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A new freshwater *Psammodictyon* species in the Taihu Basin, Jiangsu Province, China

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Abstract: We describe a new species of diatom, *Psammodictyon taihuensis* sp. nov., collected from the Taihu Basin, Jiangsu Province, China. There are several features of this diatom that suggest it should be included in the genus *Psammodictyon*, notably the possession of panduriform valves characterized by a longitudinal fold near the apical axis, coarsely areolate striae, and a keeled raphe system present on the valve margin. This species is distinct from others in the genus by its small size, being only 16.5–25.0 µm long and 10.0–12.5 µm wide in the central region, and with the widest valve being 10.5–13.5 µm in width. There are 8–11 distinct fibulae per 10 µm and the striae are composed of 18–22 coarse areolae per 10 µm. This is the first report of a freshwater member of the genus *Psammodictyon* in China, which expands the known geographical and ecological distributions of the genus and enhances our understanding of freshwater diatom diversity in China.

Key words: diatom, new species, *Psammodictyon*, Taihu Lake, taxonomy

Introduction

The genus *Psammodictyon* D.G. Mann (in Round et al. 1990) was established mainly based on *Nitzschia* sect. Panduriformes Grunow, as well as several species of *Tryblionella* W. Smith. This is a small genus comprising less than 20 taxa recorded to date (Guiry & Guiry 2019; Kociolek et al. 2019). The genus was originally characterized as predominantly marine in origin (Round et al. 1990) and all taxa included in the genus are known from marine waterbodies, with the exception of the type species *Psammodictyon panduriforme* (Gregory) D.G. Mann, which was recorded by Day et al. (1995) in a non–marine waterbody in Australia. It is worth mentioning that no new taxa in this genus has been described since the 1970s, although several studies have been conducted recently (Lobban 2015; Louvrou & Economou–Amilli 2012; John 2016, 2018).

Although Round et al. (1990, p. 612) proposed establishment of the genus *Psammodictyon*, the combination of features used in its diagnosis include no unique characters. However, there are several features found in all members of the genus. Notably, the panduriform or broadly linear valves, with a raphe arranged on opposing sides of the valves of the frustule (similar to the diagonal symmetry of other members of the family Nitzschiaceae). The valve surface is undulate (similar to that of *Tryblionella*), and the keel is separated by a central nodule. The areolae are large, round, polygonal, and/or irregular in shape, and distinctive when viewed under a light microscope. The most advalvar girdle band typically bears two to several transverse rows of small round poroids (Round et al. 1990).

Three marine species of *Psammodictyon* have been reported from China, namely, *P. panduriforme* (Gregory) D.G. Mann (*N. panduriformis* Gregory) in the Xisha islands, Sanya, Beihai, Qingdao, and the East China Sea (Jin 1982); *P. corpulentum* (Hendey) D.G. Mann (*N. corpulenta* Hendey) in Fujian and Zhejiang (Jin 1982); and *P. constrictum* (Gregory) D.G. Mann (*N. constricta* Gregory) in the Qiongzhou Strait, Hong Kong, Sanya, and the South China Sea (Jin et al. 1992). Currently, no freshwater species of this genus have been reported from China.

During the investigation of freshwater diatom diversity in the Taihu Basin, we observed a new species *Psammodictyon taihuensis* sp. nov. The purpose of this study was to document and formally describe the species based on light microscopy (LM) and scanning electron

microscopy (SEM) observations, and to compare it with morphologically similar taxa. To the best of our knowledge, this is the first record of a *Psammodictyon* taxon from a freshwater habitat in China.

Material and Methods

For this study we observed samples that were collected from Taihu Basin, which includes Taihu Lake (30°55'40"–31°32'58"N, 119°52'32"–120°36'10"E), Taipu River (30°0'52"–30°01'46"N, 120°49'42"–121°04'19"E), and Yangcheng Lake (31°21'24"–31°29'50"N, 120°39'27"–120°50'34"E), located in the Jiangsu Province (Fig 1). Taihu Lake, located in the southern edge of the Yangtze River Delta, is the third largest freshwater lake in China. The Taipu River, which is 57.2 km long, is an important river of the Taihu Lake Basin. It is formed by the merging of Taihu Lake with the Huangpu River. Yangcheng Lake is one of the lower reaches of the Taihu Lake. In the field, several water chemistry characteristics were recorded, including: pH, habitat, longitude and latitude, temperature and dissolved oxygen (table 1). These were all measured using a YSIPro Plus multiparameter meter (YSI, Ohio, USA). Diatom samples were collected from natural substrates, including stones, or from navigation buoys, by clean toothbrushes, and the samples were placed in a bottle and preserved with formalin (4% final concentration). Several samples of planktonic and epilithic diatoms were collected in January, April and May of 2018.

In the laboratory, samples were treated with concentrated nitric acid using the Microwave Accelerated Reaction System (Model MARS, CEM Corporation, Charlotte, USA) and a pre–programmed digestion scheme (temperature: 180 °C, ramp: 15 min, hold: 15 min). Cleaned diatoms were mounted in Naphrax® as following the procedure described in YOU et al. (2017) for light microscopy (LM) analysis or otherwise spread on aluminum foil and mounted onto stubs for scanning electron microscopy (SEM). LM observations were made with an Olympus BX53 microscope fitted with DIC optics (100× objective, numerical aperture 1.4) and SEM examination was conducted using a Hitachi SU 8010 scanning electron microscope (2 kv) (Hitachi, tokyo, Japan).

Results

***Psammodictyon taihuensis* Q. Yang, Q–M. You et Q–X. Wang sp. nov. (Figs 2–23)**

Description: Valves panduriform, constricted in median region, with a longitudinal fold near apical axis. Valve length 16.5–25.0 µm, valve width in median region 10.0–12.5 µm, and widest part of the valve measures 10.5–13.5 µm. Keeled raphe system present on valve margin, with 8–11 distinct fibulae per 10 µm. Central two fibulae more distant from others. Striae uniseriate, comprising 18–22 coarse areolae per 10 µm. Striae in median region of valves parallel, radiate at the ends.

SEM observations of valve exterior show valves with one unornamented longitudinal fold near apical axis (Fig. 14, see arrow A). Raphe present on valve margin;

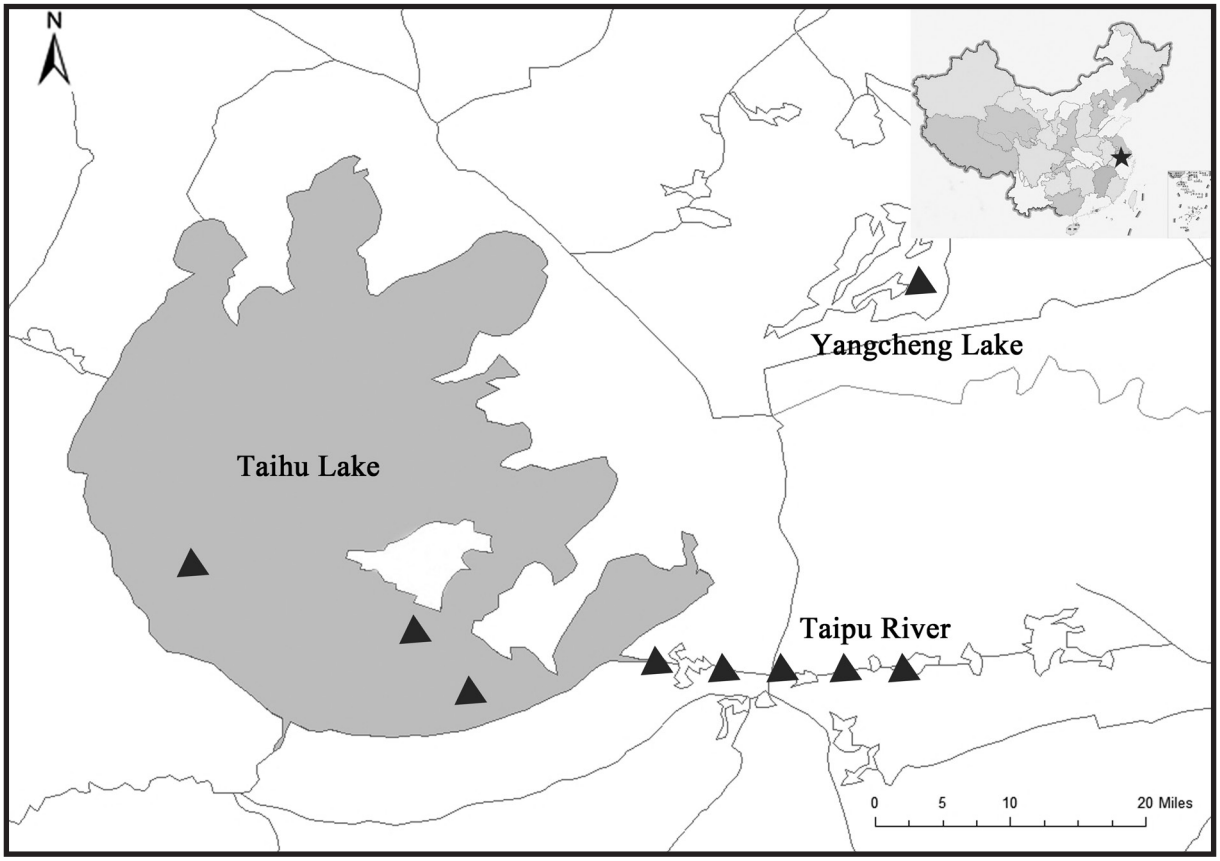

Fig 1. Location of sampling sites in the Taihu Basin.

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Table 1. Sampling sites and their geographical and chemical characteristics [(WT) Water temperature, (DO) Dissolved oxygen].

Sample number	Collection site	Habitat	Longitude and latitude	WT (°C)	pH	DO (mg.l^{-1})
JS–TH20180120	Taihu Lake	Planktonic	31°2'46"N, 120°17'16"E	2.3	7.35	13.9
JS–TH20180516	Taihu Lake	Planktonic	31°8'11"N, 120°0'42"E	22.4	8.15	8.73
JS–TH20180521	Taihu Lake	Planktonic	30°58'45"N, 120°18'0"E	23.8	8.07	8.37
JS–20180101	Hengshan, Taipu River	Periphyton	31°0'42"N, 120°32'36"E	–	–	–
JS–20180104	Lilidong, Taipu River	Periphyton	31°0'12"N, 120°44'39"E	8.5	7.9	9.46
JS–20180401	Hengshan, Taipu River	Periphyton	31°0'42"N, 120°32'36"E	–	–	–
JS–20180402	Meiyan, Taipu River	Periphyton	31°0'22"N, 120°36'3"E	–	–	–
JS–20180403	Pingwang, Taipu River	Periphyton	30°59'58"N, 120°38'51"E	8.1	7.92	10.75
JS–20180405	Fenhu, Taipu River	Periphyton	31°1'36"N, 120°50'29"E	–	–	–
JS–201910YCH	Yangcheng Lake	Planktonic	31°24'47"N, 120°49'32"N	28.9	7.98	8.56

central raphe ends slightly expanded and disconnected (Fig. 14, see arrow B) with simple terminal raphe ends (Fig. 14, see arrow C). Grooves found on both sides of valve, continuous in the centre and ending near terminal raphe ends (Fig. 14, see two arrows D). Areolae externally non–uniform, being C–shaped near raphe margin, and bone–shaped or zigzag on other margins (Figs 14, 15). Girdle bands 2–4 (mostly 3), discontinuous at both poles (Fig. 16, see arrows). Two rows of misaligned areolae on girdle band (Fig. 16). Mantle striated with one row of coarse areolae, with 22 striae per 10 μm (Fig. 15, see arrow).

Internally, valves irregular, with one unornamented longitudinal fold near the apical axis (Fig. 17, see arrow A). Number of striae between central two fibulae generally 4, and typically 2 (occasionally 1 or 3) between other two fibulae (Fig. 17). Areolae small, rounded, and occluded with rows of fine openings (Fig. 18). Raphe terminates at apices in small helictoglossae. Several (generally 5 or 6) occluded depressions present near helictoglossa (Figs 19–23, see arrows).

Holotype: SHTU!, slide JS–20180405!, Lab of Algae and Environment, College of Life Sciences, Shanghai Normal University, China, holotype illustrated in Fig. 2.
Isotypes: COLO! Material 650043, Kociolek Collection, University of Colorado, Museum of Natural History Diatom Herbarium, Boulder, USA.
Type locality: CHINA. Taipu River, Jiangsu Province, 31°1'36"N, 120°50'29"E. The new species was found on the Fenhu Lake beside Taipu River in the Fenhu Town, Suzhou, collected by Q.X. Wang et al., April of 2018.
Etymology: The species is named for Taihu Basin.

Ecology: Planktonic diatoms collected in Taihu Lake (JS–TH20180120; JS–TH20180516; JS–TH20180521), epilithic diatoms collected in Taipu River (JS–20180101; JS–20180104; JS–20180401; JS–20180402; JS–20180403; JS–20180405) and Yangcheng Lake (JS–201910YCH). For detailed collection information see Table 1.

Distribution: So far, the new species is known only from Taihu Basin.

Discussion

Members of the genera *Psammodictyon* and *Tryblionella* were previously considered to belong to the genus *Nitzschia*, and accordingly possess certain similar morphological characters, including the symmetry of the raphe on a frustule, wide valves, a longitudinal fold, and an eccentric raphe. They are distinguishable with respect to the structures of the valve, raphe, and fibula, and to a lesser extent by habitat, valve shape, and plastid position (Round et al. 1990). However, there appear to be no unique features that can be used to diagnose *Psammodictyon*, and a formal analysis of morphological features remains to be undertaken. We believe that the main features that differentiate *Psammodictyon* from *Tryblionella* are the valve outline and the structure and arrangement of the areolae. The valves of *Psammodictyon* species are panduriform and distinctively centrally constricted, and the areolae are coarse and less dense. The uniseriate striae have a regular arrangement of areolae in three directions (the direction of the transapical axis, and positive and negative 45° vs. transapical axis, see Fig. 9 a, b, c). The main features of *Tryblionella* species are valves that are linear–lanceolate to elliptic in shape, and only slightly centrally constricted. The areolae are fine and more dense and there are single or double rows of striae with a regular arrangement of areolae only in the direction of the transapical axis (Round et al. 1990; Spaulding 2011; Wang & You 2018). In a phylogenetic analysis of members of the Bacillariaceae using two

Table 2. Comparison of morphological characteristics of *Psammodictyon taihuensis* sp. nov. and closely related taxa.

Species/Feature	***P. taihuensis* sp. nov.**	***P. ferox* (Hustedt) D.G.Mann**	***P. pustulatum* (Voigt ex Meister) C.S.Lobban**	***P. roridum* (M.H.Giffen) D.G.Mann**	***P. rudum* (Cholnoky) D.G.Mann**	***N. irritans* Cholnoky**	***N. persuadens* Cholnoky**
Valve length (µm)	16.5–25.0	35.0	37.0	23.0–45.0	12.0–20.0	20.0–25.0	18.0–25.0
Valve width (µm)	10.0–12.5	14.0	18.0	9.0–11.0	5.5–6.5	8.0–10.0	6.0–7.0
Valve outline	panduriform	panduriform	panduriform	panduriform or linear	panduriform or linear	panduriform	panduriform or linear
Valve apices	slightly cuneate to rounded	rounded	rostrate	rostrate	rostrate	rostrate	rostrate
Hyaline	lateral	absent	absent	lateral	absent	absent	absent
Density of striae (10 µm)	18–22	16	21	24–27	28–30	16	32
Density of fibulae (10 µm)	8–11	6–8	12	10–12	10–14, usually 12	invisible	12
Habitat	freshwater	marine	marine	marine	marine	marine	marine
References	Current study	HUSTEDT (1952)	MEISTER (1937)	GIFFEN (1975)	CHOLNOKY (1968)	CHOLNOKY (1961)	CHOLNOKY (1961)

distinct genes (rbcL and LSU rDNA), CARBALLEIRA et al. (2017) and BARKIA et al. (2019) found *Tryblionella* and *Psammodictyon* to cluster in distinct clades within the family. RIMET et al. (2011) obtained similar results based on molecular analysis of the Bacillariaceae using 18S rDNA. These findings tend to indicate that the similarities between *Tryblionella* and *Psammodictyon* in terms of valve shape and the presence of a longitudinal fold are a consequence of the independent evolution of these features.

The morphology of *Psammodictyon taihuensis* is unique among similar species in the genus with respect to valve outline, size, striae, and structure of the fibulae. Although morphologically similar to *P. ferox* (Hustedt) D.G. Mann in ROUND et al. (1990) and *P. pustulatum* (Voigt ex Meister) C.S. Lobban, the new species is smaller than these two species. *Psammodictyon roridum* (M.H. Giffen) D.G. Mann in ROUND et al. (1990) differs from *P. taihuensis* sp. nov. mainly in shape (panduriform or linear), valve length (23–45 µm), stria density (24–27 per 10 µm), and in having rostrate apices (GIFFEN 1975), whereas *Psammodictyon rudum* (Cholnoky) D.G. Mann in ROUND et al. (1990) differs from *P. taihuensis* sp. nov. in shape (panduriform or linear) and the presence of apiculate poles, denser striae (28–30 per 10 µm), and narrower valves (width 5.5–6.5 µm) (CHOLNOKY 1968). There are also some similar species in *Nitzschia*, among which *N. irritans* Cholnoky differs from *P. taihuensis* sp. nov. mainly with respect to valve apices (distinct rostrate), valve width (8–10 µm), and stria density (16 per 10 µm) (CHOLNOKY 1961), whereas *N. persuadens* Cholnoky in CHOLNOKY (1961) differs from *P. taihuensis* sp. nov. in terms of shape (panduriform or linear), narrower valves (width 6–7 µm), and denser striae (32 per 10 µm). Moreover, in contrast to these other species, which are all marine in origin, the new species is found in freshwater habitats. Additional details regarding the comparison between *P. taihuensis* and these morphologically similar taxa are shown in Table 2. On the basis of these comparisons, we can propose a geographical expansion of the genus *Psammodictyon* into freshwater ecosystems in China.

Species now included in *Psammodictyon* were first reported more than a hundred years ago, including the type species of the genus *P. panduriforme* (Gregory) D.G. Mann and *P. constrictum* (Gregory) D.G. Mann, both of which are widely distributed in marine habitats in Europe (GREGORY 1855; KUNTZE 1898; HENDEY 1964; PANKOW 1976; SIMS 1996), North and South America (FRENGUELLI 1941; LOBBAN 2015), and the coast of China (JIN 1982; JIN et al. 1992). The species of this genus appear to be very rare in freshwaters habitats, with only *P. panduriforme* (Gregory) D.G. Mann being reported from Australian inland waters (DAY et al. 1995). The new species is widely distributed in the freshwater environment of the Taihu Basin and is the first described *Psammodictyon* species from a freshwater habitat in China. However, it remains unclear whether this species

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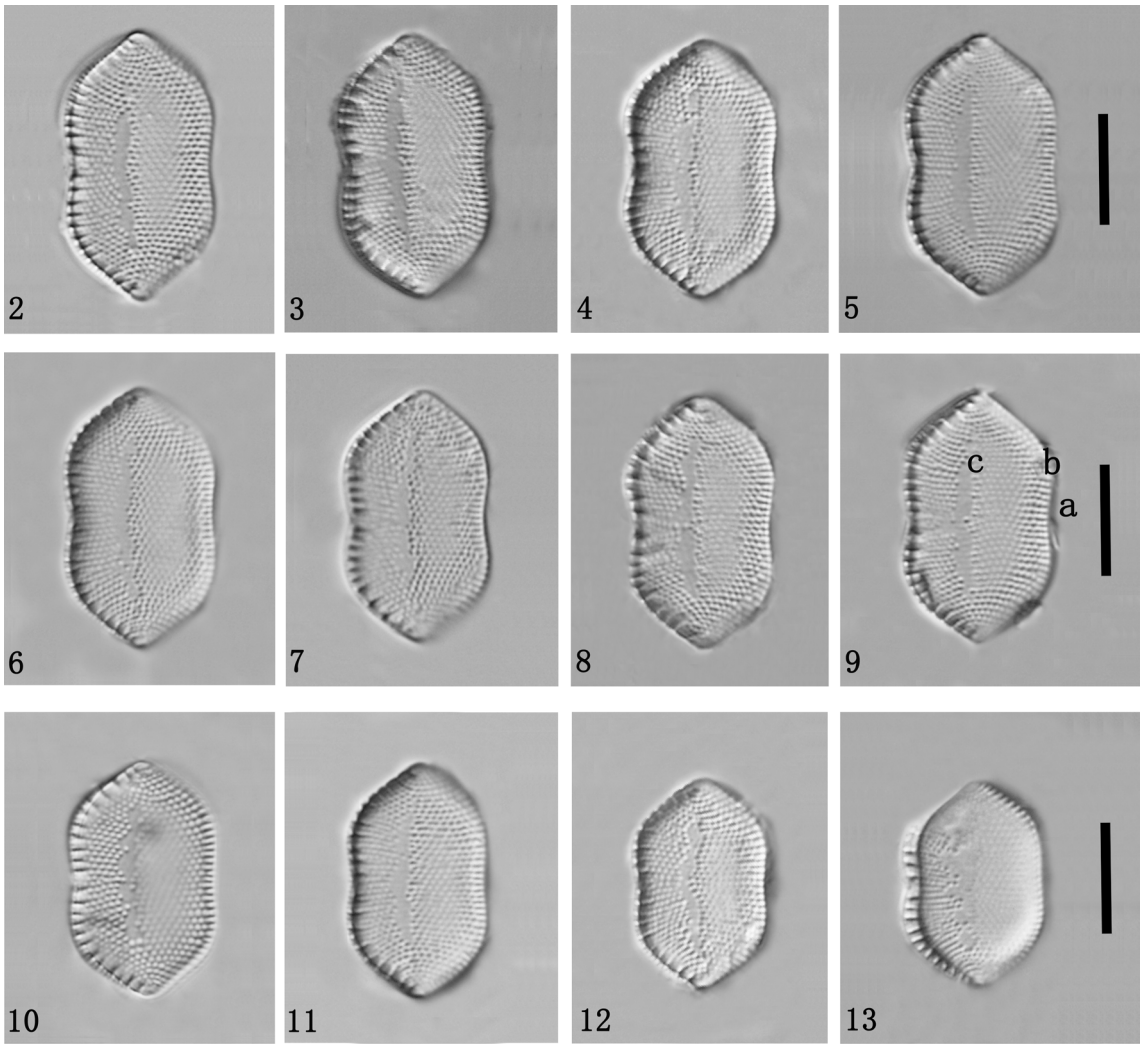

Figs 2–13. LM valve views of *Psammodictyon taihuensis* sp. nov.: (9 a, b, c) a regular arrangement of areolae in three directions, the direction of the transapical axis, and positive and negative 45° vs. transapical axis. Scale bar 10 μm.

migrated inland from coastal waters or whether it has uniquely evolved in freshwater habitats in China.

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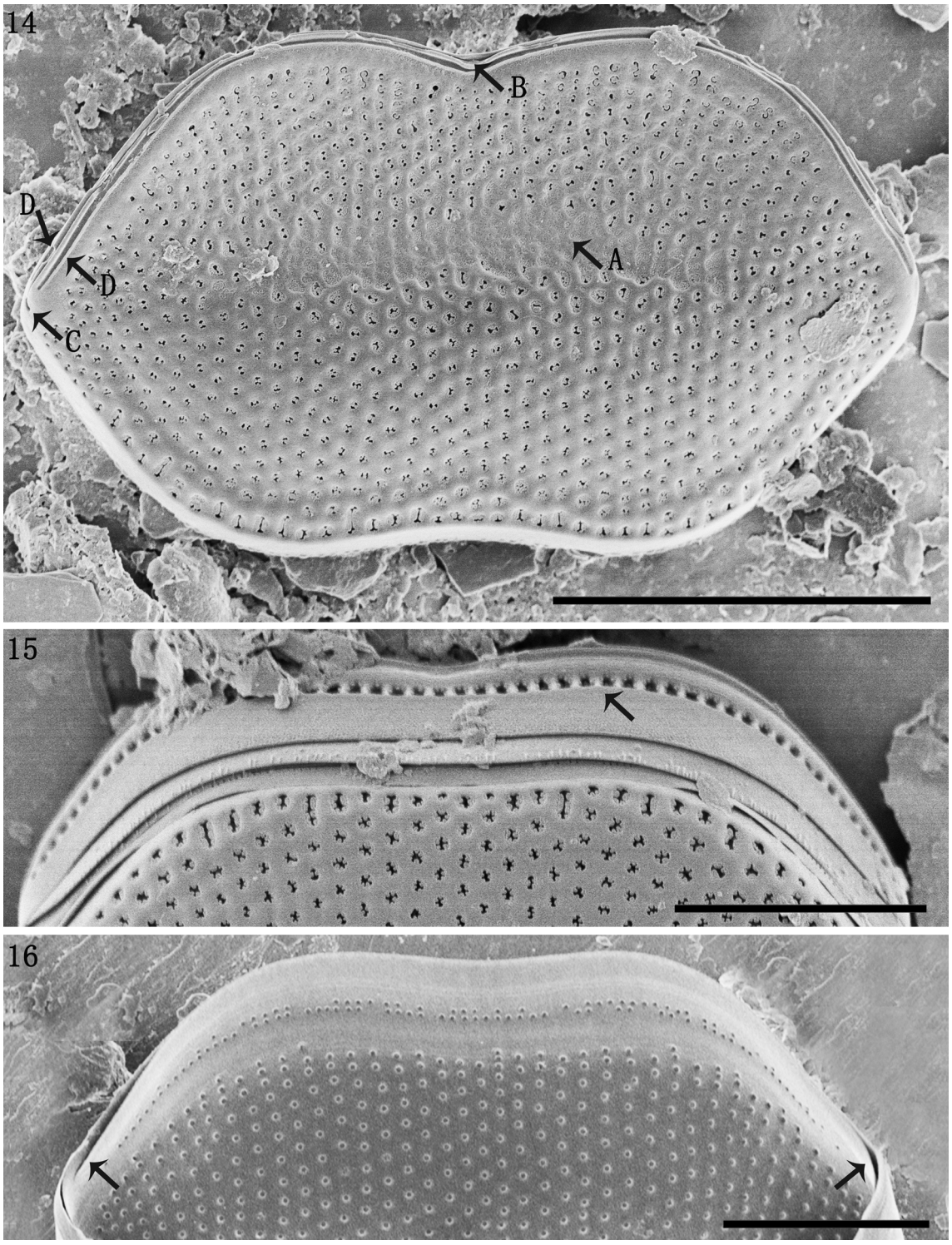

Figs 14–16. *Psammodictyon taihuensis* sp. nov., SEM views of valve: (14) general external view, (arrow A) one unornamented longitudinal fold, (arrow B) the central raphe, (arrow C) the terminal raphe, (arrow D) grooves on both sides of the valve; (15) external view of the band; (16) internal view of the mantle; arrow: the girdle bands. Scale bars 5 μm (14–16).

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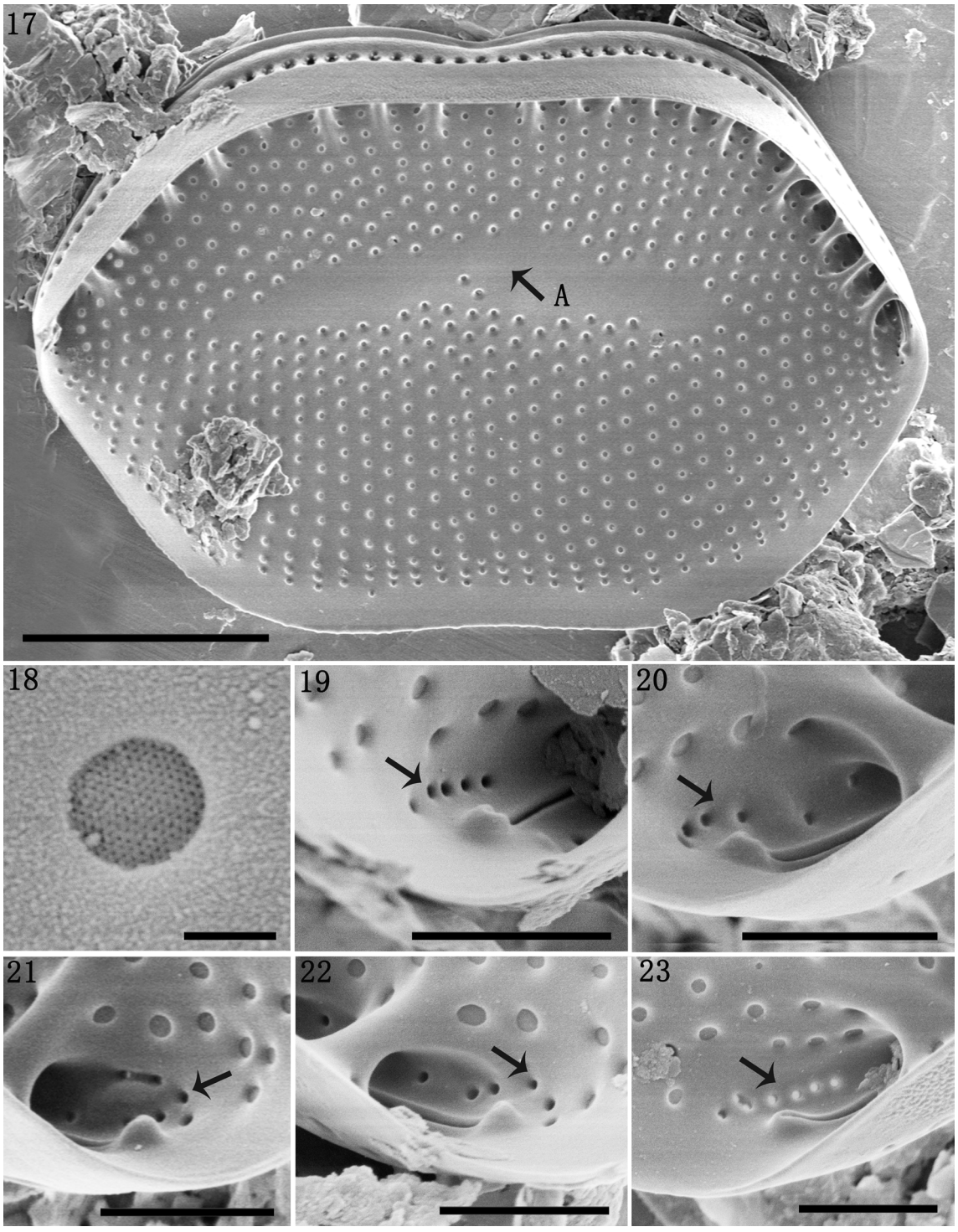

Figs 17–23. *Psammodictyon taihuensis* sp. nov., SEM views of valve: (17) general internal valve view, (arrow A) one unornamented longitudinal fold; (18) the details of the areolae on the internal valve; (19–23) detail of the apices on the internal valve, (arrow) occluded depressions. Scale bars 5 μm (17), 0.1 μm (18), 1 μm (19–23).

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