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Gomphonema svalbardense sp. nov., a new freshwater diatom species (Bacillariophyta) from the Arctic Region

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Abstract

During a survey of freshwater diatoms from lakes in the region of Petuniabukta on Spitsbergen (Svalbard Archipelago) a new *Gomphonema* species, *G. svalbardense* sp. nov., has been recorded. The new taxon was previously cited in the literature as *G. angustatum* var. *undulatum* but this identification proved to be erroneous. Detailed morphology description of *G. svalbardense* based on light and scanning electron microscopy is presented in this paper and the morphological features of the taxon have been compared with similar species. *Gomphonema svalbardense* is characterized by its typical linear, almost naviculoid outline with undulating margins, with clearly inflated central part, asymmetric central area, lateral raphe with simple straight proximal endings and the weakly radiate striae. History, ecology and biogeography of the species, mainly based on literature data, have been included.

Key words: Svalbard, Arctic Region, *Gomphonema*, diatoms, taxonomy, morphology, new species

Introduction

In the middle of the twentieth century, the diatom flora of the Arctic Svalbard Archipelago (74°–81°N, 10°–35°E) was the focus of several large morphological and taxonomic studies, published by among others Hustedt (1937), Krasske (1938) and Foged (1964), the latter listing more than 572 taxa in 207 samples. During more recent years, diatom studies on Svalbard were restricted to a few sparse floristic and (paleo-)ecological accounts (e.g., Picińska-Fałtynowicz 1988, Beyens 1989, Van de Vijver *et al.* 1999, Guilizzoni *et al.* 2006, Luoto *et al.* 2011) and only a few new taxa were described from the archipelago. Van de Vijver *et al.* (2004) described three new *Stauroneis* taxa from Svalbard in their revision of this genus in the Arctic and Antarctic Regions.

Since 2011 the interest in diatom research on Svalbard has revived with the Czech education program of polar ecology undertaken by the Centrum for Polar Ecology (University of South Bohemia). During the regular field expeditions, several lakes in the surroundings of the Petuniabukta fjord area have been studied (Reports of Czech research activities in Petuniabukta, http://polar.prf.jcu.cz/docs_cz.htm). The Petuniabukta fjord area is located in the northern part of Billefjorden, the inner branch of Isfjorden in the central part of Spitsbergen, the main island of the Svalbard Archipelago. The area is situated in the maritime High Arctic climate zone, with a mean annual temperature of about -7.5 °C and low precipitation rates of about 200 mm a year, mainly in the form of snow (Rachlewicz *et al.* 2007, Komárek *et al.* 2012, Láska *et al.* 2012). The geology of the study area is strongly correlated to the north-south facing Billefjorden Fault zone which resulted in a complex of different rock formations belonging to four structural entities differing in age and origin (Dallmann *et al.* 1999, Szczuciński & Rachlewicz 2007). The entire fjord is surrounded by steep mountains ranging between 265 and 935 m a. s. l. (Komárek *et al.* 2012). During the early Holocene, the entire area rose due to glacioisostatical uplift which resulted in the development of several good-preserved marine terraces (Szczuciński & Rachlewicz 2007). About ten glaciers, of which the tide-water glacier Nordenskiöld is the biggest, are located in the area. Since the beginning of the 20th century, the glaciers are retreating with speeds ranging from a few meters to 50 meters a year (Szczuciński

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& Rachlewicz 2007). Several lakes and pools, differing in origin, type and age, are located in the area, often situated in recent deglaciated zones or on raised marine terraces. The shores of some of these lakes are characterized by a dense moss vegetation. Due to erosion, extreme climatic conditions on exposed sites and recently deglaciated, not yet colonized, areas, large parts of Petuniabukta are not or sparsely vegetated. Vegetated parts show a rather high plant diversity, mainly with *Carex*, *Dryas* and *Silene* taxa (Prach *et al.* 2012). Due to recent deglaciation, erosion and extreme climatic conditions, large parts of Petuniabukta are not or only sparsely vegetated, although the vegetated parts show a rather high plant diversity, mainly with *Carex*, *Dryas* and *Silene* taxa (Prach *et al.* 2012). Several large bird colonies, e.g. of *Sterna paradisaea* Pontoppidan and *Rissa* sp., occur along the shores.

During the summers of 2011, 2012 and 2013 a large number of samples were collected from more than 30 different lakes, offering the opportunity for a more thorough taxonomic and ecological survey of the non-marine diatom communities of this Arctic site. Recently, analysis of the diatom flora revealed the presence of more than 300 taxa including several unknown taxa that could not be identified using the currently available (Arctic) diatom literature. In the past, most of these taxa would have been force-fitted (Tyler 1996) into Western-European or North-American diatom taxa (mainly based on Krammer & Lange-Bertalot 1986–1991), but following our current concept of diatom taxonomy (Mann 1999), this practice has been abandoned and new species need to be described as new for science.

The present paper describes a new species: *Gomphonema svalbardense* sp. nov., which was previously reported several times from the Arctic as *G. angustatum* var. *undulata* ms. Grunow (in Cleve 1894: 181).

Material & Methods

During a limnological survey in the area of Petuniabukta, epilithon, epiphyton and moss samples were taken from several ponds and lakes for further diatom analysis. During an initial screening of the samples, only four samples could be found in which the new Gomphonema taxon was present. Table 1 lists all samples and slides used in the present study are listed in table 1 together with their GPS positions and measured ecological parameters. Diatom samples were fixed with 96 % ethanol for preservation. The pH and specific conductance of the water were measured using a HANNA Combo pH/EC Tester.

Small sub-samples were prepared for LM observation following the method described in Van der Werff (1955). Small parts of the samples were cleaned by adding 37% H_2O_2 and heating to 80°C for about 1h. The reaction was completed by addition of $KMnO_4$. Following digestion and centrifugation (three times 10 minutes at 3700 x g), cleaned material was diluted with distilled water to avoid excessive concentrations of diatom valves on the slides. Cleaned diatom material was mounted in Naphrax®. For scanning electron microscopy (SEM), parts of the oxidized suspensions were filtered through a 1-µm Isopore™ polycarbonate membrane filter (Merck Millipore). The stubs were sputter-coated with a Gold-Palladium layer of 20 nm and studied in a ZEISS Ultra SEM microscope at 3 kV (Natural History Museum London, UK). As the new taxon proved to be very rare in the samples, only a few SEM observations could be made of the valves. The girdle structure was not observed. Samples and slides are stored at the BR-collection, property of the Belgian federal government and given in permanent loan to the Botanic Garden Meise (Belgium). Diatom terminology on valve outline and raphe structure follows Ross *et al.* (1979) and Round *et al.* (1990) whereas for typical gomphonemoid structures, Reichardt (1999) and Thomas *et al.* (2009) have been used. The term 'isolated pore' is used instead of the more commonly used 'stigma' as the latter term can only be used for the genus *Cymbella* (and some related genera) (Cleve 1894, p. 157) as current research showed important morphological differences in these structures in the different genera (Van de Vijver & Cox, unpubl. res.). Comparisons with other northern Hemisphere *Gomphonema* taxa, are based on Cleve-Euler (1955), Reichardt (1999), Lange-Bertalot & Genkal (1999) and Antoniades *et al.* (2008).

Results

Division Bacillariophyta

Class Bacillariophyceae Haeckel emend. Medlin & Kaczmarska 2004

Subclass Bacillariophycidae D.G.Mann in Round *et al.* 1990

Order Cymbellales D.G.Mann in Round *et al.* 1990

Family Gomphonemataceae Kütz. 1844

Genus *Gomphonema* Ehrenb. 1832

Gomphonema svalbardense *sp. nov.* (Figs 1–18)

Type:—Mathiessendalen, Petuniabukta (Central Spitsbergen—Svalbard), sample SPITS 2013/029 (78°33'47.4"N, 16°35'14.1"E), leg. E. Pinseel, coll. date 26/07/2013 (holotype, slide no. BR–4368; isotype, slide PLP–257, University of Antwerp, Belgium).

Synonym:—*Gomphonema angustatum* var. *undulatum* (Greg.) Grunow sensu Foged 1981 (p.97, plate LIII, figs 10, 11, non plate LIII, figs 9, 12, 13, 14).

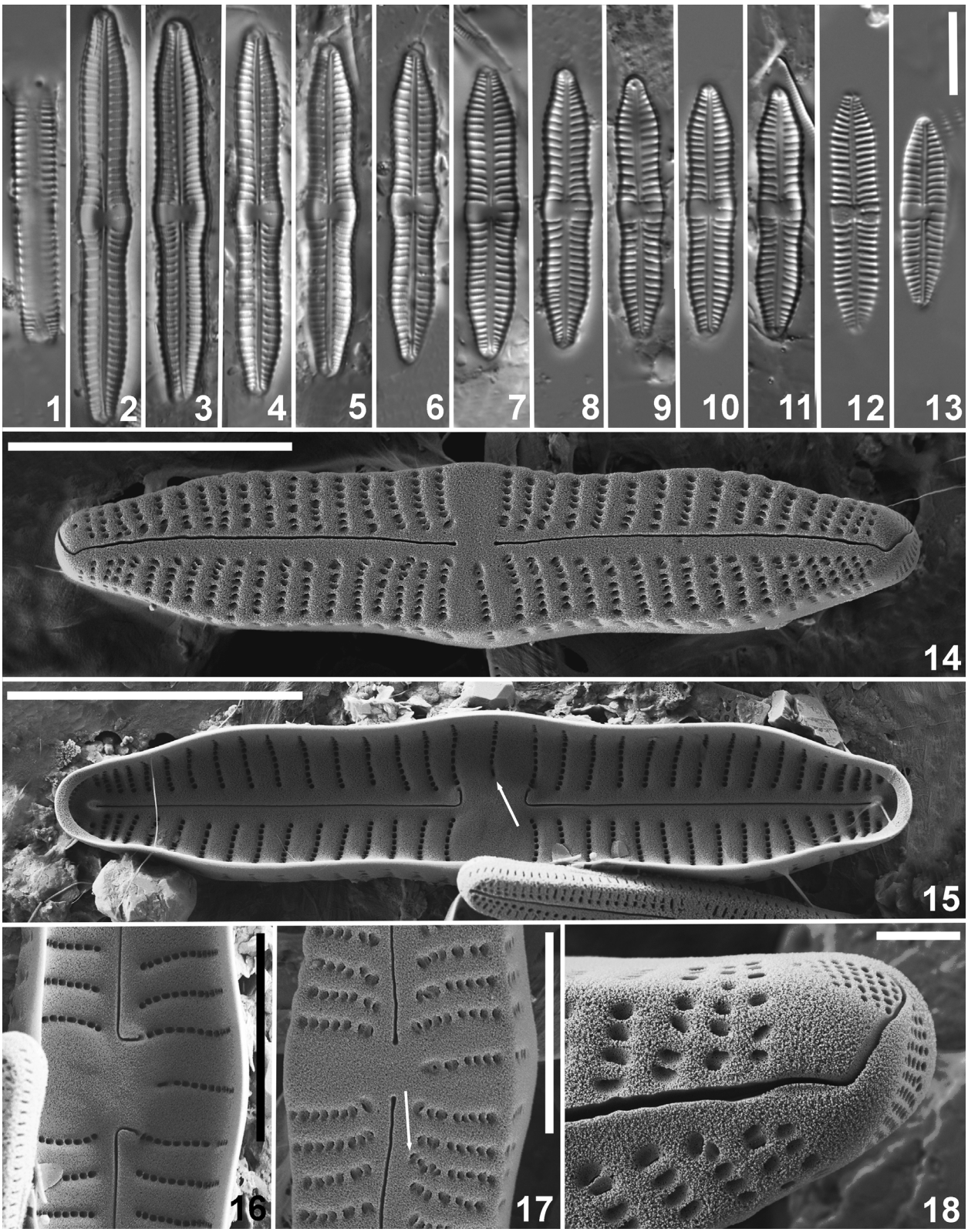
LM (Figs 1–13*)*: Valves linear, asymmetric, only weakly clavate to even naviculoid, with undulating margins and a clearly inflated central part. Headpole and footpole protracted, rostrate, narrowly rounded, the latter only slightly broader than the headpole. Valve dimension (n=30): length 23–51 µm, width 5.7–7.2 µm. Axial area narrow, linear to weakly lanceolate, almost not widening towards the central area. Central area forming a rectangular to weakly wedge-shaped, asymmetric fascia. One striae present along one margin with a terminal isolated pore. The opposite margin always lacking any striae. Raphe weakly curved and undulating, clearly lateral with straight proximal raphe endings. Distal raphe endings not discernible in LM. Striae weakly radiate near the central area, becoming more radiate towards the apices, 9–13 in 10 µm, up to 14–19 near the apices. Areolae occasionally visible but usually difficult to resolve in LM.

SEM (Figs 14–18): Striae uniseriate, occasionally biseriate near the axial area (Figs 14, 17 see arrow), composed of more or less rounded areolae that are located at the bottom of rather deep, irregularly shaped depressions. External raphe branches curved, undulating (Fig. 14). Proximal raphe endings straight, simple (Fig. 17). Distal raphe fissures hooked, curving down on the mantle, separating the apical porefield into two fields (Fig. 18). Apical porefield on the footpole composed of several (5–6) rows of small, rounded porelli, physically removed and structurally differentiated from the areolae. Internally, small pseudosepta present on both apices (Fig. 15). Internal distal raphe endings terminating on small helictoglossae (Fig. 15). Internal proximal endings terminating on a raised central nodule, hooked and even recurved towards the isolated pore (Fig. 15). Areolar openings rounded, not lying in foraminal rows. Isolated pore opening slightly transapically elongated, not very differentiated from the areolae (Fig. 15, arrow). Apical porefield details not visible due to pseudoseptum (Fig. 15). No observations on the girdle structure could be made.

Ecology and Distribution:—*Gomphonema svalbardense* is described from a small lake (Petuniabukta, Central Spitsbergen – Svalbard). The lake is characterized by an alkaline pH (8.1) and a moderately high conductance value (761 µS/cm). At the type locality, this taxon was primary found in moss samples taken from the lake's shore. Additional populations were found in various epilithon and epiphyton samples from three other localities (Table 1) with similar pH (8.6–8.9) but lower conductance value (184–336 µS/cm). The accompanying diatom flora included *Denticula kuetzingii* Grunow (1862: 546), *D. tenuis* Kütz. (1844: 43), *Meridion circulare* (Grev. 1823: 35) C.Agardh (1831: 40)*, Rossithidium petersenii* (Hust. 1937: 179–180) Aboal (in Aboal *et al.* 2003: 178), *Epithemia adnata* (Kütz. 1833: 544) Bréb. (1838: 16)*, Staurosirella* aff. *lapponica* (Grunow in Van Heurck 1881: 45) D.M.Williams & Round (1987: 274) and an at present unidentified *Achnanthidium* Kützing (1844: 75) taxon.

The new taxon has already been reported in the past from Alaska (Foged 1981), Bear Island (Metzeltin & Witkowski 1996) and Siberia (Lange-Bertalot & Genkal 1999) showing that this taxon probably has a circumpolar, Arctic distribution. Due to confusion with other taxa previously identified as *G. angustatum* var. *undulata*, its correct biogeography is unclear.

Etymology:—The specific epithet *svalbardense* refers to the Arctic Svalbard Archipelago where the new taxon was found.



Figures 1–18. *Gomphonema svalbardense* sp. nov. Light and scanning electron micrographs. All pictures taken from the type population (BR-4368). **Figs 1–13.** Light microscopy views showing variation in size and valve outline. **Fig. 14.** SEM external view of an entire valve showing the raphe and striae structure. **Fig. 15.** SEM internal view of an entire valve. The arrow indicated the opening of the isolated pore. **Fig. 16.** SEM internal detail of the central area. **Fig. 17.** SEM external detail of the central area. The arrow indicates the occasional doubling of the areolae. **Fig. 18.** SEM external detail of the apical pore field. LM scale bar = 10 µm. SEM scale bar = 10 µm except for Figs 16–17 where scale bar = 5 µm and Fig 18, where scale bar = 1 µm.

TABLE 1. List of samples used in this study with their geographic position and measured ecological parameters.

Sample(s)	Collection date	Location	Lake type	N	E	pH	Cond. (µS/cm)	Sample type
SPITS 2013/028-030	26/07/2013	Mathiessendalen	Karst lake	78°33'47.4"	16°35'14.1"	8.1	761	Epiphyton & epilithon
SPITS 2013/033	26/07/2013	Mathiessendalen	Karst lake	78°33'55.9"	16°35'44.1"	8.6	184	Epilithon
SPITS 2013/012-013	23/07/2013	Ebbadalen	Marine terraces pond	78°42'9.8"	16°36'57.2"	8.9	336	Epiphyton
SPITS 2013/014-015	23/07/2013	Ebbadalen	Marine terraces pond	78°42'10.2"	16°36'56.7"	8.9	313	Epiphyton

Discussion

Gomphonema svalbardense has been known for a long time under the name of *Gomphonema angustatum* var. *undulata*. Apart from a very brief description ('*V. triundulate. L. 0,02 to 0,028; B. 0,006 mm. Striae 10 in 0,01 mm.*') without any illustration, nothing was known about the original morphology of this taxon (Cleve 1894). Unfortunately, the original type material of this taxon could not be retrieved. Later, several authors commented on the taxonomy of the variety *undulata*, connecting this taxon to *G. parvulum* (Kütz. 1844: 83) Kütz. (1849: 65), *G. angustatum* (Kütz. 1844: 83) Rabenh. (1864: 283) and even *G. lagerheimii* A.Cleve (1895: 22). Hustedt (1942), in his overview on the freshwater diatoms from Abisko (Sweden), illustrated a whole series of *G. angustatum* f. (not var.!) *undulata* Grunow sensu Hustedt (1942: 145, Figs 67–77) and combined the taxon with two taxa previously described by Cleve-Euler: *G. parvulum* var. *undulata* A.Cleve (1895: 21) and *G. lagerheimii* var. *distans* Cleve-Euler (1934: 72). However, careful analysis of these two taxa by Lange-Bertalot & Genkal (1999) and Reichardt (1999) resulted in a renewed separation and the description of *G. distans* Lange-Bertalot & Reichardt (in Lange-Bertalot & Genkal 1999: 54) (for *G. lagerheimii* var. *distans*) and *G. astridae* Reichardt & Lange-Bertalot 1999 (in Reichardt 1999: 29) (for *G. parvulum* var. *undulata*). In addition to both taxa, a third taxon, *G. subarcticum* Lange-Bertalot & Reichardt (in Lange-Bertalot & Genkal 1999: 59), was described for some valves that could be separated from *G. angustatum* f. *undulata* (Lange-Bertalot & Genkal 1999). All three taxa can easily be separated from each other (see Table 2). Additionally, in his discussion of one of the taxa, Reichardt (1999) mentioned the presence of several other, morphologically related, taxa that have not yet been described. One of these has been illustrated in Foged (1981), Metzeltin &Witkowski (1996) and Lange-Bertalot & Genkal (1999). These three records illustrate valves belonging to the same taxon that however could not be attributed to any of the three previously mentioned taxa. Careful analysis of the illustrations showed conspecificity with the unknown taxon from Spitsbergen, justifying partly the description of the latter as the new taxon *G. svalbardense*.

All authors agreed that a combination of these taxa with either *G. parvulum*, *G. angustatum* nor *G. lagerheimii* should be excluded based on major differences in the structure of areolae and raphe and valve outline.

Although most of above mentioned *Gomphonema* taxa occur in the Arctic Region, *G. svalbardense* can easily be separated from all of them. Table 2 gives an overview of the morphological features of all more or less linear taxa with undulating margins. For comparison, several other taxa such as *G. nathorstii* Foged (1964: 138) and *G. lapponicum* (A.Cleve 1895: 21) Cleve-Euler (1934: 72) have been added. Both the latter taxa show a more typical gomphonemoid (i.e. clavate) outline with a clear head- and footpole with a higher stria density (up to 15 in 10 µm) and more parallel striation pattern, contrary to *G. svalbardense* that has less dense and more radiate striae. *Gomphonema subarcticum* has a less tumid central part, broader apices and a more clavate outline. Most valves have a lower valve width (max. 6.5 µm) and are comparably smaller (max. length up to 40 µm). Additionally, differences in the structure of the central area (with a shortened stria on both sides), the less lateral raphe, the more expanded proximal raphe endings and the typical deep internal foraminal rows (absent in the new taxon), exclude all conspecificity with *G. svalbardense*. *Gomphonema astridae* shows more similarities in valve outline although the much lower valve dimensions exclude all confusion. Moreover, *G. astridae* lacks the typical inflation of the central part, lacks a complete fascia due to the presence of a shortened striae on both sides of the central area and has an almost filiform raphe. The most similar seems to be *G. distans*, although showing somewhat lower valve

length (up to 46 µm).*G. distans* has a comparable, even higher valve width (6.5–9.0 µm). The latter can also be separated by its lower stria density (max. 9 in 10 µm), a more clavate valve outline with a less inflated central part, a larger headpole, a more prominently visible isolated pore and a different central area with a shortened striae on both sides.

Table 2. Overview of the main morphological features of closely related *Gomphonema* taxa that can be confused with *G. svalbardense*.

	G. svalbardense	*G. distans*	*G. astridae*	*G. subarcticum*	*G. nathorstii*	*G. lapponicum*
	this study	Lange-Bertalot & Genkal 1999	Reichardt 1999	Lange-Bertalot & Genkal 1999	Foged 1964	Cleve-Euler, A. (Cleve) 1934
Valve length (µm)	23–51	38–46	24–30.5	22–40	27–57	22–46
valve width (µm)	5.7–7.2	6.5–8	3.8–4.5	5–6.5	9–10	7.5–9.8
valve outline	almost naviculoid, linear with parallel, undulating margins, central part inflated	rather clavate, with undulating margins, central part slightly inflated	rather clavate, linear with parallel undulating margins, central part almost not inflated	rather clavate, linear with parallel, undulating margins	clavate, undulating margins, central part slightly inflated	clavate, undulating margins
apices	headpole and footpole protracted, rostrate, narrowly rounded, the foodpole slightly broader than the headpole	headpole and footpole slightly protracted, narrowly rounded, the headpole slightly broader than the footpole	headpole and foodpole protracted, rostrate, narrowly rounded	headpole and footpole slightly protracted, narrowly rounded, the headpole slightly broader than the footpole	headpole and footpole protracted, broadly rounded, headpole slighlty broader than footpole	headpole and footpole protracted, broadly rounded, headpole clearly broader than footpole
axial area	narrow, linear to weakly lanceolate, almost not widening towards the central area	narrow, linear to weakly lanceolate, not widening towards the central area	narrow, linear to weakly lanceolate, not widening towards the central area	narrow, linear to weakly lanceolate not widening towards the central area	narrow, linear, not widening towards the central area	narrow, linear to weakly lanceolate not widening towards the central area
central area	rectangular to weakly wedge-shaped, asymmetric fascia, one stria present along one margin with a terminal isolated pore	rectangular to weakly wedge-shaped, asymmetric fascia, one stria present on both sides with a terminal isolated pore on one side	rectangular, asymmetric fascia, one stria present along both margins with a terminal isolated pore on one side	rectangular to weakly wedge-shaped, asymmetric fascia, one shortened stria present at each side with a terminal isolated pore	rectangular to weakly wedge-shaped, asymmetric fascia with varying numbers of striae, each with a terminal isolated pore	wedge-shaped, asymmetric fascia, variable numbers of short striae present
raphe	weakly curved, undulating, lateral with straight proximal raphe endings	weakly curved, undulating, lateral with straight proximal raphe endings and curved distal raphe endings	weakly curved, undulating, lateral with straight proximal raphe endings	weakly curved, undulating, lateral with straight proximal raphe endings	filiform, lateral with straight proximal raphe endings and curved distal raphe endings	curved, undulating lateral with straight proximal raphe endings and curved distal raphe endings
striae	weakly radiate near the central area, becoming more radiate towards the apices	weakly radiate near the central area, becoming parallel towards the apices	weakly radiate near the central area, becoming only slightly more radiate towards the apices	weakly radiate near the central area, becoming parallel towards the apices	weakly radiate near the central area, becoming parallel towards the apices	strongly radiate near the central area becoming parallel towards the apices
number of striae (in 10 µm)	9–13 up to 14–19 towards the apices	5–9	13.5–16	9–11	13–14	12–15

Gomphonema svalbardense shows some interesting features that seem to be unique within the genus *Gomphonema*, such as the structure of the areolae and the structure of the internal isolated pore. Hardly any known *Gomphonema* taxon shows similar areolar openings. In most taxa and complexes, the areolae are either rounded poroids [e.g., *G. micropus* Kützing (1844: 84) or *G. drutelingense* Reichardt (1999: 38)] (Reichardt 1999) or c-, e-

or s-shaped with or without central flaps [e.g., *G. acuminatum* Ehrenberg (1832: 88)-complex and the *G. truncatum* Ehrenberg (1832:88)-complex] (Reichardt 1999, 2001). Occasionally species show depressed areolae such as in *G. vibrioides* (Reichardt 1991: 524) or *G. latipes* Reichardt (2001: 196), but never as deep as in *G. svalbardense* where the areolae are small rounded poroids each positioned eccentrically at the bottom of a deep, irregularly shaped depression. Reichardt (1999) showed one picture of *G. lapponicum* (Plate 46, fig. 10) where rounded areolae are visible at the bottom of shallow, rounded depressions but this structure is entirely different from the areolae in *G. svalbardense*. The internal opening of the isolated pore is hardly separated from the areola series in the central area. In most *Gomphonema* taxa, the internal opening is usually a slit-like, elongated opening, positioned between the internal proximal raphe endings (see for instance *G. acuminatum* in Reichardt 1999, plate 55, Fig. 4) or located at the end of a (shortened) series of areolae (*G. angustatum* in Reichardt 1999, plate 23, Figs 15–16) but then the opening can always be distinguished as an elongated, thin slit contrary to the short slit in *G. svalbardense*.

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