

Navicula gongshanensis sp. nov., a new diatom species from a high altitude lakes in southwest China

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ABSTRACT

A new diatom species, *Navicula gongshanensis* sp. nov., was described from high-altitude lakes of Gongshan County in southwestern China. Detailed morphological characteristics of this species are documented based on light microscopy (LM) and scanning electron microscopy (SEM). *Navicula gongshanensis* sp. nov. is similar to *N. radiosa*, *N. irmengardis*, *N. radiosafallax*, *N. broetzii* and *N. baicalirmengardis* in its narrow-lanceolate valve outline, but it differs from these species in terms of its valve size, stria and areolae density and the unique shape of its external areolae openings. Meanwhile, we retrieved 106 novel species (1982–2025) from the Web of Science database and compared the external areola opening shapes of *Navicula gongshanensis* sp. nov. with these retrieved taxa. These findings increase our understanding of the variability of species assigned to the genus and the morphology and distribution of the genus *Navicula* in China.

KEYWORDS

diatoms, morphology, new species, *Navicula*, electron microscopy

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INTRODUCTION

The diatom genus *Navicula* was established by Bory de Saint-Vincent (1822) as a broad taxonomic concept. Over the following centuries, its circumscription underwent substantial refinement through a series of critical revisions. Key works by Cleve (1894, 1895), Hustedt (e.g. 1959, 1961–1964), Patrick (1959) and Cox (1979) were instrumental in this process, particularly through the formal typification of the genus

with the neotype *Navicula tripunctata* (O.F.Müller, 1786, p. 52) Bory (1827, p. 563) (basionym: *Vibrio tripunctatus* O.F.Müller, 1786, p. 52). This foundational step prompted the progressive segregation of numerous genera from the broadly defined original genus *Navicula*, such as *Haslea* Simonsen (1974), *Luticola* D.G.Mann (Round et al., 1990), *Fallacia* Stickle et D.G.Mann (Round et al., 1990), *Lyrella* Karayeva (Karayeva, 1978), and *Aneumastus* D.G.Mann et Stickle (Round et al., 1990) among many others. As a result of this extensive taxonomic reorganization, the contemporary

understanding of *Navicula* Bory *sensu stricto* is now narrowly defined (Round, et al. 1990; Lange-Bertalot, 2001) as encompassing only the members of the section Lineolatae Cleve (1895).

Species within *Navicula* are characterized by a distinctive morphological suite of features, including a lanceolate valve outline with diverse apices, a variably asymmetrical sternum, and a straight, filiform raphe with unilaterally deflected proximal ends and strongly recurved distal ends. The striae are uniseriate, consisting of apically elongated areolae (lineolae), and this feature serves as a key diagnostic feature. These structural attributes collectively enable the clear delineation of *Navicula* from other diatom genera (Lange-Bertalot, 2001). According to AlgaeBase, the genus currently includes nearly 1768 accepted species names (Guiry & Guiry, 2025).

Yunnan Province in southwestern China is recognized as both a critical reservoir of China's biodiversity and a global biodiversity hotspot (Myers, et al. 2000). In recent years, continuous discoveries of new diatom taxa have been reported from the region, including new genera (e.g., *Qinia*, Liu et al., 2023) and new species (e.g., *Cymbella erhaiensis* (Zheng et al., 2025), *Navicula fuxianensis* (Guo et al., 2025), *Liparogyra sinensis* (Xiang et al., 2025), *Epithemia cistulina*, *Epithemia sinensis*, *Epithemia yunnaniana* (Ren et al., 2025), *Eunotia yunnanica*, *Eunotia sinensis*, *Eunotia obtusisaculea* (Liu et al., 2024), *Navicula sinicomeniscus* (Xiao et al., 2023), *Nupela shimenensis*, *Nupela yunnanica*, *Nupela magna*, *Nupela sinensis*, *Nupela comperei* (Liu et al., 2023). Notably, the report of *Oricymba gongshanensis* from Gongshan City in northwestern Yunnan (Guo et al., 2021) marked the first record of the genus *Oricymba* in the province. In this study, we discovered a novel species of *Navicula* in Gongshan City. In the present study, we identified a novel species of *Navicula* from the same area, distinguished by a unique external pore opening morphology—a feature not previously documented within the genus.

This study aims to describe a new taxon, *Navicula gongshanensis* sp. nov., discovered in a lake surface sediment sample from Gongshan City. The aims of this paper are: 1) present its morphological characteristics based on LM and SEM observations, and 2) compare its external pore opening shape with those of 89 previously reported *Navicula* species, as documented in the Web of Science literature.

MATERIAL AND METHODS

Gongshan County, situated in Yunnan Province, China (27°29'–28°23'N, 98°08'–98°56'E), covers an area of 4506 km² with an altitude span of 1170–5128 m. It features a typical temperate climate, recording an annual mean temperature of approximately 14.8 °C and an annual mean precipitation of 2700–4700 mm. Due to its unique geographical location and topographical characteristics, the county serves as a climatic and biodiversity corridor linking southern and northern regions.

In October 2015, the studied sample was collected from surface sediments (0.5 cm) in Gongshan-3 Lake, Gongshan County, Yunnan Province, China. Field measurements of lake water pH,

specific conductance, and dissolved oxygen were conducted using a YSI 650 multi-parameter display system (650 MDS, YSI Incorporated, 1700/1725 Brannum Lane, Yellow Springs, OH 45387, USA) equipped with a 600XL probe. Total nitrogen (TN) was determined following the persulfate digestion method described by Chen and Zhang (2015). Total phosphorus (TP) contents were analyzed via colorimetric analysis with molybdenum blue reagent, adhering to the protocol proposed by Qian et al. (1990). Laboratory sample cleaning followed the protocol described by Battarbee (1986). Specifically, calcium carbonate was dissolved using 10% HCl, and organic matter was oxidized with 30% H₂O₂. Following three cycles of rinsing and decantation in distilled water, diatom slides were prepared: a portion of the cleaned diatom material was air-dried on coverslips, which were then mounted on glass slides with Naphrax®. Holotype permanent slides and cleaned samples were deposited in the Herbarium of the Institute for Ecological Research and Pollution Control of Plateau Lakes, Yunnan University, Kunming, P.R. China (YUK), while isotype slides were stored at the Key Laboratory of Biodiversity of Aquatic Organisms, Harbin Normal University.

Morphological features of diatoms were examined using a light microscope (LM; OLYMPUS BX51) equipped with Differential Interference Contrast (DIC) optics, a ×1500 oil immersion objective lens (numerical aperture = 1.4), and an Olympus C5060 digital camera for image acquisition. For each surface sediment sample, a minimum of 500 diatom valves were taxonomically identified and enumerated to ensure statistical representativeness. For scanning electron microscopy (SEM) observations, aliquots of the cleaned diatom sample were air-dried onto glass cover slips, which were then mounted intact onto aluminum stubs. The stubs were sputter-coated with a 20 nm-thick gold (Au) layer using an EMSCOP SC 500 sputter coater to enhance electron conductivity. Coated samples were analyzed and imaged using a LEO 1530 SEM operated at an acceleration voltage of 5–10 kV. All SEM and LM micrographs were processed for brightness, contrast, and plate arrangement using Adobe Photoshop (CS5, Version 12.1; Adobe Systems Inc., San Jose, CA, USA). Taxonomic descriptions of the new diatom species followed the terminology established by Lange-Bertalot (2001).

RESULTS

Division Bacillariophyta Haeckel, 1878, p. 95.

Class Bacillariophyceae Haeckel 1878 emend D.G.Mann in Round et al., 1990, p. 651.

Subclass Bacillariophycidae D.G.Mann in Round et al., 1990, p. 125

Order Naviculales Bessey, 1907, p. 284

Table 1. Physical and chemical parameters in Gongshan-3 Lake.

Latitude (°N)	27°45'19"
Longitude (°E)	98°28'2"
Altitude (m)	3655
pH	6.34
Dissolved oxygen (mg·L ⁻¹)	6.01
Conductivity (μs·cm ⁻¹)	7
TP (μg·L ⁻¹)	82.6
TN (μg·L ⁻¹)	19.3
SD (m)	9.5

Family Naviculaceae Kützing, 1844, p. 88
Genus Navicula Bory, 1822, p. 128
Section Lineolatae sensu Cleve 1895

Navicula gongshanensis Y.-L. Li sp. nov. (Figures 1–25)

Description

LM (Figures 1–13): Valves narrow-lanceolate with rather acutely rounded ends, never protracted. Length 28.5–37.5 μm , width 4.7–5.0, length/width ratio 6.1–7.5 μm ($n=30$). Raphe filiform with proximal ends that weakly lateral to the secondary side. Striae 16–18 in 10 μm . Central area small, one to two shortened striae occur on both sides in the central area. The transapical striae are strongly radiate, bent in the valve center and convergent near the poles.

SEM (Figures 14–25): Externally, raphe sternum externally slightly raised. Central raphe endings deflected to the secondary side, weakly drop-like expanded (Figure 18, black arrows). The terminal fissures appear hooked towards the secondary side of the valve (Figures 17, 19, white arrows). Striae uniseriate, composed of apically elongated lineolae, “P”-shaped, a small portion of C-shaped (Figure 18, white arrowheads). At the apices, several areolae visible (Figures 17, 19, black arrowheads).

Internally, striae lie in shallow transapical depressions (Figure 24, black arrows). Raphe sternum slightly widened at centre (Figure 24, white arrows). Central raphe endings weakly deflected to the secondary valve side, intermissio present (Figure 24, white arrowheads); distal raphe endings with well-developed helictoglossae (Figure 23 and 25, black arrowheads).

Holotype: PYU! slide no. GS2015101501, deposited in Yunnan University, Kunming, China. The holotype slide contains multiple specimens; Figures 1–13 illustrate the size range and morphological variability of the holotype population, with Figure 2 showing a representative valve. **Isotype:** HANU! slide no. YUNGL20220801, deposited in Harbin Normal University, Harbin, China.

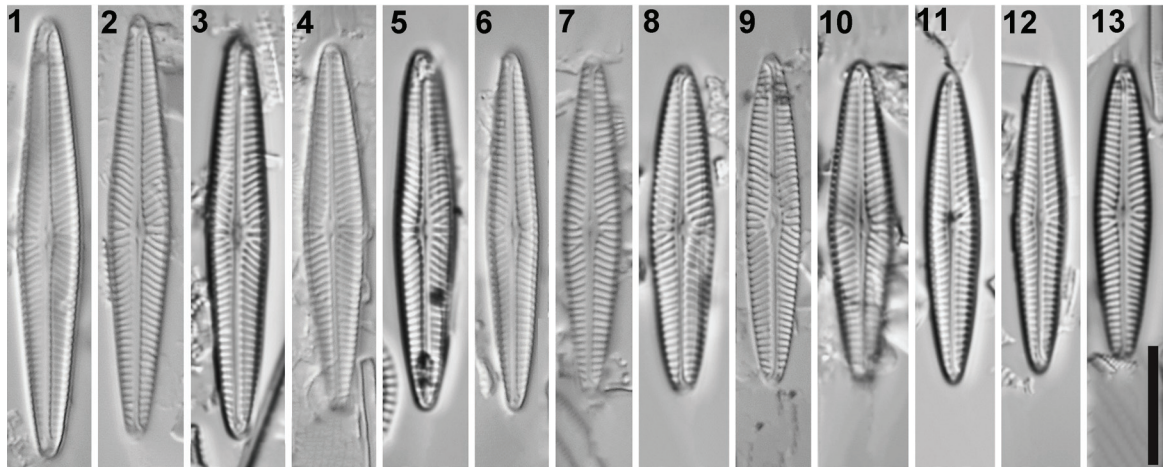
Type locality: China. Yunnan Province: Gongshan country, Gaoligong Mountain, 27°45'19"N, 98°28'2"E, elevation 3655 m a.s.l., 15 October 2015, surficial sediment samples collected by Prof. Yan-Ling Li.

Etymology: gongshanensis referring to the type locality from which the new species was described.

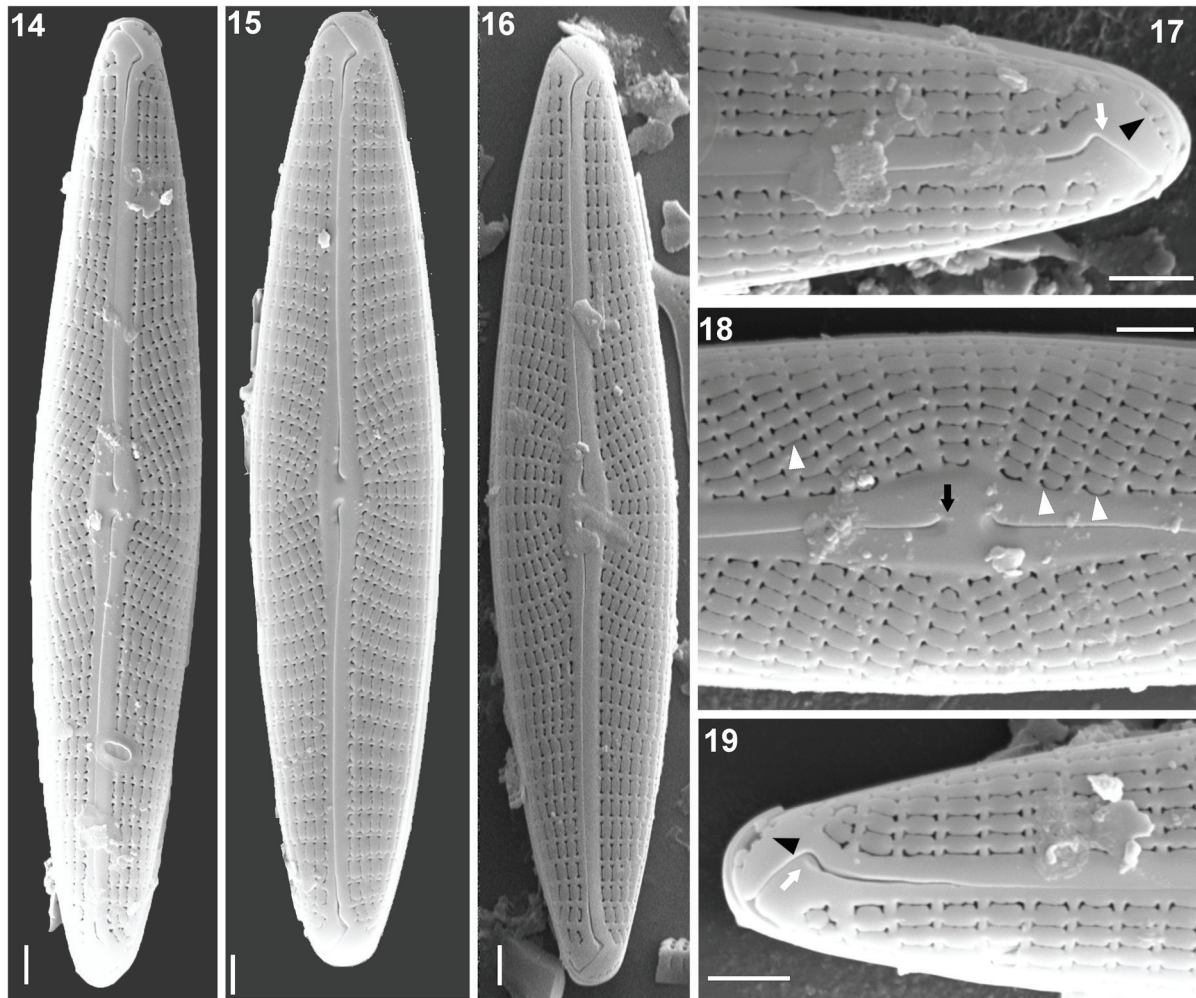
Ecology: *Navicula gongshanensis* is known from the surface sediments of GS3, situated at 3655 m a.s.l. Environmental measurements from the site at the time of collection include pH (6.34), dissolved oxygen of 6.01 $\text{mg}\cdot\text{L}^{-1}$, conductivity of 7 $\mu\text{S}\cdot\text{cm}^{-1}$, total nitrogen of 82.6 $\mu\text{g}\cdot\text{L}^{-1}$, total phosphorus of <10 $\mu\text{g}\cdot\text{L}^{-1}$, ammonia nitrogen of 19.3 $\mu\text{g}\cdot\text{L}^{-1}$ (Table 1). At this site, diatom assemblages were dominated by *Achnanthes curtissima* J.R.Carter (1963, p. 200), *Achnantheidium minutissimum* (Kützing) Czarnecki (1994, p. 157), *Psammothidium subatomoides* (Hustedt) Bukhtiyarova et Round (1996, p. 13), *Aulacoseira distans* (Ehrenberg) Simonsen (1979, p. 57), *Encyonema silesiacum* (Bleisch) D.G.Mann (1990, p. 667), *Eunotia bilunaris* (Ehrenberg) Schaarschmidt (1881 “1880”, p. 159), *Gomphonema parvulum* (Kützing) Kützing (1849, p. 65).

Table 2. Morphological and morphometric comparison of *Navicula gongshanensis* sp. nov. to the most similar taxa.

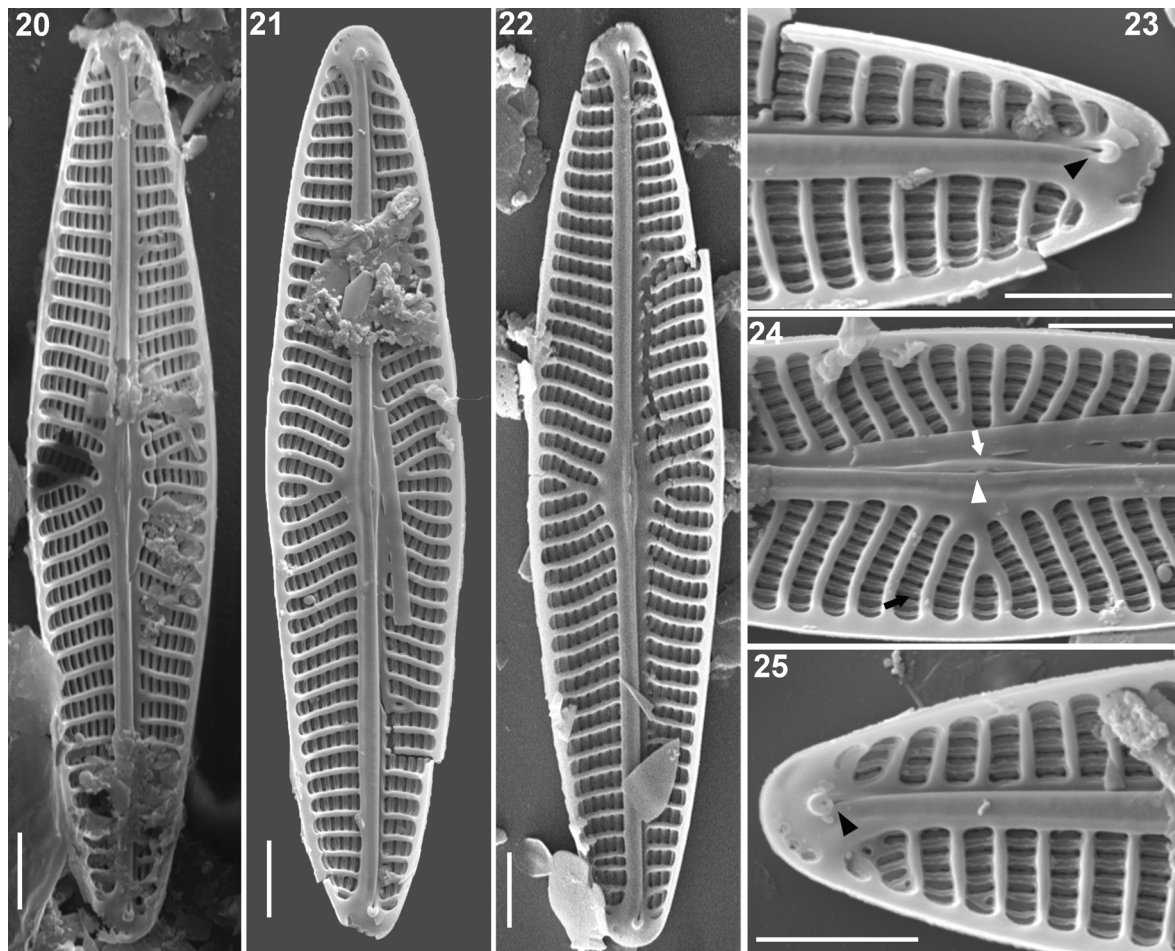
	<i>Navicula gongshanensis</i>	<i>N. radlosa</i>	<i>N. imengardis</i>	<i>N. radlosifallax</i>	<i>N. broetzii</i>	<i>N. baicalimengardis</i>
Valve outline	Narrow-lanceolate	Narrow-lanceolate	Narrow-lanceolate	Linear-lanceolate	Lanceolate	Narrow-lanceolate
Valve apices	Acutely rounded, never protracted	Narrowing to acutely rounded	Acutely rounded, never protracted	Obtusely wedge-shape, not protracted	Wedge-shape, not protracted, almost acutely rounded	Acutely rounded, never protracted
Valve length (μm)	28.5–37.5	40–120	25–46	30–50	38–70	28–44
Valve width (μm)	4.7–5.0	8–12	4.5–5.5	5.6–6.6	6.5–9	5.0–7.9
Number of striae in 10 μm	16–18	10–12	15–16	13–14	11–13	16–18
Number of lineolae in 10 μm	ca. 50 (SEM)	28–32	30	33–35	31–35	ca. 40 (SEM)
Areolae	“P”-shaped, C-shaped	Lineolae	-	-	Lineolae	Lineolae
Reference	This study	Lange-Bertalot 2001	Lange-Bertalot 1996	Lange-Bertalot & Metzeltin 1993	Lange-Bertalot & Metzeltin 1996	Kulikovskiy et al. 2012



Figures 1–13. *Navicula gongshanensis* sp. nov., LM, DIC. Valve views, showing size range and variability of the type population. Figure 2 represents a typical valve of the species. Scale bar 10 μ m.



Figures 14–19. *Navicula gongshanensis* sp. nov., SEM, external views. (14–16) External view of an entire valve. (17, 19) Valve apices, the terminal fissures appear hooked towards the secondary side of the valve (white arrows), several areolae visible (black arrowheads). (18) External view of valve center, central raphe endings deflected to the secondary side, weakly drop-like expanded (black arrows), striae uniseriate, “I”-shaped, a small portion of C-shaped (white arrowheads). Scale bar 1 μ m.



Figures 20–25. *Navicula gongshanensis* sp. nov., SEM, internal views. (20–22) Internal view of an entire valve. (23, 25) Valve apices, distal raphe endings with well-developed helictoglossae (black arrowheads). (24) Internal view of valve center, raphe sternum slightly widened at center (white arrows), intermissio present (white arrowheads). Scale bar 2 μ m.

DISCUSSION

The newly described species *Navicula gongshanensis* possesses the complex of morphological characters, notably the narrow-lanceolate valve shape, the straight raphe with unilaterally curved proximal ends and strongly deflected distal ends, and uniseriate striae that help assign it to the genus *Navicula*. This species also shares features with specific *Navicula* species in its narrow-lanceolate valve outline, such as: *N. radiosa* Kützinger (1844, p. 91), *N. irmengardis* Lange-Bertalot (in Lange-Bertalot & Metzeltin 1996, p. 78), *N. radiosafallax* Lange-Bertalot (1993, p. 131), *N. broetzii* Lange-Bertalot & E.Reichardt (in Lange-Bertalot & Metzeltin 1996, p. 77) and *N. baicalirmengardis* Kulikovskiy, Lange-Bertalot & Metzeltin (2012, p. 179). However, it is distinguished from other species by denser striae, higher density of areolae, and the unique shape of its external areolae openings. The characters of *Navicula gongshanensis* are compared with those of four congeners in Table 2, informing the subsequent comparative discussion and contrast of taxonomic features.

Navicula gongshanensis shares a similar valve

outline with *N. radiosa* and *N. irmengardis*, as all are narrow-lanceolate. However, regarding cell dimensions, *Navicula gongshanensis* ($28.5\text{--}37.5 \times 4.7\text{--}5.0$ μ m) is smaller than *N. radiosa* ($40\text{--}120 \times 8\text{--}12$ μ m) and *N. irmengardis* ($25\text{--}46 \times 4.5\text{--}5.5$ μ m). Secondly, a comparison of striae density reveals that *Navicula gongshanensis* possesses 16–18 striae in 10 μ m, significantly higher than that of *N. radiosa* (10–12 in 10 μ m) and *N. irmengardis* (15–16 in 10 μ m). Similarly, the number of lineolae in 10 μ m for *Navicula gongshanensis* (ca. 50, based on SEM) is considerably greater than that of *N. radiosa* (28–32 in 10 μ m) and *N. irmengardis* (30 in 10 μ m). Compared to *N. radiosafallax* and *N. broetzii*, *Navicula gongshanensis* can primarily be distinguished by its valve outline: *Navicula gongshanensis* is narrow-lanceolate, while *N. radiosafallax* is linear-lanceolate and *N. broetzii* is lanceolate. Furthermore, *Navicula gongshanensis* has smaller cell dimensions, along with a higher density of both striae and lineolae per 10 μ m. *N. gongshanensis* is similar to *N. baicalirmengardis* in valve outline, valve apices, and the number of striae in 10 μ m, but *N. baicalirmengardis* has larger cell dimensions ($28\text{--}44 \times 5.0\text{--}7.9$ μ m) and a sparser areolae density

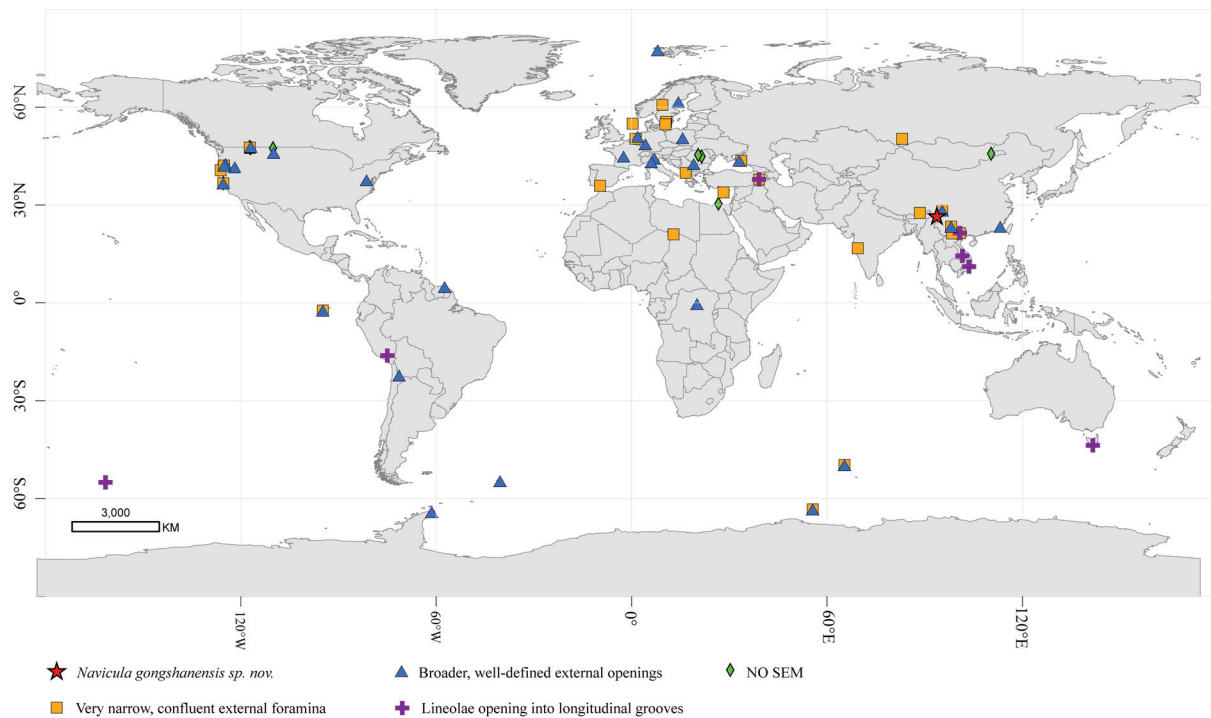
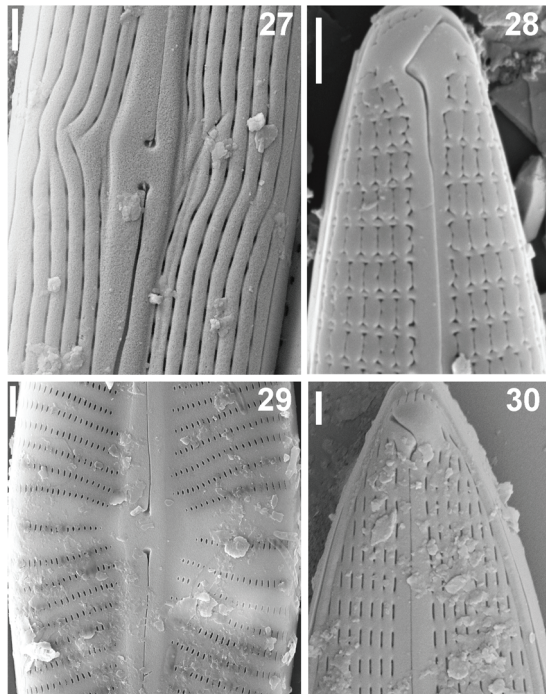


Figure 26. Distribution map of 106 newly reported *Navicula* species from 1982 to 2025. pentagram shape denote locations where *Navicula gongshanensis* sp. nov. was discovered; squares represent species with very narrow, confluent external foramina; triangles denote broader, well-defined external openings; cross shape indicate lineolae opening into longitudinal grooves; rhombuses denote NO SEM.

(ca. 40 in 10 μ m). Finally, regarding the areolae shape, *Navicula gongshanensis* exhibits a significant difference from the other species. The areolae of *Navicula gongshanensis* are predominantly “I”-shaped, with a minority being C-shaped, whereas those of *N. radiosa*, *N. broetzii* and *N. baicalirmengardis* are characterized as lineolae.

The genus *Navicula* is principally defined by the presence of slit-like areolae, or lineolae, as described by Round et al. (1990), Cox (1999) and Lange-Bertalot (1980, 2001). These lineolae are typically arranged in uniseriate striae, situated internally within alveoli or between broad, elevated interstriae (virgae, sensu Lange-Bertalot). Unlike valve shape or symmetry, which are prone to intraspecific variation due to vegetative cell size reduction during asexual reproduction, the lineolate striae structure remains consistent across different size classes of conspecific individuals (Cox, 2025). Additional diagnostic characteristics include a naviculoid valve shape and a slit-like raphe, the ends of which are curved toward the secondary side of the valve. Furthermore, as Cox (1999) noted, the external openings of these lineolae exhibit differentiation, ranging from very narrow, occasionally confluent foramina to broader, well-defined openings. To investigate this morphological diversity a systematic literature search was conducted using the Web of Science database, focusing on recently described species within *Navicula*. This process identified 106 novel species described between 1982 and 2025, which were selected for comparative analysis of their external areolae openings (Supplementary Table 1). The descriptions of these openings could be classified into three main types:

“Very narrow, confluent external foramina” (Figure 30, Cox 1999, figures 22, 27, 38, 40–42), “Broader, well-defined external openings” (Figure 29, Cox 1999, figures 1–3, 11, 16, 39) and “Lineolae opening into longitudinal grooves” (Figure 27). Notably, *Navicula gongshanensis* displays a distinctive I-shape in its apically elongated external openings, a morphology not reported in any of the other 106 species examined, thereby distinguishing it from all previously documented representatives. The discovery of the distinctive I-shaped areolae openings in *Navicula gongshanensis* suggests a previously unrecognized morphological diversity within the genus. This aligns with broader insights from naviculoid diatom systematics: as Cox (2025) emphasizes, morphological structural features—such as areolar structure, occlusion types (e.g., hymenate or cribrate), rib systems, and raphe characteristics—are more reliable than traditional valve shape and symmetry for revealing phylogenetic relationships. These so-called “building-block” structures not only persist stably within a species even during size reduction, conferring significant taxonomic value, but are also primarily determined by genetic and developmental programs rather than rapid phenotypic plasticity in response to environmental conditions. Supporting this, in species reported in relevant literature from 1982 to 2025, taxa sharing the same areolar structure type have been documented in distinctly different habitats (Supplementary Figures S1, S2), yet their core areolar morphology does not vary significantly with environmental shifts. This further confirms that areolar type is a relatively stable homologous trait reflecting deep evolutionary history



Figures 27–30. Different areolar opening types of *Navicula* species. (27) Presents *Navicula perangustissima* with “lineolae opening into longitudinal grooves”. (28) Shows *Navicula gongshanensis* sp. nov. with an I-shaped opening. (29) Illustrates *Navicula fuxianensis* displaying “broader, well-defined external openings”. (30) Depicts *Navicula fuxianturiformis* featuring “very narrow, confluent external foramina”. Scale bar 1 μ m (27, 28, 30), 2 μ m (29).

among lineages rather than convergent adaptation, and thus should be prioritized as a core character indicative of phylogenetic affinity in naviculoid diatom classification and phylogeny. Similar ideas have been put forward by Nikolaev and Harwood (2002) for centric diatoms, Kulikovskiy et al. (2020) for monoraphid diatoms and Mironov et al. (2024) for cymbelloid diatoms.

Species of the genus *Navicula* exhibit extremely strong ecological adaptability, distributed across all continents and various aquatic ecosystems worldwide. They are widespread and form considerable populations in both marine and freshwater environments. In recent years, newly reported species have been found in diverse habitats such as lakes (e.g. Jiang et al., 2025; Yilmaz et al., 2024), streams (e.g. Cantonati et al., 2024), spring (e.g. Cid-Rodríguez et al., 2024) and reservoir (e.g. Kulikovskiy et al., 2022). The newly discovered species in this study, however, show specific distribution in a particular alpine lake, whose core habitat characteristics are high altitude, low disturbance, and oligotrophy. This specific distribution not only reveals the adaptability potential of *Navicula* species to extreme habitats but also provides an important basis for the research and conservation of diatom diversity in alpine freshwater ecosystems.

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