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RESEARCH ARTICLE

Three new *Achnanthidium* (Bacillariophyceae) species from Lake Salda (Anatolia, Turkey), a deep soda lake

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Abstract

Background and aims – Kützing separated the genus *Achnanthidium* from the genus *Achnanthes* based on two species: *Achnanthes minutissima* and *Achnanthidium microcephalum*. These two genera were distinguished by the presence of stalks in the *Achnanthes* genus and their absence in *Achnanthidium*. Before electron microscopy, the difference between *Achnanthes* and *Achnanthidium* was not clear, especially in *Achnanthidium minustissimum* sensu lato. The aim of the study is to describe three new species of *Achnanthidium* from Lake Salda.

Material and methods – Lake Salda is located in southwestern Anatolia, in Turkey. The diatoms were collected seasonally from four stations in the lake between 2016 and 2020, from different substrata (epipelic, epiphytic, and epilithic).

Key results – Three new species belonging to the genus *Achnanthidium* have been found in Lake Salda, Turkey. Based on the morphological observations, all new taxa are part of the *Achnanthidium minutissimum* complex. *Achnanthidium barlasii* sp. nov. and *A. dumlupinarii* sp. nov. show a high degree of similarity to each other, but can be separated based on valve outline and a denser areolation, especially in striae close to the apices of the raphe valve. Both species can be distinguished from *A. minutissimum* based on more separate apices and less elliptic valves. In the case of *A. dumlupinarii* sp. nov., large specimens show slight undulations of the valve, which is a unique feature. *Achnanthidium anatolicum* sp. nov. is the most characteristic based on its valve width, broadly rounded valve apices, and almost straight valves in girdle view. All newly described *Achnanthidium* species can be found in lentic environments, with alkaline water and high calcium ion content.

Conclusion – The newly described taxa occurred in the unique habitat of a soda lake. The environment of the lake is highly alkaline, rich in magnesium and calcium, and derived from limestone and dolomitic limestone rocks.

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Keywords

Achnanthidium, Bacillariophyceae, new species, Lake Salda, Turkey

INTRODUCTION

Kützing (1833, 1844) separated the genus *Achnanthidium* Kütz. from the genus *Achnanthes* Bory based on two species: *Achnanthes minutissima* Kütz. and *Achnanthidium microcephalum* Kütz. These two genera were separated based on the presence of stalks in *Achnanthes* and their absence in *Achnanthidium*. However, the lack of electron microscopy observations prevented a better separation between *Achnanthes* and *Achnanthidium*, especially in the complex of species around *Achnanthidium minutissimum* (Kütz.) Czarn. sensu lato. Round and Bukhtiyarova (1996) redefined the genus and informally divided it into two subgroups: the *Achnanthidium minutissimum* complex with straight terminal raphe fissures and the *A. pyrenaicum* (Hust.) H.Kobay. complex with hooked terminal raphe fissures (Kobayashi 1997; Potapova and Hamilton 2007).

Representatives of the genus are small in size, usually less than 30 μm (generally 10–20 μm) in length, and less than 5 μm in width (Round and Bukhtiyarova 1996). *Achnanthidium* species are difficult to identify due to their small sizes. Members of the genus are common in all types of freshwaters and often abundant, occurring in springs, rivers, and lakes, typically dominating periphytic assemblages (Krammer and Lange-Bertalot 1991; Potapova and Hamilton 2007; Wojtal et al. 2011; Pinseel et al. 2015). In relation to the use of diatoms in biomonitoring assessments, a correct identification of the species is important because different species thrive in a broad variety of ecological conditions, ranging from oligotrophic to eutrophic waters (Cantonati and Lange-Bertalot 2006; Novais et al. 2015; Charles et al. 2021).

In Turkish inland waters, the genus comprises a small group with 13 identified species. Among them, *Achnanthidium affine* (Grunow) Czarn., *A. lineare* W.Sm., *A. minutissimum*, and *A. pyrenaicum* are common, whereas *A. eutrophilum* (Lange-Bert.) Lange-Bert., *A. exiguum* var. *heterovalvum* (Krasske) Czarn., *A. deflexum* (Reimer) Kingston, *A. exile* (Kütz.) Heib., *A. gracillimum* (F.Meister) Lange-Bert., *A. jackii* Rabenh., *A. minutum* Cleve, *A. rivulare* Potapova & Ponader, and *A. saprophilum* (H.Kobay. & Mayama) Round & Bukht. are less common in Turkish waters (Solak et al. 2012; Taşkın et al. 2019).

The aim of the present study is to describe three new species of *Achnanthidium* from Lake Salda, a soda lake in Turkey. The morphology of the new species is compared with all similar taxa worldwide in the *Achnanthidium minutissimum* group, based on literature data. Notes on their ecology are added and briefly discussed.

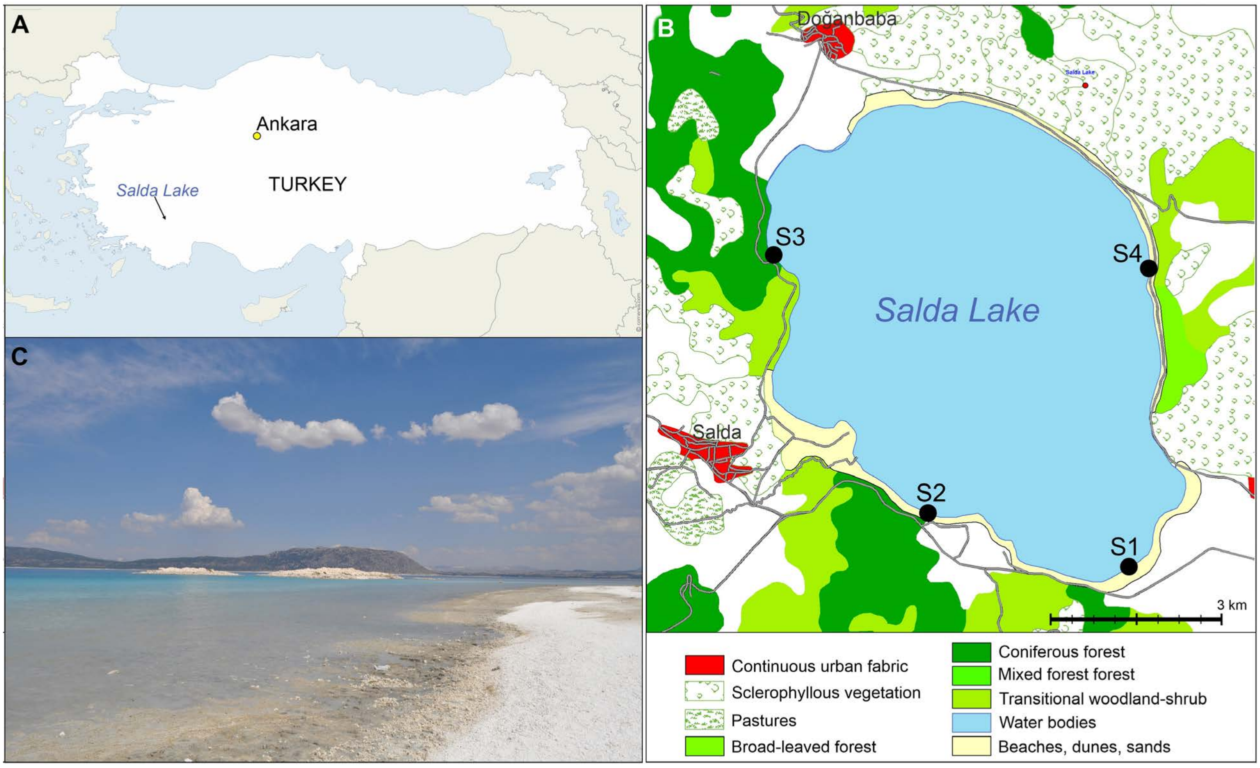

Figure 1. Study area. **A**. Location of Lake Salda in Turkey. **B**. Location of the sampling stations (S1–S4) around the lake. **C**. General view of the lake (photo by Cüneyt Nadir Solak).

MATERIAL AND METHODS

Study area

Lake Salda (37°33'N, 29°41'E) is located in southwestern Anatolia, Turkey (Fig. 1A). The lake, a depression basin formed by the effect of tectonism at the end of the Neogene (Lise et al. 2013), is one of the deepest enclosed lakes in Turkey and the deepest soda lake in the world. It has a maximum length of 8 km and is up to 6 km wide. The catchment area of the lake is 147.6 km^2 and the bedrock is composed of ultramafic and karstified carbonate rocks. Its water depth generally ranges up to 104 m, but there are several local depressions with depths of 180–200 m (Kazanci et al. 2004). The lake shows annual water level fluctuations of ca 0.5 meter, depending, however, on a hydraulic relationship with karstic aquifers, extensive evaporation during summer, and extensive irrigation use of the surrounding groundwater sources (Kazanci et al. 2004). In the lake, the hydromagnesite stromatolites develop around cool groundwater seepages (Zedef et al. 2000). The lake belongs to a carbonate saline waters type and is part of the mixo–oligohaline group of lakes (Bulger et al. 1993).

The water of the lake is alkaline (pH 8.3–9.7) with a high conductivity level (2.47–2.91 $mS.cm^{-1}$), resulting from the high concentrations of some ions, such as Ca^{2+} (20.04–120.2 $mg.L^{-1}$), Mg^{2+} (97–364.7 $mg.L^{-1}$), and Cl^{-} (51.8–1276.6 $mg.L^{-1}$). The nutrient concentrations (NO_2^-, NO_3^{2-}, NH_4^+, and PO_4^{3-}) on the other hand are however low and remained below detection limits (Kazanci et al. 2004).

The importance of the lake is related to its extreme conditions, ornithological relevance, and the presence of hydromagnesite stromatolites. The lake does not freeze in the winter due to the high mineral content and is available to overwintering birds (Kazanci et al. 2004).

The map (Fig. 1) was made with QGIS v.3.10 (QGIS Development Team 2019).

Diatom sampling and processing

Diatoms were collected seasonally between 2016 and 2020 from different substrata (epipelic, epiphytic, and epilithic) at four stations in the lake (Fig. 1B). Epilithic samples were collected using a toothbrush on submerged stones, whereas epipelic samples were collected using a pipette aspirator (Taylor et al. 2006).

To remove organic matter, the collected materials were boiled in a 30% hydrogen peroxide (H_2O_2) and HCl mixture. The resulting cleaned material was mounted using Naphrax® synthetic resin (Brunel Microscopes Ltd, Wiltshire, UK). Diatom observations were performed using a Nikon Ci Light Microscope (LM) at Dumlupınar University, using a 100× Plan Apochromatic oil immersion objective (NA = 1.40). Three hundred diatom valves were counted with LM to establish the species composition of each sample. Scanning electron microscope (SEM) observations were made at the University of Rzeszów using a Hitachi SU8010 (Tokyo, Japan), with acceleration voltages from 5 to 10 kV. For SEM, samples were filtered through a 3 µm mesh polycarbonate membrane (Whatman Nuclepore, Fisher Scientific, Schwerte, Germany), airdried, attached to aluminum stubs, and sputtered with 20 nm gold using a turbo–pump Q150T ES coater (Quorum, East Sussex, UK).

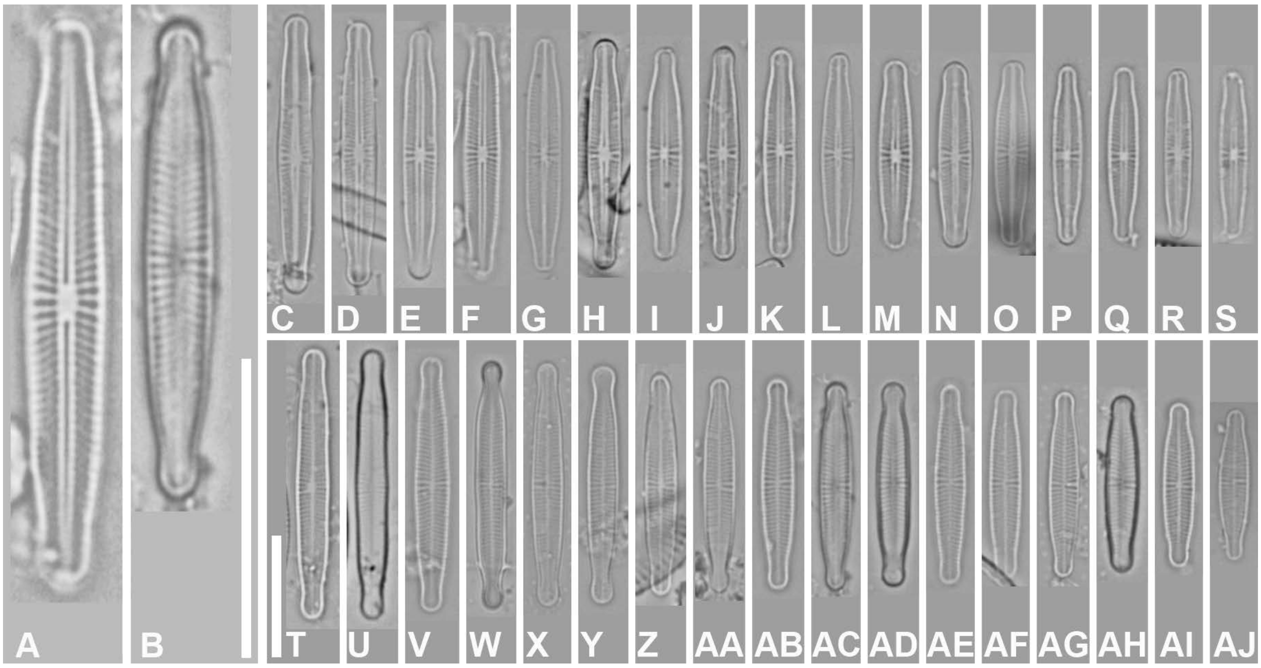

Figure 2. *Achnanthidium barlasii* sp. nov., LM micrographs. **A**, **C**–**S**. LM views of raphe valves. **B**, **T**–**AJ**. LM views of rapheless valves. Scale bar = 10 µm (A, B: 2500×; C–AJ: 1000× magnification).

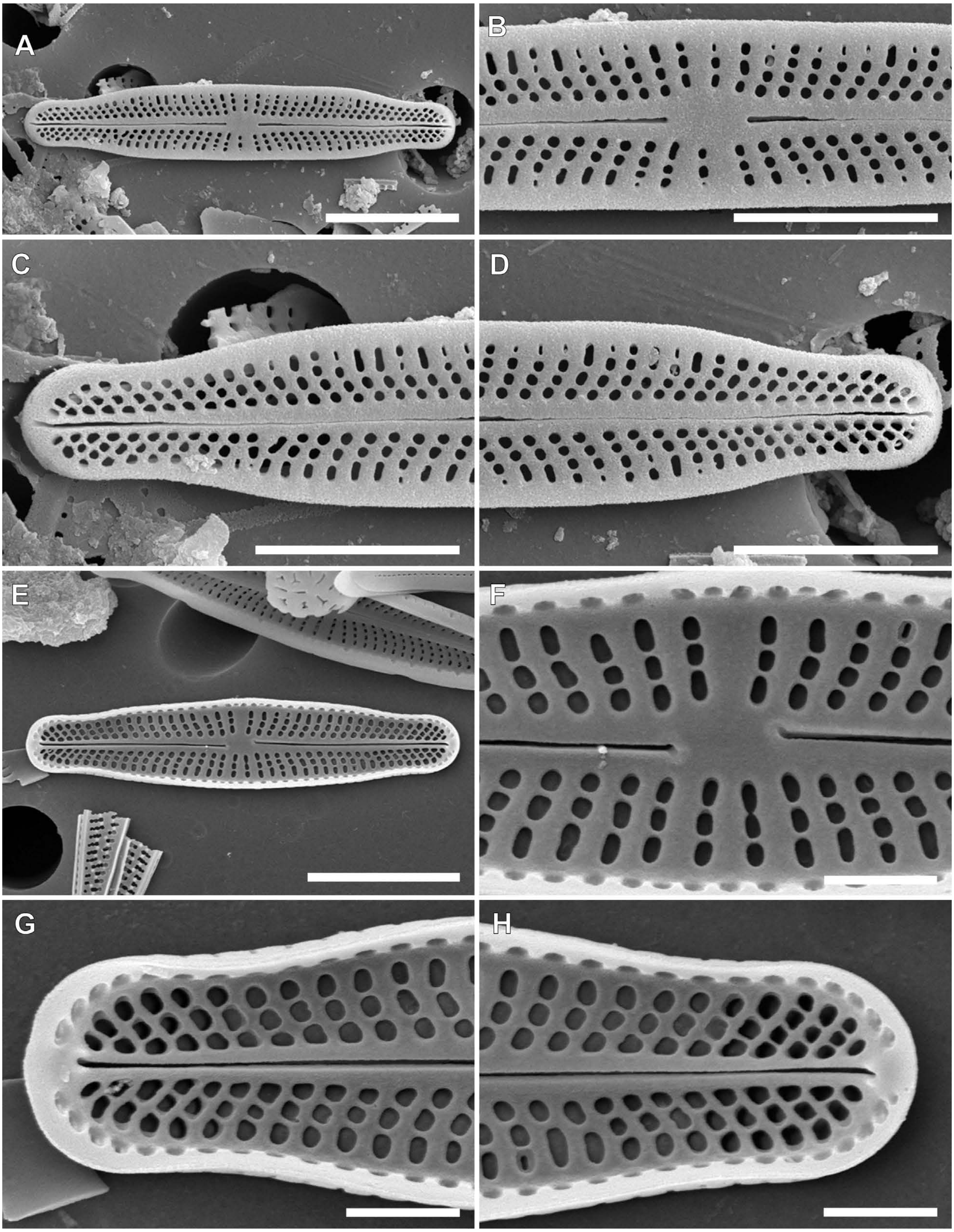

Figure 3. *Achnanthidium barlasii* sp. nov., SEM micrographs. **A**. General external valve view of a raphe valve. **B**. Details of central area. **C, D**. Details of apices. **E**. General internal valve view of a raphe valve. **F**. Details of central area. **G**, **H**. Details of apices. Scale bars 5 µm (A, E), 3 µm (B–D), 1 µm (F–H).

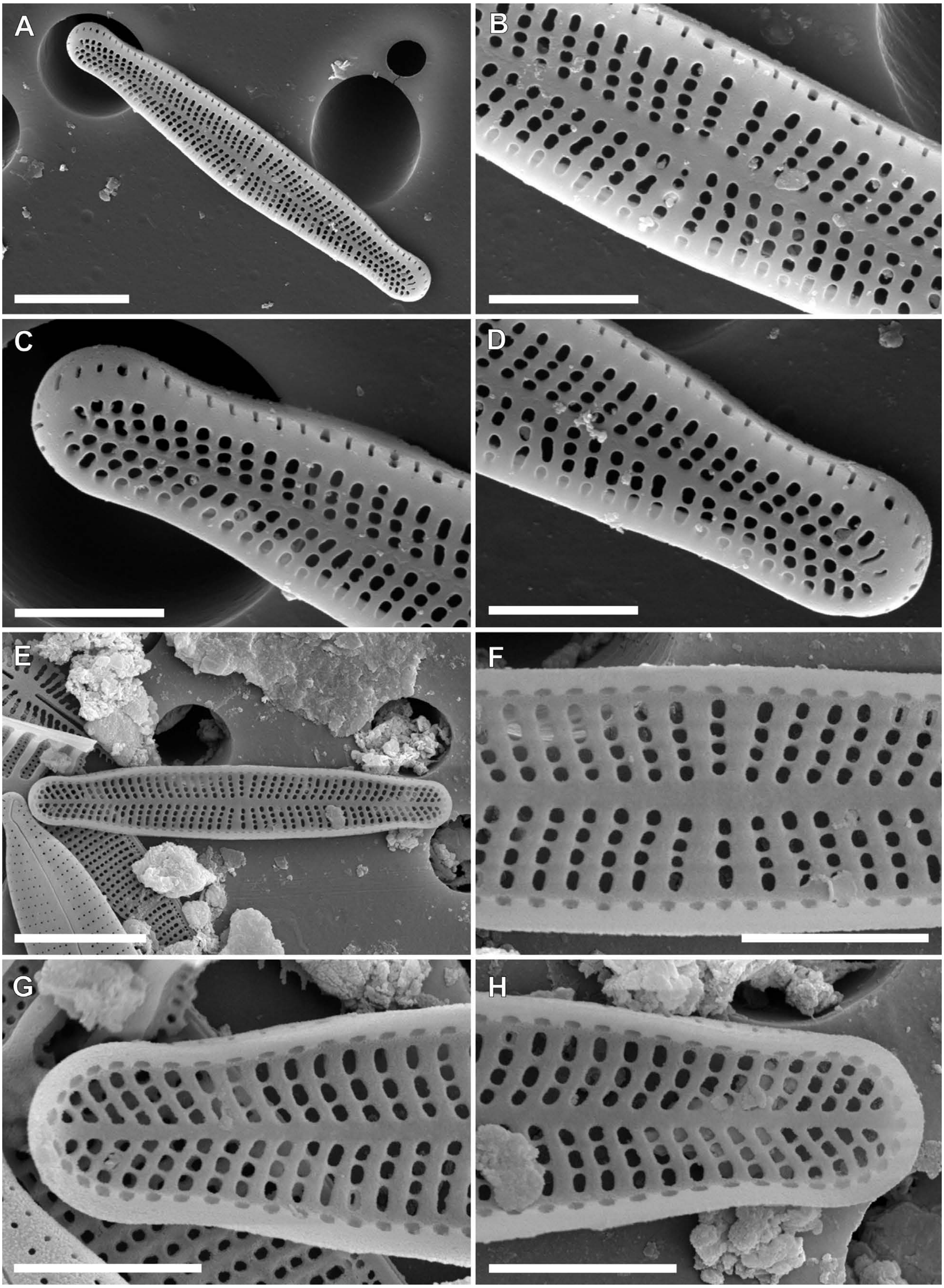

Figure 4. *Achnanthidium barlasii* sp. nov., SEM micrographs. **A**. General external valve view of a rapheless valve. **B**. Details of central area. **C**, **D**. Details of apices. **E**. General internal valve view of a rapheless valve. **F**. Details of central area. **G**, **H**. Details of apices. Scale bars 5 µm (A, E), 2 µm (F–H), 1 µm (B–D).

Table 1. Comparison of morphological characteristics of *Achnanthidium barlasii* sp. nov., *A. dumlupinarii* sp. nov., and morphologically similar taxa.

	***Achnanthidium barlasii* sp. nov.**	***Achnanthidium dumlupinarii* sp. nov.**	***Achnanthidium minutissimum***	***Achnanthidium polonicum***	***Achnanthidium ertzii***	***Achnanthidium sieminskiae***	***Achnanthidium tropicocatenatum***
Valve length (µm)	12.0–21.5	15.0–26.0	8.8–17.4	11.4–21.5	18–22	11–18	10.3–23.9
Valve width (µm)	2.0–3.0	2.5–3.5	2.2–4.1	2.6–4.0	2.2–2.6	2–3	2.7–3.5
Valve outline	linear with parallel margins and lanceolate	linear–lanceolate to linear–rhombic, and clearly inflated in central portion	linear-elliptic to linear-lanceolate	narrow clearly lanceolate with convex margins	linear-lanceolate with convex margins	linear-lanceolate	linear-lanceolate, slightly inflated in the central portion
Valve apices	protracted	subcapitate to capitate	rostrate to subcapitate protracted or as a rectangular fascia	subcapitate	clearly capitate	protracted and capitate	protracted, subcapitate to capitate
Striation pattern	strongly radiate, throughout the valve and denser near the apices	strongly radiate throughout the valve, denser towards the apices	strongly radiate and denser near the apices	radiate throughout the valve and more strongly radiate near the apices	-	radiate throughout, strongly radiate near apices	radiate throughout the valve, denser towards the apices
				Raphe valve			
Central area	slightly rhombic with 1–2 spaced striae composed of 3, rounded rectangular areolae	small bordered by 1–3 widely spaced stria both sides	almost absent, slightly rounded or as a rectangular fascia (more rarely)	rectangular fascia, in some valves with one shortened striae near the valve margins	rounded, never forming a fascia due to presence of several shortened spaced central striae	irregular, 1–2 shortened striae	small rounded, bordered by one more widely spaced stria on one or both sides
Striae (in 10 µm)	27–30	27–28	30 (up to 35 near the apices)	33–34 (up to 35–38 near the apices)	28–30	30–32	36–40 (up to 45 near the apices)
Number of areolae (per striae)	3 (1–2 at the apices)	4 at the central area, 3–4 at the apices	3–4 (rarely 2)	3–5	2–3	3–4	3–6
				Rapheless valve			
Central area	absent	absent or slightly rhombic	weakly elliptical and almost absent	small, never forming a fascia with striae slightly more spaced than the striae located towards the apices	almost non-existing, discernable due to several more widely spaced striae	irregular, 1–2 shortened striae	indistinct or narrow lanceolate
Striae (in 10 µm)	27–30	28–29	35 (up to 40 near apices)	28–30 (35–38 up to near the apices)	28–34	30–32	38–40
Number of areolae (per striae)	4 (2–3 at the apices)	4–5 at the central area, 3–4 at the apices	3–5	3–5	2–3	3–5	3–6
Reference	This study	This study	Novais (2015)	Wojtal et al. (2011)	Van de Vijver et al. (2011)	Witkowski et al. (2012)	Marquart et al. (2017)

The length and width of the diatom valves were measured with ImageJ (Schneider et al. 2012).

RESULTS

Water parameters

During the studies conducted, water pH was in the range of 9.7–9.9, water temperature was 23.0–28.2°C. Conductivity ranged between 1,384–1,712 µS.cm^{-1}, whereas oxygen content was between 6.6–7.5 mg.L^{-1}.

Taxonomic treatment

Achnanthidium barlasii C.N.Solak, Wojtal, S.Blanco, Peszek & M.Rybak, **sp. nov.**

Figs 2–4

Type. TURKEY • Lake Salda; 37°33'37.88"N, 29°43'1.94"E; 1316 m a.s.l.; 14 Oct. 2017; *Cüneyt Nadir Solak*; holotype: slide n° 27295, valves illustrated here in Fig. 2E & V: deposited in the collection of Andrzej Witkowski at the University of Szczecin, Poland; isotype: slide n° TR_BRD_Salda Lake_EPF_3_Oct2017: deposited at Kütahya Dumlupınar University, Turkey.

Description. Valves linear to lanceolate, with parallel margins. Apices protracted (Fig. 2). Valve dimensions (n = 75): valve length 12.0–21.5 µm, valve width 2–3 µm (Table 1). Raphe valve (Figs 2A, C–S & 3A–H) linear with parallel margins. Axial area linear, gradually widening (Fig. 3A). Central area inconspicuous, delimited by 1–3 more distantly spaced striae composed of three, rounded areolae (Fig. 3B, F). Raphe straight, expanding at both central endings and terminal raphe fissures. Central raphe endings straight, terminal raphe fissures short (Fig. 2B–D). Transapical striae arched, strongly radiate throughout entire valve, more densely spaced near apices. Striae composed of 3 (1–2 at apices) rounded to rectangular areolae (Fig. 2B–D). Internally, central raphe endings terminating on a raised central nodule, weakly deflected in opposite directions (Fig. 2E–F). Rapheless valve (Figs 2T–AJ & 4A–H) lanceolate with convex margins. Central area absent (Fig. 3A, B, F). Transapical striae radiate and evenly spaced throughout the entire valve, 27–30 in 10 µm. Striae composed of 4 (2–3 at the apices) rounded areolae (Fig. 3B–D).

Etymology. The species is named after our colleague Prof. Dr Murat Barlas, a hydrobiologist specialised in freshwater ecology in Turkey.

Achnanthidium dumlupinarii C.N.Solak, Wojtal, S.Blanco, Peszek & M.Rybak, **sp. nov.**

Figs 5–7

Type. TURKEY • Lake Salda; 37°30'41.43"N, 29°42'41.78"E; 1316 m a.s.l.; 4 Nov. 2016; *Cüneyt Nadir Solak*; holotype: slide n° 27293 illustrated here in Fig. 5F & V: deposited in the collection of Andrzej Witkowski at the University of Szczecin, Poland; isotype: slide n° TR_BRD_Salda Lake_Nov2016_EPL_1; deposited at Kütahya Dumlupınar University, Turkey.

Description. Valves linear-lanceolate to linear-rhombic, clearly inflated in the central portion. Apices subcapitate to capitate, larger specimens slightly undulate (Fig. 5B).

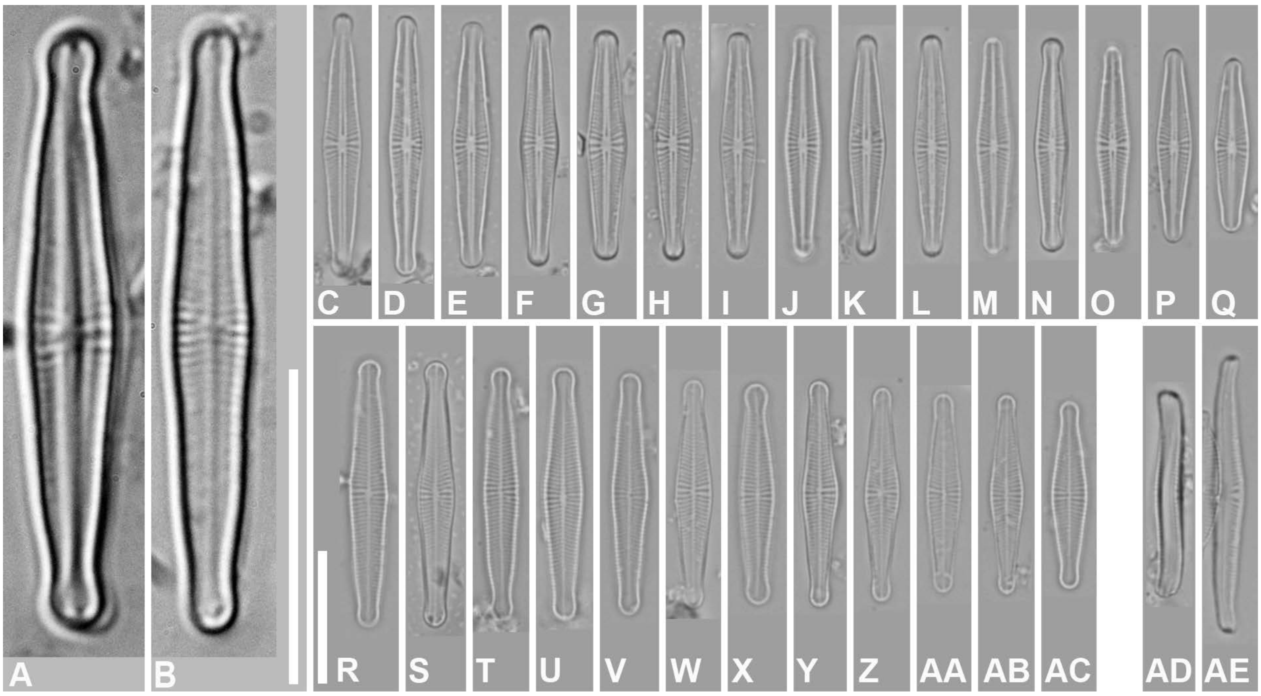

Figure 5. *Achnanthidium dumlupinarii* sp. nov., LM micrographs. **A**, **C–Q**. views of raphe valves. **B**, **R–AC**. Views of rapheless valves. **AD**, **AE**. Views of raphe valves in girdle view. Scale bar = 10 µm (A, B: 2500×; C–AE: 1000× magnification).

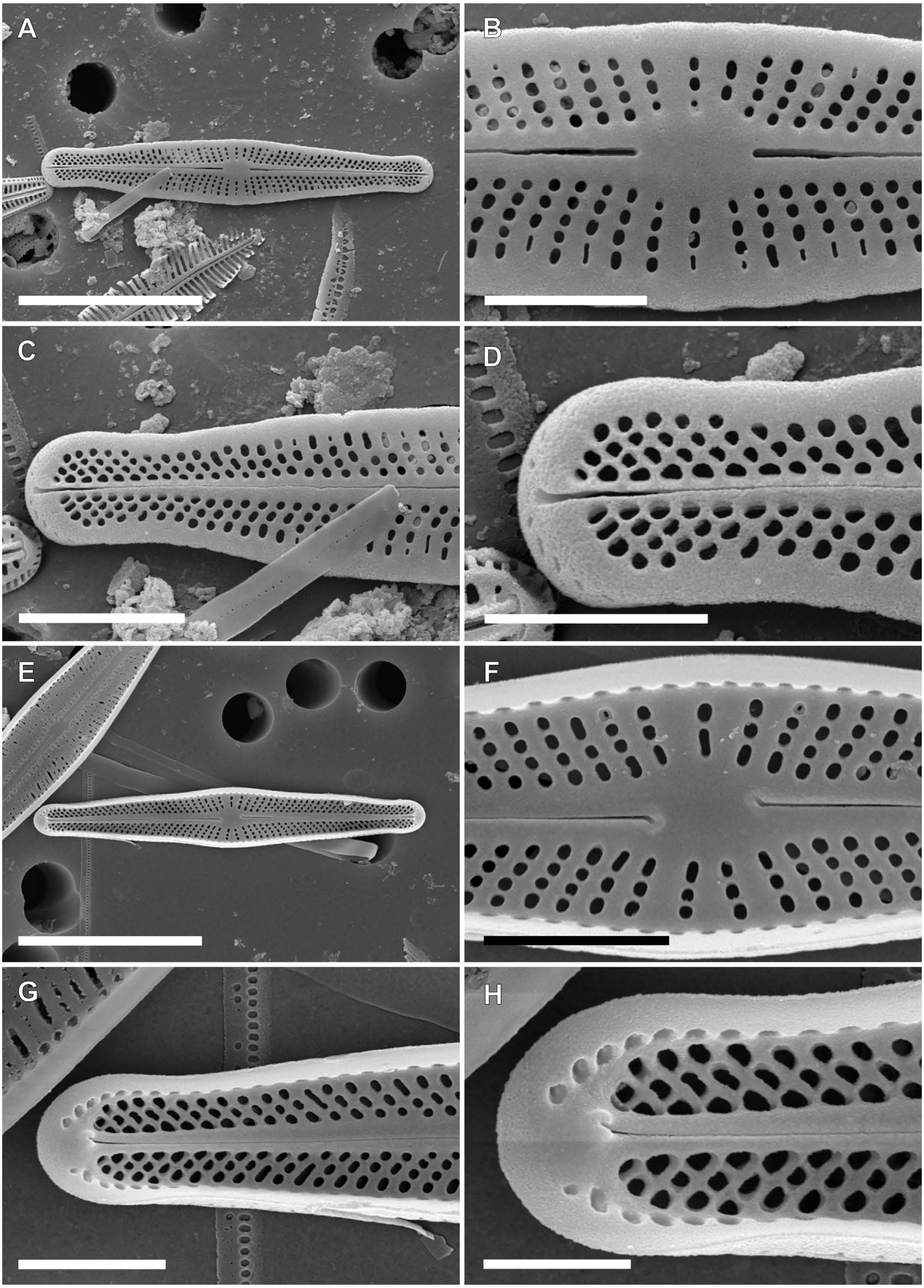

Figure 6. *Achnanthidium dumlupinarii* sp. nov., SEM micrographs. **A**. General external valve view of a raphe valve. **B**. Detail of the central area of a raphe valve showing the slit–like areolae in the margins. **C**, **D**. Details of apices. **E**. General internal valve view of a raphe valve. **F**. Details of central area. **G**, **H**. Details of apices. Scale bars 10 µm (A, E), 3 µm (D), 2 µm (B, C, F, G), 1 µm (H).

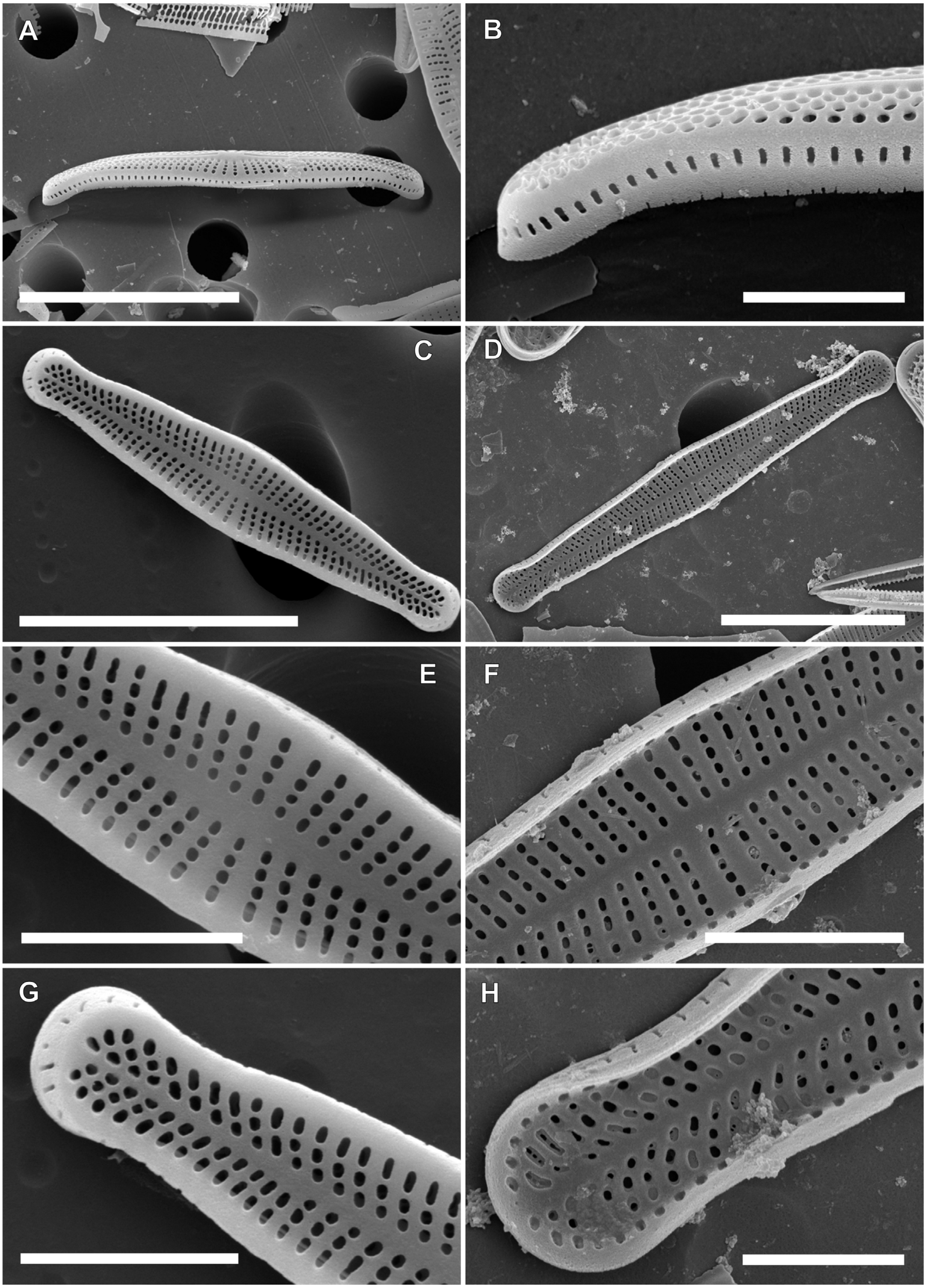

Figure 7. *Achnanthidium dumlupinarii* sp. nov., SEM micrographs. **A**, **B**. External girdle view of a raphe valve showing the row of areolae in the mantle. **C**. General external valve view of a rapheless valve. **D**. General internal valve view of a rapheless valve. **E**, **F**. Details of central area. **G**, **H**. Details of apices. Scale bars 10 μm (A, C, D), 2 μm (B, E–H).

Valve dimensions (n = 60): valve length 15–26 µm, valve width 2.5–3.5 µm (Table 1). Raphe valve (Figs 5A, C–Q & 6A–H): small central area, bordered by 1–3 widely spaced striae on one or both sides (Fig. 6B, F). Striae visible in LM. Externally, raphe straight, filiform, with slightly expanded central endings and short terminal raphe fissures (Fig. 6A–D). Internally, central raphe endings slightly deflected in opposite directions and terminal endings terminating onto small helictoglossae (Fig. 6E–H). Transapical striae strongly radiate throughout entire valve, more dense towards apices, 27–28 per 10 µm. Striae composed of 3–4 rounded to rectangular areolae, sometimes slit-like near the valve margin (Fig. 6B–D, F–H). Rapheless valve (Fig. 7C–H): central area bordered by 1–2 more widely spaced striae on one or both sides (Figs 5B, R–AC & 7C–H). Transapical striae strongly radiate throughout entire the entire valve, more densely spaced towards the apices, 28–29 per 10 µm at central area. Striae composed of 3–5 rounded areolae (Fig. 7D–H). On both valves, a single row of elongated areolae present on the mantle, separated from the striae on the valve face by a hyaline area (Fig. 7A, B). In girdle view, valves C-shaped at the apices (Figs 5AD, AE & 7A, B).

Etymology. The species is named after Dumlupınar University, which supports diatom research in Turkey. According to art. 60.4 of the International Code of Botanical Nomenclature, the spelling of the name Dumlupınar is changed to Dumlupinar (Turland et al. 2018).

Achnanthidium anatolicum C.N.Solak, Wojtal, S.Blanco, Peszek & M.Rybak, **sp. nov.**

Figs 8–10

Type. TURKEY • Lake Salda; 37°33'37.88"N, 29°43'1.94"E; 1316 m a.s.l.; 16 Nov. 2019; *Cüneyt Nadir Solak*; holotype: slide n° 27306, illustrated here in Fig. 8H & V: deposited in the collection of Andrzej Witkowski at the University of Szczecin, Poland; isotype: slide n° TR_BDR_Salda Lake_Nov2019_EPL_3: deposited at Kütahya Dumlupınar University, Turkey.

Description. Valves linear, inflated in the centre. Apices subcapitate (Fig. 8). Valve dimensions (n = 34): valve length 11.5–23.0 µm, valve width 2.5–3.5 µm (Table 2). Raphe valve (Figs 8A, C–P & 9A–H) with almost straight margins, especially in larger valves (Figs 8C & 9A). Striae in the central area more widely spaced. Striae mainly composed of 4–5 rounded to rectangular areolae (Fig. 9B–D). Externally, raphe straight, filiform, with slightly expanded central endings and terminal raphe fissures (Fig. 9A–D). Internally, central raphe endings slightly deflected into opposite directions. Terminal raphe endings terminating onto small helictoglossae (Fig. 9E–H). Transapical striae radiate throughout the entire valve, more densely spaced towards the apices, 26–28 per 10 µm. Rapheless valve (Figs 8B, Q–AD & 10A–D) bordered by 3–4 more widely spaced striae on one or both sides (Fig. 10A, B). Striae radiate throughout the entire valve, more densely spaced towards the apices, 27–29 per 10 µm. Central area almost absent with 2–4 isolated striae. Striae mainly composed of 4–5 rounded areolae (Fig. 10A–D). On both valves, one row of single elongated areolae present on the mantle, separated from the striae on valve face by hyaline area (Fig. 10A).

Etymology. The species name refers to the geographic region Anatolia (Latin adjective: *anatolicus*) in Western Turkey where Lake Salda is located.

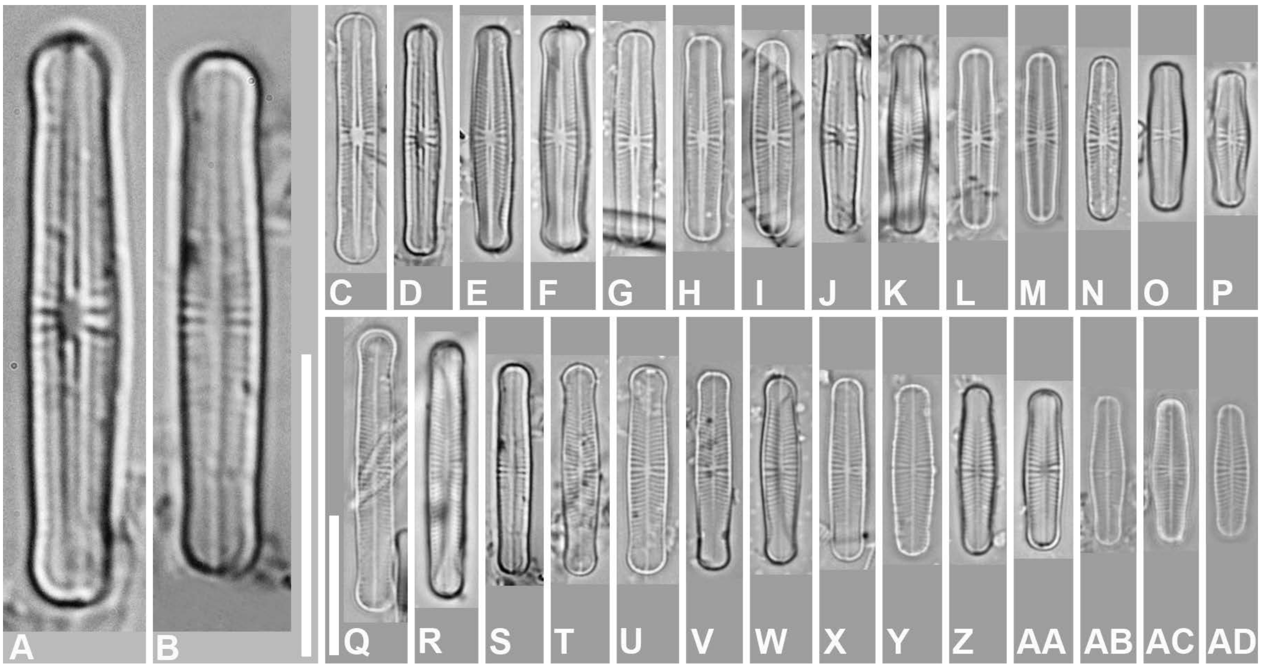

Figure 8. *Achnanthidium anatolicum* sp. nov., LM micrographs. **A**, **C**–**P**. Views of raphe valves. **B**, **Q**–**AD**. Views of rapheless valves. Scale bar = 10 µm (A, B: 2500×; C–AD: 1000× magnification).

Table 2. Comparison morphological characteristics of *Achnanthidium anatolicum* sp. nov. and morphologically similar taxa.

	***Achnanthidium anatolicum* sp. nov.**	***Achnanthidium minutissimum***	***Achnanthidium catenatum***	***Achnanthidium lusitanicum***
Valve length (µm)	11.5–23.0	8.8–17.4	10.0–17.5	5.3–13.0
Valve width (µm)	2.5–3.5	2.2–4.1	2.8–3.6	2.3–3.0
Valve outline	linear	linear-elliptic to linear-lanceolate	slender	elliptic, linear-elliptic to linear-lanceolate, slightly inflated in the middle part of the valve
Valve apices	subcapitate	rostrate to subcapitate protracted or as a rectangular fascia	capitate endings becoming subcapitate in smaller specimens	rostrate, protracted
Striation pattern	radiate, denser and more strongly radiate near the apices	radiate, more strongly radiate and denser near the apices	radiate in the central and weakly radiate or almost parallel	radiate and almost equidistant, more radiate and denser towards the apices
		Raphe valve		
Central area	small bordered by 3–4 widely spaced stria both sides	almost absent, slightly rounded or as a rectangular fascia (more rarely)	rounded, in smaller specimens almost absent	inconspicuous to small rounded
Striae (in 10 µm)	26–28	30 (up to 35 near the apices)	30–32	35 (up to 40 near the apices)
Number of areolae (per striae)	4 (5, rarely 2–3 at apices)	3–4 (rarely 2)	4–6	4–5
		Rapheless valve		
Central area	almost absent	weakly elliptical and almost absent	small lanceolate to rhomboidal	absent or small, elliptical
Striae (in 10 µm)	27–29	35 (up to 40 near apices)	30–34	30–35
Number of areolae (per striae)	4–5 (rarely 2, 3 at apices)	3–5		3–4 (5–6)
Reference	This study	Novais et al. (2015)	Hlubikova et al. (2011)	Novais et al. (2015)

Associated diatom flora

The most common species in the community assemblages in which the three new species were found, was *Encyonopsis minuta* Krammer & E.Reichardt, ranging from 21.7% in epilithic assemblages to more than a 60% in assemblages developing on macrophytes. *Brachysira liliana* Lange-Bert. accounted for up to 5.6–13.1% in the epilithon and 19% in the epiphyton. Additionally, several unidentified *Gomphonella* species (14.5% in epilithon) were observed. Frequent taxa, although lacking a significant share in the assemblages, include *Encyonema lacustre* (C.Agardh) Pant., *Rhopalodia gibba* (Ehrenb.) O.Müller, *Anomoeoneis costata* (Kütz.) Hust., *Navicymbula pusilla* (Grunow) Krammer, *Navicula capitatoradiata* H.Germ., and *Mastogloia elliptica* (C.Agardh) Cleve.

DISCUSSION

Based on valve morphology, especially the raphe structure, the new species described in the present paper, clearly belong to the *Achnanthidium minutissimum* complex. Because of the small size, striation structure and morphological variability, identification of individual species from this complex is difficult using routine methods, making scanning electron microscope observations crucial for reliable identification (Pérès et al. 2014; Novais et al. 2015).

Of all three species described here, *A. anatolicum* is the most characteristic, based on its valve outline and unbent valve in girdle view. *Achnanthidium anatoliacum* has broadly rounded valve apices, distinguishing them from *A. minutissimum* (Table 2) (Novais et al. 2015). The most characteristic feature of *A. anatolicum* is a flat valve, as most of the *Achnanthidum* species typically have more or less arched valves. The most similar to the newly described species is *A. catenatum* (J.Bilý & Marvan) Lange-Bert., easily distinguished based on a higher stria density and its typical valve shape. *Achnanthidium catenatum* valves have their largest valve width in middle part of the valve, whereas *A. anatolicum* have apices and midvalve parts showing the same width. Moreover, the striation patterns differ with *A. catenatum* having striae that become parallel near the apices, while the striae in *A. anatolicum* become more radiate near the apices (Hlúbiková et al. 2011). Another similar species is *A. lusitanicum* Novais & M.M.Morais, but this taxon has a higher stria density (~35 per 10 µm on raphe valves, and 30–35 per 10 µm on rapheless valves) and a lower valve length (5.3–13.0 µm vs

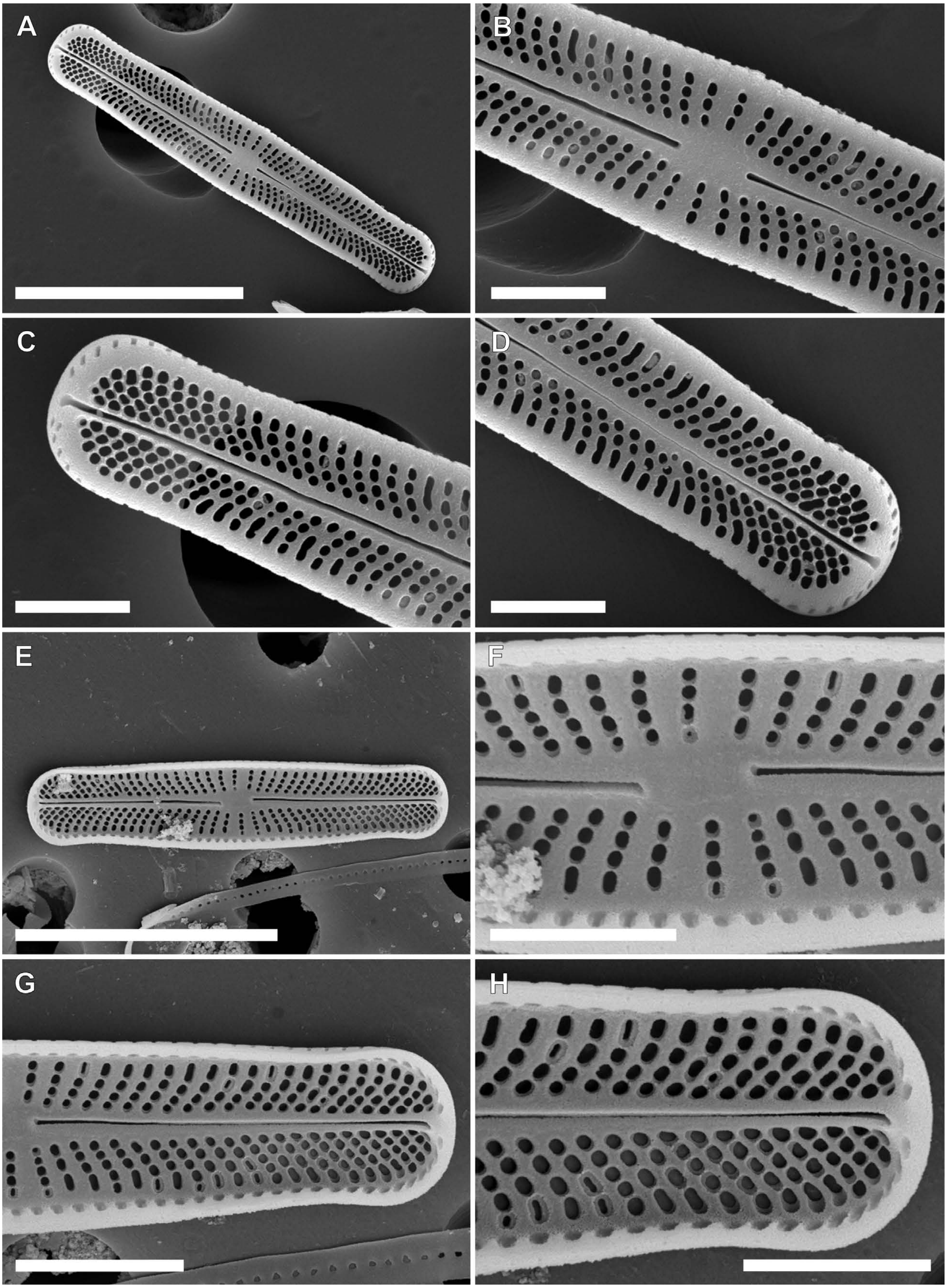

Figure 9. *Achnanthidium anatolicum* sp. nov., SEM micrographs. **A**. General external valve view of a raphe valve. **B**. Details of central area. **C**, **D**. Details of apices. **E**. General internal valve view of a raphe valve. **F**. Details of central area. **G**, **H**. Details of apices. Scale bars 10 μm (A, E), 2 μm (B–D, F–H).

11.3–22.9 μm). Moreover, they have bent terminal raphe fissures, whereas *A. anatolicum* has straight raphe fissures (Novais et al. 2015).

Achnanthidium barlasii and *A. dumlupinarii* show a high similarity to each other, but they can be separated based on differences in their valve outline and a denser areolation, especially on striae close to apices in the raphe valve. Both taxa can be distinguished from *A. minutissimum* based on more distinct apices and less elliptic valves (Novais et al. 2015). Larger specimens of *A. dumlupinarii* show slight undulations in their valve outline, considered to be a unique feature in the genus *Achnanthidium*. *Achnanthidium polonicum* Van de Vijver et al. shows some similarity but possesses a higher stria density, with a central area of the raphe valve lacking any striae (Table 1) (Wojtal et al. 2011). *Achnanthidium sieminskiae* Witkowski, Kulikovskiy & Riaux-Gob. has a higher stria density on both valves. Additionally, the linear-lanceolate valves of *A. sieminskiae* can be distinguished from *A. barlasii*, having valves with parallel margins, and the linear-rhombic valves of *A. dumlupinarii* (Witkowski et al. 2012). Unlike those found in described taxa, the valves of *A. ertzii* Van de Vijver & Lange-Bert. are clearly capitate, often with protracted ends and an easily noticeable rounded central area (Van de Vijver et al. 2011). Another species showing some morphological similarity to the newly described species, is *Achnanthidium tropicocatenatum* Marquardt, C.E.Wetzel & Ector, which can be distinguished based on a higher stria density (both on raphe valves and rapheless valves) and a strongly-arched valve in girdle view (Marquardt et al. 2017).

All newly described species were observed in the unique habitat of a soda lake. The environment of this lake is highly alkaline, rich in magnesium and calcium, and derived from limestone and dolomitic limestone rocks (Varol et al. 2020). The dominant species in this lake, *Encyonopsis minuta*, is widely distributed in temperate and boreal regions (Krammer 1997), and is locally abundant in lakes and streams with alkaline waters (Lange-Bertalot et al. 2017). The latter species was also frequent in the relatively warm waters of Cyprus, geographically close to Anatolia (Cantonati et al. 2020). *Brachysira liliana*, the second most frequent species in the lake, is also known to prefer alkaline, calcium-enriched, oligotrophic lakes with a moderate electrolyte content (Lange-Bertalot and Moser 1994). Species such as *Encyonema lacustre*, *Anomoeoneis costata*, *Navicymbula pusilla*, *Mastogloia elliptica*, *Rhopalodia gibba*, and *Navicula capitatoradiata* mainly occur in lakes with moderate or high electrolyte content, often brackish or with a high calcium content, and in alkaline waters (Witkowski et al. 2000; Krammer 2003; Hofmann et al. 2011; Lange-Bertalot et al. 2017). The presence of these co-dominating species in Lake Salda can help to establish the ecological preferences of the newly described *Achnanthidium* species in the present study.

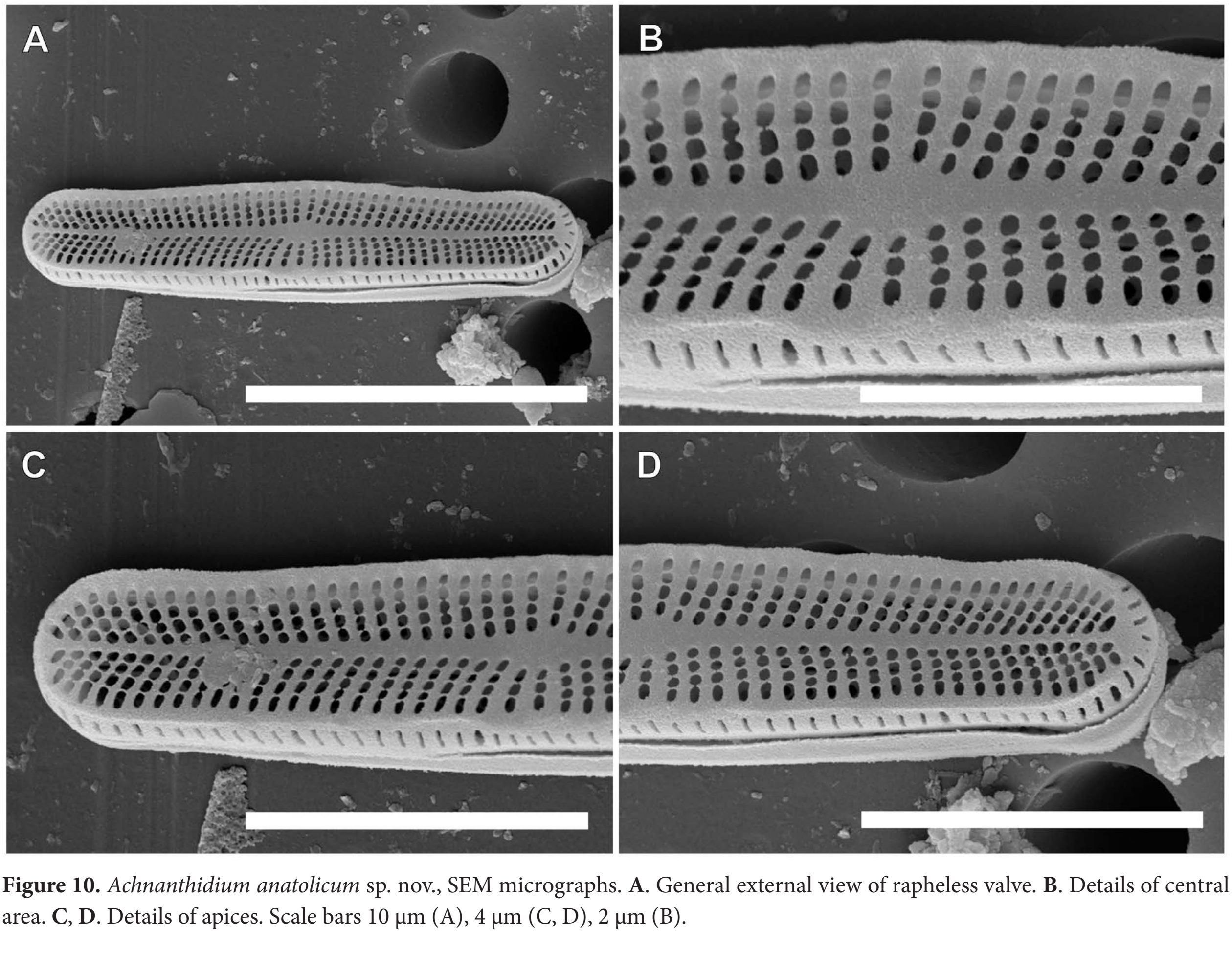

Figure 10. *Achnanthidium anatolicum* sp. nov., SEM micrographs. **A**. General external view of rapheless valve. **B**. Details of central area. **C**, **D**. Details of apices. Scale bars 10 μm (A), 4 μm (C, D), 2 μm (B).

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