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Morphology of four *Miliolinella* species (Foraminifera, Protozoa) with description of a new species, *Miliolinella obesa* nov. spec., from the tropical West Pacific Ocean

LEI Yanli[1, 4, 5*], LI Tiegang[2, 3, 4*]

[1] Department of Marine Organism Taxonomy and Phylogeny, Institute of Oceanology, Chinese Academy of Sciences, Qingdao 266071, China

[2] Key Laboratory of Marine Sedimentology and Environmental Geology, the First Institute of Oceanography, State Oceanic Administration, Qingdao 266061, China

[3] Laboratory for Marine Geology, Pilot National Laboratory for Marine Science and Technology (Qingdao), Qingdao 266061, China

[4] Center for Ocean Mega-Science, Chinese Academy of Sciences, Qingdao 266071, China

[5] University of Chinese Academy of Sciences, Beijing 100049, China

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Abstract

Foraminiferal oozes were sampled from the tropical West Pacific seamount and seabed of deep sea, by a remotely operated vehicle (ROV) in December 2014 and March 2016. Using standard morphological method, four *Miliolinella* species, including *Miliolinella obesa*, *M. circularis*, *M. suborbicularis* and *M. subrotunda* were described. Among the four species, *M. obesa* is a new species. It is a large member (about 500 μm in length) of the genus. This species is characterized by having a very stout and transverse broadly circular outline, and its body width is greater than the body length. In addition, its chamber demarcations are obscure from the exterior appearance. Three chambers are unclearly visible on one side and two chambers are visible on the opposite. Finally, we provided very detailed taxonomic microphotographs and the ecological distribution information for each species.

Key words: deep sea, foraminifera, *Miliolinella*, seamount, seabed, West Pacific Ocean

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1 Introduction

Class Foraminifera Lee, 1990 was affiliated with the Phylum Granuloreticulosa Lee, 1990, Kingdom Protozoa (Goldfuss, 1818) von Siebold, 1845 (Cavalier-Smith, 1998). *Miliolinella* species is an important member of benthic porcelaneous foraminifera. The Genus *Miliolinella* was established by Wiesner (1931) and the type species is *Vermiculum subrotundum* Montagu, 1803. This genus has been variously interpreted, and species with a flaplike tooth, a long simple tooth, or without a tooth have been included therein. The specimen illustrated by Loeblich and Tappan (1964) has a distinct flaplike tooth and two chambers per whorls in a crypto-quinqueloculine arrangement, and closely resembles the original figures of *Vermiculum subrotundum* Montagu, 1803, which was described as having a "shell composed of three compartments".

In view of Loeblich and Tappan (1987), the species within *Miliolinella* is referred to the reinstated crypto-quinqueloculine *Triloculinella* Riccio arrangement. The early stage of *Miliolinella* species is in quinqueloculine arrangement. Later stage becomes planispiral style. Chambers are added alternately as in *Massilina* or may have slightly more than two chambers in the final whorl, from four or five to as many as seven chambers visible from the exterior. Till now, more than 50 species were described within this genus (Hayward et al., 2017).

In 2013, Chinese Academy of Sciences launched the Strategic Priority Research Program "Western Pacific deep-sea environment and ecosystem". The aim of this program is to obtain high resolution of environment parameters in the tropical West Pacific plain and typical seamount, in addition, to reveal characteristics of biodiversity and ecosystem structure in deep-sea environment. We sampled benthic foraminifera from the West Pacific seabed and seamount from 2014 to 2016. More than 300 benthic species were obtained, including four *Miliolinella* species. Due to great differences in habitats, most of them have been poorly known in the China seas. In this study we provide very detailed taxonomic and ecological information as well as high resolution of microphotographs to the science of the four *Miliolinella* species, and among them, *Miliolinella obesa* is a new member to the science.

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*Corresponding author, E-mail: leiyanli@qdio.ac.cn; tgli@fio.org.cn

2 Materials and methods

2.1 *Study sites and samplings*

Foraminiferal oozes were sampled by a remotely operated vehicle (ROV) in December 2014 and March 2016. *Miliolinella obesa* was collected from the West Pacific seamount (Sta. FXDive19) (8°51′N, 137°46′E) in 2014, where water depth was 311.00 m, temperature was 6.82°C, salinity was 35.58. *Miliolinella circularis* was collected from three stations of the tropical West Pacific seabed (Stas 64, 66 and 67) (11°18′–11°19′N, 139°18′–139°21′E) in 2016, where water depth was 20.50–575.00 m, temperature was 6.90–28.15°C, salinity was 16.74–34.73. *Miliolinella suborbicularis* and *M. subrotunda* were both collected from one station of the tropical West Pacific seabed (Sta. 66) (11°18′N, 139°21′E) in 2016, where water depth was 26.70–263.00 m, temperature was 16.15–28.15°C, salinity was 34.63–34.73.

2.2 *Sample treatment*

The sediments were fixed using 95% ethanol mixed with 1 g/L Rose Bengal in board such that live and dead specimens could be distinguished. In the laboratory, each sediment was dried in the oven below 50°C for 24 h and weighed. The sediments were soaked in water and were sieved through 63 μm and 150 μm meshes. The foraminiferal specimens were concentrated by an isopycnic separation technique using tetrachloromethane (D=1.59). For the ecological study, benthic foraminifera were counted in >150 μm size fraction. For the taxonomic study, foraminifera in both size fractions were observed.

2.3 *Taxonomy*

Foraminiferal specimens were isolated and mounted on slides, and were identified and enumerated under stereomicroscope Nikon SSZ1500, with continuous zooming to a maximum amplification of 225×. Specimens were studied and photographs were taken under the microscopes Nikon SSZ1500 and Nikon SMZ-25 (with continuous zooming to a maximum amplification of 315×). Size measurements were taken during photographing. Foraminifera were identified to species level based on relative literature. Foraminiferal classification systematics was based on those of Loeblich and Tappan (1987) and Lee et al. (2000), as to the genus- and the species- levels we also referred to Hayward et al. (2017).

3 Results

Order Miliolida Delage et Hérouard, 1896

Family Hauerinidae Schwager, 1876

Genus *Miliolinella* Wiesner, 1931

3.1 *Miliolinella obesa nov. spec. (Fig. 1, Table 1)*

Diagnosis. Size about 530 μm long, length:width ratio about 0.8:1. Test very stout, transverse broadly circular in outline. Body width greater than length. Transverse view transverse circular, width: thickness ratio about 1.4:1. Periphery rounded. Sutures somewhat indistinct, chambers more or less obscure, chamber demarcation unclearly looking from the exterior appearance. On one side three chambers indistinctly visible from the exterior, while two chambers on the opposite. Wall calcareous, imperforate, porcelaneous, surface smooth. Aperture an arch, terminal on the final chamber, with a small and low flap. Aperture width about 1/3 of the body thickness.

Etymology. The Latin adjective *obesus* (obese) refers to transverse broadly circular test shape, a typical feature of this species.

Type material. Holotype (IOCA WP115 Holotype) and one paratypes (IOCAS WP115 Paratype-01) are lodged in the Marine Biological Museum of Chinese Academy of Sciences (MBMCAS). In addition, one paratype specimen (IOCAS WP115 Paratype-02) is lodged in the Department of Marine Organism Taxonomy and Phylogeny, Institute of Oceanology, Chinese Academy of Sciences (IOCAS).

Type locality. The West Pacific seamount (Sta. FXDive19) (8°51′N, 137°46′E), water depth 311.00 m, temperature 6.82°C, salinity 35.58, abundance 0.59 ind./g sediment

Distribution. West Pacific seamount.

Description. Size 510–540 μm in length, on average about 530 μm long, length:width ratio about 0.8:1. Test very stout, transverse broadly circular in outline. Body width greater than length. Lateral view slightly compressed, transverse view transverse circular, width:thickness ratio about 1.4:1. Periphery rounded. Sutures somewhat indistinct, thus chambers more or less obscure, chamber demarcation sometime unclear looking from the exterior appearance.

Chamber rather obese, sometimes the aperture was slightly shielded by the inflated chamber in frontal and dorsal view. On one side three chambers indistinctly visible from the exterior, while two chambers on the opposite. Wall calcareous, imperforate, porcelaneous, surface fine and smooth. Aperture an arch, terminal on the final chamber, with a flap. The flap small and low, somewhat oblique. Aperture small, width about 1/3 of the body thickness.

3.2 *Miliolinella circularis (Bornemann, 1855) (Fig. 2, Table 1)*

Triloculina circularis Bornemann, 1855, p. 349, Pl. 19, Fig. 4; Cushman, 1917, p. 67, Pl. 25, Fig. 4; 1921, p. 462, Pl. 92, Figs 1, 2; Natland, 1950, p. 11, Pl. 3, Figs 14a–c.

Miliolinella circularis (Bornemann), Asano, 1951, p. 9, Figs 65–67; 1956, p. 71, Pl. 8, Figs 4, 8; Matsunaga, 1963, p. 30, Fig. 3; Chiji and Lopez, 1968, p. 108, Pl. 10, Fig. 5; Matoba, 1970, p. 56, Pl. 3, Fig. 5; van Voorthuysen, 1973, p. 53, Pl. 8, Fig. 11; Hubei Institute of Geosciences, 1978, p. 61, Pl. 14, Fig. 11; Poag, 1981, p. 72, Pl. 59, Fig. 3, pl. 60, Fig. 3; Zheng, 1988, p. 249, Pl. XX, Figs 8, 9, pl. XXXIII, Fig. 10; Yassini and Jones, 1995, p. 87, Figs 227–228, 231; Parker, 2009, p. 120, Figs 85a–c; Debenay, 2012, p. 109, 275.

Occurrence and ecology. Tropical West Pacific seabed (Stas 64, 66 and 67) (11°18′–11°19′N, 139°18′–139°21′E), water depth 20.50–575.00 m, temperature 6.90–28.15°C, salinity 16.74–34.73, abundance 2.60–6.02 ind./g sediment.

Distribution. Tropical West Pacific seabed, Bohai Sea, East China Sea, South China Sea, Celtic Sea, English Channel, Japan, Maldives, Micronesia, North Atlantic Ocean, South Korea, United States, Southwest Pacific (New Caledonia), Vineyard Sound, Gulf of Mexico.

Description. Size about 320 μm in length and 310 μm in width, length:width ratio about 1.0:1. Frontal view broadly rotund in outline, body width similar to the length. Lateral view compressed, body width:thickness about 1.4:1, transverse section elliptical. Early stage quinqueloculine, later planispiral. Chambers added alternately as in *Massilina* and three chambers visible in the final whorl. Sutures distinct. Periphery smooth and rounded. Wall calcareous, imperforate, porcelaneous, surface fine and smooth. Aperture an open arch, terminal on the final chamber, with a broad and low apertural flap. Aperture width about 1/2 of body thickness.

3.3 *Miliolinella suborbicularis (d'Orbigny, 1839) (Fig. 2, Table 1)*

Triloculina suborbicularis d'Orbigny, 1839, p. 177, Pl. 10, Figs 9–11; Asano, 1951, p. 16, Figs 108, 109.

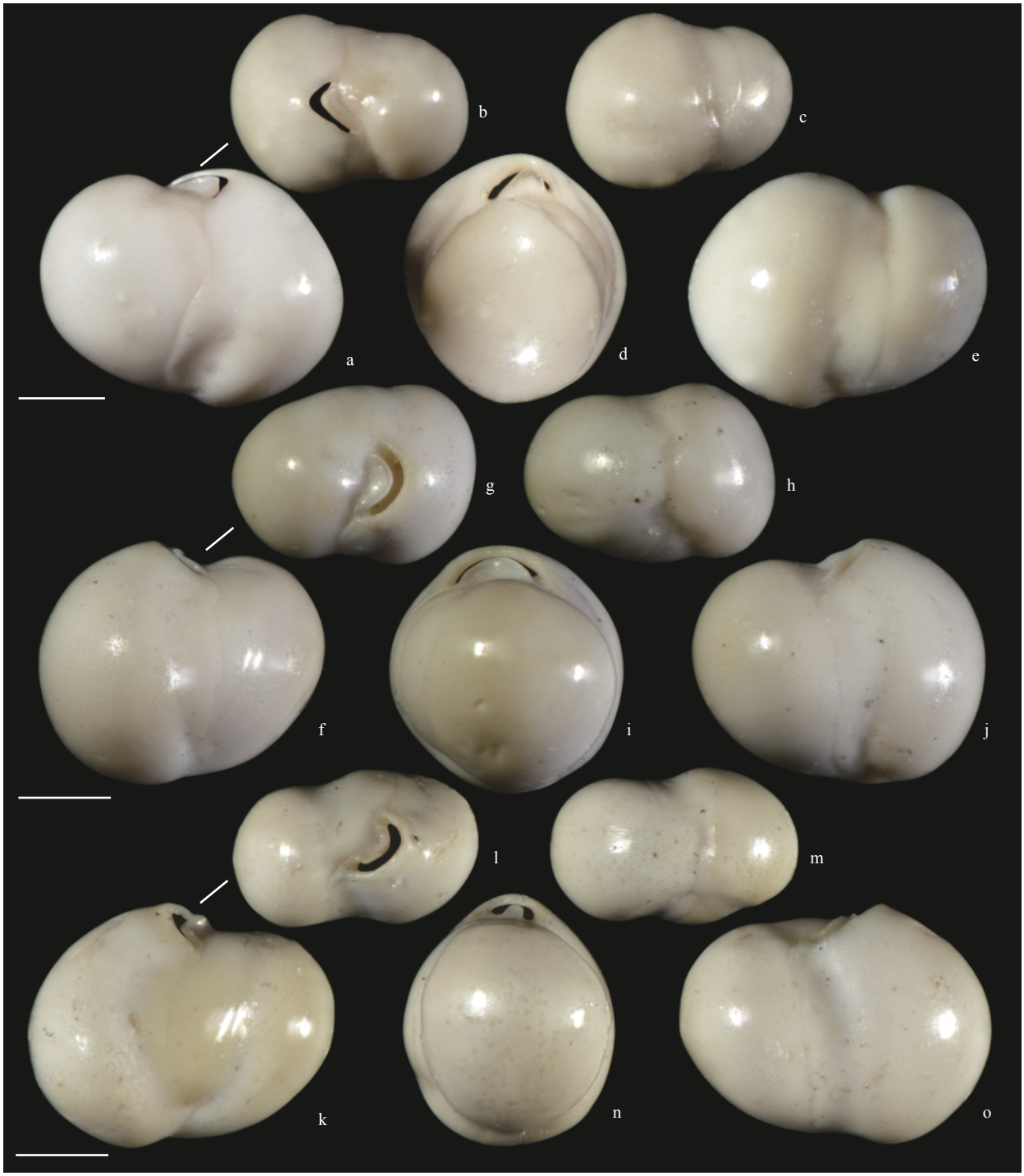

Fig. 1. Micrographs of *Miliolinella obesa* nov. spec., three specimens showing morphological variabilities. a–e. The holotype specimen with frontal (a), apical (b), antapical (c), lateral (d) and reverse (e) views. f–j. The paratypes-01 specimen with frontal (f), apical (g), antapical (h), lateral (i) and reverse (j) views. k–o. The paratypes-02 specimen with frontal (k), apical (l), antapical (m), lateral (n) and reverse (o) views. Scale bars: 200 μm.

Quinqueloculina suborbicularis d'Orbigny, Schlumberger, 1893 (non *Quinqueloculina suborbicularis* d'Orbigny in Fornasini, 1905, p. 67, Pl. 4, Fig. 3), p. 73, Pl. 2, Figs 63, 64, Pl. 3, Fig. 67.

Miliolina suborbicularis (d'Orbigny), Millett, 1898, p. 502, Pl. 11, Fig. 13.

Miliolinella sp. Graham and Militante, 1959, p. 38, Pl. 9, Figs 3, 4.

Miliolinella suborbicularis (d'Orbigny), Ponder, 1974, p. 200, text Fig. 3; Loeblich and Tappan, 1994, p. 52, Pl. 89, Figs 1–9, Pl. 96, Figs 11–16.

Occurrence and ecology. Tropical West Pacific seabed (Sta. 66) (11°18′N, 139°21′E), water depth 26.70–263.00 m, temperature 16.15–28.15°C, salinity 34.63–34.73, abundance 0.13 ind./g sediment.

Table 1. Morphometric characterization of *Miliolinella obesa* nov. spec., *M. circularis*, *M. suborbicularis* and *M. subrotunda*

Species	Body length/μm	Body width/μm	Body thickness/μm
Miliolinella obesa nov. spec.	541	683	498
	529	628	500
	510	631	438
Mean	527	647	479
Miliolinella circularis	328	343	247
	381	355	242
	247	232	199
Mean	319	310	229
Miliolinella suborbicularis	429	381	309
	493	427	293
Mean	461	404	301
Miliolinella subrotunda	367	343	259

Distribution. Tropical West Pacific seabed, South China Sea, Sahul Shelf and Timor Sea (Austria), Indian Ocean, Japan, North Atlantic Ocean, North Pacific Ocean, United States, Gulf of Mexico.

Description. Size about 460 μm in length and 400 μm in width, length:width ratio about 1.1:1. Frontal view ovate in outline, body width similar to the length. Lateral view compressed, body width: thickness about 1.3:1, transverse section elliptical. Early stage quinqueloculine, later planispiral. Chambers added alternately as in *Massilina* and three chambers visible in the final whorl. Sutures rather distinct. Periphery smooth and rounded. Wall calcareous, imperforate, porcelaneous, thin, surface with longitudinal striae or grooves. Aperture an open arch, terminal on the final chamber, with a broad and low apertural flap. Aperture width about 1/2 of body thickness, lip distinct.

3.4 *Miliolinella subrotunda* (Montagu, 1803) (Fig. 2, Table 1)

Vermiculum subrotundum Montagu, 1803, p. 521, Pl. 1, Fig. 4.

Miliolinella subrotunda (Montagu), Loeblich and Tappan, 1964, p. C466, Figs 355, No. 1; Murray, 1971, p. 73, Pl. 28, Figs 5, 6; Haynes, 1973, p. 56, Pl. 5, Figs 5, 6, 12, 13, Pl. 31, Figs 8, 9; Ponder, 1974, p. 201, Pl. 1, Figs 1, 2, Pl. 2, Figs 6–11; Haake, 1975, p. 39, Pl. 5, Figs 94–97; Hao et al., 1980, p. 61, Pl. 11, Figs 2, 3; Loeblich and Tappan, 1987, p. 340, Pl. 350, Figs 1–12; Zheng, 1988, p. 252, Pl. XXI, Fig. 5; Cimerman and Langer, 1991, p. 42, Pl. 38, Figs 4–9; Schiebel, 1992, p. 28, Pl. 5, Fig. 1; Jones, 1994, p. 20, Pl. 4, Fig. 3; Murray, 2003, p. 15, Fig. 4, No. 6; Debenay et al., 2005, p. 334, Pl. 2,Fig. 8; Rasmussen, 2005, p. 64, Pl. 4, Fig. 15; Figueroa et al., 2006, p. 269, Figs 37a–c; Parker, 2009, p. 124, Figs 88a–j, 89a–g; van Hengstum et al., 2009, Pl. 1, Figs F5, M5; Avşar et al., 2009, p. 134, Pl. 1, Figs 22, 23; Milker et al., 2009, p. 215, Pl. 1, Fig. 18; Milker and Schmiedl, 2012, p. 63, Figs 16.31–32; Debenay, 2012, p. 110, 275.

Occurrence and ecology. Tropical West Pacific seabed (Sta. 66) (11°18′N, 139°21′E), water depth 26.70–263.00 m, temperature 16.15–28.15°C, salinity 34.63–34.73, abundance 0.07 ind./g sediment.

Distribution. Tropical West Pacific seabed, Bohai Sea, East China Sea, South China Sea, Bay of Biscay, Canada, Celtic Sea, English Channel, Gulf of Saint Lawrence, Irish Sea and Sta. George's Channel, Japan, New Zealand, North Atlantic Ocean, Norway, Sea of Marmara, South Korea, United States, Southwest Pacific (New Caledonia), Scotian Shelf, Northwest Weddell Sea, Black Sea, Gulf of Mexico, Mediterranean Sea.

Description. Size about 370 μm in length and 340 μm in width, length:width ratio about 1.1:1. Frontal view ovate in outline, body width similar to the length. Lateral view compressed, body width:thickness about 1.3:1, transverse section somewhat triangular. Early stage quinqueloculine, later planispiral. Chambers added alternately as in *Massilina* and four chambers visible in the final whorl, some chambers more or less angular in outline. Sutures rather distinct. Periphery smooth and rounded. Wall calcareous, imperforate, porcelaneous, thin, surface smooth. Aperture an arch, nearly closed, terminal on the final chamber, with a broad and low apertural flap. Aperture width about 1/2 of body thickness.

4 Discussion

The Genus *Miliolinella* contains more than 50 valid species according to Hayward et al. (2017). The new species, *Miliolinella obesa,* is easily distinguished from most congeners by having a very stout and transverse circular test outline and having a small aperture (only about 1/3 of the test thickness); in addition, its chamber demarcations are obscure from the exterior appearance. At the first glance, *M. obesa* is easily to be confused with *Biloculinella* species if it is not carefully observed. However, the different aperture feature and chamber arrangement differ this species from all the *Biloculinella* species. *Miliolinella obesa* is somewhat similar to *M. labiosa* and *M. subrotunda* in frontal view, but differs from the obscure chamber boundary and very broad transverse view.

Miliolinella circularis was sampled from three stations of the tropical West Pacific seabed. This species has been report from the modern sediment of East China Sea (Zheng, 1988) and the Tertiary sediment of South China Sea (Hubei Institute of Geosciences, 1978). Our specimen matched well in the main taxonomic features of the test shape, the aperture character and the chamber arrangement of Southwest Pacific population (Debenay, 2012) and East China Sea population. It usually occurred in the Pacific Ocean and the Atlantic Ocean.

Miliolinella suborbicularis was sampled from the tropical West Pacific seabed. It is a very distinct species because its test wall has many longitudinal striae or grooves. Thus it is very easy to be distinguished from most of the other congeners (Loeblich and Tappan, 1994). *Miliolinella webbiana* also has longitudinal striae, but has a slightly twisted test and triangular cross section, thus is different from each other (Debenay, 2012).

Miliolinella subrotunda was sampled from the tropical West Pacific seabed. This species has been reported from many studies (e.g., Hao et al., 1980; Zheng, 1988; Figueroa et al., 2006) and diverse geographical locations (see Distribution Part). Our West Pacific specimens matched most of the taxonomic features described by other reports (Hengstum et al., 2009; Milker and Schmiedl, 2012; Debenay, 2012), but slightly differs by having a more triangularly body shape. Whether this difference was caused by special environmental habitat is waiting for further studies to reconfirm.

Miliolinella obesa was discovered only from the seamount of tropical West Pacific region but not from the other stations in several time samplings of our cruise. It might be an endemic species of the seamount habitat. The other three Miliolinella species were sampled from several stations of the West Pacific seabed area. They have been described several times by previous studies from diverse geological areas (see Distribution Part). Likely, the three known Miliolinella species have a widely ecosphere distribution pattern than the new species.

Fig. 2. Micrographs of *Miliolinella circularis* (a–h), *M. suborbicularis* (i–p) and *M. subrotunda* (q–v). a–e. The same specimen of *M. circularis* showing different side of views, f–h. another specimen of *M. circularis*, i–m. the same specimen of *M. suborbicularis*, n–p. another specimen of *M. suborbicularis*, and q–v. the same specimen of *M. subrotunda*. a, f, i, n and q. Frontal views; b, j and r. apical views; c, k and t. antapical views; d, h, l, p, s and u. lateral views; and e, g, m, o and v. reverse views. Scale bars: 100 μm.

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