

Shallow-water benthic foraminifers from Mecherchar Jellyfish Lake (Ongerul Tketau Uet), Palau

SHUNGO KAWAGATA

*Geomarine Research, 49 Swainston Road, St. Johns,
Auckland, New Zealand
Email: s.kawagata@geomarine.org.nz*

MAKOTO YAMASAKI¹

*Center for Advanced Marine Core Research, Kochi University,
B200 Monobe Nankoku, Kochi, 783 8502 Japan*

RIEKO GENKA

*Department of Earth and Environmental Sciences,
Faculty of Science, Yamagata University,
Yamagata, 990 8560 Japan*

RICHARD W. JORDAN²

*Center for Advanced Marine Core Research, Kochi University,
B200 Monobe Nankoku, Kochi, 783 8502 Japan*

Abstract—A sediment core taken from Mecherchar Jellyfish Lake (officially called Ongerul Tketau Uet), a marine lake in the Republic of Palau, was initially investigated for siliceous microfossils, however, a carbonate layer (67–78 cm below the sediment surface) was found to contain moderately preserved benthic foraminifers. Ten species have been identified from these samples to date, and most are common in subtropical to tropical shallow marine environments. The assemblage is dominated by two species, *Helena* cf. *H. anderseni* and *Rosalina globularis*, with the other species being less common to rare. The presence of this carbonate layer below siliceous muds and anoxic bottom waters is assumed to represent the drier, cooler climate of the Little Ice Age which ceased about 100 years ago.

¹Present address: Department of Earth Science and Technology, Faculty of Engineering and Resource Science, Akita University, Akita, 010 8502 Japan

²Present address: Department of Earth and Environmental Sciences, Faculty of Science, Yamagata University, Yamagata, 990 8560 Japan

Introduction

Mecherchar Jellyfish Lake (or Ongerul Tketau Uet in the Palauan language) is an unusual tropical marine lake which has remained relatively cut off from the surrounding sea for about the last 10,000 years and is home to millions of endemic jellyfish (Lobban & Scheffer 1997). Previous investigations of this lake have focused largely on its geochemical, microbial and water properties (Hamner et al. 1982, Burnett et al. 1989, Venkateswaran et al. 1993), although some faunal, macroalgal and microalgal studies have also been conducted (Hamner & Hauri 1981, Hamner et al. 1982, Hara et al. 2002). However, observations on foraminiferal assemblages either preserved in the Mecherchar Jellyfish Lake sediments (Lipps & Langer 1999) or living in the reefal and lagoonal habitats outside the lake have been limited (Lessard 1980, Hallock 1981, 1984, Langer et al. 1997).

Here we present ten species of foraminifer from Mecherchar Jellyfish Lake sediments, briefly compare our findings with those of Lipps & Langer (1999) and provide an updated check-list of species from the lake.

Methods

SAMPLING LOCALITY AND ENVIRONMENTAL SETTING

Mecherchar Jellyfish Lake is situated on Mecherchar Island (7°09.5'N, 134°22.5'E; formerly known as Eil Malk Island; Fig.1), one of the numerous islands making up the Republic of Palau in the western Pacific Ocean. The lake lies in the northeast of the island, is 420 m long and 100 m wide, with a surface area of about 50,000 m², and is up to 30 m deep in the western basin (Hamner et al. 1982). The lake is marine, generally with a surface salinity of 27–31‰ and surface water temperatures around 30°C. The lake is permanently stratified (meromictic) with an oxic upper layer (epilimnion) and an anoxic lower layer (hypolimnion) below 15 m. At 12–15 m water depth there is a bacterial layer, composed largely of a *Chromatium* sp. (Venkateswaran et al. 1993), which seemingly acts as a sponge for descending particles—the waters being clear below this layer (Hamner et al. 1982). Relatively low concentrations of nutrients occur in the epilimnion, but levels increase dramatically below 15 m (i.e. there is a strong chemocline). The lake is surrounded by a dense jungle, with the lake edge dominated by mangroves. Fallen leaves, especially from the mangroves, are a major source of the organic matter in the lake sediments (Orem et al. 1991).

CORE COLLECTION AND BASIC DESCRIPTION

Given the relative inaccessability of Mecherchar Jellyfish Lake (and other lakes sampled during our 3 year research programme) it was decided to use a diver, rather than a more conventional gravity corer, to retrieve lake cores. Burnett et al. (1989), who also used a diver, suggested that a gravity corer may destroy the sediment-water interface due to the flocculent nature of the surface sediments.

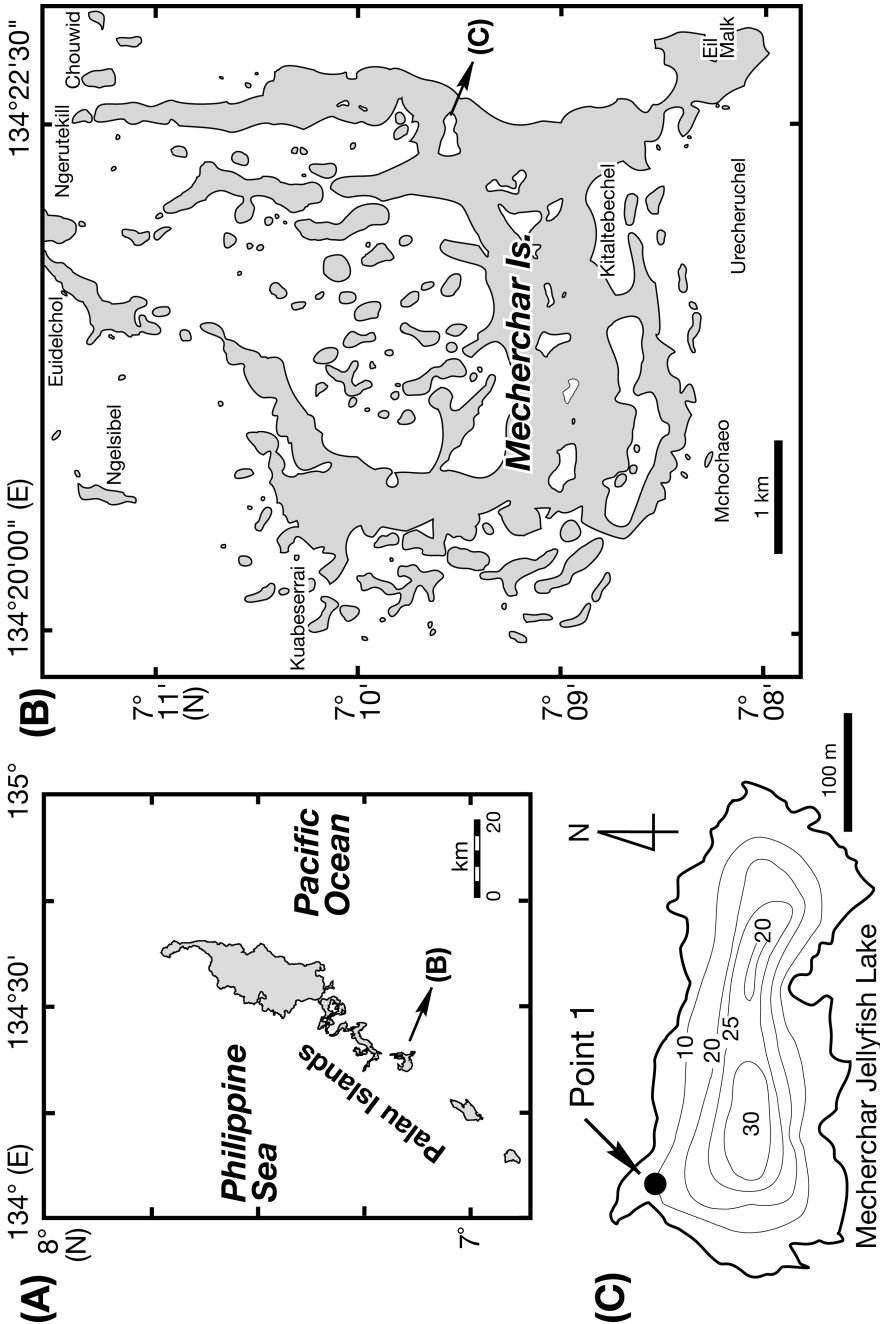


Figure 1. (A) Map of the Republic of Palau, (B) Map of Mecherchar Island, (C) Map of Mecherchar Jellyfish Lake, showing the locations of the underwater channels (A, B and C) and Point 1. Isobaths are in metres. Modified from Hamner et al. (1982).

One additional benefit of the diver method is that a longer core tube could be assembled, with the hope that >50 cm cores could be recovered. Up to six 50 cm acrylic core tubes were joined together with vinyl tape and chopsticks to make a 2–3 m composite core tube. The core tube was inserted into the lake sediments by the diver, with a bung used to seal the upper core tube, then the lower end was sealed after extraction of the core tube, before the diver returned to the lake surface with the core tube in a vertical position. As only 0.5–1.5 m of core material were usually recovered due to the soft flocculent nature of the lake sediments, ‘empty’ core tubes from the upper section were removed and the composite core tube was resealed. Later, the core tube was transported back to Carp Island (our base camp) for sampling and examination.

The sediment core used in this study was taken from Point 1 (about 10 m water depth) on the 15 November 2001 (Fig.1). The core length was 78 cm, and samples were taken at 1 cm intervals. The core top was a little soupy (as also noted by Orem et al. 1991), but the water content gradually decreased downcore. The upper part of the core (0–66 cm) was dark blackish brown, and similar sediments have been previously shown to contain about 60% organic matter derived from vascular plants such as mangroves (Orem et al. 1991). Faecal pellets from silverside fish are also recognisable. In addition, the upper sediments contain relatively high numbers of biogenic silica particles such as diatoms and sponge spicules (Orem et al. 1991). Below this layer (67–78 cm) the sediments gradually change from dark blackish brown to white, as the amount of carbonate increases and shell fragments are visible. It is now known that in this layer diatoms and sponge spicules are absent, whilst benthic foraminifers are moderately preserved. Orem et al. (1991) suggested that organic matter in these carbonate-rich sediments were more likely to be algal derived than from vascular plants.

SAMPLE PREPARATION AND OBSERVATION

Ten subsamples from the carbonate-rich layer (67–78 cm) and two from the layer above (0–1 cm, 50–51 cm) were sieved through a 63 µm mesh and the retained particles were placed in a plastic petridish to dry. Individual foraminifers were picked out using a fine paint brush and transferred to a microslide for identification and separation into discrete species. Specimens were attached to EM stubs by double-sided tape and observed (uncoated) in a JEOL Field Emission 6500F scanning electron microscope at an accelerating voltage of 1 kV. The specimens were photographed and saved in digital format.

Results and Discussion

SPECIES DIVERSITY AND ECOLOGY

Lipps & Langer (1999) looked at a total of 361 specimens from 10 depth differentiated surface sediment samples and identified 15 species of benthic foraminifer. In this study 1142 specimens from 12 samples in a sediment core were observed and 10 species were identified (Table 1). Surprisingly, only two of

Table 1. Distribution and raw count data of the benthic foraminifers found in this study.

species	samples (cm downcore)											
	0-1	50-51	67-68	68-69	69-70	70-71	72-73	73-74	74-75	75-76	76-77	77-78
<i>Acarotrochus lobulatus</i>	0	0	0	0	0	0	4	0	0	3	0	15
<i>Ammonia</i> sp. A	0	0	1	5	0	0	0	0	0	0	0	0
<i>Ammonia</i> sp. B	1	1	2	0	3	6	6	7	2	17	0	58
<i>Bolivina</i> cf. <i>B. lutea</i>	0	0	0	1	4	0	12	2	0	3	3	5
<i>Bolivina striatula</i>	0	0	0	3	0	7	6	5	1	6	6	12
<i>Elphidium oceanicum</i>	0	0	0	0	0	0	1	0	0	0	0	2
<i>Elphidium sagrum</i>	0	1	0	0	0	0	1	0	0	0	0	0
<i>Evolutononion mattsugordani</i>	0	0	0	0	0	0	4	0	1	0	0	4
<i>Helenina</i> cf. <i>H. anderseni</i>	1	0	10	27	23	33	191	30	34	59	17	221
<i>Rosalina globularis</i>	0	0	0	0	0	3	48	20	21	34	20	129
total number of specimens	2	2	13	36	30	49	273	64	59	122	46	446

the species are common to both studies, though there is a difference between the sediment materials (surface sediments vs core sediments).

An updated check-list of benthic foraminiferal species for Mecherchar Jellyfish Lake which combines the results of the two main studies is shown in Table 2.

Lipps & Langer (1999) have stated that the assemblages found in Mecherchar Jellyfish Lake are similar to those from other mangrove habitats around the world, especially in high tidal marshes and mangrove swamps of various Pacific (e.g., Lipps & Langer 1999, Hayward et al. 1999) and Central American (e.g., Saunders 1957, 1958, Culver 1990) regions. These assemblages are usually low in species diversity (<40 species; Boltovskoy 1984), compared to those communities outside the lake in the surrounding coral reefs and lagoons which may comprise 200–300 species (Lipps & Langer 1999). The Mecherchar Jellyfish Lake species are characterized by mostly thin-shelled, highly delicate tests (Lipps & Langer 1999). Of the taxa found in our study, the 7 genera are all

Table 2. Check list of the benthic foraminifers found in the Jellyfish Lake, which is compiled from two studies, Lipps & Langer (1999) and this study.

species	Lipps & Langer (1999)	this study
<i>Acarotrochus lobulatus</i> Kawagata, in Kawagata et al. 2005		X
<i>Ammonia</i> sp.	X	
<i>Ammonia</i> sp.A		X
<i>Ammonia</i> sp.B		X
<i>Bolivina</i> cf. <i>B. lutea</i> Sliter 1969		X
<i>Bolivina striatula</i> Cushman 1922*	X	X
<i>Bolivina variabilis</i> (Williamson 1858)	X	
<i>Cycloforina</i> sp.	X	
<i>Elphidium oceanicum</i> Cushman 1933		X
<i>Elphidium sagrum</i> (d'Orbigny 1839)		X
<i>Elphidium</i> sp.	X	
<i>Evolutononion matagordanum</i> (Kornfeld 1931)		X
<i>Glomospira fijiensis</i> Brönnimann et al. 1992	X	
<i>Helenina</i> cf. <i>H. anderseni</i> (Warren 1957)**	X	X
<i>Planorbulinella larvata</i> (Parker & Jones 1865)	X	
<i>Pseudotriloculina</i> sp.1	X	
<i>Pseudotriloculina</i> sp.2	X	
<i>Quinqueloculina incisa</i> Vella 1957	X	
<i>Reophax scoriurus</i> de Montfort 1808	X	
<i>Rosalina globularis</i> d'Orbigny 1826		X
<i>Rectobolivina raphana</i> (Parker & Jones 1865)***	X	
<i>Textularia</i> cf. <i>T. foliacea</i> Heron-Allen & Earland 1915	X	
<i>Trichohyalus aguayoi</i> (Bermudez 1935)	X	

*described as *Brizalina striatula* Cushman 1922 by Lipps & Langer (1999)

***Helenina* sp. of Lipps & Langer (1999) is synonymized with *Helenina* cf. *H. anderseni* (Warren 1957)

***described as *Siphogenerina raphana* Parker & Jones 1865 by Lipps & Langer (1999)

hyaline, calcareous forms belonging to the suborder Rotaliina. The most dominant taxa, *Helenina* cf. *H. anderseni* and *Rosalina globularis* have hitherto been reported from slightly brackish (e.g. Hayward et al, 1997) estuaries and on slightly rocky substrates, respectively.

BRIEF COMMENTS ON THE POSSIBLE AGE OF OUR FORAMINIFERS

Orem et al. (1991) noted that the downcore abundances of carbonate, organic carbon and organic oxygen shifted dramatically between 54–76 cm in their core 8, which corresponded to an age of 77–108 B.P., given a sedimentation rate of 0.7 cm yr⁻¹ (Burnett et al. 1989). The presence of our carbonate layer (67–78 cm in our core) is assumed to be contemporaneous with the above core. This period of time is coincident with the end of the Little Ice Age (ca 1400–1900 AD; Cronin et al. 2003) when the climate had been cooler and drier but was becoming warmer and wetter (Orem et al. 1991, Gagan et al. 2000). During cooler and drier conditions, the sea-level would have been lower than today, possibly resulting in a lessening of the lake depth and a restriction of the mangrove growth around the lake (and thus its contribution to the organic matter in the lake sediments). A combination of these two factors may have promoted algal growth and encouraged benthic fauna such as foraminifers and bivalves. Macroalgal seagrass is well known to be the host plant of epifaunally living benthic foraminifers (e.g. Fujita & Hallock 1999). One of the dominant species, *Rosalina globularis*, is characterized by its plano-convex test morphology, which is now thought to be adapted well to an epifaunal, sessile habitat on rocky substrates and seagrasses, and is also suggested to be a passive herbivore which gathers food from around the site of attachment within the photic zone (Murray, 1991). According to culture study by Sliter (1965), *Rosalina globularis* grazes actively when food (diatoms) is scarce, but becomes a passive herbivore when diatoms are abundant. This is concordant with the fact that no diatoms were found in the calcareous layer in our core, but *Rosalina globularis* was abundant, particularly in the lower part of the calcareous layer (Table 1), together with a macroalgal growth signal (Orem et al. 1991). These suggest the dominance of *Rosalina globularis* in our samples was caused by the increase of host phytal substrates, macroalgal seagrass, in the lake during the Little Ice Age.

Systematic Paleontology

This section follows the classification scheme of Loeblich & Tappan (1987). All specimens illustrated here are lodged in the collection at the Institute of Geoscience, University of Tsukuba, Japan, with catalog numbers prefixed by IGUT.

Order FORAMINIFERIDA Eichwald 1830
Suborder ROTALIINA Delage & Hérouard 1896
Superfamily BOLIVINACEA Glaessner 1937
Family BOLIVINIDAE Glaessner 1937

Genus *Bolivina* d'Orbigny 1839*Bolivina* cf. *B. lutea* Sliter 1969

Pl. 1, Figs. 1, 2

Compared with:

Bolivina lutea Sliter 1969, p. 2, pl. 1, fig. 1, pl. 3, figs. 1–2, pl. 4, figs. 1–3; Sliter 1970, p. 160, pl. 2, figs. 4, 5, pl. 8, figs. 10, 11.

Material: IGUT13735 (Pl. 1, Figs. 1, 2) from 72–73 cm downcore.

Occurrence: Mecherchar Jellyfish Lake, Palau.

Remarks: The specimen treated here is characterized by having a test with distinctly raised ridges developed on the middle portion of the test and probably should be assigned to *Bolivina lutea*. However, it does not have irregular shaped later chambers, which tend to become centrally located as seen in typical full-grown specimens (Sliter 1970). The specimen examined here differs from *Bolivina pseudoplicata* Heron-Allen & Earland 1930 in showing non-reticulated ornamentation and from *Bolivina doniezi* Cushman & Wickenden 1929 and *Bolivina lepida* Sliter 1969 in having a test surface with a much coarser texture.

Bolivina striatula Cushman 1922

Pl. 1, Figs. 3, 4

Bolivina striatula Cushman 1922, p. 254, pl. 7, fig. 101; Boltovskoy et al. 1980, p. 18, pl. 3, figs. 9–13; Oki 1989, p. 111, pl. 10, figs. 3a–b; Hayward et al. 1999, p. 127, pl. 8, fig. 21.

Brizalina striatula (Cushman). Sliter 1970, p. 170, pl. 7, fig. 6, pl. 8, fig. 19; Hottinger et al. 1993, p. 112, figs. 3–8.

Brizalina striatula Cushman. Lipps & Langer 1999, pl. 1, figs. 10, 11.

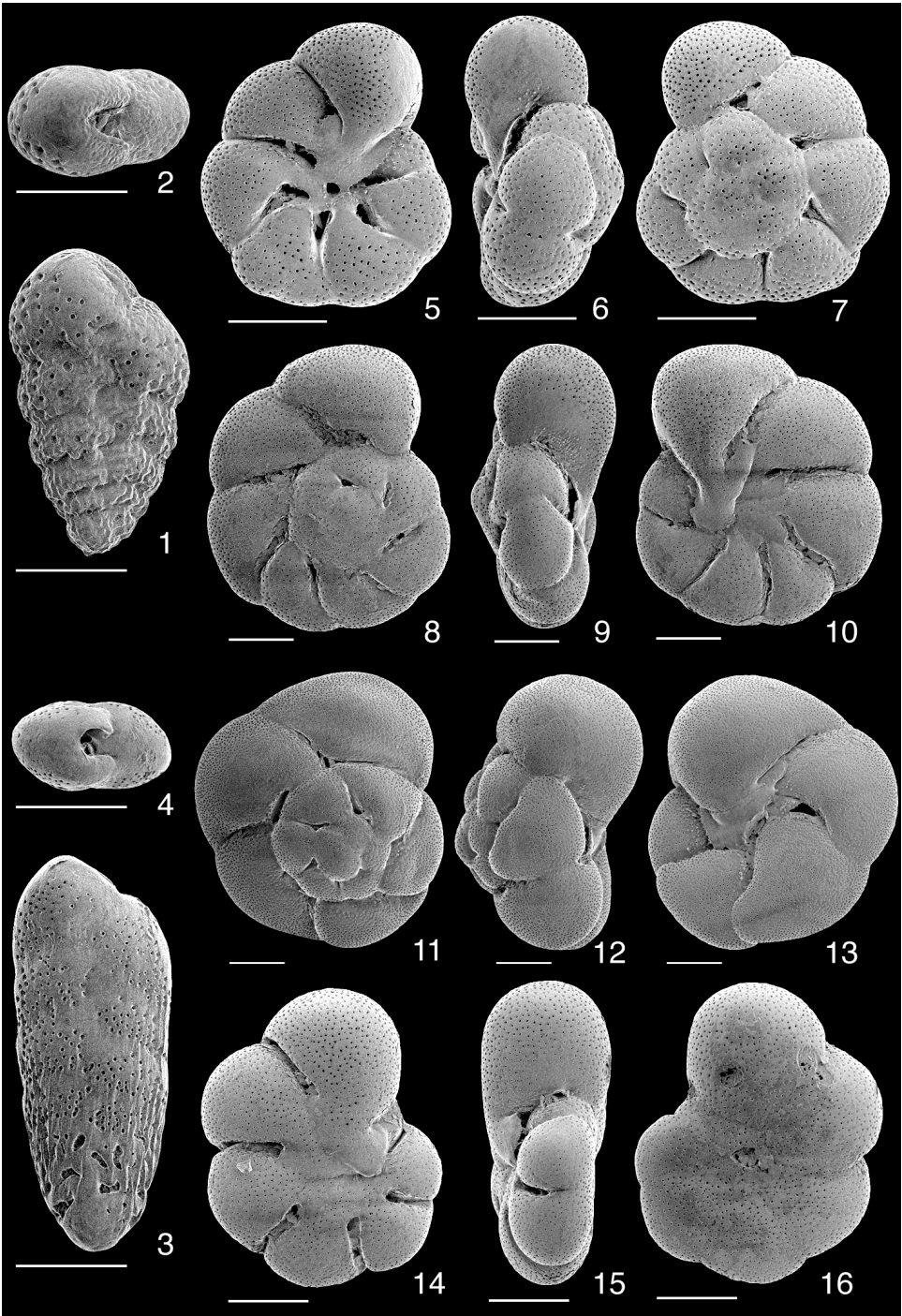
Material: IGUT13736 (Pl. 1, Figs. 3, 4) from 72–73 cm downcore.

Occurrence: Mecherchar Jellyfish Lake, Palau.

Remarks: The specimen treated here is characterized by a test with rather fine longitudinal striations over the earlier half of the test surface, which coalesce and become broad ridges in the earlier portion. This morphological feature compares well with those specimens from shallower marine environments around the world (see above list).

PLATE 1 (all scale bars = 50 µm)

1, 2. *Bolivina* cf. *lutea*, IGUT13735; 1 side view, 2 apertural view. 3, 4. *Bolivina striatula*, IGUT13736; 3 side view, 4 apertural view. 5–7. *Helenina* cf. *H. anderseni*, IGUT13738; 5 umbilical view, 6 apertural view, 7 spiral view. 8–10. *Helenina* cf. *H. anderseni*, IGUT13739; 8 spiral view, 9 apertural view, 10 umbilical view. 11–13. *Helenina* cf. *H. anderseni*, IGUT13740; 11 spiral view, 12 apertural view, 13 umbilical view. 14–16. *Acarotrochus lobulatus*, IGUT13739; 14 umbilical view, 15 apertural view, 16 spiral view.



Superfamily DISCORBACEA Ehrenberg 1838
 Family DISCORBIDAE Ehrenberg, 1838
 Genus *Acarotrochus* Kawagata, *in* Kawagata et al. 2005
Acarotrochus lobulatus Kawagata, *in* Kawagata et al. 2005
 Pl. 1, Figs. 14–16

Acarotrochus lobulatus Kawagata, *in* Kawagata et al. 2005, p. 47, pl. 1, figs. 1–18, pl.2, figs.1–7.

Material: IGUT13737 (Pl. 1, Figs. 14–16) from 77–78 cm down core.

Occurrence: Mecherchar Jellyfish Lake, Palau.

Remarks: This species was found as a new species from the intervals between 72 and 78 cm downcore (Kawagata et al. 2005), where a possible age of 100 years B.P. are suggested (see discussion). Kawagata et al. (*in press*) examined the internal and external morphologies and placed this species in the family Discorbidae on the basis of the nature of the foramenal plate.

Family HELENINIDAE Loeblich & Tappan 1987
 Genus *Helenina* Saunders 1961
Helenina cf. H. anderseni (Warren 1957)
 Pl. 1, Figs. 5–13

Compared with:

Pseudoeponides anderseni Warren 1957, p. 39, pl. 4, figs. 12–15; Parker & Athearn 1959, p. 341, pl. 50, figs. 28–31.

Helenia anderseni (Warren). Saunders 1957, p. 374; Todd & Low 1961, p. 18, text–fig. 2, figs. 2a, b; Todd & Low 1971, p. C15, pl. 3, fig. 1.

Helenina anderseni (Warren). Saunders 1961, p. 148; Scott & Medioli 1980, pl. 5, figs. 10, 11; Hayward & Hollis 1994, p. 213, pl. 3, figs. 1–3; Hayward et al. 1999, p. 138, pl. 10, figs. 1–3.

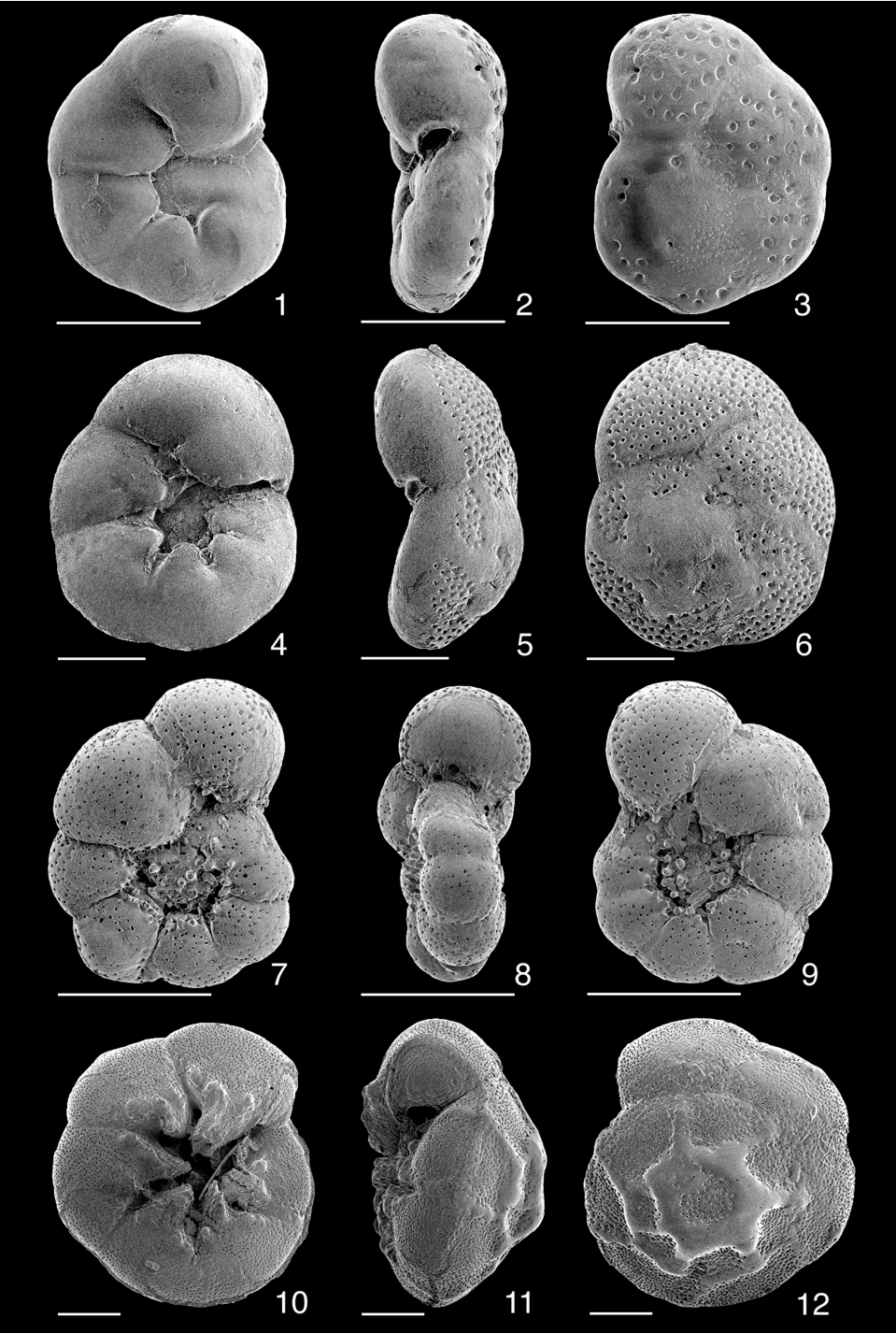
Helenina sp. 1. Lipps & Langer 1999, pl. 1, figs. 2, 5.

Material: IGUT13738 (Pl. 1, Figs. 5–7) from 77–78 cm downcore; IGUT13739 (Pl. 1, Figs. 8–10) from 75–76 cm downcore; IGUT13740 (Pl. 1, Figs. 11–13) from 77–78 cm downcore.

Occurrence: Mecherchar Jellyfish Lake, Palau.

PLATE 2 (all scale bars = 50 µm)

1–3. *Rosalina globularis*, juvenile, IGUT13739; 1 umbilical view, 2 apertural view, 3 spiral view.
 4–6. *Rosalina globularis*, IGUT14198; 4 umbilical view, 5 apertural view, 6 spiral view. 7–9. *Evolutononion mattagordanum*, IGUT14199; 7 side view, 8 apertural view, 9 opposite side view of fig. 7. 10–12. *Ammonia* sp.A, IGUT14200, 10 umbilical view, 11 apertural view, 12 spiral view.



Remarks: The specimens found in the Jellyfish Lake sediments are characterized by a lobulate test with somewhat globular chambers and depressed sutures, although the specimens cited above are characterized by a nearly circular outlined test with nearly flushed intercameral sutures, except for the supplementary umbilical sutural openings. The specimens treated here show variation in the number of chambers in the last coil, five (Pl. 1, Figs. 11–13) to seven (Pl. 2, Figs. 5–10), and in the degree of test convexity.

Family ROSALINIDAE Reiss 1963
 Genus *Rosalina* d'Orbigny 1826
Rosalina globularis d'Orbigny 1826
 Pl. 2, Figs. 1–6

Rosalina globularis d'Orbigny 1826, p. 271, pl. 13, figs. 1, 2; Loeblich & Tappan 1994, p. 140, pl. 286, figs. 7–15.
Discorbina globularis (d'Orbigny). Brady 1884, p. 643, pl. 86, figs. 13.
Discorbis globularis (d'Orbigny). Cushman 1931, p. 22, pl. 4, figs. 9a–c.
 ? *Rosalina* sp. Apthorpe 1980, pl. 26, fig. 5.

Material: IGUT14197 (Pl. 2, Figs. 1–3) from 76–77 cm downcore; IGUT14198 (Pl. 2, Figs. 4–6) from 73–74 cm downcore.

Occurrence: Mecherchar Jellyfish Lake, Palau.

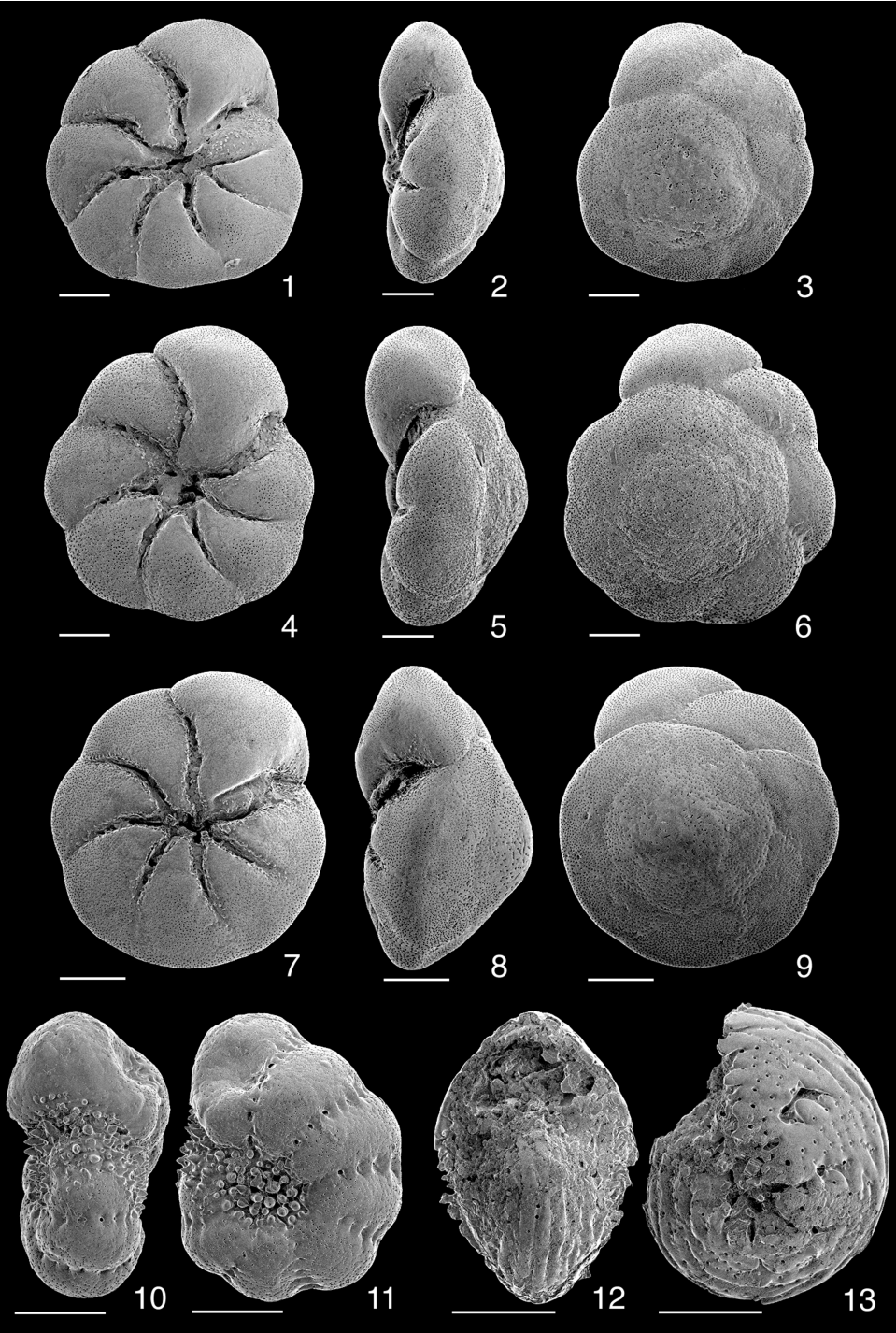
Remarks: The forms referred to as *Rosalina globularis* by Loeblich & Tappan (1994) are probably the same as those examined here, which are characterized by a low plano-convex test, which is coarsely punctated on the spiral side and lacks perforations on the lateral and umbilical sides.

Superfamily NONIONACEA Schultze 1854
 Family NONIONIDAE Schultze 1854
 Genus *Evolutononion* Wang 1964
Evolutononion mattagordanum (Kornfeld 1931)
 Pl. 2, Figs. 7–9

Nonion depressulum (Walker & Jacob), var. *mattagordanum* Kornfeld 1931 (*fide* Cushman & McCulloch 1940); Cushman & McCulloch 1940, p. 145, pl. 17, figs. 1a, b.

PLATE 3 (all scale bars = 50 µm)

1–3. *Ammonia* sp.B, IGUT14201; 1 umbilical view, 2 apertural view, 3 spiral view. 4–6. *Ammonia* sp.B, IGUT14202; 4 umbilical view, 5 apertural view, 6 spiral view. 7–9. *Ammonia* sp.B, IGUT14203; 7 umbilical view, 8 apertural view, 9 spiral view. 10, 11. *Elphidium oceanicum*, IGUT14204; 10 apertural view, 11 side view. 12, 13. *Elphidium sagrum*, IGUT14205; 12 apertural view, 13 side view.



Nonion depressula (Walker & Jacob), var. *mattagordana* Kornfeld. Phleger & Parker 1951, p. 11, pl. 5, fig. 17.

Elphidium matagordanum [sic] (Kornfeld). Sellier de Civrieux 1977, pl. 6, figs. 9, 10.

Evolutononion mattagordanum (Kornfeld). Kawagata 2001, p. 101, figs. 12–6a, b.

Material: IGUT14199 (Pl. 2, Figs. 7–9) from 72–73 cm downcore

Occurrence: Mecherchar Jellyfish Lake, Palau.

Remarks: This species has been placed by several authors in the genus *Nonion*, however, because of its advolute rather than involute chamber arrangement it should be retained in the genus *Evolutononion*.

Superfamily ROTALIACEA Ehrenberg 1839

Family ROTALIIDAE Ehrenberg 1838

Subfamily AMMONIINAE Saidova 1981

Genus *Ammonia* Brünnich 1772

***Ammonia* sp. A**

Pl. 2, Figs. 10–12

Material: IGUT14200 (Pl. 2, Figs. 10–12) from 68–69 cm downcore.

Occurrence: Mecherchar Jellyfish Lake, Palau.

Remarks: *Ammonia* sp. A is characterized by having a minute-sized test which shows strongly raised, limbate sutures on the convex spiral side, particularly in the earlier portion, and by the pointed folier extensions of the chamber with calcite beads on the umbilical side. It resembles the Recent *Ammonia* molecular types T4 (from Japan) and T5A (described as *Ammonia aoteana* from Australia and New Zealand) of Hayward et al. (2004) and *Ammonia convexa* (Collins 1958). However, it is distinguished from these molecular types and *A. convexa* by its smaller dimension of the test, lack of distinct umbilical plugs, and the fewer number of chambers per whorl.

***Ammonia* sp. B**

Pl. 3, Figs. 1–9

Material: IGUT14201 (Pl. 3, Figs. 1–3) from 77–78 cm downcore; IGUT14202 (Pl. 3, Figs. 4–6) from 77–78 cm downcore; IGUT14203 (Pl. 3, Figs. 7–9) from 77–78 cm downcore.

Occurrence: Mecherchar Jellyfish Lake, Palau.

Remarks: *Ammonia* sp. B is characterized by a smaller sized test with minute pustules on umbilical folia, but no secondary calcite on the test and umbilical plug. It resembles several inornate molecular types of *Ammonia* recognized by Hayward et al. (2004), but differs from them in being much more vaulted on the spiral side of the test, though the test convexity varies in the core samples (e.g. Pl. 3, Figs. 2, 5, 6).

Family ELPHIDIIDAE Galloway 1933
Subfamily ELPHIDIINAE Galloway 1933
Genus *Elphidium* de Montfort 1808
Elphidium oceanicum Cushman 1933
Pl. 3, Figs. 10, 11

Elphidium oceanicum Cushman 1933, p. 52, pl. 12, figs. 7a,b; Cushman 1939, p.59, pl. 16, fig. 23; Hayward et al. 1997, p. 88, pl. 15, figs. 1–5.

Polystomella sp. (?). Cushman 1924, p.49, pl. 16, fig. 5.

Material: IGUT14204 (Pl. 3, Figs. 10, 11) from 72–73 cm downcore.

Occurrence: Mecherchar Jellyfish Lake, Palau.

Remarks: According to Hayward et al. (1997), this species is distributed in the modern tropical Southwest Pacific (Samoa, Tonga and Fiji) and eastern Australasian region (Queensland, New South Wales, Victoria, Tasmania, and Lord Howe Island).

Elphidium sagrum (d’Orbigny 1839)
Pl. 3, Figs. 12, 13

Polystomella sagra d’Orbigny 1839, p. 55, pl. 6, figs. 19, 20.

Elphidium sagrum (d’Orbigny). Cushman 1930, p. 24, pl. 9, figs. 5, 6; Cushman 1939, p. 55, pl. 15, figs. 1–3.

Material: IGUT14205 (Pl. 3, Figs. 12, 13) from 72–73 cm downcore.

Occurrence: Mecherchar Jellyfish Lake, Palau.

Remarks: *Elphidium sagrum* is characterized by having a small, rounded test with distinct reticulation over the test surface, which extends nearly parallel to the periphery. *Elphidium schencki* of Hayward et al. (1997) resembles the species examined here, but differs in having less rounded sides, distinct retral processes and a number of tubercles within the umbilical part.

Acknowledgements

The authors would like to thank Hajime Kudoh (Yamagata University), who pushed the core tubes into the lake sediments during numerous dives to the lake bed. The manuscript has benefited from invaluable comments of two reviewers and the editor, Chris Lobban (University of Guam). This study was supported by a Grant-in-Aid from the Ministry of Education, Science and Culture of Japan (13304065) awarded to Professor Y. Hara (Dept. of Biology, Yamagata University), of which R.W. Jordan was a co-recipient.

References

- Apthorpe, M. 1980. Foraminiferal distribution in the estuarine Gippsland Lake System, Victoria. *Royal Society of Victoria Proceedings* 91: 207–232.
- Bermudez, P. J. 1935. Foraminiferos de la costa norte de Cuba. *Sociedad Cubana de Historia Natural, Memoir* 9: 1–204.
- Boltovskoy, E. G. Guissani, S. Watanabe & R. Wright. 1980. Atlas of Benthic Shelf Foraminifera of the Southwest Atlantic. Hague-Boston-London, Dr. W. Junk: 1–147.
- Boltovskoy, E. 1984. Foraminifera of mangrove swamps. *Physis*, section A 42: 1–9.
- Brady, H. B. 1884. Report on the foraminifera dredged by the H.M.S Challenger, during the years 1873–1876. Reports of the Scientific Results of the Voyage of H.M.S. Challenger, *Zoology* 9: 1–814.
- Brönnimann, P., J. E. Whittaker & L. Zaninetti. 1992. Brackish water foraminifera from mangrove sediments of south-western Viti Levu, Fiji Islands, South Pacific. *Revue de Paléobiologie* 11: 13–65.
- Burnett, W. C., W.M. Landing, B. Lyons & W. Orem. 1989. Jellyfish Lake, Palau, a model anoxic environment for geochemical studies. *EOS* 70: 776–778.
- Collins, A. C. 1958. Foraminifera. Great Barrier Reef Expedition 1928–29. *Scientific Reports, British Museum (Natural History)* 6: 335–437.
- Cronin, T. M., G. S. Dwyer, T. Kamiya, S. Schwede & D. A. Willard. 2003. Medieval Warm Period, Little Ice Age and 20th century temperature variability from Chesapeake Bay. *Global and Planetary Change* 36: 17–29.
- Culver, S. J. 1990. Benthic foraminifera of Puerto Rican mangrove-lagoon systems: potential for paleoenvironmental implications. *Palaos* 5: 34–51.
- Cushman, J. A. 1922. Shallow-water foraminifera of the Tortugas region. Publication of the Carnegie Institution of Washington 311, Department of Marine Biology 17: 1–85.
- Cushman, J. A. 1924. Samoan foraminifera. Publication of the Carnegie Institution of Washington 342, Department of Marine Biology 21: 1–75.
- Cushman, J. A. 1930. The foraminifera of the Atlantic Ocean. Part 7. Nonionidae, Camerinidae, Peneroplidae and Alveolinellidae. *Bulletin of the Smithsonian Institution, U.S. National Museum* 104: 1–79.
- Cushman, J. A. 1931. The foraminifera of the Atlantic Ocean. Part 8. Rotaliidae, Amphisteginidae, Calcarinidae, Cymbaloporettidae, Globorotaliidae, Anomalinidae, Planorbulinidae, Ruppertiidae and Homotremidae. *Bulletin of the Smithsonian Institution, U.S. National Museum* 104: 1–179.
- Cushman, J. A. 1933. The foraminifera of the tropical Pacific collections of the “Albatross,” 1899–1900, Part 2; Lagenidae to Alveolinellidae. *Bulletin of the Smithsonian Institution, U.S. National Museum* 161: 1–79.
- Cushman, J. A. 1939. A monograph of the foraminiferal family Nonionidae. *Geological Survey Professional Paper* 191: 1–100.
- Cushman, J. A. & I. McCulloch. 1940. Some Nonionidae in the collections of the Allan Hancock Foundation. *Allan Hancock Pacific Expedition* 6: 145–178.

- D'Orbigny, A. 1826. Tableau méthodique de la classe des Céphalopodes. Annales des Sciences Naturelles 1: 96–169.
- D'Orbigny, A. 1839. Foraminifères. Histoire physique, politique et naturelle de l'île de Cuba. Paris, Arthus Bertrand.
- Fujita, K. & P. Hallock. 1999. A comparison of phytal substrate preferences of *Archaias angulatus* and *Sorites orbiculus* in mixed macroalgal-seagrass beds in Florida Bay. Journal of Foraminiferal Research 29: 143–151.
- Gagan, M. K., L. K. Ayliffe, J. W. Beck, J. E. Cole, E. R. M. Druffel, R. B. Dunbar & D.P. Schrag. 2000. New views of tropical paleoclimates from corals. Quaternary Science Reviews 19: 45–64.
- Hallock, P. 1981. Production of carbonate sediments by selected large benthic foraminifera on two Pacific coral reefs. Journal of Sedimentary Petrology 51: 467–474.
- Hallock, P. 1984. Distribution of selected species of living algal symbiont-bearing foraminifera on two Pacific coral reefs. Journal of Foraminiferal Research 14: 250–261.
- Hamner, W. M., R. W. Gilmer & P. P. Hamner. 1982. The physical, chemical, and biological characteristics of a stratified, saline, sulfide lake in Palau. Limnology and Oceanography 27: 896–909.
- Hamner, W.M. & I.R. Hauri. 1981. Long-distance horizontal migrations of zooplankton (Scyphomedusae: *Mastigias*). Limnology and Oceanography 26: 414–423.
- Hara, Y., T. Horiguchi, N. Hanzawa, K. Ishida, A. Yokoyama, R. Hoshina, H. Kudoh, A. Ochi & M. Konno. 2002. The phylogeny of marine microalgae from Palau's marine lakes. Kaiyo Monthly 29: 19–26. [in Japanese]
- Hayward, B. W., H. R. Grenfell, C. M. Reid & K. A. Hayward. 1999. Recent New Zealand Shallow-water benthic foraminifera: Taxonomy, ecologic distribution, biogeography, and use in paleoenvironmental assessment. Institute of Geological and Nuclear Sciences Monograph 21: 1–258.
- Hayward, B. W. & C. J. Hollis. 1994. Brackish foraminifera in New Zealand: a taxonomic and ecologic review. Micropaleontology 40: 185–222.
- Hayward, B. W., C. J. Hollis & H. R. Grenfell. 1997. Recent Elphidiidae (Foraminiferida) of the South-west Pacific and Fossil Elphidiidae of New Zealand. Institute of Geological and Nuclear Sciences Monograph 16: 1–170.
- Hayward, B. W., M. Holzmann, H.R. Grenfell, J. Pawlowski & C.M. Triggs. 2004. Morphological distinction of molecular types in *Ammonia*—towards a taxonomic revision of the world's most community misidentified foraminifera. Marine Micropaleontology 50: 237–271.
- Hottinger, L., E. Halicz. & Z. Reiss. 1993. Recent Foraminiferida from the Gulf of Aqaba, Red Sea. Slovenska Akadenija Znanosti in Umetnosti, Ljubljana: 1–179.
- Kawagata, S. 2001. Late Neogene Benthic Foraminifera from Kume-jima Island, Central Ryukyu Islands, Southwestern Japan. Science Report, Institute of Geoscience, University of Tsukuba, Sec. B. 22: 61–123.

- Kawagata, S., M. Yamasaki & R. W. Jordan. 2005. *Acarotrochus lobulatus*, a new genus and species of shallow-water benthic foraminifer from Palau, north-west equatorial Pacific Ocean. *Journal of Foraminiferal Research* 35: 44–49.
- Langer, M. R., M. T. Silk & J. H. Lipps. 1997. Global ocean carbonate and carbon dioxide production: the role of reef foraminifera. *Journal of Foraminiferal Research* 27: 271–277.
- Lessard, R. H. 1980. Distribution patterns of intertidal and shallow-water foraminifera of the tropical Pacific Ocean. *Cushman Foundation Special Publication* 19: 40–58.
- Lipps, J. H. & M. R. Langer. 1999. Benthic foraminifera from the meromictic Mecherchar Jellyfish Lake, Palau (western Pacific). *Micropaleontology* 45: 278–284.
- Lobban, C. S. & M. Schefter. 1997. *Tropical Pacific Island Environments*. University of Guam Press, Mangilao, GU.
- Loeblich, A. R., Jr. & H. Tappan. 1987. *Foraminiferal Genera and Their Classification*. 2 vols, Van Nostrand Reinhold, New York, 1–1182.
- Loeblich, A. R., Jr. & H. Tappan. 1994. *Foraminifera of the Sahul Shelf and Timor Sea*. *Cushman Foundation for Foraminiferal Research Special Publication* 31: 1–661.
- Murray, J. W. 1991. *Ecology and Palaeoecology of Benthic Foraminifera*. Longman Scientific & Technical, England.
- Oki, K. 1989. Ecological analysis of benthic foraminifera in Kagoshima Bay, South Kyushu, Japan. *South Pacific Study* 10: 1–191.
- Orem, W. H., W. C. Burnett, W.M. Landing, W.B. Lyons & W. Showers. 1991. Jellyfish Lake, Palau: Early diagenesis of organic matter in sediments of an anoxic marine lake. *Limnology and Oceanography* 36: 526–543.
- Parker, F. L. & W. D. Athearn. 1959. Ecology of marsh foraminifera in Poponesset Bay, Massachusetts. *Journal of Paleontology* 33: 333–343.
- Phleger F. B. & F. L. Parker. 1951. Ecology of foraminifera, Northwest Gulf of Mexico, Part 2, Foraminiferal species. *Memoir of the Geological Society of America* 46: 1–64.
- Saunders, J. B. 1957. Emendation of the foraminiferal genus *Palmerinella* Bermúdez, 1934 and erection of the foraminiferal genus *Helenia*. *Journal of the Washington Academy of Sciences* 47: 370–374.
- Saunders, J. B. 1958. Recent foraminifera of mangrove swamps and river estuaries and their fossil counterparts in Trinidad. *Micropaleontology* 4: 79–82.
- Saunders, J. B. 1961. *Helenina* Saunders, new name for the foraminiferal genus *Helenia* Saunders, 1957, non *Helenia* Walcott, 1880. *Contributions from the Cushman Foundation for Foraminiferal Research* 12: 128.
- Scott D. B. & F. S. Medioli. 1980. Quantitative studies of marsh foraminiferal distribution in Nova Scotia: Implications for sealevel studies. *Cushman Foundation for Foraminiferal Research Special Publication* 17: 1–58.
- Sellier de Civrieux, J. M. 1977. Foraminiferos indicadores de comunicados bentonicas Recientes en Venezuela. Parte II: Ecología y distribución de los

- foraminiferos mas frecuentes de la plataforma continental en el parque nacional Mochima. Boletín del Instituto Oceanográfico, Universidad de Oriente 16: 3–62.
- Sliter, W. V. 1965. Laboratory experiments on the life cycle and ecological controls of *Rosalina globularis* d'Orbigny. Journal of Protozoology 12: 1–5.
- Sliter, W. V. 1969. Three inner-neritic Recent foraminifers from southern California. Paper of the Kansas University Paleontological Contributions 45: 1–5.
- Sliter, W. V. 1970. Inner-neritic Bolivinitidae from the eastern Pacific margin. Micropaleontology 16: 155–174.
- Todd, R. & D. Low. 1961. Near-shore foraminifera of Martha's Vineyard Island, Massachusetts. Contribution from the Cushman Foundation for Foraminiferal Research 12: 5–21.
- Todd, R. & D. Low. 1971. Foraminifera from the Bahama Bank West of Andros Island. Geological Survey Professional Paper 683-C: C1–C22.
- Venkateswaran, K., A. Shimada, A. Maruyama, T. Higashihara, H. Sakou & T. Maruyama. 1993. Microbial characteristics of Palau Jellyfish Lake. Canadian Journal of Microbiology 39: 506–512.
- Warren, A. D. 1957. Foraminifera of the Buras-Scofield Bayou region, southeast Louisiana. Contributions from the Cushman Foundation for Foraminiferal Research 8: 29–40.

Received 17 Jan. 2004, revised 27 Apr.