latter from 52 (St. Ho 6) to 362 m (St. Ch 6) (Table 1).

It seems almost to be examined by dredgers whether *Cycloclypeus* samples is alive or not. This is very important to decide whether samples are in situ or not. Chapman (1900) observed the tests from the SW end of Funafuti (St. Ch 5) stained dark green in the center, due to the presence of algae in the chamberlets, and the samples off Fuafatu (St. Ch 7) stained dark green perhaps by symbiotic algae especially towards the center. These algae are recognized as a proof that *Cycloclypeus* is

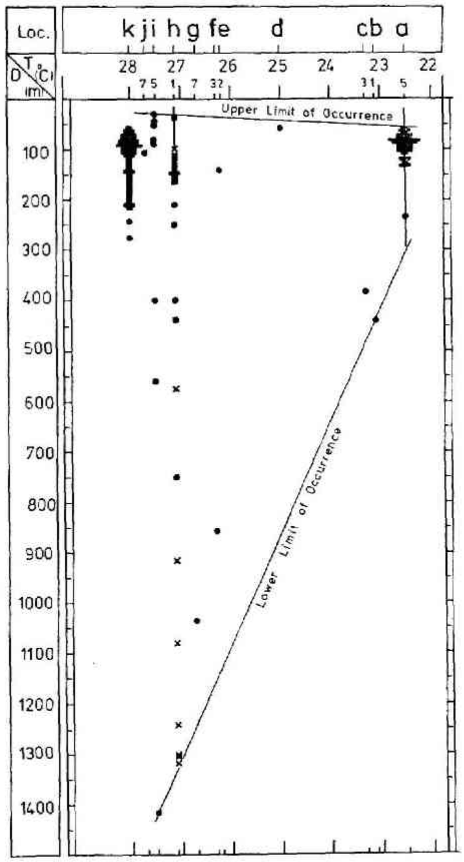

Fig. 4 Vertical distribution of Recent *Cycloclypeus* occurrence in 10 m temperature of the coldest quarter of a year.
Locations (Loc.)
a: Ryukyu Is. (Hanzawa 1951, Yamazato *et al.* 1968).
b: Tonga Is. (Chapman, 1900).
c: Fiji Is. (Brady, 1884).
d: Great Barrier Reef (Collins, 1958).
e: E. Mindoro I., Philippines (Cushman, 1921).
f: Tuamotu Is. (Cushman, 1933).
g: Between Panay I. & Negros I., Philippines (Cushman, 1921).
h: Bikini atoll (Cushman, 1954).
i: Lesser Sunda Is. (Hofker, 1927). SW. New Guinea (do.). NW. New Guinea (do.). Butung Strait, Sulawesi I. (Cushman, 1921).
j: North Balabac Strait, Philippines (do.).
k: Funafuti atoll (Chapman, 1900 & 1902).
T (°C): Temperature in °C at the coldest quarter of a year at a depth of 10 meters.
D (m): Depth in meters.
A black dot: *Cycloclypeus* sampled, at once dredging or bottom sampling.
——×: Negative in occurrence continuously or at a point.
Black polygons: Occurrence frequency within 10 m depth range is shown with the width of inking.

alive. Cushman *et al.* (1954) reported some of samples from Bikini (St. Cu 10) gave a positive reaction for protoplasm in the rose bengal test. Yamazato *et al.* (1968) also observed the genus colored.

Both locations and depths of *Cycloclypeus* are illustrated in a graph (Fig. 4). The mean temperature of the coldest quarter at the locations were estimated from Barkely's oceanographic atlas (1968). These results are arranged in the order of the coldest temperature (Table 2). The areal distribution of the genus is, as already described, primarily controlled by the mean temperature of the coldest quarter. Therefore, the vertical distribution of the genus is shown with the 10 m depth temperature of the coldest quarter of a year (Fig. 4).

Cycloclypeus tends to concentrate around 90 m among the living range from 32 to 1,419 m depth. The higher the temperature of the coldest quarter is, the higher the upper limit of its occurrence becomes. The lower limit of occurrence is in contrast with this. In other words, the lower the temperature is, the more it converges into around 90 m. Data between 23° and 27°C is insufficient.

3.3. Oceanographic data

The range of main oceanographical features for the habitation of *Cycloclcypeus* in the Northwestern Pcific ocean is shown in Table 3. Warm homogeneous water mass (about 10°C) is observed at depths from 600 to at least 4,000 m in the Sulu sea between Philippines and Borneo (St. Cu 2). Water temperatures around the Ryukyu islands are as in Table 4. As the range of temperature in *Cycloclypeus* presence stations completely includes that in absence stations, the absence in the sea surrounding Okinawa island may not result from insufficient temperature.

The Lotus III and the Equapac (H.M. Smith) Expeditions supplied some oceanographic data in August or September at stations Ch 1, B 1, Cu 5 and Ch 3–7 (Table 5).

The range of main oceanographical factors which affords the inhabitation of *Cycloclypeus* is summarized in Table 6.

As *Cycloclypeus* is a benthonic foraminifer, bottom environments should be considered, but the aquatic environment will be convincingly representative of the benthonic environment.

3.4. Discussion

3.4.1. Concentration of *Cycloclypeus* around 90 m depth

There are two reasons for the concentration. Maximum occurrence frequency in the vertical distribution of *Cycloclypeus* accords with some oceanographical or biological data. The vertical distribution of temperature, salinity and dissolved oxygen was obtained from 18 times' oceanographical observations in September, 1949 at the point near 29°N, 135°E in the southern sea of Japan (Masuzawa, 1950). The lower limit (20.8°C) of the first spring layer of temperature, the maximum layer (34.8‰) of salinity and the lower limit (5.3 ml/l) of the maximum layer of dissolved oxygen tend to a depth of 100 m (Fig. 6). The upper limit of the second spring layer is recognized near 500 m depth.

In the tropical water regions within Lat. 30°, the thermocline develops between 50 and 100 m depth, except in Winter with active vertical convection of sea water in the subtropical region. The maximum layer of salinity and the discontinuity of dissolved oxygen often concur with the thermocline (Fig. 6). The density is higher in the thermocline than in the convection layer above, and lower than in the substratosphere below. Moreover, it is very stable (Hidaka, 1955).

The circumstances of ample nutritive salts and low illuminance maximize the

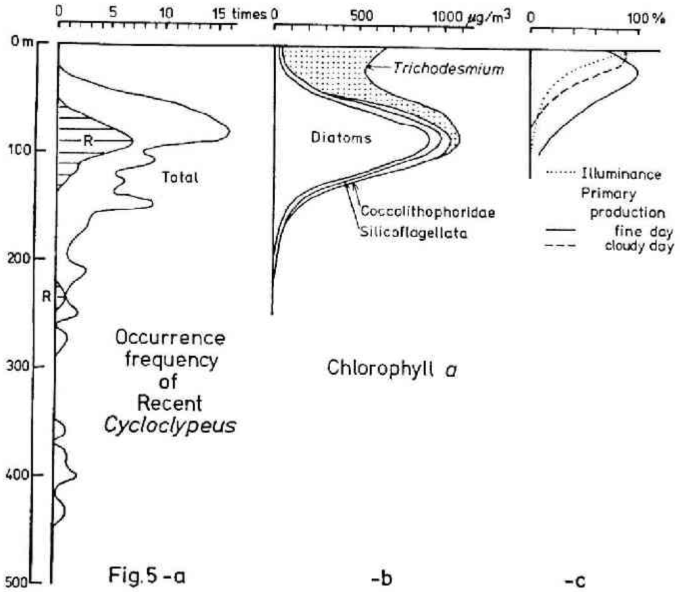

Fig. 5-a Occurrence frequency in 10-m depth range of Recent *Cycloclypeus*.
R: From the adjacent sea of the Ryukyu islands.
Fig. 5-b Production of each phytoplanktonic group at the vertical distribution of chlorophyll *a* in the warm sea (Marumo, 1974).
Fig. 5-c Depth distribution of the primary production in the tropical sea (Raymont 1963, after Aruga 1974).

quantity of chlorophyll *a* and its oxydative catabolite (pheophytine), *i.e.* phytoplankton and zooplankton respectively in the thermocline (Kawarada, 1975).

Fig. 5-b shows the quantity for which each group of phytoplankton account of chlorophyll *a* in the subtropical sea (Marumo, 1974). Diatoms command an overwhelming majority and contribute to the maximum weight of chlorophyll *a*. Silicoflagellata is scarce in cell number, and is not so variable as diatoms on the vertical distribution of cell number in Kuroshio current region, Sulu sea, Sulawesi sea and South China sea. Its maximum value lies between 50 and 75 m depth, shallower than that of diatoms. Coccolithophoridae with very small shape is wide in distribution, many in quantity and important primary producer. This vertical distribution varies with latitudes. The maximum value, not so conspicuous as diatoms, appears from 75 and 100 m depth in Summer in the tropical water of Southeast Asia. *Trichodesmium*, the most important blue green algae as marine plankton, is distributed universally in the tropical and subtropical water regions of the Pacific in Summer. It is abundant at the surface layer where scarce nutritive salts suppress diatoms in Summer. The above-mentioned facts

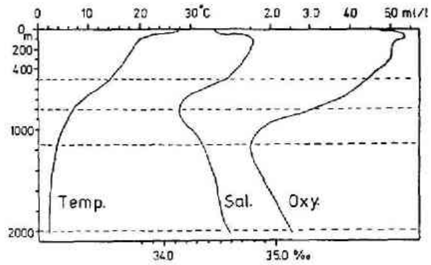

Fig. 6 Vertical distribution of temperature, salinity and dissolved oxygen in September, 1949 at the point near 29°N, 135°E in the southern sea of Japan (Masuzawa, 1950).

lead to the conclusion that *Cycloclypeus* thrives well on diatoms. It is supported by the culture experiments. The nutritional requirements of Foraminifera are various by species, but diatoms and other unicellular algae are in general the most useful food organisms (Arnold, 1974).

Cycloclypeus often has symbiotic zooxanthellae as shown in the above observation that the tests are stained dark rich green, by the presence of algae in the chamberlets (Chapman, 1900). *Heterostegina depressa*, which is allied to the above genus, was demonstrated by Rottger and Berger's experiment (1972, Lee 1974) to show enhancement of growth under optimum light conditions. The role of the symbionts in the overall carbon budget of *Heterostegina* could be clarified by critical tracer experiments (Lee, 1974). In the nutrition and growth of Foraminifera it is conditionally recognized (Rottger and Berger 1972, Lee 1974). Although the symbiotic zooxanthellae do the photosynthesis, the vertical distribution of *Cycloclypeus* in shallow water appears to have nothing to do with that of illuminance (Figs. 5-a, -c).

The other reason of *Cycloclypeus* concentration around 90 m is as follows. The lower subzone of coral reef slope is inhabited by abundant *Cycloclypeus* (Yamazato *et al.*, 1968). Many other coral reefs also seem to be similar in structure to the Ryukyu islands and their lower subzone is from 70 to about 100 m depth. Hence, the genus may be concentrated around 90 m depth.

Yamazato *et al.* (1968) observed that this benthos prefers gravelly bottom to sandy one, although it lives on the same shells, other organisms, reef limestone and muddy substratum. As substratum, *Polyzoa* (St. Ch 4), *Carpenteria* and other adherent Foraminifera (Ch 4), *Lithothamnion* (Ch 3 & 6) and *Turbinaria* are reported by Chapman (1900). *Cycloclypeus* is rarely alive on muddy bottom (globigerina ooze) hardly agitated in the deep sea. In respect of substrata, *Cycloclypeus* seems to favor the lower subzone, gentle slope composed primarily of gravel as Yamazato *et al.* observed.

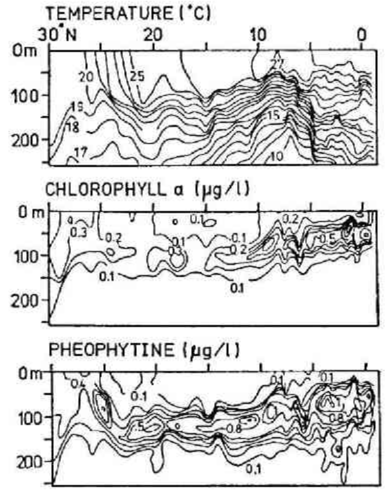

Fig. 7 Temperature, chlorophyll *a* and pheophytine along approximately 137°E from Japan to New Guinea (Kawarada and Sano 1969, after Kawarada 1975).

3.4.2. The upper limit of *Cycloclypeus* occurrence

The thermocline is constant in thickness and inclines from Lat. 0° to 30° in the Atlantic and Pacific oceans (Hidaka, 1955). Variations of temperature, chlorophyll *a* and pheophytine along approximately 137°E from Japan to New Guinea (Kawarada and Sano 1969, Kawarada 1975) are shown in Fig. 7. In the section from 30°N to 24°N, there is an isothermal zone owing to vertical convection, where chlorophyll *a* keeps approximately uniform quantity and does not have any concentrations. From 25°N to New Guinea the spring layer of water temperature and salinity appears and chlorophyll *a* and pheophytine maximize along the spring layer. Thus, the upper limit of *Cycloclypeus* is recognized to be controlled in distribution pattern by the spring layer, exactly by foods or nutrients in the spring layer.

4 Conclusion

The most important determinant for the areal distribution of *Cycloclypeus* is water temperature in ocean scale. The next seems to be food organisms. The primary factor for its vertical distribution is food organisms, *i.e.* phytoplankton, for there is lower primary organic production in the tropical water.

In coral reef scale, *Cycloclypeus* requires adequate water circulation and oxygen. It rejects variable water condition and suspended terrigenous material.

Although the lower limit of surface hermatypic coral zone varies with the intra- and inter-coral reef systems, *Cycloclypeus* inhabits the *Echinophyllia* zone abundantly (Fig. 8). This means that the distributional depths of *Cycloclypeus* and

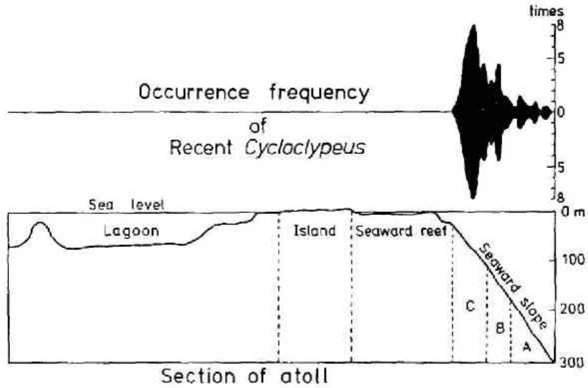

Fig. 8 Occurrence frequency of Recent *Cycloclypeus* in the section of coral reef. Occurrence frequency of Cycloclypeus in this figure is re-formed from that in Fig. 5-a. Section through windward rim and portion of lagoon at Bikini atoll is revised after Wells (1954). A: Ahermatypic coral zone. B: Deeper hermatypic coral zone. C: *Echinophyllia* zone.

hermatypic coral overlap partly. This relation between two coral reef builders is still not recognized by the immediate occurrence in the present sea.

Cycloclypeus is useful for the geohistoric reconstruction of fossil coral reef complex. Although it is difficult in general to distinguish fore-reef facies by coralgal fauna, *Cycloclypeus* is not only the indicator of fore-reef detrital facies, but also of the depth range of deposition. Moreover, it gives some data for the estimation of water temperature.

Paleoecology or paleoenvironment is built from fossils themselves and features of the rocks besides studies of organisms and sedimentary environments in the present sea. The sea-level change and depositional environments of the late Pleistocene in the Ryukyu islands will be restored from the stratigraphical or paleontological studies of the Ryukyu group by using *Cycloclypeus* as an environmental indicator later on.

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Table 1 Data concerning the

Reference	Location	Station No.	Depth (m)
Brady (1884)	19°10'S, 178°10'E St. 174C, off Kandavu, Fiji Is.	B1	384
Chapman (1900)	off Nukualofa, Tongatabu, Tonga Is.	Ch1	439
	the Macclesfield Bank, China Sea	Ch2	55
	North of Pava I.	Ch3	66-115
	off Funamanu I. (Beacon Is.)	Ch4	92 146 275
	South West of Funafuti	Ch5	82-93
	off Tutanga I.	Ch6	64, 75, 84, 92-110 247 362
	off Fuafatu	Ch7	55-220 73 110 218
	off Mauritius I.	—	—
	off the Solomon Is.	—	—
	South East of Nomuka, Tonga Is.	—	37-75
Chapman (1902)	off Tutanga I.	Ch 6, add.	110-183 214 249
Collins (1958)	Trinity Opening, Great Barirer Reef	Co 1	ca. 60
Cushman (1921)	12°38'15"N, 122°12'30"E St. D 5179, East of Mindoro I., Philippines	Cu 1	142
	10°18'30"N, 122°23'30"E, St. D 5184, between Panay and Negros, Philippines	Cu 2	1033
	8°06'40"N, 117°18'45"E, St. D 5356, North Balabac Strait, Philippines	Cu 3	58
	4°27'00"S, 122°55'40"E, St. D 5640, Butung Strait, Sulawesi I.	Cu 4	44
Cushman (1933)	North West entrance to Makemo lagoon, 1 mile SE., Tuamotu Is. (Albatross Station H 3876)	Cu 5	855
Cushman, Todd, & Post (1954)	11°19'-23'N, 167°21'-29'E, Rongerik lagoon	Cu 6 X (15 sts.)	22-45
	11°11'-23'N, 166°38'-167°01'E, inside lagoon, Rongelap atoll	Cu 7 X (13 sts.)	0-59
	11°22'-27'N, 166°54'-167°01'E, outside lagoon, Rongelap atoll	Cu 8 X (3 sts.)	59-90
	11°27'20"N, 166°43'43"E, St. 468, outside lagoon, Rongelap atoll	Cu 8	38
	11°30'-40'N, 165°13'-32'E, inside lagoon, Bikini atoll	Cu 9 X (58 sts.)	3-57

Stations are numbered by the present author after each investigator. Form A: Megalospheric *clypeus carpenteri* Brady 1881. Abundance of *Cycloclypeus* depends on each investigator's distribution of *Cycloclypeus*

Occurrence site	Specimen form	Abundance
sandy bottom, with Foraminifera of deeper coral reefs.	A	present
—	A (young)	—
bank	A	—
encrustation of *Lithothamnion*	A (immature or adult)	abundant
—	A (esp. young)	abundant ?
adherent Foraminifera	B (very large)	present
—	A (fully-developed)	present
hard rock	—	—
pink *Lithothamnion*	both	abundant
—	both	abundant
—	B	common
pteropod ooze	both	common
—	A	common
—	A	—
—	both	common
—	B	a fragment
on a *Turbinaria*	A	—
—	A	—
—	A (fully-grown)	present
reef rock	B	a fragment
reef rock	both	abundant
reef rock	A	present
reef pass	—	present
fine sandy bottom	—	abundant (more than 10 specimens)
green muddy bottom	—	common (1 specimen)
shelly and sandy bottom under a strait	—	common (2 specimens)
sandy and broken sandy bottom under a strait	—	abundant (more than 10 specimens)
reef pass	—	1 specimen
inside lagoon	*Non occurrence*	
inside lagoon	*Non occurrence*	
outside lagoon	*Non occurrence*	
outside lagoon	—	1 specimen
inside lagoon	*Non occurrence*	

form, *i.e.*, *Cycloclypeus guembelianus* Brady. 1881. Form B: Microspheric form, *i.e.*, *Cyclo-*
expression. —: No data.

Table 1

Reference	Location	Station No.	Depth (m)
	11°29'–38'N, 165°20'–32'E dredge samples, outer slopes, Bikini atoll	Cu 10 X (4 sts.)	15-88
	11°38'27"N, 165°31'46"E, St. 1460, outer slopes, Bikini atoll	Cu 10	106-167
	11°34'–50'N, 164°56'–165°33'E, bottom samples, outer slopes, Bikini atoll	Cu 11 X (4 sts.)	101, 576, 915, 1299
	11°29'31"N, 165°32'19"E, St. 812	Cu 11	146
	11°35'06"N, 165°33'34"E St. 817	Cu 11	209
	11°29'18"N, 165°30'59"E St. 814	Cu 11	249
	11°35'53"N, 165°33'30"E St. 816	Cu 11	401
	11°40'40"N, 165°14'05"E Sts. 1173 (0"-1", 1"-3", 3"-5", 5"-7", 7"-9") The above listed 9 stations are bottom samples from outer slopes of Bikini atoll.	Cu 11 (5 points)	439
	11°41'–47'N, 164°59'–165°14'E guyot samples, Bikini atoll	Cu 12 X (19 sts.)	750, 1083, 1244, 1299, 1318, 1528
	11°41'00"N, 165°14'01"E, Sts. 1174 (4"-6", 6"-8") guyot samples, Bikini atoll	Cu 12 (2 points)	750
	11°21'–33'N, 162°12'–22'E, Eniwetok lagoon	Cu 13 X (48 sts.)	0-62
	11°18'–20'N, 162°15'–16'E, outer slopes, Eniwetok atoll	Cu 14 X (5 sts.)	44, 161, 317, 392, 915
Flint (1897)	7°56'N, 79°41'W, St. 2805, Panama bay	F 1 X	93
Hanzawa	24°11'22"N, 123°27'14"E	H 1	87
(1951)	24°12'34"N, 123°27'19"E H 1, West of Iriomotejima	H 1	96
	24°15'02"N, 123°07'06"E	H 2	133
	24°27'29"N, 123°04'44"E H 2, South and South-East of Yonaguni-jima	H 2	127
	24°28'54"N, 124°50'26"E	H 3	103
	24°29'24"N, 124°53'44"E	H 3	81
	24°30'46"N, 124°52'30"E H 3, South of Taramajima	H 3	87
	24°36'57"N, 122°18'25"E off Karenko, East of Taiwan	H 4	132
	24°37'07"N, 124°48'00"E	H 5	82
	24°49'26"N, 124°37'56"E	H 5	235
	24°49'46"N, 124°38'58"E H 5, South and North of Tarama-jima	H 5	120
	25°17'30"N, 125°49'50"E	H 6	91
	25°19'04"N, 125°50'33"E	H 6	106
	25°20'33"N, 125°50'07"E	H 6	62
	25°24'13"N, 125°46'01"E H 6, between Miyako-jima and Okinawa-jima	H 6	120

(Continued)

Occurrence site	Specimen form	Abundance
outer slopes	*Non occurrence*	
outer slopes	both	15% in the Foraminiferal sample
outer slopes	*Non occurrence*	
outer slopes	—	1 specimen
outer slopes	—	2 specimens
outer slopes	—	1 specimen
outer slopes	—	1 specimen
outer slopes	—	4, 6, 3, 1, and 4 specimens
guyot	*Non occurrence*	
guyot	—	1 and 1 specimens
inside lagoon	*Non occurrence*	
outer slopes	*Non occurrence*	
inside bay	*Non occurrence*	
—	both	—
—	both	—
—	both	—
—	both	—
—	both	—
—	both	—
—	both	—
—	both	—
—	both	—
—	both	—
—	both	—
—	both	—
—	both	—
—	both	—
—	both	—

Table 1

Reference	Location	Station No.	Depth (m)
Hofker (1927)	8°23.5′S, 119°4.6′E, St. 49[a]	Ho 1	69
	10°29.0′S, 121°28.7′E, St. 57	Ho 2	1419
	Near 7°0′S, 120°34.5′E, St. 65[a]	Ho 3	400
	The above listed 3 samples are obtained in Lesser Sunda Is.		
	St. 152, Wunoh bay, NW.-coast of Waigeu I., NW. New Guinea	Ho 4	32
	0°7.2′N, 130°25.5′E, St. 154, NW. New Guinea	Ho 5	83
	St. 257, Du Roa strait, Kei Is.	Ho 6	till 52
	5°36.5′S, 132°55.2′E, St. 260	Ho 7	90
	5°53.8′S, 132°48.8′E, St. 262	Ho 8	560
	The above listed 2 samples are obtained in SW. New Guinea.		
Konda et al. (1975)	29°53.4′N, 133°20.2′E - 29°52.8′N, 133°20.1′E The 2nd Komabashi sea mount	K 1 X	975-1165
Yamazato et al. (1968)	26°47.3′N, 128°00.3′E-26°46.5′N, 128°01.3′E, St. 4, NW. Kei-sho, off Nakijin, Okinawa I.	Y 1 X	16-183
	26°45.4′N, 127°59.7′E-26°46.5′N, 128°01.3′E St. 5, SW. Kei-sho, off Nakijin, Okinawa I.	Y 1 X	17-153
	26°32.6′N, 127°53.5′E- 26°31.7′N, 127°53.6′E. St. 15, Nago-wan	Y 2 X	120-275
	26°33.2′N, 127°52.2′E-26°42.2′N, 127°52.0′E St. 16, Nago-wan	Y 2 X	280-289
	26°32.6′N, 127°55.9′E 26°32.6′N, 127°55.6′E St. 19, Nago-wan	Y 2 X	40-206
	26°23.5′N, 127°38.9′E–26°23.3′N, 127°39.4′E, St. 17, off Yomitan, Okinawa I.	Y 3 X	120-300
	26°18.0′N, 127°42.0′E-26°18.5′N, 127°41.1′E, St. 20, off Kitadani, Okinawa I.	Y 3 X	73-98
	26°02.8′N, 127°54.1′E-26°03.4′N, 127°44.7′E, St. 1, off Mabuni, S. Okinawa I.	Y 4 X	147-239
	26°05.0′N, 127°47.9′E-26°05.3′N, 127°48.2′E St. 2, off Minatogawa	Y 4 X	132-260
	26°02.7′N, 127°38.7′E-26°02.7′N, 127°39.1′E, St. 3, off Kiyabuzaki, S. Okinawa I.	Y 4 X	150-278
	26°03.7′N, 127°49.6′E-26°04.6′N, 127°49.5′E St. 21, off Hyakuna, S. Okinawa I.	Y 4 X	200-280
	26°18.2′N, 126°44.8′E-26°18.5′N, 126°46.0′E, St. 18, off Gima, Kume I.	Y 5 X	34-285 (except around 90)
	St. 18, around 90 m deep	Y 5	around 90
	24°42.6′N, 125°21.8′E-24°42.4′N, 125°21.4′E St. 6, off Tomori, Miyako I.	Y 6 X	50-230 (except 70–100)

(Continued)

Occurrence site	Specimen from	Abundance
—	both	abundant
—	A	1 specimen
—	A	8 specimens
inside bay	both	abundant
—	—	abundant
under a strait	B	1 specimen
—	A	1 specimen
—	A (young)	1 specimen
Formainiferal sandy sediments	*Non occurrence*	
coral reef, sandy and gravelly bottom	*Non occurrence*	
coral reef, sandy and gravelly bottom	*Non occurrence*	
coral reef, sandy and gravelly bottom	*Non occurrence*	
sandy and gravelly bottom	*Non occurrence*	
coral reef, sandy and gravelly bottom	*Non occurrence*	
sandy and muddy bottom	*Non occurrence*	
sandy bottom	*Non occurrence*	
sandy bottom	*Non occurrence*	
rocky, sandy and gravelly bottom	*Non occurrence*	
sandy and gravelly bottom	*Non occurrence*	
sandy and gravelly bottom	*Non occurrence*	
coral reef, sandy and gravelly bottom	*Non occurrence*	
sandy and gravelly	both forms	abundant
coral reef, sandy and gravelly bottom	*Non occurrence*	

Table 1

Reference	Location	Station No.	Depth (m)
Yamazato et al. (1968)	St. 6, between 70 m deep and 100 m deep	Y 6	70-100
	24°39.8′N, 125°15.2′E-24°40.5′N, 125°15.6′E, St. 7, off Kuruma I., near Miyako I.	Y 7 X	65-278 (except 70-110)
	St. 7, between 70 m deep and 90 m deep	Y 7	70-110
	24°23.3′N, 124°04.0′E-24°24.0′N, 124°04.9′E St. 11, off Ohsaki, Ishigaki I.	Y 8 X	38-92
	24°17.9′N, 124°26.6′E-24°17.6′N, 124°15.3′E, St. 12, off Shiraho, Ishigaki I.	Y 8 X	200-240
	24°16.2′N, 124°11.4′E-24°16.3′N, 124°10.7′E St. 13, off Hirai, Ishigaki I.	Y 8 X	100-213
	St. 13, between 98 m deep and 100 m deep	Y 8	98-100
	24°22.0′N, 124°15.7′E-24°21.9′N, 124°26.2′E St. 14, off Inoda, Ishigaki I.	Y 8 X	281-284
	24°15.8′N, 123°43.9′E-24°15.8′N, 123°43.4′E St. 10, off Kanogawa, Iriomote I.	Y 9 X	58-72
	St. 10, between 72 m deep and 90 m deep	Y 9	72-90

Table 2 Temperatures (°C) at 10 m depth.
Source: *Oceanographic Atlas of the Pacific Ocean* by Barkley (1968).

Location	Station no.	I	II	III	IV	C	D	A
Ryukyu Is.	H 1–6, Y 1–9	22.5	25.0	28.0	25.3	22.5	5.5	25.2
Tonga Is.	Ch 1	27.0	25.0	23.1	26.0	23.1	3.9	25.3
Fiji Is.	B 1	27.8	26.1	23.3	26.4	23.3	4.5	25.9
Great Barrier Reef	Co 1	27.5	27.5	25.0	27.5	25.0	2.5	26.9
E. Mindoro I. Philippines	Cu 1	28.7	29.8	29.6	26.2	26.2	3.6	28.5
Tuamotu Is.	Cu 5	28.4	27.5	26.4	26.3	26.3	2.1	27.2
Between Panay & Negros, Philippines	Cu 2	29.5	29.5	29.9	26.7	26.7	3.2	28.9
Bikini	Cu, 8, 10 11, 12	27.3	27.1	28.6	28.7	27.1	1.6	27.9
Lesser Sunda Is.	Ho 1–3	27.5	29.0	27.5	27.5	27.5	1.5	27.9
SW. New Guinea	Ho 7, 8	27.5	29.2	27.5	27.5	27.5	1.7	27.9
NW. New Guinea	Ho 4, 5	28.0	29.3	27.5	27.5	27.5	1.8	28.1
Butung Strait, Sulawesi I.	Cu 4	27.7	27.5	29.2	27.5	27.5	1.7	27.9

(Continued)

Occurrence site	Specimen form	Abundance
sandy and gravelly bottom	both	abundant
coral reef, sandy bottom	*Non occurrence*	
gravelly bottom	both	abundant
inside bay coral reef, sandy and gravelly bottom	*Non occurrence*	
sandy and gravelly bottom	*Non occurrence*	
coral reef, sandy and gravelly bottom	*Non occurrence*	
gravelly bottom	both	abundant
rocky bottom	*Non occurrence*	
coral reef	*Non occurrence*	
sandy and gravelly bottom	both	abundant

Table 2

Location	Station no.	I	II	III	IV	C	D	A
North Balabac Strait, Philippines	Cu 3	28.7	29.1	29.8	27.7	27.7	2.1	28.8
Funafuti	Ch 3–7	29.5	29.5	28.0	29.2	28.0	1.5	29.1

I: Mean temperature in Jan., Feb. and Mar.
II: Mean temperature in Apr., May and Jun.
III: Mean temperature in Jul., Aug. and Sep.
IV: Mean temperature in Oct., Nov. and Dec.
C: The coldest mean temperature among I-IV quarters.
D: Difference between mean temperatures in the warmest quarter and in the coldest.
A: Annual mean temperature.

Table 3 Oceanographic data in the Northwestern Pacific Ocean, at depths which *Cycloclypeus* was found.

Station no.	R.D. (m)	T mean (°C)	T max (°C)	T min (°C)	T ar. (°C)	Salinity (‰)	D.O. (ml/l)	T. (m)
H 1–6, Y 5–9	100	23.2-24.0	25.4-27.2	20.3-21.3	5.1-5.9	34.7-34.9	4.2-4.6	25
Cu 1	142	20.4	21.2	18.2	3.0	34.4	2.4	25−
Cu 2	1033	10.0	10.0	10.0	0.0	34.4	1.6	25−
Cu 8, 10–12	38-439	27.2-8.1	—	—	—	34.7-34.5	4.5-1.1	35−
Ho 4, 5	32-83	27.6-25.4	28.5-27.4	25.9-23.0	2.6-4.4	34.6-35.0	4.2-3.8	25+
Cu 3	106	21.0	24.0	19.0	5.0	34.3	2.7	25

R.D. (m): Representative depth in meters. T mean: Mean temperature in °C. T max: 1/10 maximum temperature in °C. T min: 1/10 minimum temperature in °C. T ar.: Annual range of temperature in °C. S (‰): Mean salinity per mil. D.O. (ml/l): Mean dissolved oxygen in milliliters per liter. T(m): Mean transparency in meters.
Source: *Marine Environmental Atlas, Northwestern Pacific Ocean* compiled by Japan Oceanographic Data Center (1975).

Table 4 Temperature (°C) in the Southern Ryukyu Is., at depths which *Cycloclypeus* was examined.

Station no.	Presence (+) or Absence (−)	R.D. (m)	T mean (°C)	T max (°C)	T min (°C)	T ar. (°C)
H 1	+	90	24.0	27.2	21.3	5.9
H 2	+	130	22.2	25.3	19.8	5.5
H 3	+	90	23.6	26.6	20.8	5.8
H 4	+	132	19.5	23.5	15.4	8.1
H 5	+	90	23.6	26.6	20.8	5.8
	+	235	18.5	20.5	16.5	4.0
	+	120	22.7	25.1	19.9	5.2
H 6	+	106	23.1	25.4	20.4	5.0
	+	62	24.0	27.3	20.7	6.6
Y 1	—	20-185	24.3-19.9	28.1-21.2	21.3-18.5	6.8-2.7
		90	22.6	25.0	20.2	4.8
Y 2	—	40-280	23.8-17.3	27.2-18.6	20.5-16.1	6.7-2.5
		90	22.6	25.0	20.2	4.8
Y 3	—	70-297	23.1-16.8	27.7-18.2	20.5-15.5	7.2-2.7
		90	22.6	25.0	20.3	4.7
Y 4	—	130-280	21.5-17.3	23.5-18.7	19.6-16.0	3.9-2.7
		90	22.6	25.0	20.3	4.7
Y 5	+	90	23.2	25.4	20.3	4.7
Y 6,7	+	90	23.6	25.9	20.7	5.2
Y 8,9	+	72-100	24.4-23.8	27.6-27.0	21.5-21.0	6.1-6.0

R.D. (m): Representative depth in meters. T mean (°C): Mean temperature in °C. T max (°C): 1/10 maximum temperature in °C. T min (°C): 1/10 minimum temperature in °C. T ar. (°C): Annual range of temperature in °C.
Source: *Marine Environmental Atlas, Northwestern Pacific Ocean* compiled by Japan Oceanographic Data Center (1975).

Table 5 Oceanographic data in the Southern Pacific Ocean, at depths which *Cycloclypeus* was found.

Station no.	Expd.	Date	Depth (m)	Temp. (°C)	Salinity (‰)	D.O. (ml/1)	P (μg-at./1)
Ch 1	L	Sep., 1958	439	10-12	34.6-34.8	3-4	1-2
B 1	L	Sep., 1958	384	ca. 12	34.8-35.0	3-4	ca. 1
Cu 5	E	Sep., 1956	855	4-5	34.3-34.4	3-4	ca. 2.25
	E	Aug., 1956	855	4-5	34.3-34.4	4.5	2-2.5
Ch 3-7	E	Sep., 1956	55	26-28	35.8-36.0	4.5-5.0	0.5-1
	E	Sep., 1956	220	20-22	35.6-35.8	3-4	ca. 1
	E	Sep., 1956	247	ca. 18	ca. 35.4	ca. 3	1-2
	E	Sep., 1956	275	ca. 16	ca. 35.2	ca. 3	ca. 1.5
	E	Sep., 1956	362	10-12	34.6-34.8	3-2	2-2.25
	E	Sep., 1956	366	ca. 10	ca. 34.7	3-2	ca. 2
	E	Sep., 1956	100	ca. 26	ca. 36.2	4.5	0.5-1

L: Lotsu III Expedition. E: Equapac (H.M. Smith) Expedition. Temp. (°C): Temperature in °C. D.O. (ml/1): Dissolved oxygen in milliliters per liter.
P (μg-at./1): Inorganic phosphate-phosphorus in microgram-atoms per liter.
Source: *Intermediate Waters of the Pacific Ocean* by Reid (1965)

Table 6 The range of oceanographic factors which *Cycloclypeus* inhabits.

T mean (°C)	T max (°C)	T min. (°C)	T ar. (°C)	Salinity (‰)	D.O. (ml/1)	P (μg-at./1)	T (m)
8.1 (4)-27.6	10.0-28.5	10.0-25.9	0.0-5.9	34.3-35.0 (36.2)	1.1-4.6 (5.0)	0.5-2.25	ca. 25

Each abbreviation is explained in Tables. 3 & 5. Figures in parentheses are quoted from the data which was observed only once in August or September (Reid, 1965).