

# A report of three newly recorded benthic foraminiferal species from Korea

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Foraminifera are unicellular eukaryotes widely distributed in marine and transitional marine environments. They play important roles in marine food webs and geochemical cycles and have physiological properties like the formation of calcareous tests and nitrogen respiration. Research on species diversity, distribution and endemism are essential in biogeography and biodiversity conservation. Here, we report three unrecorded species of foraminifera (*Hemiroteria foraminulosa*, *Planispirillina denticulogranulata* and *Oolina brevisolenia*) collected from Jeju Island and the South Sea (Korea). *Planispirillina denticulogranulata* is the second *Planispirillina* species recorded in Korea, which can be distinguished from congeners by its tubercles on the ventral side and grooves on the spiral suture. *Hemiroteria foraminulosa* is differentiated from the only congener *H. calvifacta* by multiple-scattered pits on the umbilicus, and it is the first report of *Hemiroteria* from Korean water. *Oolina brevisolenia* has specific bifurcating costae that characterize it from other congeners. This study contributes to documentation of the foraminiferal biodiversity in Korea, moreover, provides an essential basis for the expanded studies on modern foraminifera.

Keywords: biogeography, Chromista, Protist, Rhizaria, South Korea, unrecorded species

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## INTRODUCTION

The Phylum Foraminifera d'Orbigny, 1826 belongs to the Kingdom Chromista (Ruggiero *et al.*, 2015) and is represented by unicellular eukaryotic organisms, widely distributed in marine and transitional marine environments. They commonly have a test (i.e., shell), which can be made of organic, agglutinated sediment materials, or calcium carbonate (Sen Gupta, 2003). Modern benthic foraminifera are one of the most dominant meiobenthos group and an important component in the marine food web because of their wide range of feeding strategies (Boltovskoy and Wright, 1976) including grazing, suspension-feeding, deposit-feeding, carnivory, parasitism and symbiosis (Debenay, 2012). Moreover, foraminifera contribute to biogeochemical cycles like playing an important role in the benthic carbon cycling (e.g., Moodley *et al.*, 2002).

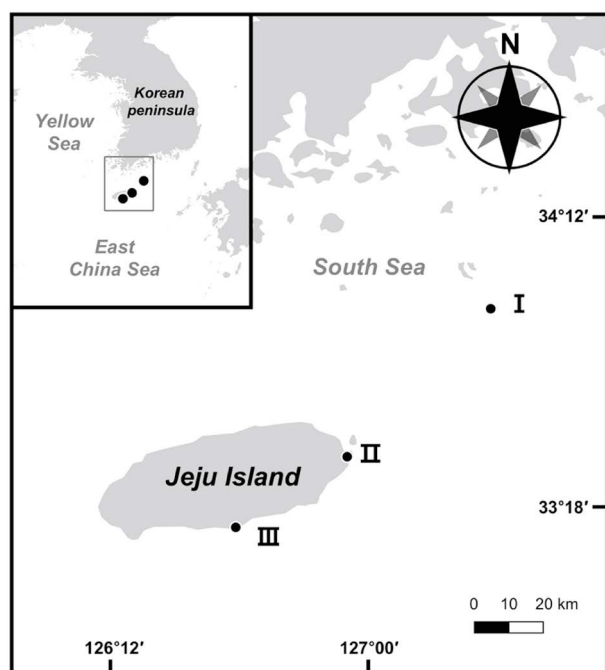
On the basis of the World Register of Marine Species database, a total of 8,924 marine species of foraminifera has been reported as extant, while the reported fossil species number is 39,796 (WoRMS, 2022). These figures are

particularly high when compared with other phyla of the Kingdom Chromista, and represent about 44% and 98% of extant and fossil species in the Chromista in the database, respectively. In Korea, a total of 1,354 foraminiferal species including both extant and fossil taxa have been reported, and it accounts for about 55% of the overall species within protozoa, based on the National List of Species of Korea, 2021 (NIBR, 2022). Despite such a high species diversity, there is still a high probability to discover new or unrecorded species including non-marine species, organic-walled species, and invasive species (Lejzerowicz *et al.*, 2010; Schmidt *et al.*, 2015; Siemensma *et al.*, 2017; 2021; Eichler *et al.*, 2018; Holzmann *et al.*, 2021). Likewise, in Korea, research has been continuously conducted to understand foraminiferal species diversity. In particular, Kim *et al.* (2016) performed a comprehensive survey on modern Korean species and a study on diversity in the waters surrounding Jeju Island. Furthermore, over the past five years, one new species and 13 unrecorded species have been described (Lee and Lee, 2019; 2020; Lee *et al.*, 2019; 2021). However, there is no record of freshwater or soil species. Additionally, continuous monitoring and res-

earch on foraminiferal biodiversity serve as an essential cornerstone for further ecological studies to understand biotic and abiotic processes on ecosystems as well as the baseline to identify invasive species. In line with the importance and necessity, we document and describe three unrecorded benthic foraminiferal species from the South Sea and Jeju Island.

## MATERIALS AND METHODS

Sample collection was performed in August 2020 and 2022 near Jeju Island and the South Sea of the Korean Peninsula, respectively (Fig. 1, Table 1). Sediments from the stations near Jeju Island were sampled by SCUBA diving with acrylic corer or 250 mL sampling bottles. Samples of the station in the South Sea were obtained by using plastic spoons and zipper bags from the sediments captured by the Smith-McIntyre grab sampler during R/V



**Fig. 1.** Map of sampling sites. This map is made with QGIS software v.3.16.13 and the Natural Earth, free vector and raster map data.

Saedongbaek (Chonnam National University). Samples collected by SCUBA diving were washed through a 63  $\mu$ m mesh sieve with tap water and fixed with 99% ethanol. Samples from the grab sampler were directly frozen on-board and transported to the Biodiversity Laboratory at Hanyang University (Seoul, South Korea), washed with tap water and a 63  $\mu$ m mesh sieve, and fixed with 99% ethanol. Sieved sediment samples were observed under a stereomicroscope (Olympus SZ40, SZX12, Tokyo, Japan) and foraminiferal specimens were hand-picked and placed in micropaleontology slides. For detailed morphological observations, multi-focus images of the newly recorded species were taken using a digital camera (Canon EOS 90D, Tokyo, Japan) attached to dissecting microscope (Olympus SZX12, Tokyo, Japan), and merged using Helicon Focus 7.6.4 software (Helicon Soft Ltd). In addition, in the case of *Oolina brevisolenia*, multi-focus images were taken under bright field condition, while submerged in 99% ethanol to confirm the entosolenian tube, an internal structure of the test, extending inward from the aperture. Furthermore, selected specimens were used for scanning electron microscope (SEM) analysis. These specimens were attached on sample stub and coated with sputter (COXEM SPT-20, Daejeon, Korea) and inserted into a tabletop SEM (COXEM EM30, Daejeon, Korea), in order to observe detailed morphological characters. Species identification was carried out based on relevant references including Ellis and Messina (1940), Loeblich and Tappan (1987), Hayward *et al.* (1999), Parker (2009), Lei and Li (2016). The hierarchical classification and worldwide distribution were referred to WoRMS (2022). The voucher specimens of the newly recorded species were preserved in micropaleontology slides, registered in an online database Marine Bio Resource Information System (MBRIS), issued sample number, and deposited to the National Marine Biodiversity Institute of Korea (MABIK).

## SYSTEMATICS

Class Tubothalamea Pawlowski, Holzmann & Tyszka, 2013

Order Spirillinida Hohenegger & Piller, 1975

Family Planispirillinidae Piller, 1978

Genus *Planispirillina* Bermúdez, 1952

**Table 1.** Information of the sample collection.

No	Locality	Date	Latitude (N)	Longitude (E)	Depth	Method
I	R/V Saedongbaek cruise st. 4	2022-08-17	33°54'55"	127°22'46"	79 m	Smith-McIntyre Grab
II	Sungsan Seom-yeo diving point, Jeju	2020-08-02	33°27'21.54"	126°56'3.06"	18.3 m	SCUBA diving
III	Seop-seom, Kaldong-gul diving point, Jeju	2020-08-03	33°14'12.10"	126°35'19.34"	23.1 m	SCUBA diving

**1. *Planispirillina denticulogranulata* (Chapman, 1907)  
(Plate 1, figs. 1, 2)**

*Spirillina denticulogranulata* Chapman, 1907, p. 133, pl. 10, fig. 6a–c; Hayward *et al.*, 1999, pl. 92, pl. 3, figs. 5, 6.

*Planispirillina denticulogranulata*: Parker, 2009, p. 74, fig. 53a–j.

**Material examined.** Sungsan Seom-yeo diving point, Seogwipo Jeju Island, 33°27'21.54"N 126°56'3.06"E, 2 August 2020, by SCUBA diving, collected by Heerin Kim, Jisu Yeom and Wonchoel Lee. MABIK ID: MABIK PR00044173, MABIK PR00044174.

**Diagnosis.** Test discoidal, consisting of a globular proloculus and tubular, undivided planispirally coiled second chamber. Periphery not strongly acute, thickened at spiral side margin. Spiral side of test evolute, three to four whorls visible. Spiral suture limbate, prominently raised. Sutural border ornamented with numerous depressions or short grooves perpendicular to the suture. Opposite side flattened to slightly concave, suture unclear due to numerous pustules covering almost entire surface. Wall calcareous perforate, aperture simple opening at the end of tubular chamber. Test diameter about 340 µm, thickness about 87 µm.

**Remarks.** The type species of the genus *Planispirillina* Bermúdez, 1952 is *P. papillosa* (Cushman, 1915), and there are total of 13 extant, accepted species belonging to the genus. Among those species, *P. papillosa* and *P. tuberculatolimbata* (Chapman, 1900) are most similar to *P. denticulogranulata* (Chapman, 1907) in having papillose ventral side and prominent, limbate spiral suture. However, based on the original descriptions (Chapman, 1900; 1907; Cushman, 1915), *P. denticulogranulata* is distinguished from the other species by the presence of ornamentation on the edge of spiral suture. Additionally, the borders of spiral suture in *P. papillosa* are almost wavy (Cushman, 1915), whereas in *P. denticulogranulata*, the waviness of sutural borders is not clearly observed. On the other hand, *P. papillosa* and *P. tuberculatolimbata* are morphologically very similar, so they were once recorded as synonym by Cheng and Zheng (1978). However, according to Hatta and Ujjié (1992), test wall of the spiral side in *P. papillosa* is more finely perforate, as can be seen in the original figure (Cushman, 1915) and the re-drawing by Loeblich and Tappan (1964).

*Planispirillina denticulogranulata* has been reported in Australia (Chapman, 1907; Parker, 2009), and New Zealand (Hayward *et al.*, 1999). According to Parker (2009), the spiral suture grooves become stronger in the later whorl, forming a coarse reticulum. The specimens reported by Hayward *et al.* (1999) have slightly weaker ridges than those of Parker (2009) but have also stronger spiral suture grooves on the later whorl than the first. In Kore-

an specimens, the grooves appear to be weaker than the others, however the ridges seem to be projecting in from the outer margin of suture, so in this respect it matches the type illustration well. Furthermore, coarse ridges on the later whorls as the other specimens can also be observed, which are partially obscured by debris and diatom particles.

**Distribution.** Korea, Australia, and New Zealand.

Class Globothalamea Pawlowski, Holzmann & Tyszka, 2013

Order Rotaliida Delage & Hérouard, 1896

Family Ammoniiidae Saidova, 1981

Genus *Hemirootalia* Lei & Li, 2016

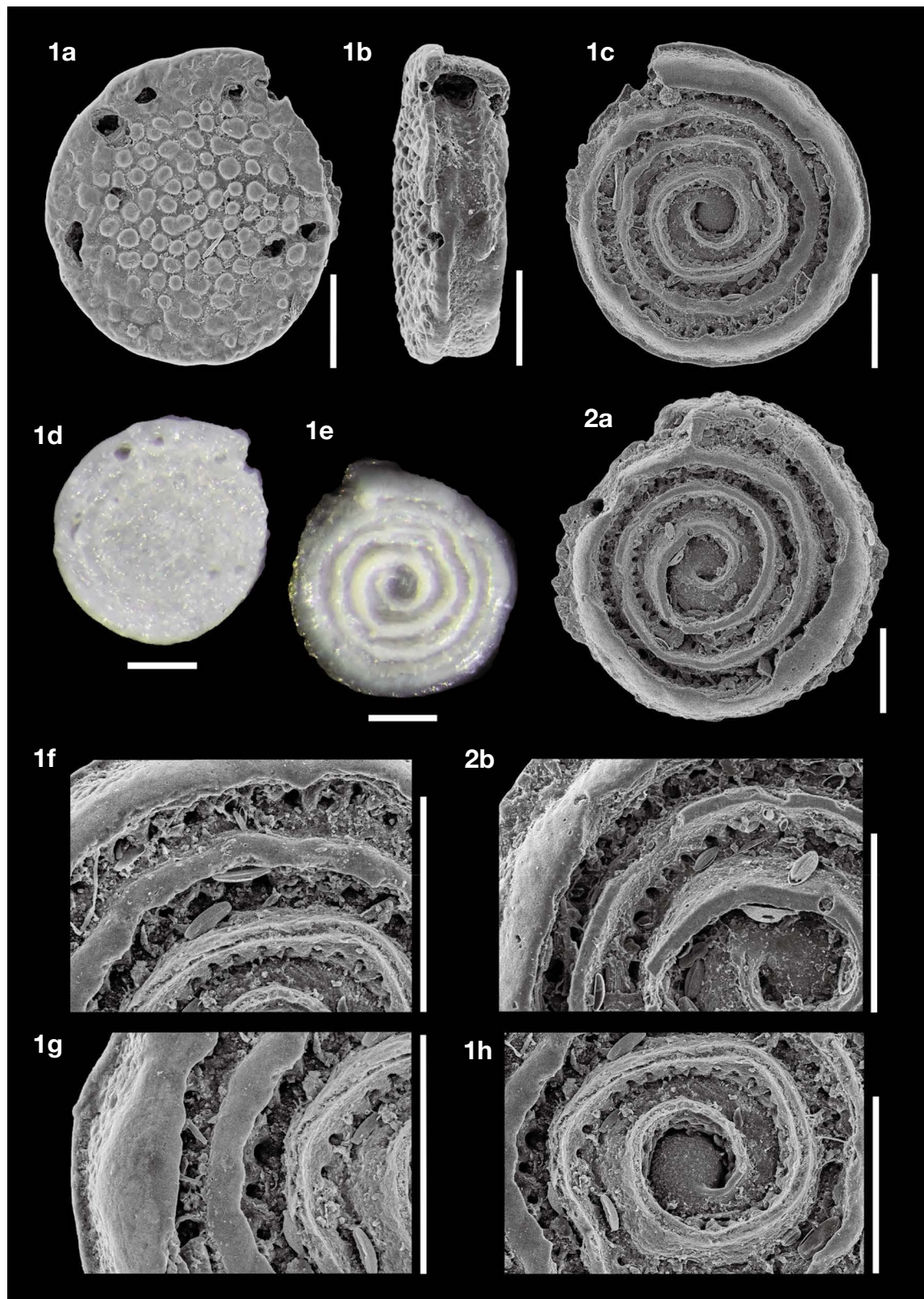
**2. *Hemirootalia foraminulosa* Lei & Li, 2016  
(Plate 2, figs. 1–4)**

*Hemirootalia foraminulosa* Lei & Li, 2016, p. 346, figs. 76, 77.

**Material examined.** Korea, the South Sea, R/V Saedongbaek (Chonnam National University) cruise st. 4, 33°54'55"N, 127°22'46"E, 17 Aug 2022, by Smith-McIntyre grab, collected by Jaehyun Kim. MABIK ID: MABIK PR00044175–44178.

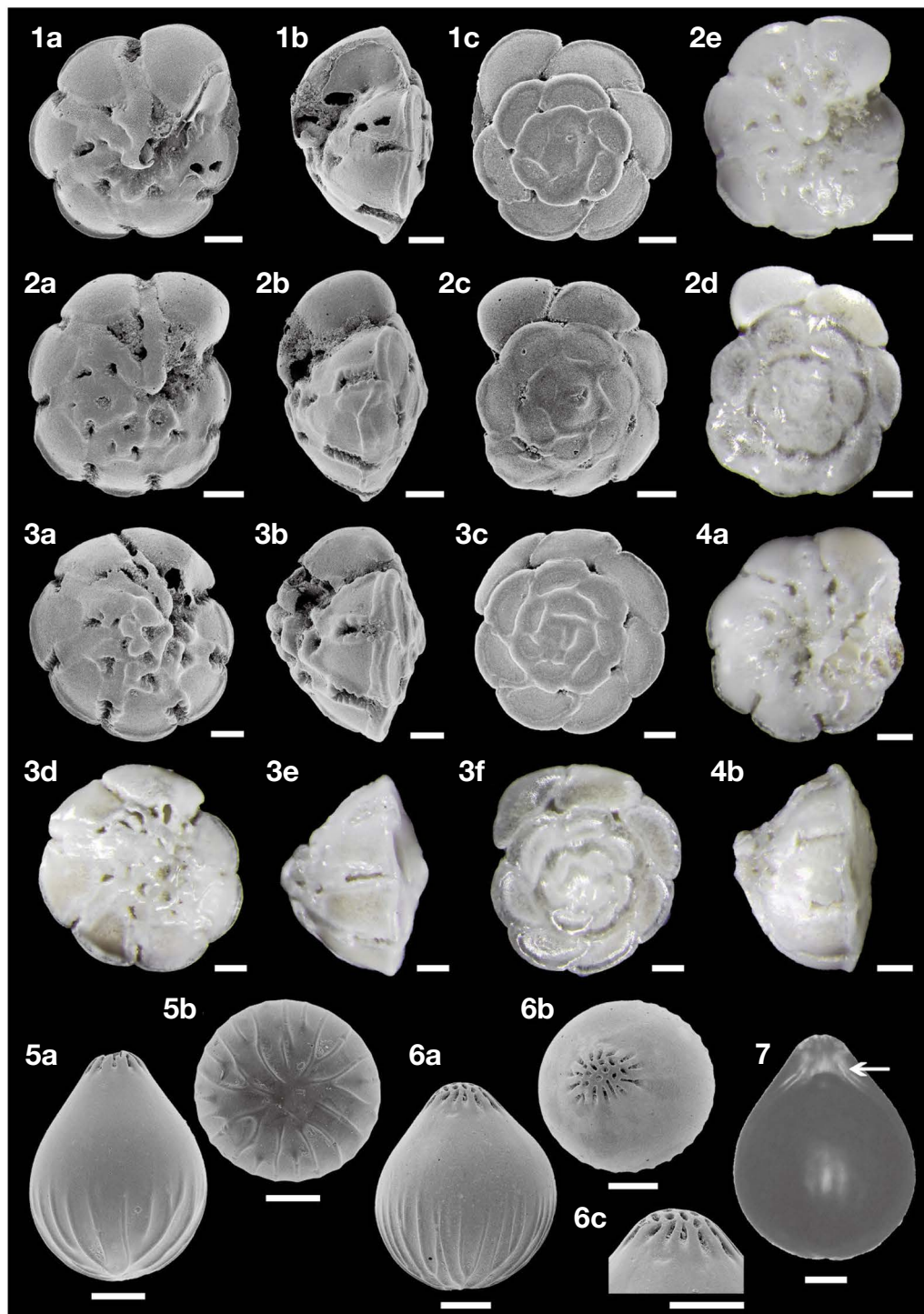
**Diagnosis.** Test trochospiral, planoconvex to slightly bi-convex with lobate, carinate periphery. Ventral side involute, more convex, spiral side flattened to slightly convex, consisting of about three whorls. Chamber size gradually increasing as added, about seven chambers in the final whorl. Chamber shape rounded to trapezoidal on spiral side, and indistinct to semi-triangular on umbilical side. Sutures on umbilical side deeply incised at periphery, length about a quarter of the distance from the umbilicus to the peripheral edge. Umbilicus somewhat pointed, without a plug, covered with folia with scattered multiple pits. Wall calcareous, perforate, except for sutures, carina, and folia. Aperture an indistinct, loop-shaped, interiomarginal slit. Test dimension about 650 µm.

**Remarks.** There are two species belonging to the genus *Hemirootalia* Lei & Li, 2016: *H. calvifacta* Lei & Li, 2016, the type species, and *H. foraminulosa* Lei & Li, 2016. These two species and the genus *Hemirootalia* were first described from Chinese waters (i.e., Bohai Sea and Yellow Sea), by Lei and Li (2016). This is the first record of *Hemirootalia* from Korea. *Hemirootalia foraminulosa* differs from *H. calvifacta*, by its scattered pits on the folium of umbilical region, somewhat acutely keeled periphery, and shorter length of sutural incisions on ventral side. *Hemirootalia calvifacta* has a smooth umbilical region with a single pit, and the folium is not clearly distinguishable. Additionally, the length of sutural incisions is about half the distance from the umbilicus to peripheral edge in *H. calvifacta*, whereas in *H. foraminulosa*, it is about a



**Plate 1.** Photomicrograph and SEM image of the newly recorded species. All scales are 100  $\mu\text{m}$ . 1, 2. *Planispirillina denticulogranulata* (Chapman, 1907); 1. (a–h) MABIK PR00044173; 1a. Ventral side view, SEM image; 1b. Lateral side view, SEM image; 1c. Spiral side view, SEM image; 1d. Ventral side view, photomicrograph; 1e. Spiral side view, photomicrograph; 1f–h. Close-up of spiral suture ornamentation, SEM image. 2. (a, b) MABIK PR00044174; 2a. Spiral side view, SEM image; 2b. Close-up of spiral suture ornamentation, SEM image.





**Plate 2.** Photomicrograph and SEM image of the newly recorded species. All scales are 100  $\mu\text{m}$  unless otherwise noted. 1–4. *Hemirota foraminulosa* Lei and Li, 2016; 1. (a–c) MABIK PR00044175; 1a. Ventral side view, SEM image; 1b. Lateral view, SEM image; 1c. Spiral side view, SEM image. 2. (a–e) MABIK PR00044176; 2a. Ventral side view, SEM image; 2b. Lateral view, SEM image; 2c. Spiral side view, SEM image; 2d. Spiral side view, photomicrograph; 2e. Ventral side view, photomicrograph. 3. (a–f) MABIK PR00044178; 3a. Ventral side view, SEM image; 3b. Lateral view, SEM image; 3c. Spiral side view, SEM image; 3d. Ventral side view, photomicrograph; 3e. Lateral view, photomicrograph; 3f. Spiral side view, photomicrograph. 4. (a, b) MABIK PR00044177; 4a. Ventral side view, photomicrograph; 4b. Lateral view, photomicrograph. 5–7. *Oolina brevisolenia* Zheng, 1979; 5. (a, b) MABIK PR00044179; 5a. Lateral view, SEM image; 5b. Basal view, SEM image. 6. (a–c) MABIK PR00044180; 6a. Lateral view, SEM image; 6b. Apertural view, SEM image; 6c. Close-up of aperture, SEM image. 7. MABIK PR00044181; Lateral view, photomicrograph under bright field, white arrow pointing entosolenian tube.

quarter. Lei and Li (2016) did not provide SEM images or detailed images of the type specimens, and neither difference between individuals in the description, the convexity of the umbilical side and spiral side in lateral view, and the inclination from the umbilicus to periphery, appear in a rather wide range.

**Distribution.** Korea, China.

Class Nodosariata Mikhalevich, 1992 emend. Rigaud *et al.*, 2015

Order Polymorphinida Mikhalevich, 1980

Family Ellipsolagenidae A. Silvestri, 1923

Genus *Oolina* d'Orbigny, 1839

**3. *Oolina brevisolenia* Zheng, 1979 (Plate 2. figs. 5–7)**

*Oolina brevisolenia*, Zheng, 1979, pp. 148 (Chinese), 213 (English), pl. 12, fig. la–c.

**Material examined.** Seop-seom Kaldong-gul diving point, Seogwipo, Jeju Island, Korea. 33°14'12.10"N, 126°35'19.34"E, 3 August 2020, collected by Heerin Kim, Jisu Yeom and Wonchoel Lee. MABIK ID: MABIK PR00044181; Sungsan Seom-yeo diving point, Seogwipo Jeju Island, 33°27'21.54"N 126°56'3.06"E, 2 August 2020, by SCUBA diving, collected by Heerin Kim, Jisu Yeom and Wonchoel Lee. MABIK ID: MABIK PR00044179, MABIK PR00044180.

**Diagnosis.** Test unilocular, ovate, tapering toward apertural end, basal end broader and rounded. Surface ornamented with somewhat irregularly distributed, bifurcating longitudinal costae, which extending from basal end to the middle or slightly upper middle part of test. Wall calcareous hyaline, thick, surface smooth except the longitudinal costae. Aperture terminal, radiate, short entosolenian tube at the inner part of apertural end, not extending into the chamber cavity. Test length about 420 µm, width about 350 µm.

**Remarks.** This species was originally reported by Zheng (1979), from a shallow depth (30 m) near Xisha Islands in the South China Sea. The longitudinal costae, somewhat irregularly spaced and sometimes bifurcating, are the unique feature that distinguishes this species from other congeners. According to the original description (Zheng, 1979), this species resembles *Oolina borealis* Loeblich & Tappan, 1954, in having globose test and longitudinal costae, but *O. brevisolenia* Zheng, 1979 differs from *O. borealis* in having tapering apertural end rather than ovate outline, and the longitudinal costae which are irregular, bifurcating, and not extending to the apical end. According to WoRMS (2022), this species has been found and documented only from Chinese waters and this is the second report of *O. brevisolenia* from other countries except for China. In Korean specimens, there is a slight difference in the number and thickness of costae between individuals.

**Distribution.** Korea, China.

## CONCLUSION

Three species of recent benthic foraminifera belonging to three genera (*Hemirota*, *Oolina*, and *Planispirillina*), three families (Ammoniidae, Ellipsolagenidae, Planispirillinae), and three orders (Polymorphinida, Rotaliida, Spirillinida) were newly reported from the waters near Jeju Island and the South Sea, Korea. All the species were previously documented from Pacific regions, and two of them, *H. foraminulosa* and *O. brevisolenia*, were originally described from Chinese waters (Yellow Sea and South China Sea). Based on the World Register of Marine Species, it is the first report of the species from a country other than China. By documenting the newly recorded species, the present study contributes to updating the basic knowledge of the species diversity of Korean benthic foraminifera, and the status of the worldwide distribution of the species.

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