

Taxonomy of the *Gomphoneis tetrastigmata* species complex

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Abstract Two new, recent diatoms, *Gomphoneis okunoi* sp. nov. and *Gomphoneis pseudookunoi* sp. nov. are described from River Arakawa and Lake Shikotsu, where they were previously identified either as *Gomphonema tetrastigmatum*, *Gomphonema quadripunctatum*, or *Gomphonema olivaceoides*. Two new combinations, *Gomphoneis olivaceoides* (Hust.) J.R. Carter & Bailey-Watts ex. Tuji comb. nov. and *Gomphoneis calcifuga* (Lange-Bert. et E. Reichardt) Tuji comb. nov. are also proposed, based on SEM observations. The forms of vegetative valve and initial valve structure are compared. *G. okunoi* differs from *Gomphoneis tetrastigmata* in morphology of central area and the length of polar terminals. *G. okunoi* also differs from *G. quadripunctatum* by lacking a septum. *G. pseudookunoi* differs from *G. okunoi* by the small size its vegetative and initial valves.

Key words: *Gomphoneis okunoi* sp. nov., *Gomphoneis pseudookunoi* sp. nov., *Gomphoneis olivaceoides* (Hust.) J.R. Carter & Bailey-Watts ex. Tuji comb. nov., *Gomphoneis calcifuga* (Lange-Bert. et E. Reichardt) Tuji comb. nov., *Gomphoneis tetrastigmata*, *Gomphonema quadripunctatum*, lectotype.

Introduction

Species of *Gomphoneis* are important components of the freshwater periphyton and sometimes become the dominant species in Japanese rivers and lakes (Tuji, 1995). The taxonomy of the *Gomphoneis quadripunctatum* species complex was first studied by Kociolek & Stoermer (1988). However, their paper focused primarily on specimens from Lake Baikal; no Japanese specimens were considered.

For species of *Gomphoneis* from Japan, Okuno (1944) described the fossil species *Gomphonema tetrastigmatum* Horik. et Okuno from Yatuka deposit, Japan; Okuno (1974) later reported this taxon from a Recent freshwater habitat. However, it appears that *G. tetrastigmatum* sensu Okuno (1974) differs from *G. tetrastigmatum* sensu Okuno 1944 (Tuji, 2004). More recently, Ohtsuka (2002) transferred *G. tetrastigmatum* to the genus *Gomphoneis* based on specimens from Hii River. However, Ohtsuka's specimens are not related to those of *G. tetrastigmatum* Okuno 1944 but are more similar to those used by Okuno in 1974.

Thus, *G. tetrastigmatum* sensu Okuno (1974) requires re-description, as a new taxon, *Gomphoneis okunoi* sp. nov. A further new species, *Gomphoneis pseudookunoi* sp. nov., is described from recent freshwater habitat.

Materials and Methods

The following materials have been examined:

1. Material numbered AS6642 from Hustedt collection in BRM, the type material of *Gomphonema olivaceoides* (Simonsen, 1987).
2. Material numbered AS1262 from Hustedt collection in BRM, the type material of *Gomphonema olivaceum* var. *minutissimum* (Simonsen, 1987).
3. Slide numbered 4368 from Østrup collection in C, the holotype *Gomphonema olivaceum* var. *quadripunctata*.
4. Material numbered TNS-AL-54241 in TNS collected from R. Arakawa by A. Tuji on 25th November, 2004.
5. Material numbered TNS-AL-TW-1331 from T. Watanabe collection in TNS collected from

Tikubu-shima, Lake Biwa (Sample No: C2) by T. Watanabe on 4th July, 1988.

6. Material numbered TNS-AL-TW-6274 from T. Watanabe collection in TNS collected from northern part of Minae, Lake Shikotsu by T. Watanabe on 24th June, 1990.

Results and discussion

Gomphoneis quadripunctatum (Østrup) P.A. Dawson ex R.Ross et P.A.Sims, *Bacill.* **1**: 162.

(Plate 1: 1-9)

Basionym: *Gomphonema olivaceum* var. *quadripunctatum* Østrup, *Nov. Hedw.* **48**: 85. f. 11. 1908.

Synonym: *Gomphonema quadripunctatum* (Østrup) Wislouch, *Ber. dt. bot. Ges.* **42**: 166. 1924.

Lectotype (designated here): 4368 in Østrup collection in C. (Plate 1: 7-9).

Type locality: Kossogol, Mongolia.

Distribution: Mongolia (Edlund et al., 2001), Lake Baikal (Skvortzov and Meyer, 1928) and USA? (Patrick and Reimer, 1975).

Previous examination of type specimens was undertaken by Foged (1971) and Kociolek & Stoermer (1988); my own observations are in accord with their descriptions. The valvocoupla of *Gomphoneis quadripunctatum* has a very clear septum (Plate 1: 3, 6, 7, Skvortzov and Meyer, 1928, Foged 1971, Kociolek and Stoermer, 1988). This character also occurs in *Gomphoneis hastata* (Wislouch) Kociolek & Stoermer, *Gomphoneis tumida* (Skvortzov) Kociolek & Stoermer and *G. tumida* var. *oestrupii* from Lake Baikal (Kociolek & Stoermer, 1988). Although *G. quadripunctatum* is very similar to Japanese *Gomphoneis* species described below, the septum is not so obvious in LM's of Japanese species.

Gomphoneis olivaceoides (Hust.) J.R.Carter

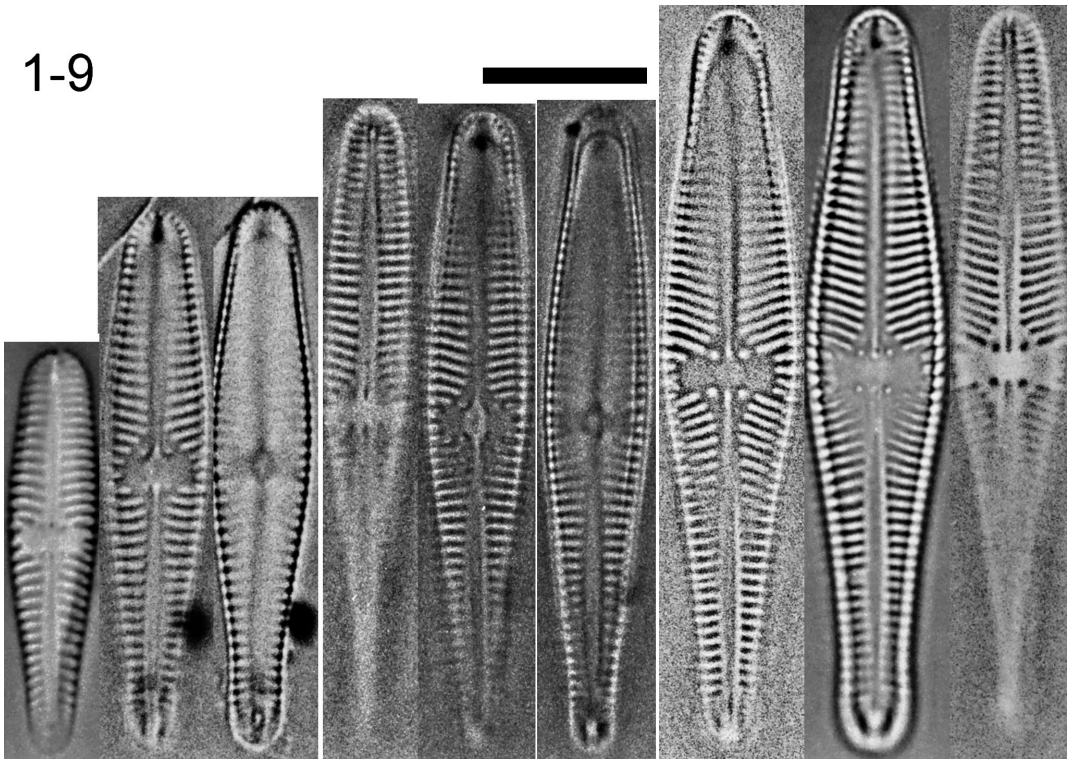


Plate 1. 1-9. *Gomphoneis quadripunctatum* (Østrup) P.A.Dawson ex R.Ross et P.A.Sims. Slide 4368 in Østrup collection in C. LM. 7-9. Lectotype (designated here). Bar: 1 μ m.

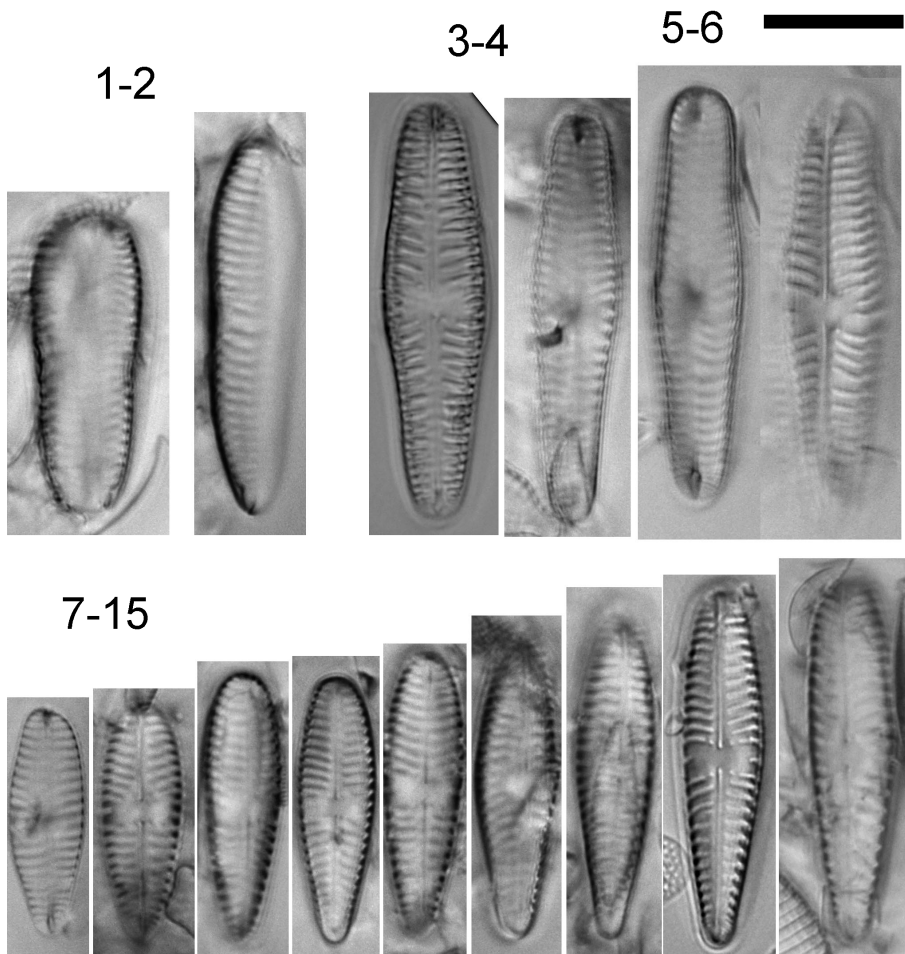


Plate 2. 1–15. *Gomphoneis olivaceoides* (Hust.) J.R.Carter and Bailey-Watts ex. Tuji comb. nov. AS6642 from Hustedt collection in BRM (Type material). LM. Bar: 1 μ m.

and Bailey-Watts ex. Tuji comb. nov.

(Plate 2: 1–15, Plate 3: 1–4, Plate 4: 1–5)

Basionym: *Gomphonema olivaceoides* Hust., *Arch. Hydrobiol.* **3**: 397. pl. 37. f. 9–12. 1950.

Holotype: S3/2. Schaalsee, Krustenstein. (micrographs in Simonsen 1987: Plate 543/28–35).

Type locality: Schaalsee, Germany.

Synonym: *Gomphoneis olivaceoides* (Hust.) J.R.Carter and Bailey-Watts, *Nov. Hedw.* **33**: 566. pl. 9. f. 49–51. 1981. excl. figs et desc.

Distribution: Germany, Ireland (Foged 1977), USA (Patrick and Reimer 1975), Canada (Reavie & Smol, 1998).

This taxon is best placed in the genus *Gomphoneis* as it has four stigmata in its central area

(Plate 1: 3–15) and biseriate striae (Plate 3: 1–4, Plate 4: 1–5). Foged (1971) studied this taxon and similar taxa, suggesting *G. tetrastigmatum* Horik. et Okuno and *Gomphonema separatipunctatum* H.Kobayasi (both described from Japan) as synonyms. Carter and Bailey-Watts (1981) noted this taxon from the Shetland Isles, transferring it *Gomphoneis*. However, their transfer is invalid as it lacked a complete citation of the basionym; it is transferred here. Nomenclature to one side, the specimens illustrated in Carter & Bailey-Watts (1981) and Krammer & Lange-Bertalot (1991) are not those implied by Hustedt, but of *Gomphoneis calcifuga* (Lange-Bert. et E. Reichardt) Tuji comb. nov. described below. Huizhog and Ji-

ayou (2000) reported *G. olivaceoides* from China but a girdle septum is clearly illustrated and hence it cannot be *G. olivaceoides* but another taxon.

Gomphoneis calcifuga (Lange-Bert. et E. Reichardt) Tuji comb. nov.

(Plate 5: 1–17, Plate 6: 1–4, Plate 7: 1, Plate 8: 1–2)

Basionym: *Gomphonema calcifugum* Lange-Bert. & E.Reichardt in Lange-Bert., *Iconogr. Diatomol.* **6**: 53. 1999, nom. nov.=*Gomphonema olivaceum* var. *minutissimum* Hustedt.

Holotype: S1/52. Passau, Brunnen. (micrographs in Simonsen 1987: Plate 195/8-11).

Type locality: Bayern (springs near Passau), Germany

Synonym: *Gomphonema olivaceum* var. *minutissimum* Hustedt in Pascher, *Süssw.-Fl.*, ed. **2**, **10**: 378, f. 720. 1930.

Gomphonema separatipunctatum H.Kobayasi, *Bull. Chichibu Mus. Nat. Hist.* **12**: 74, pl. 15, f. 57, 1964, nom. invalid.

Gomphonema separatipunctatum H.Kobayasi, *J. Jap. Bot.* **40**: 350. pl. 13. f. 8. 1965, nom. invalid.

Distribution: Europe (Carter and Bailey-Watts 1981 as *G. olivaceoides*), USA (Patrick and Reimer, 1975), The far east of Russia (Watanabe personal data), Japan. Freshwater lakes and rivers.

Kramer & Lange-Bertalot (1985) considered *Gomphonema olivaceum* var. *minutissimum* to be a synonym of *G. olivaceoides*, a viewpoint adopted by many diatomists (e.g. Watanabe, 1990). However, Simonsen (1987) pointed out the differences between *G. olivaceum* var. *minutissimum* and *G. olivaceoides*: difference in density of striae, the form of central area and the size range of the valves. Hence, *G. olivaceum* var. *minutissimum* should be considered a distinct species. As it possesses biseriate striae (Plate 6: 1–4, Plate 8: 1), it should be placed in *Gomphoneis*. As specimens in Japanese Lakes (Lake Shikotsu: Plate 1: 16–17, Lake Masyu: Watanabe 1990 as *G. olivaceoides*) and rivers (R. Arakawa: Kobayasi 1965 as *Gomphonema separatipuncta-*

tum) are narrower than European specimens (including type specimens: plate 5: 1–15), it is thought that there may be distinct varieties. However, no clear differences were observed in SEM observations (Japan: Plate 8: 1–2, Europe: Plate 6: 1–4, Plate 7: 1), thus the Japanese specimens are included in this taxon. Foged (1971) suggested that *G. separatipunctatum* is a synonym of *G. olivaceoides*. More study is needed to establish the relationship between European and Japanese individuals of this species.

Gomphoneis tetrastigmata (Horik. et Okuno) T.Ohtsuka, *Diat.* **18**: 32. 2002.

(Plate 9: 1–12, Plate 10: 1–4, Plate 11: 1–3)

Basionym: *Gomphonema tetrastigmatum* Horik. et Okuno in Okuno, *Bot. Mag. Tokyo.* **58**: 10. f. 3e. 1944.

non: *Gomphonema tetrastigmata* sensu Okuno, *Diat. Elektr. Mikr.* **9**: 36–37. f. 911–912. 1974.

non: *Gomphoneis tetrastigmata* sensu T.Ohtsuka, *Diat.* **18**: 32. f. 77–80. 2002

Holotype: Slide no. 1110 in HIRO. (may be destroyed)

Lectotype: A photo dry plate numbered 1221 in TNS (designated in Tuji 2004). (Plate 9: 12)

Type Locality: Yatuka Deposit, Okayama Prefecture, Japan.

Distribution: Japanese Freshwater lakes.

Some information from the original material of this taxon is given in Tuji (2004). Although *Gomphoneis tetrastigmata* was described from fossil material, it has also been discovered in recent material, from Tikubu-shima, Lake Biwa, Japan (TNS-AL-11719). The morphological variation and ultrastructure were examined using this material. Specimens belong to the genus *Gomphoneis* as they possess biseriate striae (Plate 10: 1–4, Plate 11: 1–3), which are very coarse. There is a wide central area (Plate 9: 1–12), the head and foot pole are separated away from the valve ends and there are long terminal raphe fissures. These characters make identification simple for this species. It is rare in Lake Biwa.

Gomphoneis okunoi Tuji sp. nov.

(Plate 12: 1–10, Plate 13: 1–4, Plate 14: 1–5)

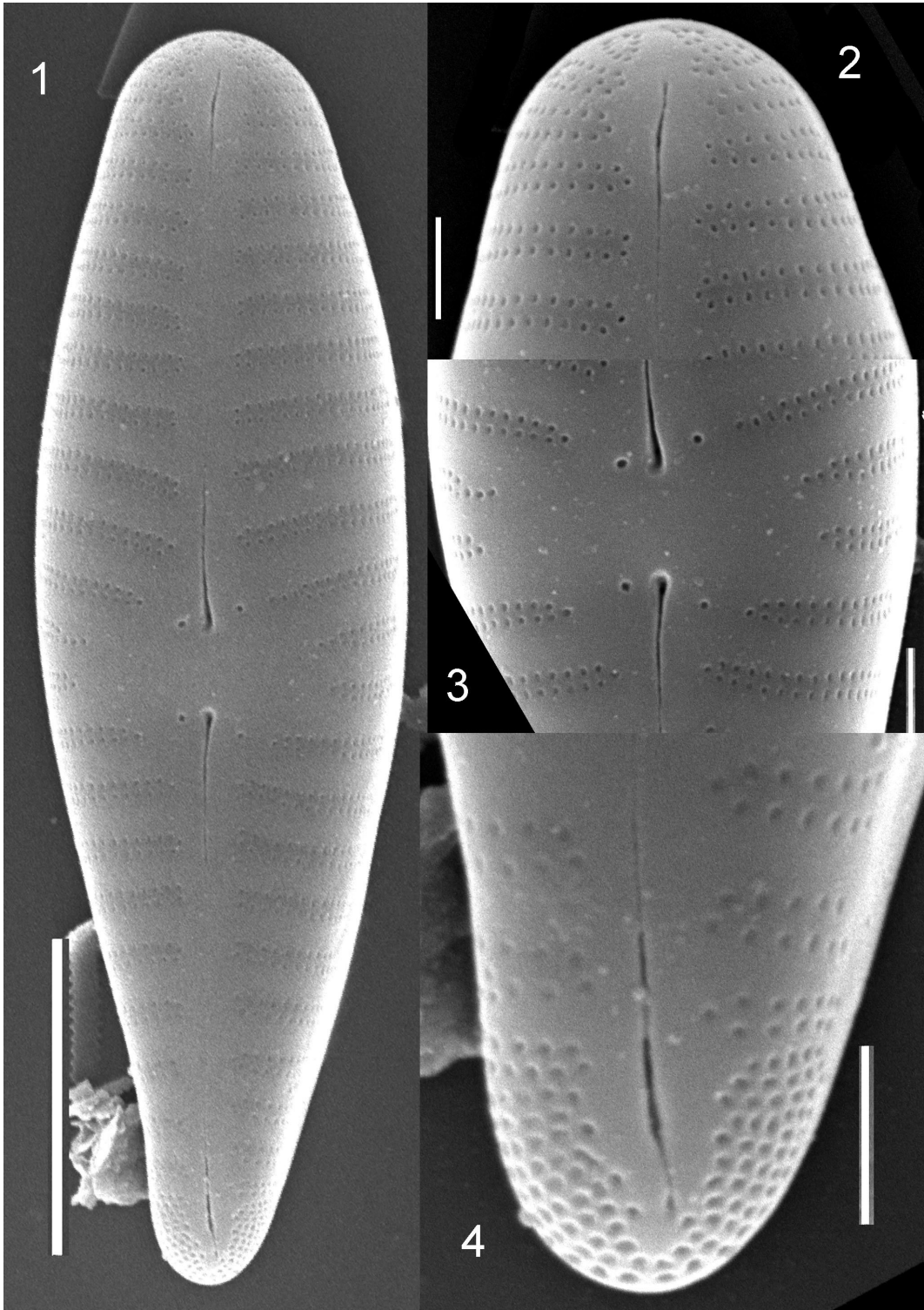


Plate 3. 1–4. *Gomphoneis olivaceoides* (Hust.) J.R.Carter and Bailey-Watts ex. Tuji comb. nov. AS6642 from Hustedt collection in BRM (Type material). SEM. Bar. 1: 5 μ m, 2–4: 1 μ m.

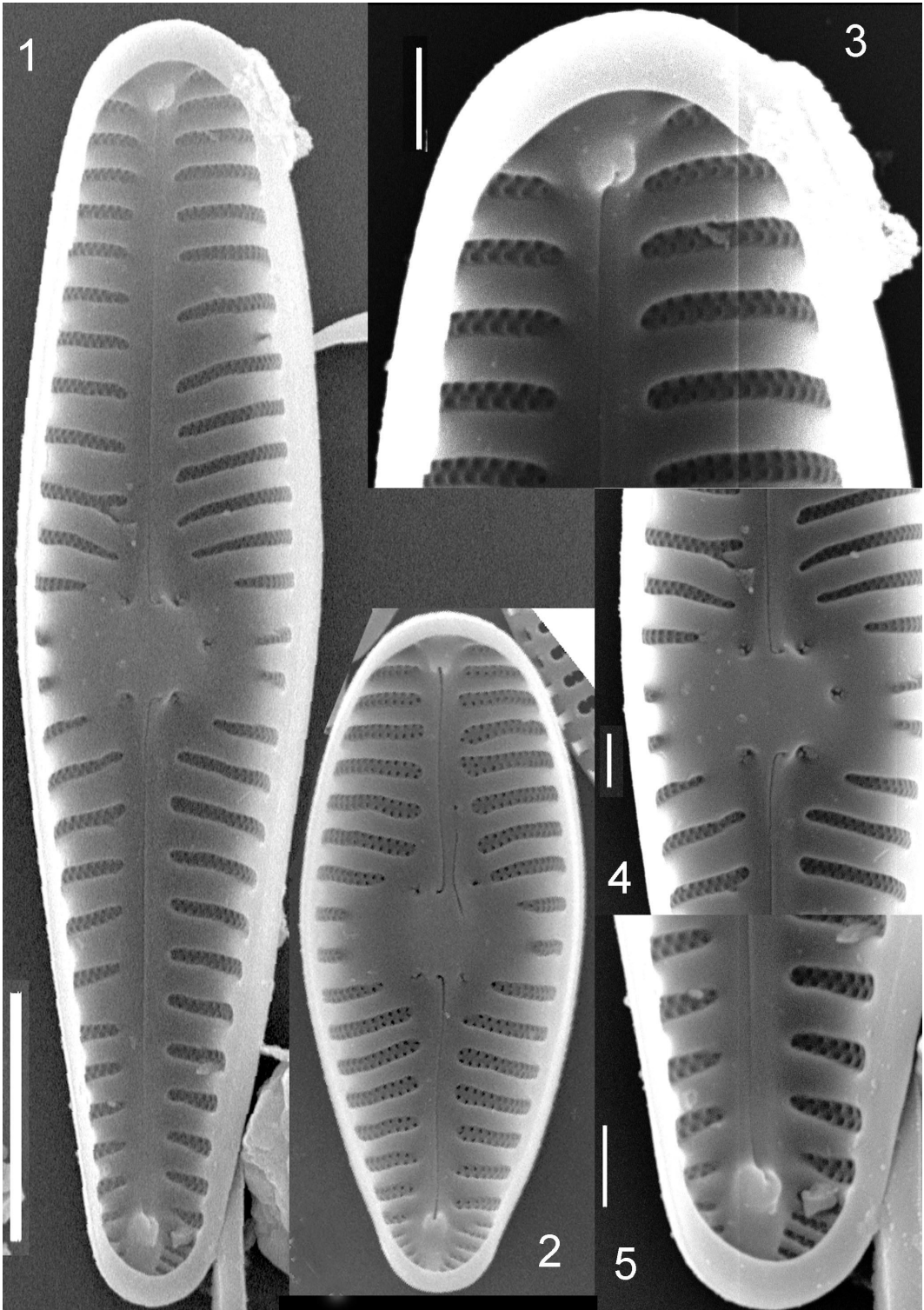


Plate 4. 1–5. *Gomphoneis olivaceoides* (Hust.) J.R.Carter and Bailey-Watts ex. Tuji comb. nov. AS6642 from Hustedt collection in BRM (Type material). SEM. Bar. 1–2: 5 μm , 3–5: 1 μm .

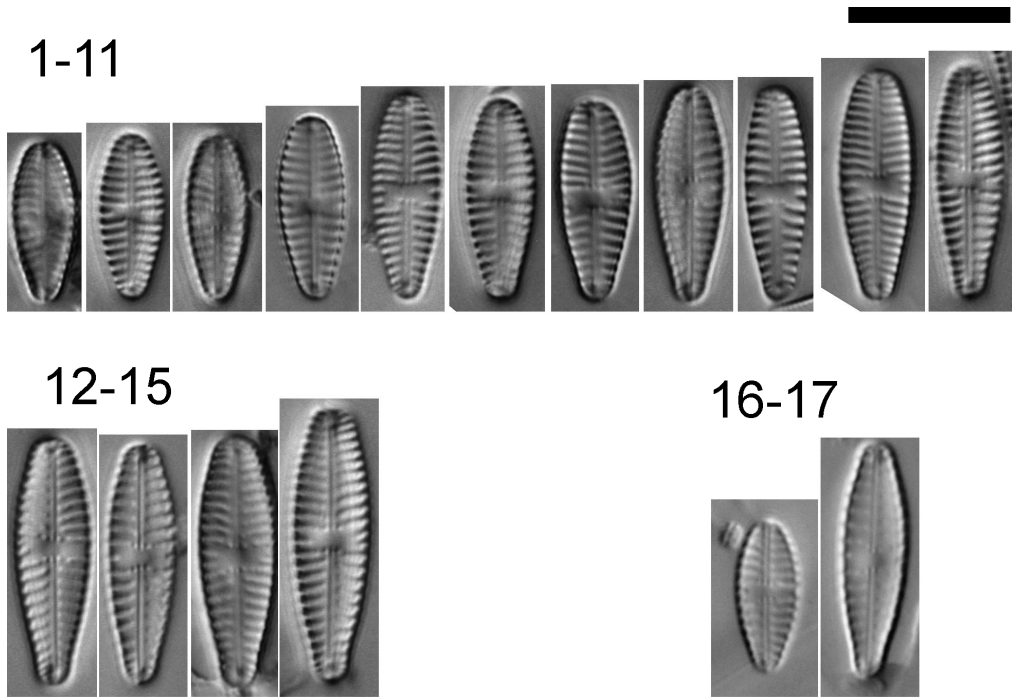


Plate 5. 1–17. *Gomphoneis calcifuga* (Lange-Bert. et E. Reichardt) Tuji comb. nov. 1–15. AS1262 from Hustedt collection in BRM (Type material). 16–17. TNS-AL-TW-6274 from L. Shikotsu. LM. Bar: 10 μm .

Holotype: A slide numbered TNS-AL-54241sc in TNS. (Plate 1: 10).

Type material; TNS-AL-54241m in TNS collected from R. Arakawa by A. Tuji on 25th November, 2004.

Isotype: BM101269 in BM, CAS221093 in CAS.

Synonym: *Gomphonema tetrastigmatum* sensu Okuno, *Diat. Elektr. Mikr.* **9**: 36–37. f. 911–912. 1974.

Gomphoneis tetrastigmata sensu T.Ohtsuka, *Diat.* **18**: 32. f. 77–80. 2002.

Habitat: Japanese freshwater lakes and rivers.

Descriptio: *Valvae clavatae, polo capitali quam pedali latius rotundatoobtuso, 14–50 μm longae, 7–11 μm latae. Differt A Gomphoneis tetrastigmata striae medianae semper subtilis. Puncta visa difficulter* (Plate 1: 1–10).

Description: Valve clavate, head pole more broadly rounded-obtuse than foot pole, length 14–50 μm , breadth 7–11 μm . Resembles *Gom-*

phoneis tetrastigmata, differs from it by finer median striae. Puncta difficult to dissolve (Plate 1: 1–10).

Striae gently radiate to parallel at valve ends, biseriate. Central area circular to acute-angled sub-fascia, four pores at central area, polar terminals closed to valve ends.

This taxon has often been confused with *G. tetrastigmatum* and *G. quadripunctatum* in Japan. Ohtsuka (2002) transferred *Gomphonema tetrastigmatum* to the genus *Gomphoneis* using Hii River specimens. The specimens used by Ohtsuka are not *G. tetrastigmatum* either. Despite Ohtsuka's misidentification, the name *Gomphoneis tetrastigmata* (Horik. et Okuno) T.Ohtsuka is correct for *Gomphonema tetrastigmatum* (International Code of Botanical Nomenclature). Most of the reports of *G. tetrastigmatum* and *G. quadripunctatum* from Japan are probably misidentified. Though the form of vegetative valves in this taxon is varies widely, the initial

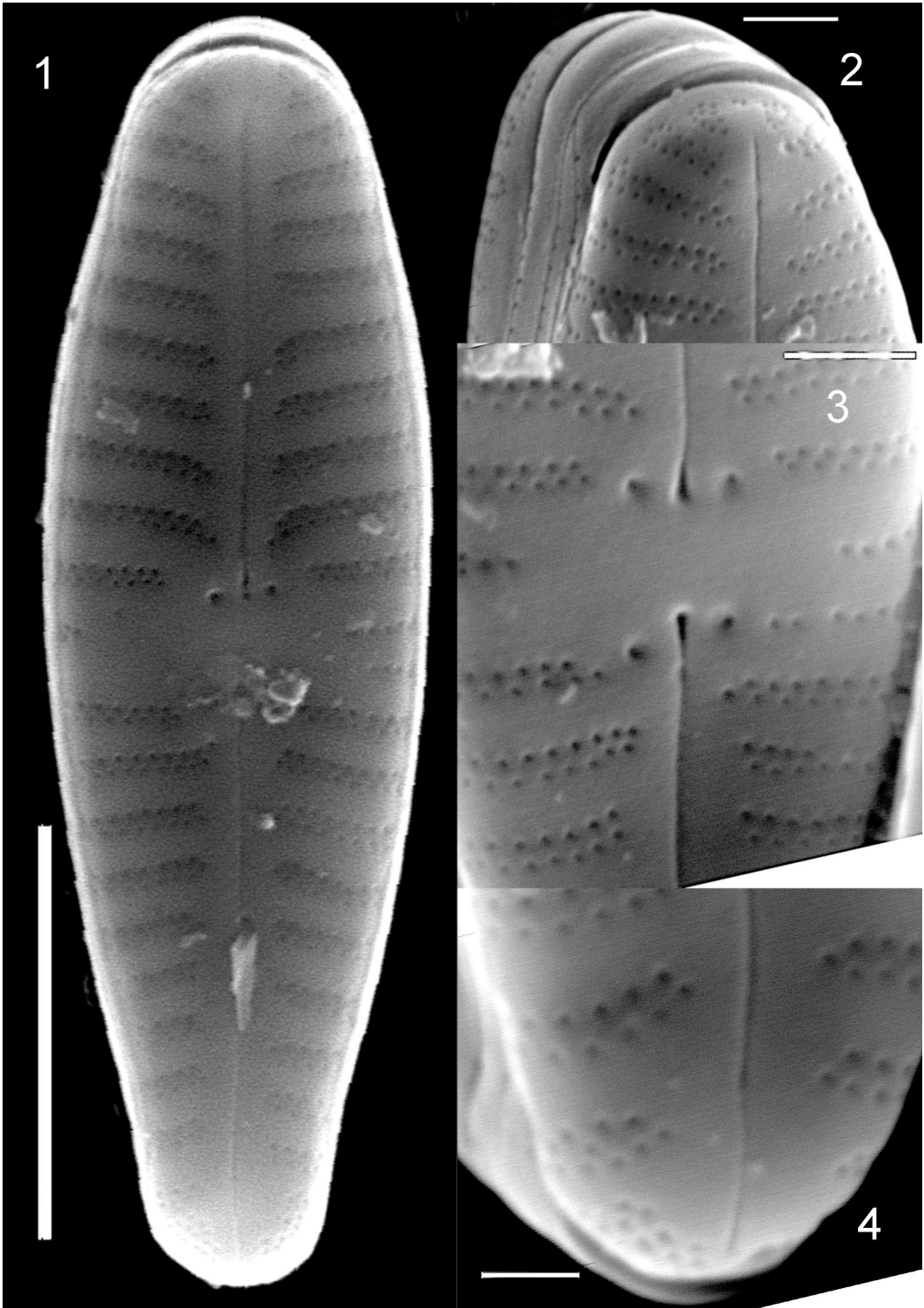


Plate 6. 1–4. *Gomphoneis calcifuga* (Lange-Bert. et E. Reichardt) Tuji comb. nov. AS1262 from Hustedt collection in BRM (Type material). SEM. Bar. 1: 5 μ m, 2–4: 1 μ m.

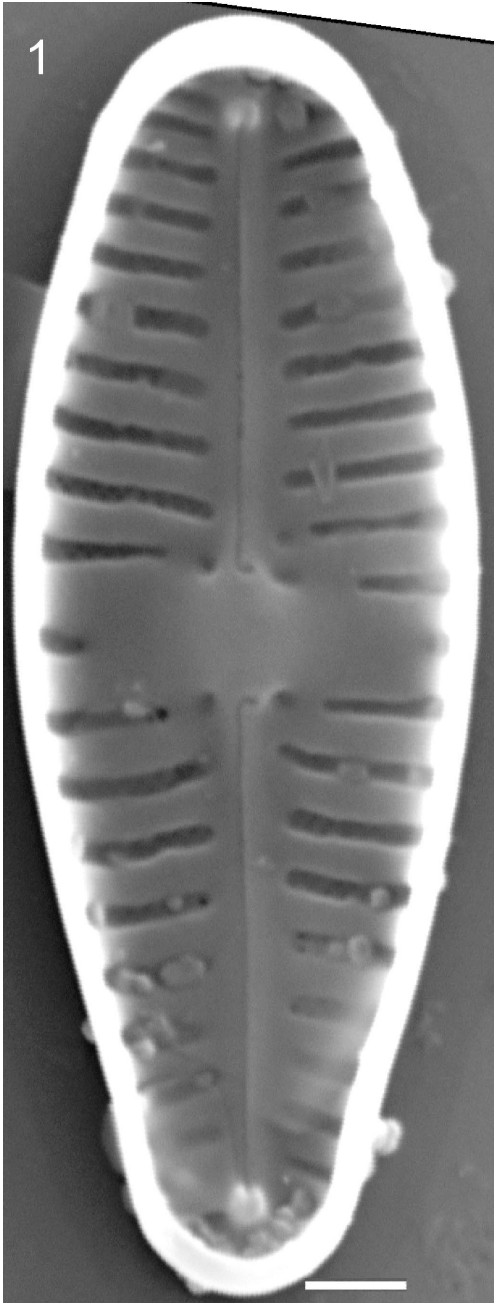


Plate 7. 1. *Gomphoneis calcifuga* (Lange-Bert. et E. Reichardt) Tuji comb. nov. AS1262 from Hustedt collection in BRM (Type material). SEM. Bar: 1 μm .

valve structure is very similar and varies within one taxon.

Seasonal succession and colonization process

of this taxon was reported by Tanaka & Watanabe (1990), Tuji (1995) and Tuji (2000a) under the name *G. quadripunctatum*. Autecology of this taxon related to light intensity also reported by Tuji (2000b) as *G. quadripunctatum*. This species occurred in the winter season in Japanese rivers (Tanaka & Watanabe, 1990) and Lakes (Tuji, 1995), and prefers low temperatures. In the culture condition (Tuji, 2000b), this taxon grew at 10°C and 200 $\mu\text{mol}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$ and did not grow 20°C and 200 $\mu\text{mol}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$ (Tuji unpublished data). These data also support the field information. This taxon is observed in less polluted rivers and lakes (xenosaprobic to oligosaprobic in saprobic level) and regarded as saproxenus taxon (Watanabe & Asai, 1992, Watanabe et al., 2005).

Gomphoneis pseudookunoi Tuji sp. nov.

(Plate 15: 1–15, Plate 16: 1–5, Plate 17: 1–5)

Holotype: A slide numbered TNS-AL-TW-6274 sc in TNS. (Plate 15: fig. 15).

Type material (Isotype): TNS-AL-TW-6274m in TNS collected from northern part of Minae, L. Shikotsu by T. Watanabe on 24th June, 1990.

Isotype: BM101270 in BM, CAS221094 in CAS.

Distribution: Japanese freshwater lake.

Descriptio: *Valvae clavatae, polo capitali quam pedali latius rotundatoobtusio, 12–37 μm longae, 5–7 μm latae. Differt A Gomphoneis okunoi proprie magnitudine semper minore. Puncta visa difficulter* (Plate 15: 1–15).

Description: Valve clavate, head pole more broadly rounded-obtuse than the foot pole, length 12–37 μm , breadth 5–7 μm . Resembles *Gomphoneis okunoi* but differs from it by smaller valves. Puncta difficult to dissolve (Plate 15: 1–15).

This taxon is also similar to *G. olivaceoides* but has a wider head pole and finer striae in the central area (Plate 15: 1–15). This taxon was found only in the type locality and is rare in Japan.

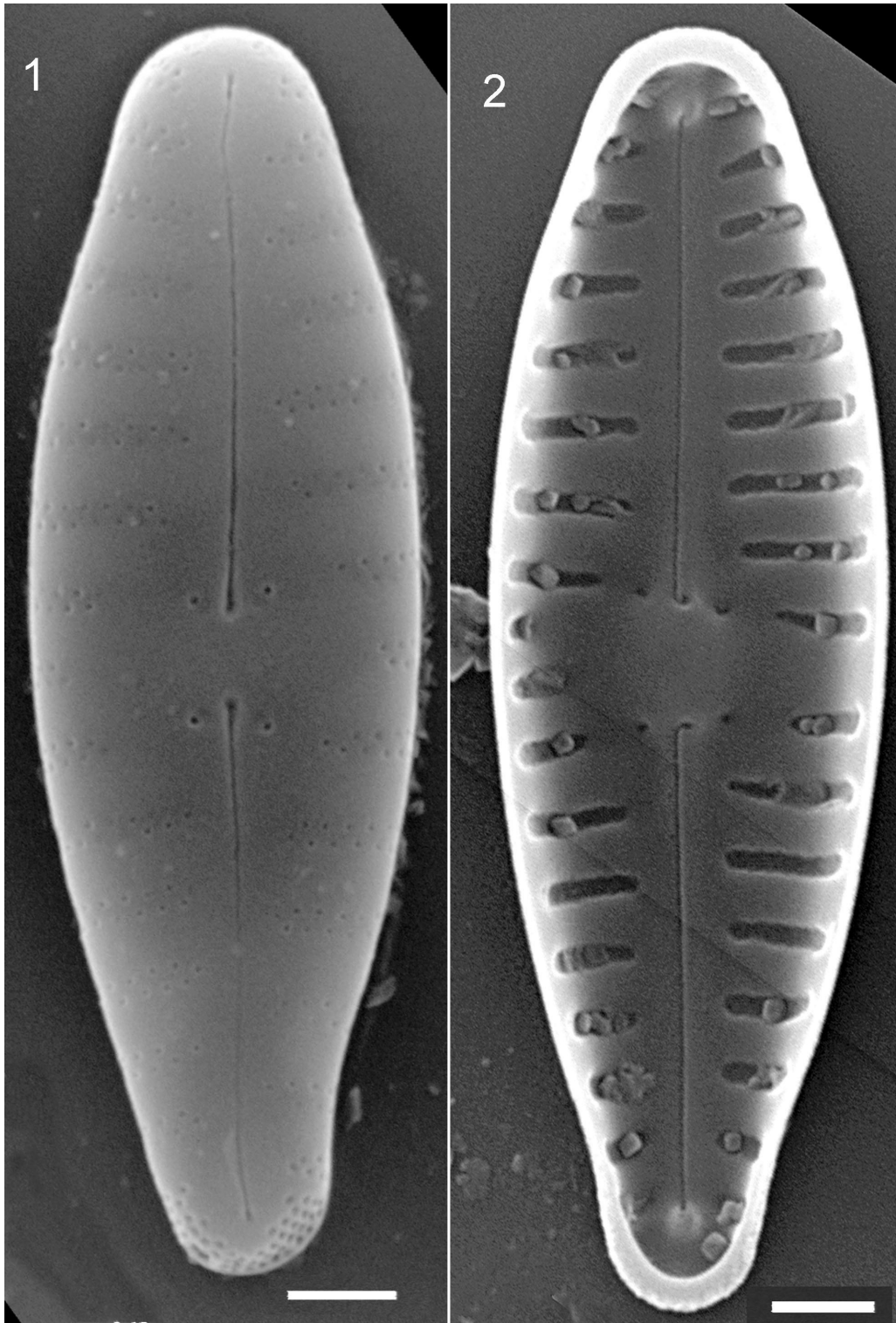


Plate 8. 1–2. *Gomphoneis calcifuga* (Lange-Bert. et E. Reichardt) Tuji comb. nov. TNS-AL-TW-6274 from L. Shikotsu. SEM. Bar: 1 μ m.

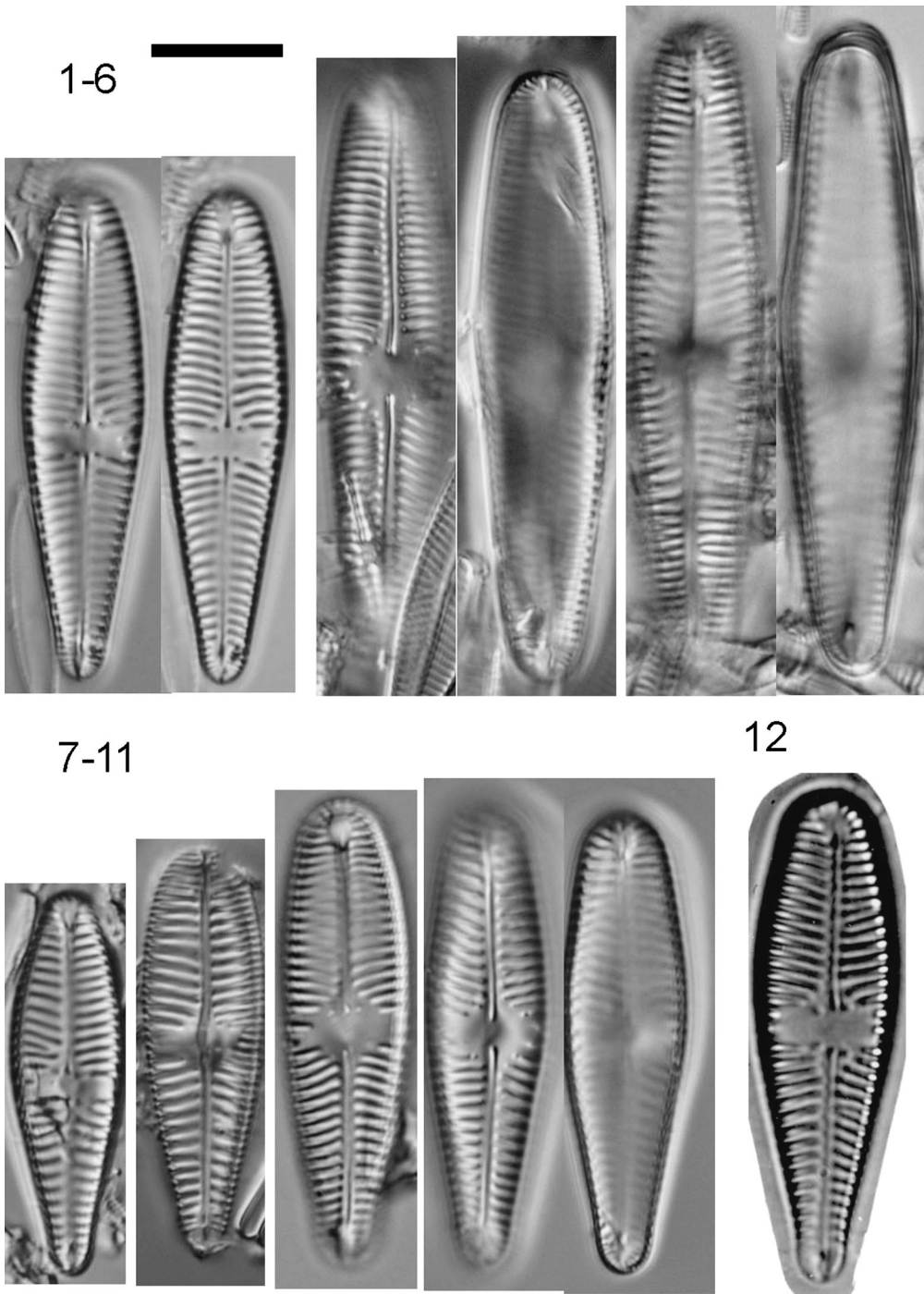


Plate 9. 1–12. *Gomphoneis tetrastigmata* (Horik. et Okuno) T.Ohtsuka. 1–11. TNS-AL-TW-1331 from Tikubushima, Lake Biwa. 12. Lectotype. A photo dry plate numbered 1221 in Okuno Coll. in TNS. LM. Bar: 10 μ m.

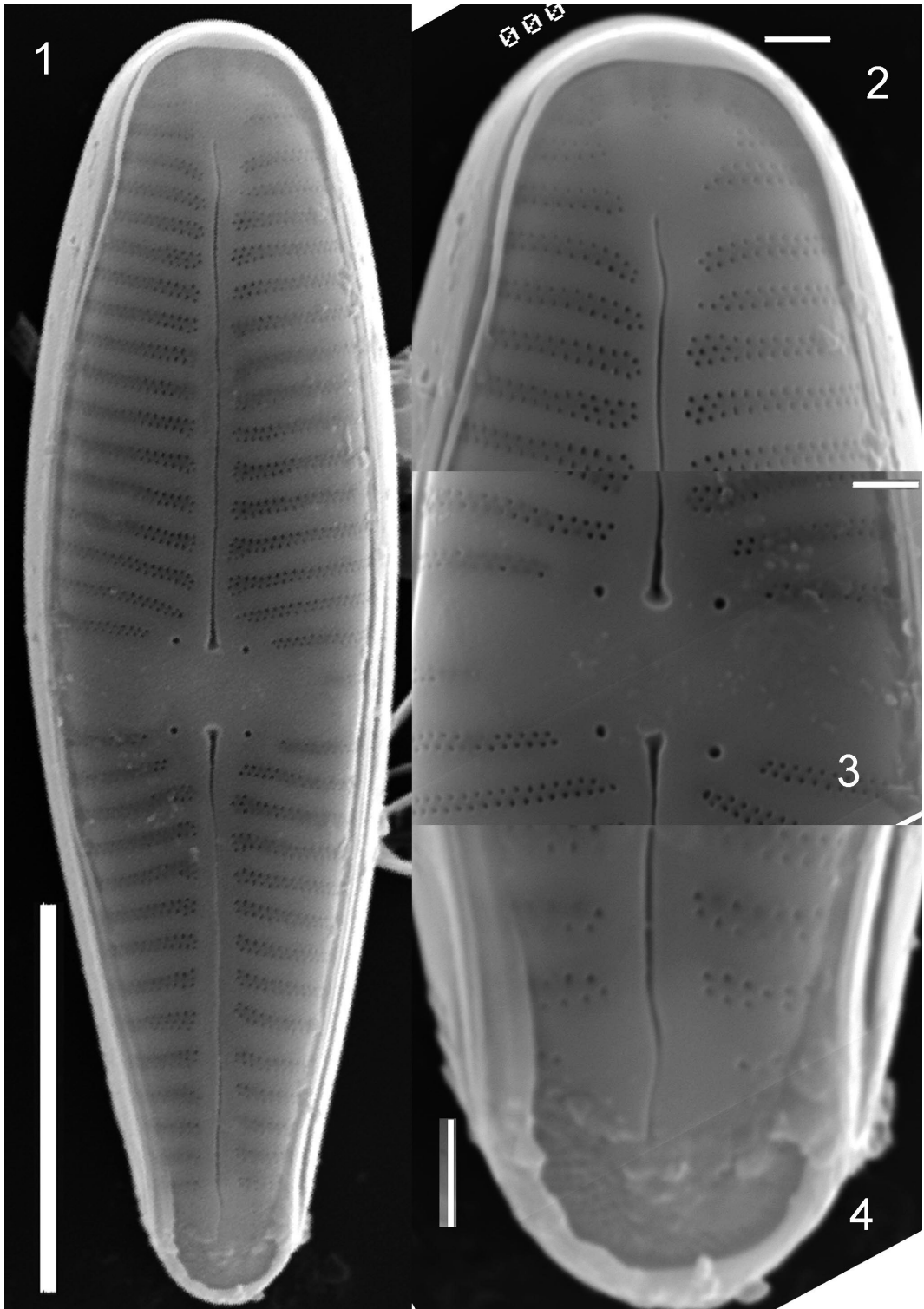


Plate 10. 1–4. *Gomphoneis tetrastigmata* (Horik. et Okuno) T.Ohtsuka. TNS-AL-TW-1331 from Tikubu-shima, Lake Biwa. SEM. Bar. 1: 5 μ m, 2–4: 1 μ m.

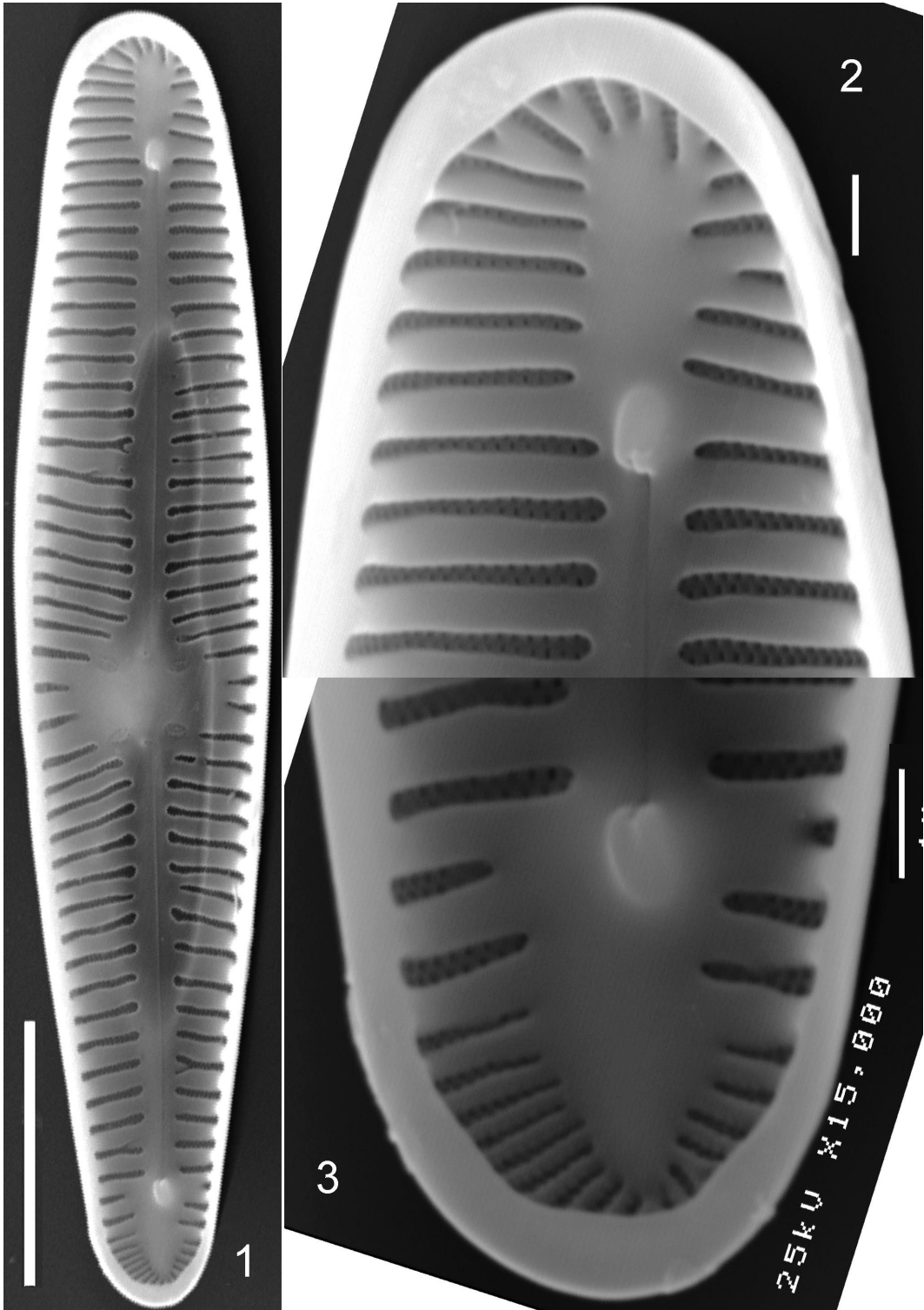


Plate 11. 1–3. *Gomphoneis tetrastigmata* (Horik. et Okuno) T.Ohtsuka. TNS-AL-TW-1331 from Tikubu-shima, Lake Biwa. SEM. Bar. 1: 5 μ m, 2–3: 1 μ m.

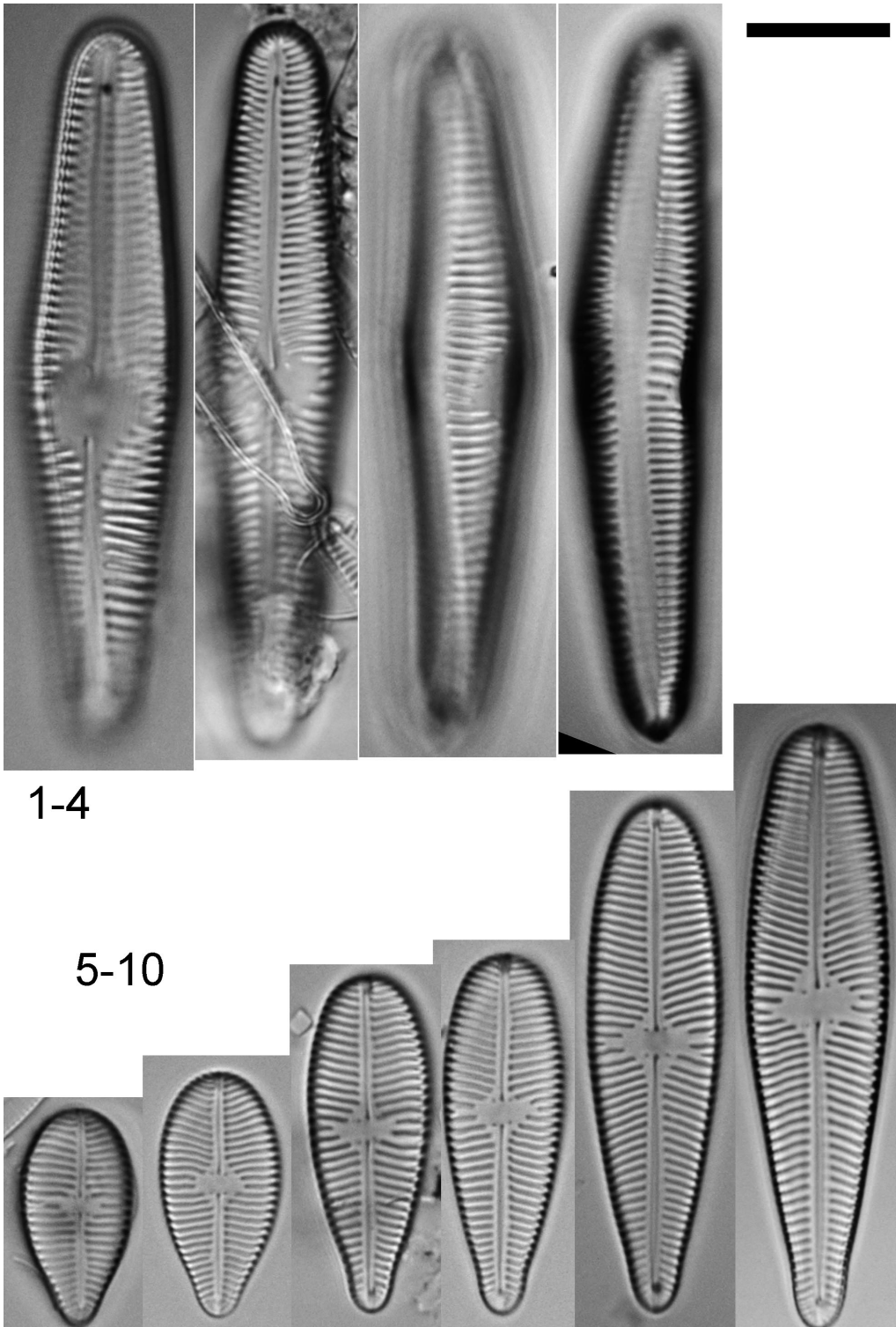


Plate 12. 1–10. *Gomphoneis okunoi* Tuji sp. nov. TNS-AL-54241sc. 10. Holotype. LM. Bar: 10 μ m.

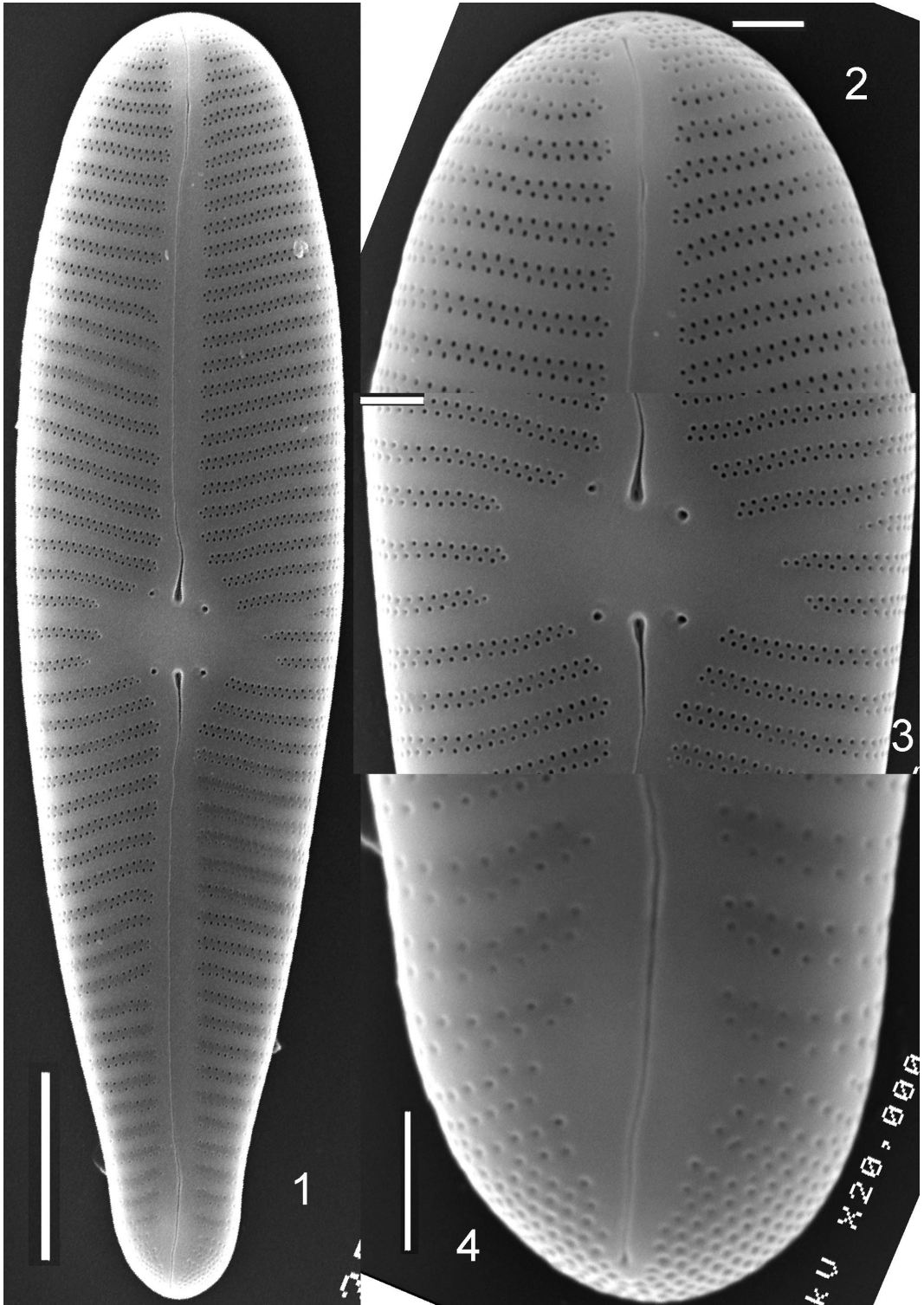


Plate 13. 1–4. *Gomphoneis okunoi* Tuji sp. nov. TNS-AL-54241m (Type material). SEM. Bar. 1: 5 μm , 2–4: 1 μm .

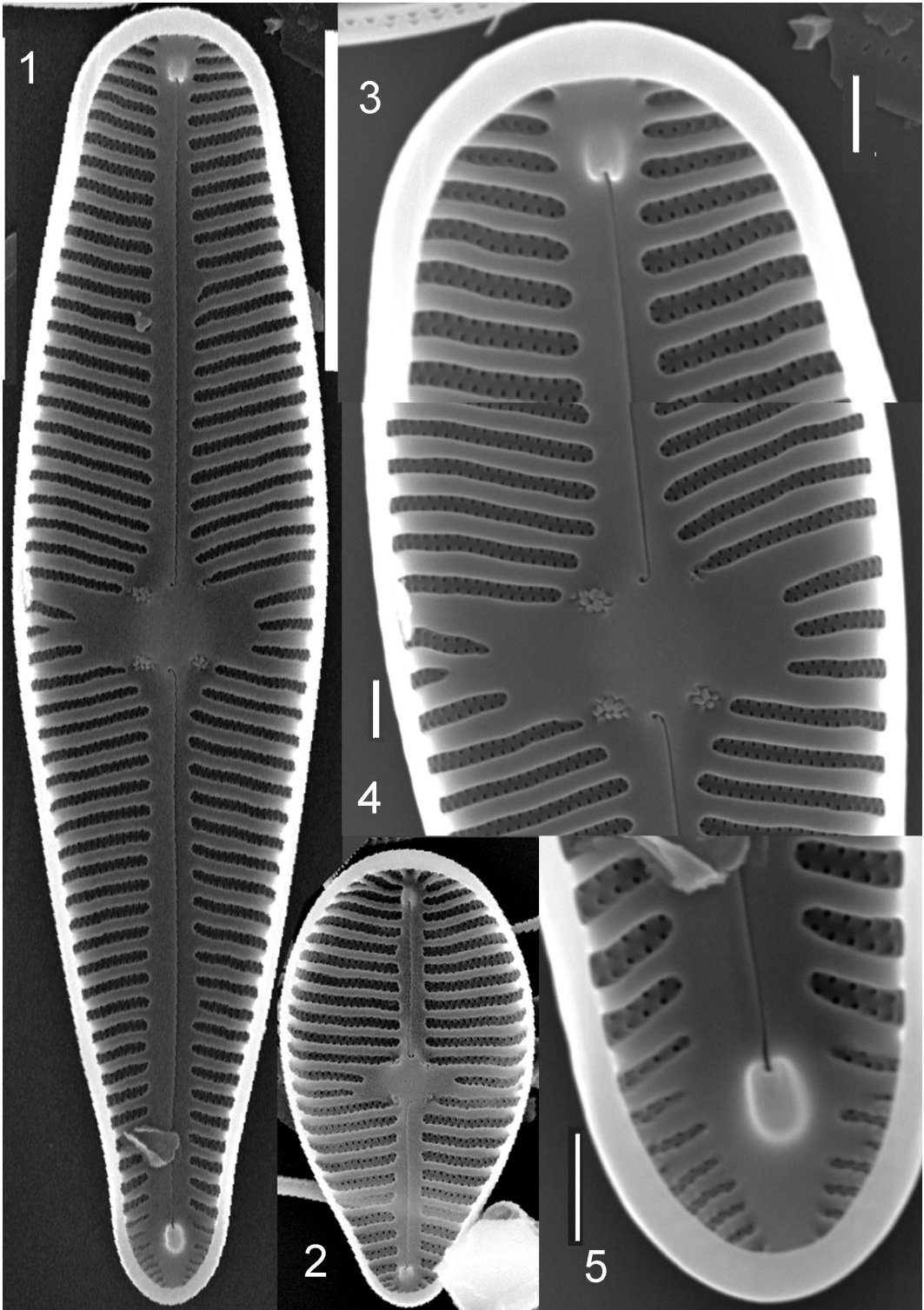


Plate 14. 1–5. *Gomphoneis okunoi* Tuji sp. nov. TNS-AL-54241m (Type material). SEM. Bar. 1–2: 5 μm , 3–5: 1 μm .

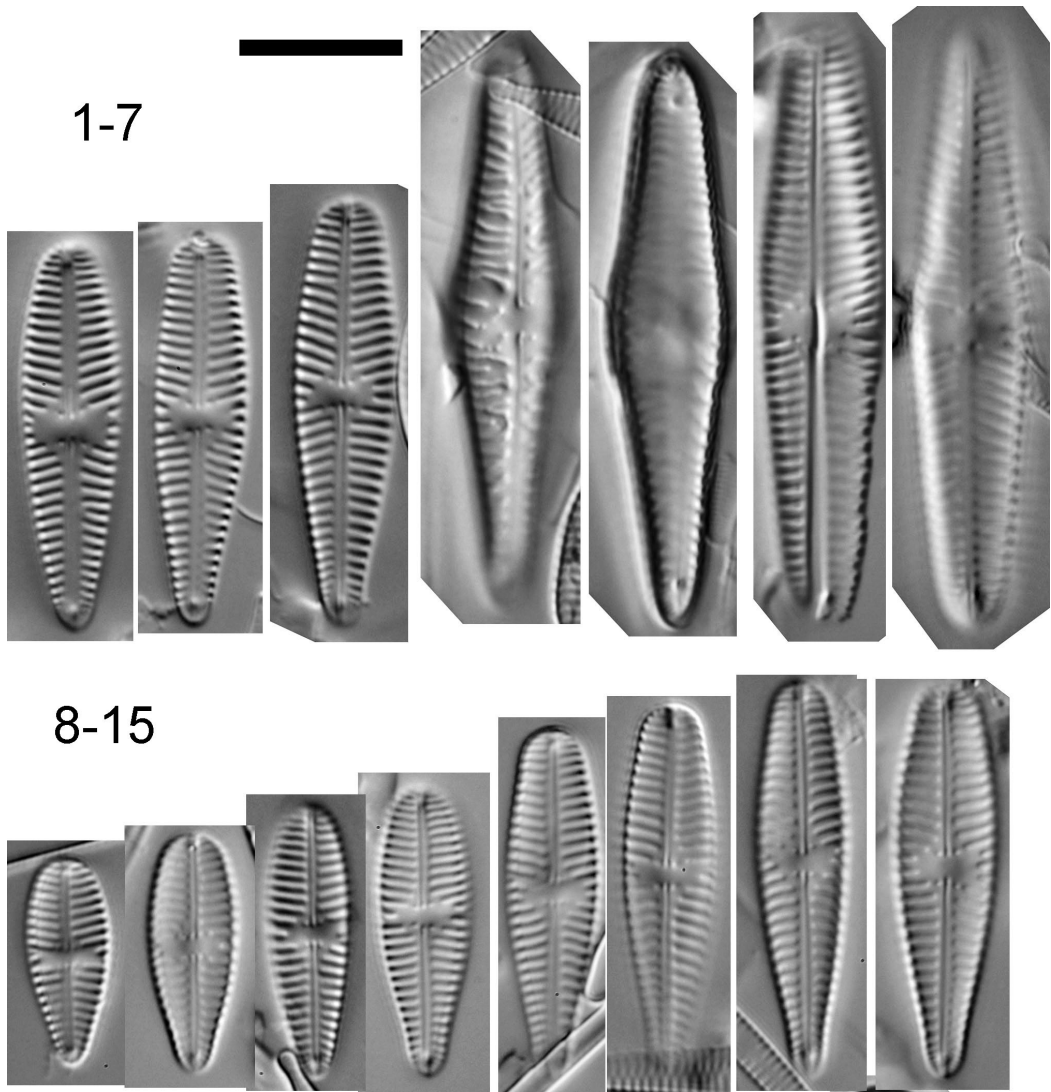


Plate 15. 1–15. *Gomphoneis pseudookunoi* Tuji sp. nov. TNS-AL-TW-6274sc. Holotype. LM. Bar: 10 μ m.

Conclusions

This species complex has previously been reported from the Northern Hemisphere; it has not been discussed from areas in the Southern Hemisphere (Australia: Foged 1978 and John 1983, New Zealand: Foged 1979 and Cassie 1989, New Caledonia: Moser 1999); there are no records from tropical or subtropical regions (Sri Lanka: Foged, 1976, Papua New Guinea: Vyverman, 1991, Sumatra: Watanabe & Usman, 1987).

Thus, this species complex may be understood as a northern element of the Northern Hemisphere.

Each species within the complex has a limited area of distribution, except for *Gomphoneis calcifuga*, which has a large variation. However, there is limited information and more study is needed to establish the taxonomy and distribution of this species complex. The size and form of initial valves are useful for understanding this species complex.

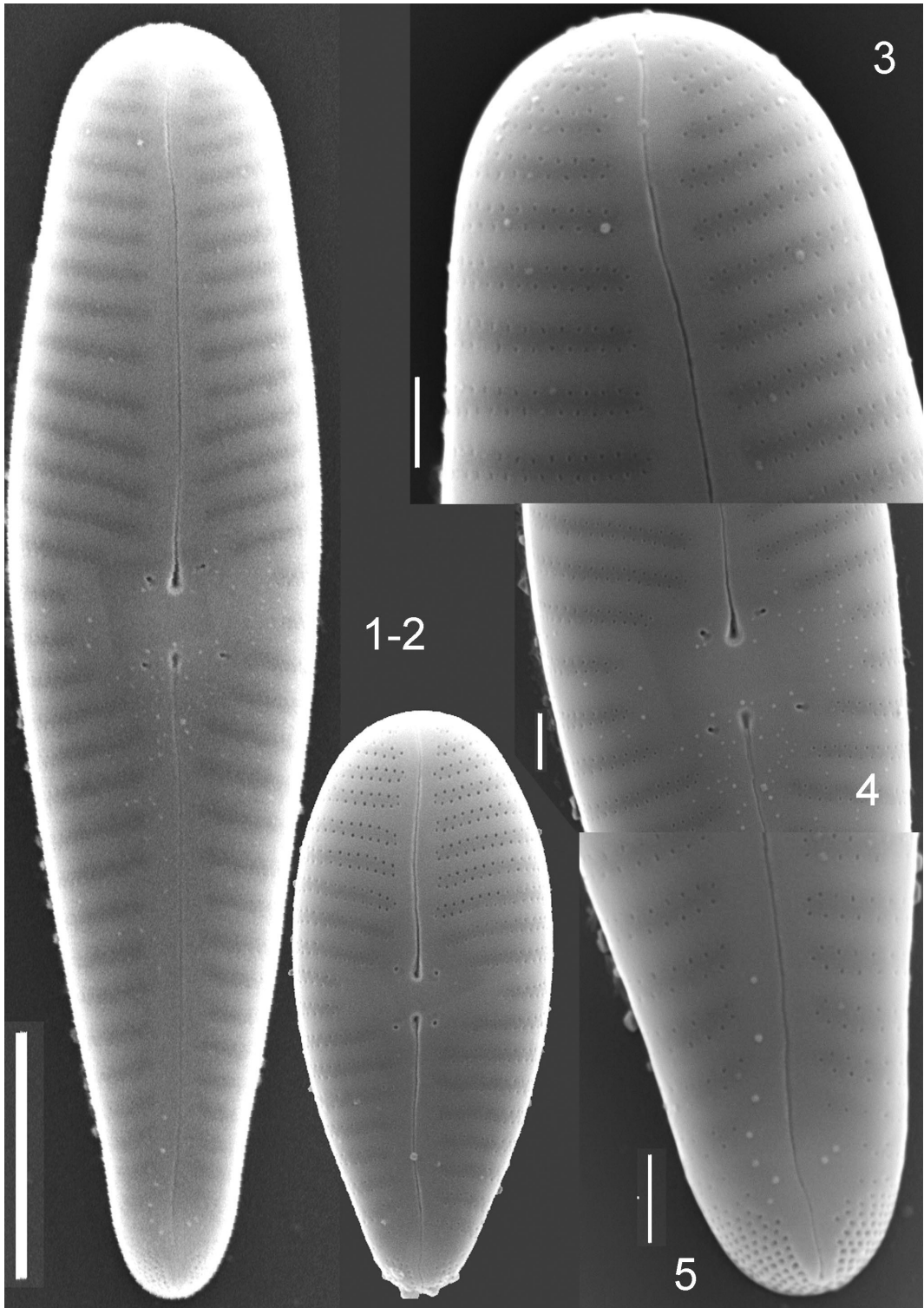


Plate 16. 1–5. *Gomphoneis pseudookunoi* Tuji sp. nov. TNS-AL-TW-6274m. SEM. Bar. 1–2: 5 μ m, 3–5: 1 μ m.

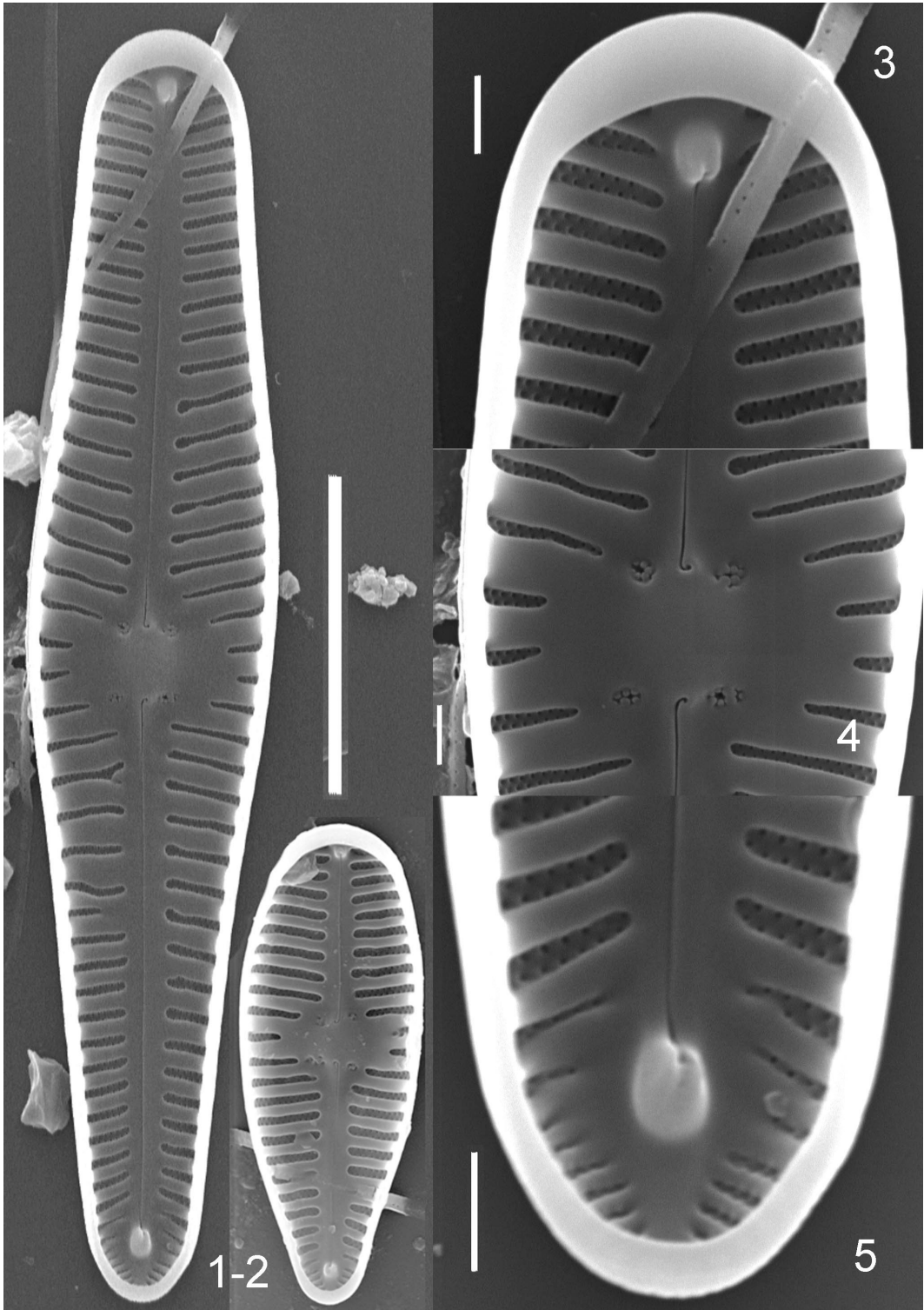


Plate 17. 1–5. *Gomphoneis pseudookunoi* Tuji sp. nov. TNS-AL-TW-6274m. SEM. Bar. 1–2: 5 μ m, 3–5: 1 μ m.

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