

Five newly recorded foraminifera from off the southern coast of Jeju Island, Korea

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In this study, we briefly describe five newly recorded foraminiferal species from off the southern coast of Jeju Island: *Ammolagena clavata*, *Neoepionides bradyi*, *Nodosaria lamnulifera*, *Rhabdammina abyssorum*, and *Uvigerina schwageri*. *Ammolagena clavata* and *Rhabdammina abyssorum* are the first reports of the genera *Ammolagena* and *Rhabdammina* in Korea. In addition, *R. abyssorum* is reported from a depth of 103 m, which is a relatively shallow record within the distribution depth range for this agglutinated deep-sea species. *Ammolagena clavata* also shows interesting characteristics that the test usually attaches to substrates including shell fragments, sediment particles, or other foraminiferal tests. All other three species have typical calcareous and hyaline tests. The present report on unrecorded species improves the understanding of foraminiferal species diversity in Korean waters and confirms the need for the further research on foraminifera in the adjacent seas of Korea.

Keywords: benthic foraminifera, East China Sea, unrecorded species, protists

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INTRODUCTION

Foraminifera are unicellular eukaryotes usually with calcareous or agglutinated tests, distributed in diverse marine environments (Sen Gupta, 2003; Murray, 2006). Since foraminifera are one of the dominant organisms in the benthic environments, and exhibit wide range of feeding mechanisms, they are regarded as one of the key groups in the marine food web (Gooday *et al.*, 1992; Moodley *et al.*, 2000; Debenay, 2012; Chronopoulou *et al.*, 2019). Foraminifera are one of the most sensitive organisms to environmental change and their assemblage is closely related to environmental factors (Murray, 2006; Sabbatini *et al.*, 2012). Therefore, research on diversity and community structure of foraminifera is important for understanding the marine environment (Annin, 2001; Albani *et al.*, 2007). To date, 8,857 species of marine extant foraminifera have been reported worldwide (WoRMS, 2020) and 1,192 species have been reported in Korea (NIBR, 2020). Since the 1,192 species include some of fossil species and synonyms, a clear understanding of species diversity of modern foraminifera in Korea is necessary. In this regard, Kim *et al.* (2016) documented 818 extant benthic species through a literature survey and emphasized the high possibility of additional discoveries

of unrecorded species through further investigations. Indeed, in 2017, 30 unrecorded species were reported from the western and eastern coasts of Korea (Lee *et al.*, 2017), and in 2019, one new species and three newly recorded species were reported from the northern East Sea and southern Jeju Island (Lee and Lee, 2019; Lee *et al.*, 2019). In the present study, we report five unrecorded species discovered from off the southern coast of Jeju Island, with brief diagnosis and photomicrographs.

MATERIALS AND METHODS

The newly recorded foraminifera were discovered in the bottom sediment samples from a cruise (R/V Saedongbaek, Chonnam National University) conducted from August 5 to 8 off the southern coast of Jeju Island, East China Sea (Table 1). The samples were collected using a Smith-McIntyre grab sampler. Immediately after the collection, sediments of 0–1 cm in the surface layer were directly sieved through 125 µm mesh using the sea water from each collection site. Sieved sediments were stored with filtered natural sea water from the collection site in 250 mL bottles. The bottles were kept in a cool box and air was continuously provided with a portable aerator un-

Table 1. Information on the sample collection sites.

Station	Latitude (N)	Longitude (E)	Depth (m)
6	33°00'	126°30'	103
7	33°00'	127°00'	103
10	32°30'	127°00'	118

til transported to the laboratory.

For the morphological analysis, samples were examined using a stereomicroscope (Olympus SZ40) and foraminifera were picked using a fine brush. Isolated specimens were moved to micropaleontology slides and dried at room temperature. Selected specimens were photographed at multiple foci using a digital camera (Olympus PEN Lite E-PL3) attached to a stereomicroscope (Olympus SZX12) and the focus stacking was done using Helicon Focus 7.6.4. software (Helicon soft). Scanning electron microscope (SEM) analysis was performed using COXEM EM-30 SEM. Specimens selected for the SEM examination were mounted on a stub with carbon tape attached, and coated with Au under 4 mA, 220 s in a COX-EM Ion Coater SPT-20. Taxonomic identification was carried out based on relevant references, including Cushman (1910; 1913; 1918; 1921), Ellis and Messina (1940), Loeblich and Tappan (1987; 1994), Jones (1994), Szarek (2001), and Hayward *et al.* (2010). A systematic classification and distribution survey were carried out by referring to following references: Loeblich and Tappan (1987), Kaminski (2014), WoRMS (2020). Examined specimens were transferred to micropaleontology slides and deposited in the Marine Foraminifera Resources Bank of Korea (MFORBK) in department of Life Science, College of Natural Science, Hanyang University and National Institute of Biological Resources (NIBR).

SYSTEMATICS

Phylum Foraminifera d'Orbigny, 1826
 Class Monothalamea Haeckel, 1862
 Order Astrorhizida Lankester, 1885
 Family Rhabdamminidae Brady, 1884
 Genus *Rhabdammina* Sars in Carpenter, 1869

1. *Rhabdammina abyssorum* Sars in Carpenter, 1869 (Plate 1, fig. 1)

Rhabdammina abyssorum Sars in Carpenter, 1869, p. 60; Goës, 1894, p. 19, pl. 4, figs. 67–68; Cushman, 1910, p. 24, text figs. 8–10; 1918, p. 15, pl. 6, fig. 1; pl. 7, fig. 1; Höglund, 1947, p. 25, pl. 1, fig. 2; Jones, 1994, p. 32, pl. 21, figs. 1–8, 10–13; Zheng and Fu, 2001, p. 220, pl. 113, figs. 3–5.

Material examined. Korea, off southern coast of Jeju, St. 7, 33°00'00"N, 127°00'00"E, 5 Aug 2019, by Smith-McIntyre grab, collected by Nayeon Park and Somjin Lee. NIBR ID: NIBRPR0000110833, MFORBK ID: MFORBK K00287.

Diagnosis. Test is large, free and consists of a central globular chamber and three radiating straight, tubular chambers with nearly uniform diameter. Three tubular chambers are on the same plane, and their ends are open to form apertures. Sutures are not distinct because of the attached sediment grains on test surface. Wall is agglutinated with fine to coarse sediment particles and surface is rough. Aperture is multiple, simple rounded, at the terminal of each tubular chamber. Test length is about 5 mm including tubular chambers.

Remarks. This species is the type species of the genus *Rhabdammina*, and this is the first record of the genus in Korea. There are 25 recent species belonging to the genus *Rhabdammina*, and the present species is quite similar to *R. linearis* in that it has the central globular chamber with tubular chambers. However, *R. linearis* has only two tubular chambers extending in opposite directions while *R. abyssorum* has more than three radiating chambers. According to previous reports, the genus *Rhabdammina* is related to low temperature and deep water depth. The depth of the type locality of *R. abyssorum* is 823.5 m (450 fathom) and has been reported from deep waters worldwide: from 130–3220 m in the North Pacific Ocean (Cushman, 1910; Zheng and Fu, 2001), 150–3742 m in the Atlantic Ocean (Cushman, 1918), 48–3171 m in the Laptev Sea (Lukina, 2001), and 71.1–386 m from the Turkish coasts of the east Aegean Sea (Meriç *et al.*, 2004). The present Korean specimen was collected at a depth of 103 m, which is quite shallow, but within the previously reported distribution depth range. This species can have more than three tubular chambers, and the color and grain size vary depending on the materials composing the test (Brady, 1884; Cushman, 1910; Loeblich and Tappan, 1987). Particularly, referred to Cushman (1910; 1918), the materials composing the test wall depend to the bottom sediment condition, and specimens from shallower depth tend to be composed of coarse sediment grains. The present specimen is composed of relatively coarser particles than those reported in other regions. The shallow water specimen reported from the coast of Japan by Cushman (1910) is also composed of coarse granules.

Distribution. Korea, China, Japan, New Zealand, Sea of Marmara, Bay of Biscay, Aegean Sea, Turkey, Norway, Gulf of Saint Lawrence, United States, Cuba, Laptev Sea.

Class Tubothalamea Pawlowski,
 Holzman & Tyszk, 2013
 Order Ammodiscida Mikhalevich, 1980

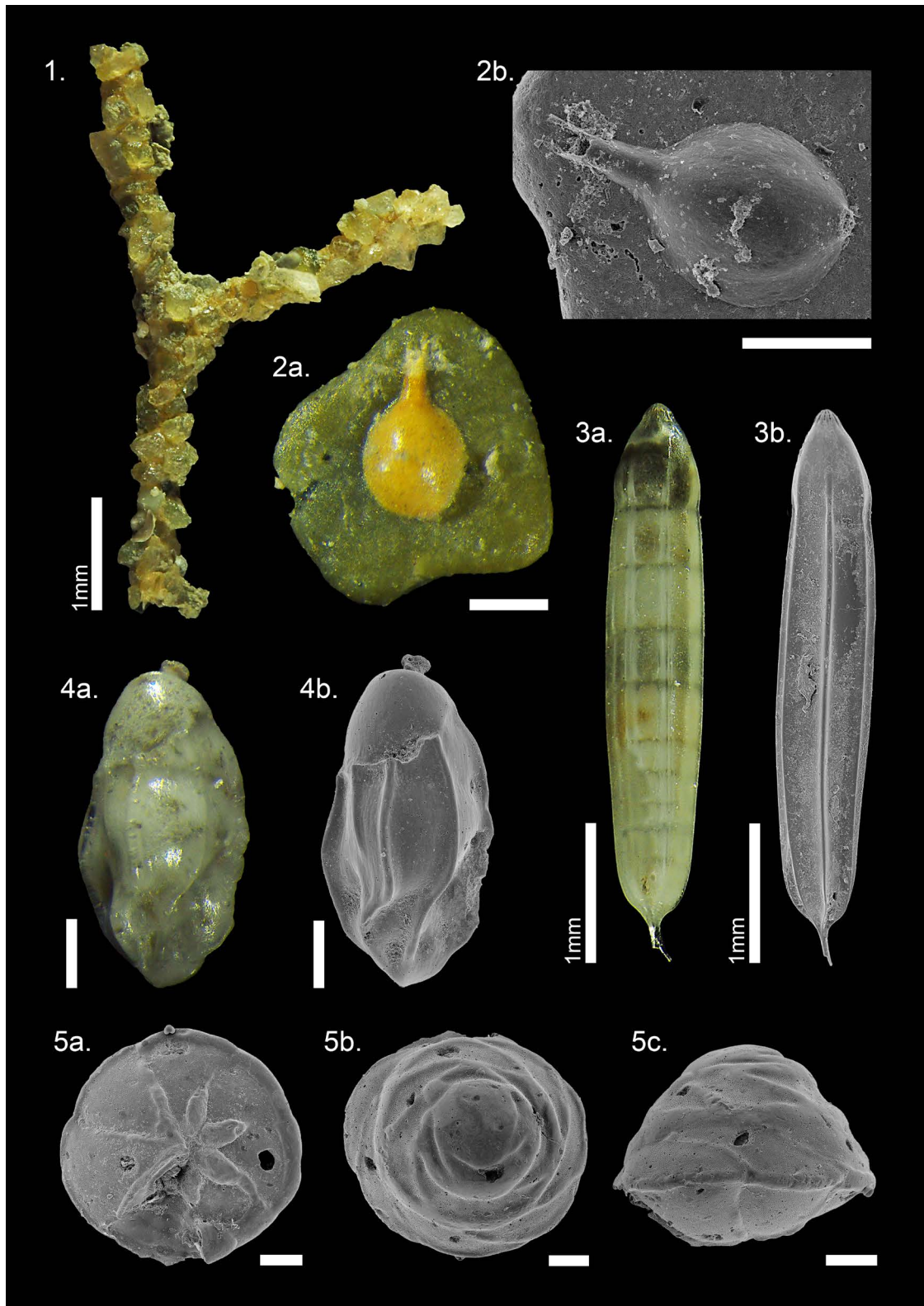


Plate 1. Photomicrograph and SEM image of the newly recorded species. 1. *Rhabdammina abyssorum* Sars in Carpenter, 1869; side view. 2. (a–b) *Ammolagena clavata* (Jones & Parker, 1860); 2a. Side view; 2b. Side view SEM image; scales: 200 μm . 3. (a–b) *Nodosaria lamnifera* Boomgaard, 1950; 3a. Side view; 3b. Side view SEM image. 4. *Uvigerina schwageri* Brady, 1884; 4a. Side view; 4b. Side view SEM image; scales: 200 μm . 5. (a–c) *Neoepionides bradyi* (Le Calvez, 1974); SEM image; 5a. Ventral side view; 5b. Spiral side view; 5c. Lateral side view; scales: 200 μm .

Family Ammolagenidae Kaminski, Henderson,
Cetean & Waśkowska, 2009
Genus *Ammolagena* Eimer & Fickert, 1899

**2. *Ammolagena clavata* (Jones & Parker, 1860)
(Plate 1, fig. 2a–b)**

Trochammina irregularis var. *clavata* Jones and Parker,
1860.

Webbina clavata: Brady, 1884, p. 349, pl. 41, figs. 12–
16; Wright, 1891, p. 470, pl. 20, figs. 2–3; Goës, 1894,
p. 32, pl. 6, figs. 245–246.

Ammolagena clavata: Eimer and Fickert, 1839, p. 673;
Cushman, 1910, p. 68, text figs. 86–88; 1918, p. 89, pl.
34, figs. 2–5; pl. 35, figs. 1–3; 1921, p. 61, pl. 6, figs.
1–4; pl. 10, figs. 3–4; Jones, 1994, p. 46, pl. 41, figs.
12–16; Loeblich and Tappan, 1994, p. 14, pl. 4, figs.
1–4; Szarek, 2001, p. 78, pl. 2, fig. 9; Debenay, 2012, p.
75; Hayward *et al.*, 2010, p. 130, pl. 2, figs. 13–14.

Material examined. Korea, off southern coast of Jeju,
St. 7, 33°00'00"N, 127°00'00"E, 5 Aug 2019, by Smith-
McIntyre grab, collected by Nayeon Park and Somin Lee.
NIBR ID: NIBRPR0000110834, MFORBK ID: MFORB
K00332.

Diagnosis. Test consists of a large, oval proloculus and
narrow tubular rectilinear second chamber, and attached
to substrate such as shell fragments, sediment particles,
or other foraminiferal tests. Wall is finely agglutinated,
and surface is smooth, glossy and yellowish-brown in
color. Primary aperture is simple, round, and at the end
of tubular chamber. Secondary aperture is at the basal
end of proloculus and surrounded by slight lip. Test
length is about 270 µm, width is about 42 µm including
the tubular second chamber.

Remarks. This species is the type species of genus *Am-
molagena*, and this is the first report of the genus in Ko-
rea. *Ammolagena clavata* was originally described as a
variety of *Trochammina irregularis* by Jones and Parker
(1860), and later Eimer and Fickert (1839) added the spe-
cies into the genus *Ammolagena*. There are three species
belonging to the genus *Ammolagena* and the present spe-
cies differs from the others in terms of its larger size, less
slender, inflated, rounded shape, and much finer particles
composing the wall. According to Kaminski and Grad-
stein (2005), the definition of this species and the genus
Ammolagena needs to be amended to consider the pres-
ence of a secondary aperture at the basal end. There is no
report about the supplementary aperture in the descrip-
tions by Loeblich and Tappan (1987), and the original
description by Jones and Parker (1860). However, spec-
imens reported by other researchers often have the sec-
ondary aperture at the base (Wright, 1891). The present
specimen also has a secondary aperture at the basal end.
The length of the tubular chamber differs from individual

to individual. The present specimen has a short tubular
chamber, and most similar to the specimen reported by
Wright (1891).

Distribution. Korea, China, Japan, New Caledonia, New
Zealand, Aegean Sea, Bay of Biscay, Mediterranean Sea,
Celtic Sea, Norway, United States.

Class Nodosariata Mikhalevich, 1992

Order Nodosariida Calkins, 1926

Family Nodosariidae Ehrenberg, 1838

Genus *Nodosaria* Lamarck, 1816

**3. *Nodosaria lamnulifera* Boomgaard, 1950
(Plate 1, fig. 3a–b)**

Nodosaria bradyi Boomgaard, 1949, p. 79, pl. 6, fig. 11.

Nodosaria lamnulifera: Thalmann, 1950, p. 42; Jones,
1994, p. 76, pl. 64, figs. 6–10.

Nodosaria raphanus: Brady, 1884, p. 512, pl. 64, figs.
6–10; Cushman, 1913, p. 59, pl. 26, figs. 12–13.

Material examined. Korea: off southern coast of Jeju,
St. 6, 33°00'00"N, 126°30'00"E, 5 Aug 2019, by Smith-
McIntyre grab, collected by Nayeon Park and Somin Lee.
NIBR ID: NIBRPR0000110836, MFORBK ID: MFORB
K00281.

Diagnosis. Test is large, elongated, uniserial, rectilinear,
and slightly tapering toward basal end. Chamber height
is increasing as added. Sutures are straight and right-an-
gled to the vertical axis. Surface is ornamented by strong,
raised longitudinal costae extending from basal spine to
around the aperture of final chamber. Basal spine is slight-
ly oblique to vertical axis. Wall is calcareous and hyaline
with smooth and glossy surface. Aperture is terminal, ra-
diate, and slightly produced outward. Test length is about
3.5 mm including the basal spine.

Remarks. This species was originally identified as *Nodo-
saria raphanus* by Brady (1884), then Boomgaard (1949)
proposed this species as a new species with a new name,
Nodosaria bradyi in his doctoral dissertation based on the
inconsistency between the type figures of *N. raphanus*
and Brady's specimens. Later, Thalmann (1950) reported
a new name, *Nodosaria lamnulifera* because *N. bradyi*
was a homonym of *Dentalina bradyi* Spandel, 1901 = *No-
dosaria (Dentalina) bradyi* (Spandel). *Nodosaria lamnu-
lifera* differs from *N. raphanus* based on the fewer longi-
tudinal costae, non-lobulate periphery and less tapering
test. The present specimen is most similar to the specimen
of figure 7 in plate 64 reported by Brady (1884), and has
a slightly more produced aperture than other specimens
(figs. 6, 8–10) in Brady's plate.

Distribution. Korea, New Zealand, Fiji, Aegean Sea.

Class Globothalamea Pawlowski,
Holzmann & Tyszka, 2013

Order Rotaliida Delage & Hérouard, 1896
 Family Uvigerinidae Haeckel, 1894
 Genus *Uvigerina* d'Orbigny, 1826

4. *Uvigerina schwageri* Brady, 1884
 (Plate 1, fig. 4a–b)

Uvigerina schwageri Brady, 1884, p. 575, pl. 74, figs. 8–10; Cushman, 1913, p. 97, pl. 37, figs. 3–4; 1921, p. 270, pl. 56, figs. 3–5; Hatta and Ujiié, 1992, p. 176, pl. 2, fig. 7; Jones, 1994, p. 85, pl. 74, figs. 8–10; Szarek, 2001, p. 131, pl. 18, figs. 14–17.

Euuvigerina schwageri: Loeblich and Tappan, 1994, p. 128, pl. 249, figs. 10–20.

Material examined. Korea, off southern coast of Jeju, St. 10, 32°30'00"N, 127°00'00"E, 8 Aug 2019, by Smith-McIntyre grab, collected by Nayeon Park and Somin Lee. NIBR ID: NIBRPR0000110835, MFORBK ID: MFORBK00221.

Diagnosis. Test is large, elongate, sub-ovate, rounded in cross-section, and tapering toward a blunt point at the basal end. Chamber arrangement is triserial in early portion, later becomes loose and almost uniserial. Sutures are distinct, depressed, and somewhat oblique. Surface is ornamented by irregular longitudinal costae. Wall is calcareous, perforate, and the surface is somewhat glassy. Aperture is rounded at the terminal of short neck and surrounded by lip. The area around the neck on the final chamber is slightly depressed. Test length is about 930 µm, including neck.

Remarks. *Uvigerina schwageri* was originally reported from the Fiji Islands by Brady (1884). This species is similar to *U. bermudezi* in general appearance, but the latter has a more ovate, stout outline and blunt basal end than *U. schwageri*. Szarek (2001) reported two morphotypes of this species presumed to represent the megalospheric and microspheric form. One is the type with large test, broad basal end, and widely spaced costae. The other type has much smaller and slender test with small, sharply pointed initial end, and more narrowly spaced costae. The same aspect seems to be observed in the specimens of Loeblich and Tappan (1994). The present specimen has a somewhat more pointed basal end than the specimens in Hatta and Ujiié (1992; pl. 27, fig. 7), and Szarek (2001; p. 18, fig. 16).

Distribution. Korea, Japan, China, Philippines, Fiji.

Family Discorbidae Ehrenberg, 1838
 Genus *Neoeponides* Reiss, 1960

5. *Neoeponides bradyi* (Le Calvez, 1974)
 (Plate 1, fig. 5a–c)

Pulvinulina berthelotiana: Brady, 1884, p. 701, pl. 106, fig. 1.

Eponides berthelotianus: Barker, 1960, pl. 106, fig. 1

Eponides bradyi Le Calvez, 1974, p. 63.

Neoeponides bradyi: Rögl and Hansen, 1984, p. 33, pl. 7, figs. 1–6; Hottinger *et al.*, 1993, p. 112, pl. 146, figs. 8–12; pl. 147, figs. 1–3; Loeblich and Tappan, 1994, p. 138, pl. 279, figs. 1–9; Szarek, 2001, p. 134, pl. 20, figs. 5–7; Debenay, 2012, p. 204.

Material examined. Korea, off southern coast of Jeju, St. 10, 32°30'00"N, 127°00'00"E, 8 Aug 2019, by Smith-McIntyre grab, collected by Nayeon Park and Somin Lee. NIBR ID: NIBRPR0000110837, MFORBK ID: MFORBK00222.

Diagnosis. Test is biconvex, high trochospiral consisting of about three whorls. Spiral side is evolute and conical with broadly rounded apex. Umbilical side is involute, consisting seven to eight chambers, and less convex than the spiral side. Periphery is rounded, circular and thickened by keel. Sutures of both sides are conspicuously limbate and imperforate. Sutures on the umbilical side tend to be stronger near the center. Wall is calcareous, hyaline, and densely perforated except the sutures. Aperture is interiomarginal, extraumbilical with a slight lip. Test diameter is about 1.1 mm.

Remarks. The original name of this species, *Eponides bradyi* Le Calvez was a junior homonym of *Eponides bradyi* Earland, and later accepted to *Neoeponides bradyi* (Le Calvez) by Rögl and Hansen (1984). Based on the original descriptions and previous reports, this species is most similar to *N. procerus*, among other congeneric species in having high trochospiral, conical test with rounded apex (Ellis and Messina, 1940; Hottinger *et al.*, 1993; Szarek, 2001; Hayward *et al.*, 2010). However, *N. procerus* has a flat, truncated umbilical face and higher conical spiral side with a larger number of whorls than those in *N. bradyi*. Additionally, the sutures of *N. procerus* are indistinct unlike those of *N. bradyi*. The present Korean specimen is most similar to the specimen reported by Szarek (2001) from the Sunda Shelf.

Distribution. Korea, Sunda Shelf, New Caledonia, Maldives, Papua New Guinea.

CONCLUSION

From off the southern coast of Jeju Island, five species of benthic foraminifera belonging to five genera (*Ammolagena*, *Neoeponides*, *Nodosaria*, *Rhabdammina*, and *Uvigerina*), five families (Ammolagenidae, Discorbidae, Nodosariidae, Rhabdamminidae, and Uvigerinidae), four orders (Ammodiscida, Astrorhizida, Nodosariida, and Rotaliida) were newly reported. These species have been previously reported in the North or Southwest Pacific region, but are recorded for the first time in Korea. In partic-

ular, the agglutinated foraminiferal genera *Ammolagena* and *Rhabdammina* are reported for the first time in Korea through this study. This result expands our understanding of foraminiferal species diversity in Korea and suggests the need for further investigations in a wider range of Korean adjacent seas.

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