

## Article

# A New *Aulacoseira* Thwaites (Bacillariophyta) Species from Wyoming, USA

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**Abstract:** A new species, *Aulacoseira wyomingensis*, is described from a small seep near Casper, Wyoming, USA, using light and scanning electron microscopy, in which it was the dominant diatom taxon. Valves have large areolae that cover the valve face. Spines, when present, are short and shield-like, precluding chain formation. Unlike most members of the genus, *A. wyomingensis* appears to lack rimoportulae. While we assign this species to the genus *Aulacoseira* within the Aulacoseiraceae based on the radial nature of its valve, its cingulum composed of fine ligulate bands, and presence of a ringleiste and collum, it does not appear to be easily assigned to any of the morphological groups within the genus.

**Keywords:** diatoms; scanning electron microscopy; new species; Aulacoseiraceae



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## 1. Introduction

Freshwater members of the Aulacoseiraceae include the genera *Aulacoseira* Thwaites (1848), *Alveolophora* Moisseeva and Nevretdinova (1990), *Eosira* Wolfe and Edlund (2005) and *Miosira* Schiller et al. (in Krammer et al., 1997). Among these, all have elongated valve mantles with many species also having spines that interdigitate with valves from opposing frustules to form chains [1]. *Eosira*, *Miosira* and *Alveolophora* are exclusively fossil genera, known from the Eocene [2], Miocene [3] and Miocene/Pliocene [4,5], respectively. They are differentiated from *Aulacoseira* by having specialized external or internal morphological features [2–5]. The family was treated taxonomically recently [6]. *Aulacoseira* has a long geological history, extending from the Cretaceous [7] to Recent (e.g., [8,9]). While *Aulacoseira* is worldwide in its distribution, *Alveolophora* is found only in the northern hemisphere [4,10], *Miosira* is known only from Europe [3] and *Eosira* is known only from North America [2].

Fossil and recent species of *Aulacoseira* species have been described from across North America. Several extant *Aulacoseira* species have been described from acidophilic habitats in the eastern and midwestern USA [11,12]. Siver and Hamilton [13] described three new species from acidic habitats along the Atlantic Coastal Plain. Kociolek et al. [14] described five new species from sediments from several lakes in Oregon and Idaho. The systematics of the genus *Aulacoseira* has been studied by Edgar and Theriot [15], who suggested there were five groupings within *Aulacoseira*, and that to maintain the monophyly of *Aulacoseira* as it is currently envisioned, *Miosira* would need to be included in the genus.

The purpose of the present report is to describe a new *Aulacoseira* from a wetland near the town of Casper, WY, USA and to comment on its systematic position within the genus.

## 2. Materials and Methods

A composite sample from a still seep near Casper, Wyoming (42.7125323 N, 106.8828493 W), USA, was collected on 22 August 2021. Except for locality and date information, no other data were collected with the sample. Approximately 25 mL of the

sample was cleaned with concentrated (70%) nitric acid. After cleaning, the sample was rinsed five times with deionized water, allowing at least 24 h between rinses. Portions of the fully-settled sample were mixed with deionized water and air-dried on coverslips. Coverslips with the dried material were mounted on microscope slides using Naphrax (refractive index 1.74). Light microscope observations were made with a BX-51 light microscope with DIC optics (100 $\times$  objective with 1.42NA) and images were taken with a DP-71 digital camera (Olympus Corporation of the Americas, Breinigsville, PA, USA).

For SEM, cleaned material was dried onto coverslips which were mounted on aluminum stubs. Stubs with the cleaned material were sputter-coated with 10 nm of platinum using a Cressington sputter coater. The coated material was viewed with a Hitachi SU 3500 SEM at a working distance of 5.7 mm and accelerating voltage set at 5.0 kV at the Colorado Shared Instrumentation in the Nanofabrication and Characterization (COSINC-CHR) facilities at the University of Colorado Boulder.

To provide an ecological context to the community present in the sample studied, 600 diatom valves were identified to species.

### 3. Results

Division Bacillariophyta Haeckel 1878.

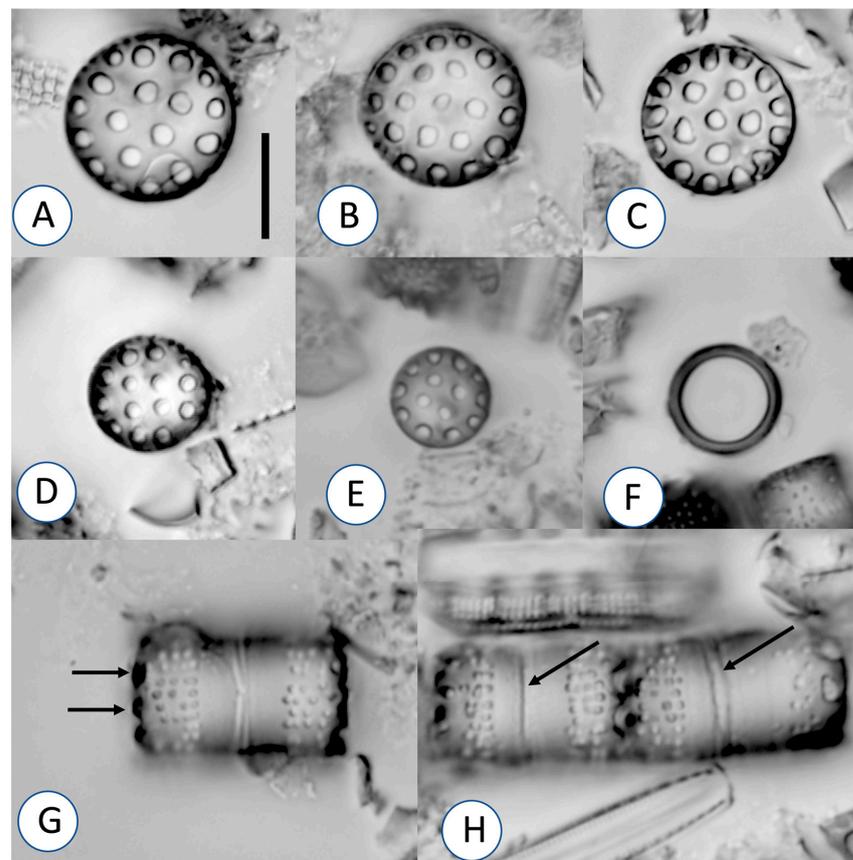
Class Coscinodiscophyceae Round and Crawford 1990.

Order Aulacoseirales Crawford 1990.

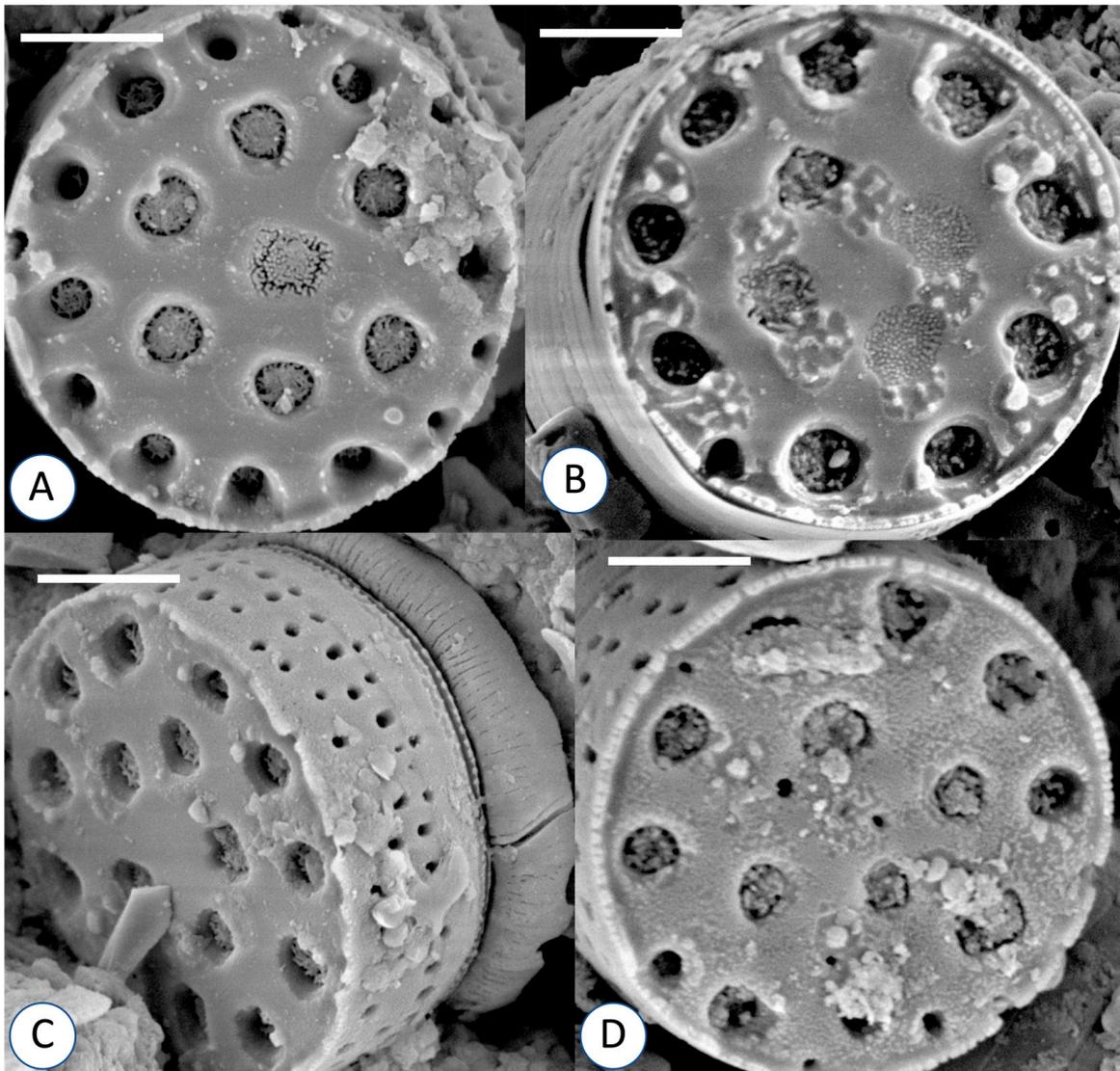
Family Aulacoseiraceae Crawford 1990.

Genus *Aulacoseira* Thwaites 1848.

*Aulacoseira wyomingensis* Greifenstein, Shea and Kociolek, sp. nov. Figures 1–4.



**Figure 1.** (A–H) *Aulacoseira wyomingensis*, sp. nov. Light microscopy. (A–E) Valve views. Size diminution series. (F) Ringleiste. (G,H) girdle views. Arrows indicate small, spine-like protrusions (G) and collum (H). All specimens are from the holotype slide. Scale bar = 10  $\mu$ m for all images.



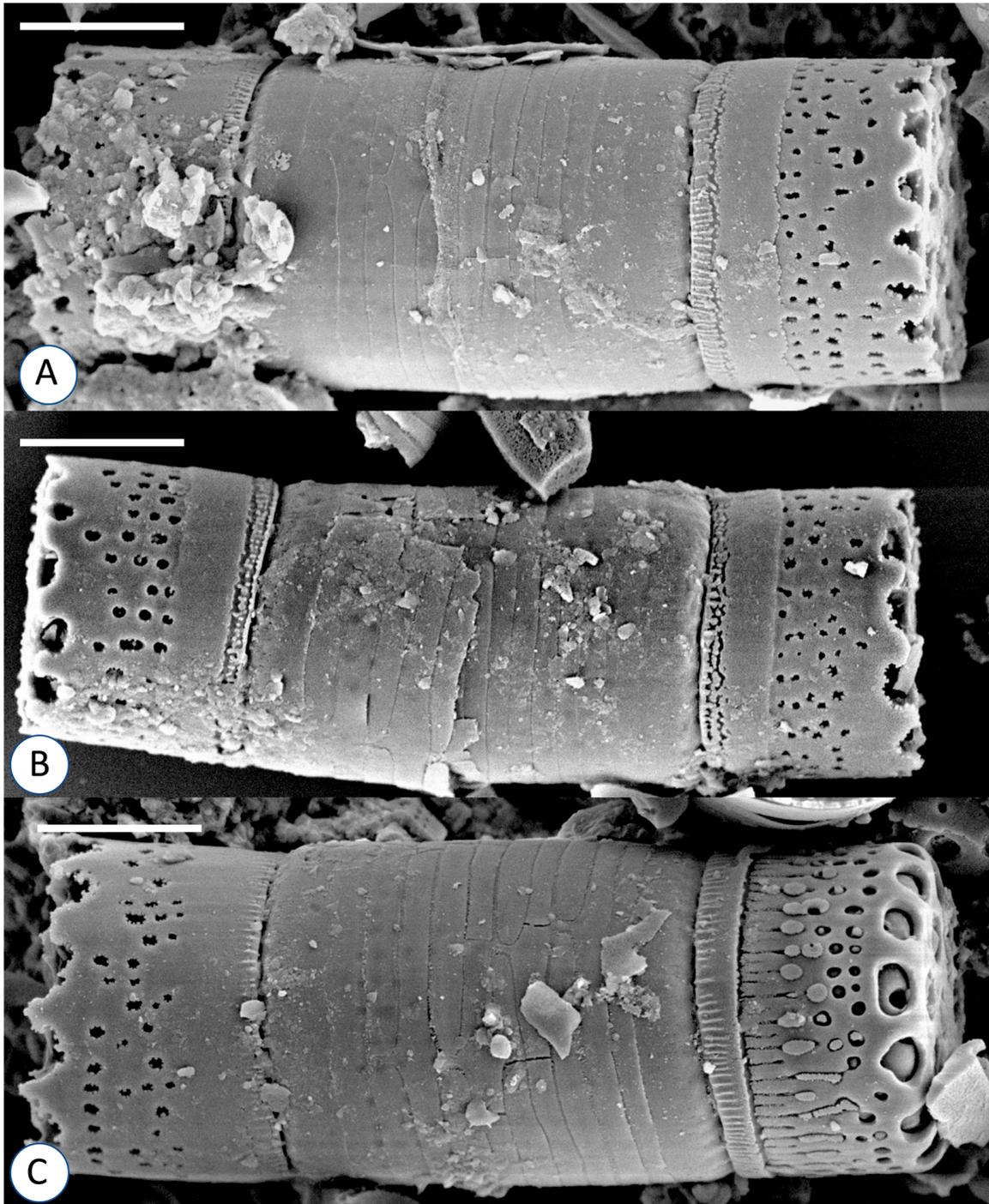
**Figure 2.** (A–D) *Aulacoseira wyomingensis*, sp. nov. Scanning electron microscopy. External valve views. Valve face is composed of areolae in deep depressions on the valve face, with covering at the base of each areola. In some cases, the areolae appear as depressions, without communication to the valve interior. Spines are mostly lacking. Scale bars = 2.5  $\mu\text{m}$ .

Holotype: Accession number 14073, JPK Collection at COLO. Holotype slide: 652059 in the JPK Collection at COLO. Isotype slides: To be deposited at ANSP and BM. Numbers to be issued upon acceptance of the manuscript.

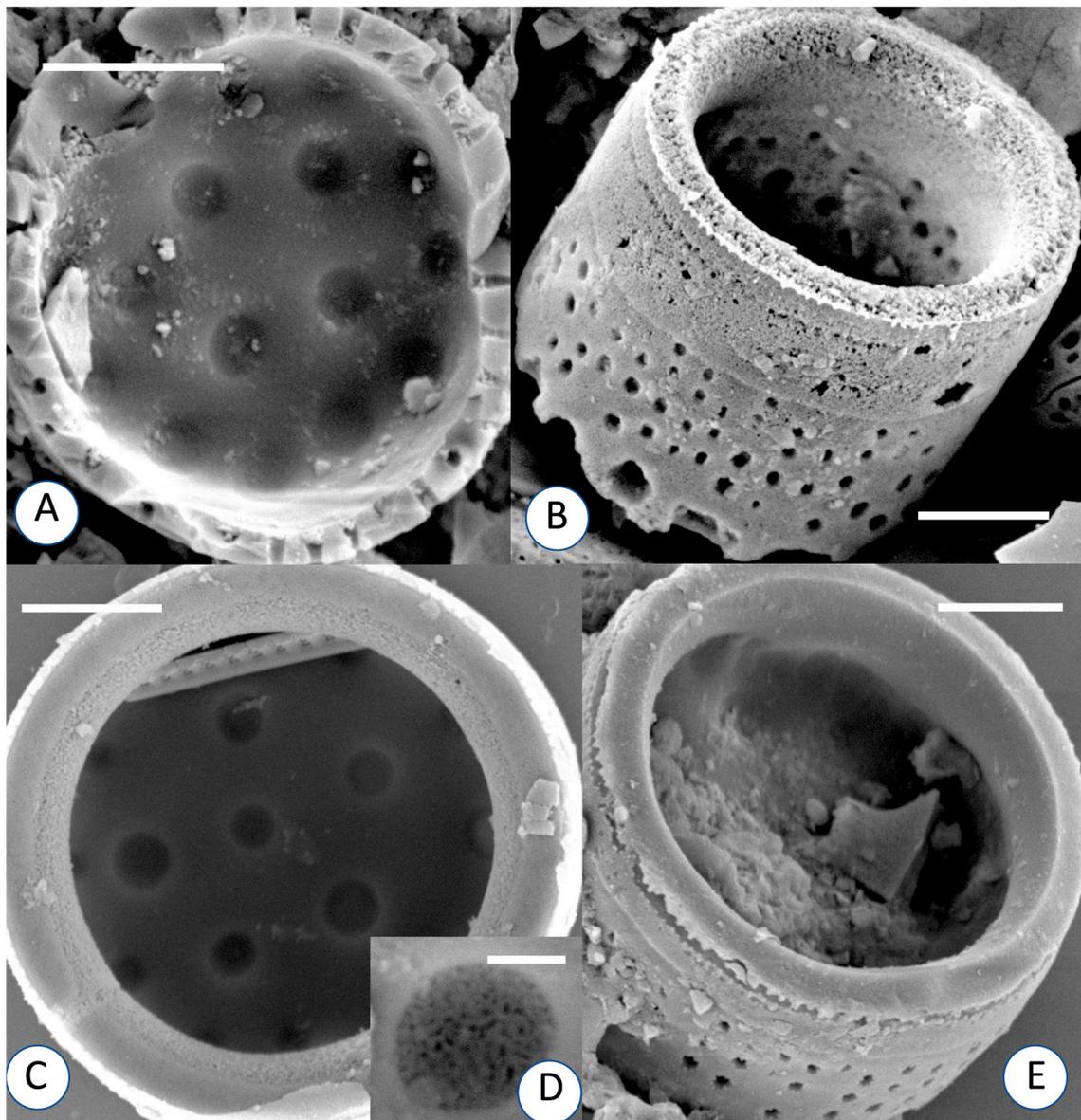
Etymology: Named for the U.S. state in which it was found.

Description: Valves are disc-shaped (Figure 1A–E), cylindrical in girdle view (Figure 1G,H) 7–14  $\mu\text{m}$  in diameter, and with a valve mantle height of 3–9  $\mu\text{m}$  ( $n = 100$ ). Frustules are single, rarely forming chains; if so, never comprising more than two frustules. Valve face has large areolae (ca. 1  $\mu\text{m}$  diameter) that are present across its entirety. In girdle view, short spine-like protrusions are evident around the valve margin. Mantle striae are straight, areolae are disorganized within a stria, two to six areolae are present per stria. Stria density on the mantle is 10–12/10  $\mu\text{m}$ . Striae are usually interrupted along their length. Striae extend from the valve margin to only  $\frac{1}{2}$  the height of the mantle, extending to the wide collum. Areolar density on the mantle is 12–16/10  $\mu\text{m}$ . Collum is evident. Ringleiste is relatively narrow (Figure 1F).

In the SEM, externally, the areolae on the valve face are seen as forming depressions occluded by volae (Figure 2A–D). Short, blunt, spine-like protrusions originate from the mantle (Figures 2C and 3A–C), shield-like, but absent from some valves. The cingulum is comprised of many narrow, ligulate bands (Figure 3A–C). The collum is ornamented with siliceous ridges (Figure 3A–C). Internally, individual areolae are covered by fine, hymenate occlusions (Figure 4A,C,D). Rimoportulae have not been observed (Figure 4A–C,E).



**Figure 3.** (A–C) *Aulacoseira wyomingensis*, sp. nov. Scanning electron microscopy. External girdle views of entire frustules. Valves have striae that are disorganized. Column has small ridges. Cingulum is composed of numerous ligulate elements. Spines are small in length and shield-like. Valve on the right in (C) appears to be incompletely formed. Scale bars = 5  $\mu$ m.



**Figure 4.** (A–C) *Aulacoseira wyomingensis*, sp. nov. Scanning electron microscopy. Internal views. (A) Valve view showing areolae and interior of valve. Scale bar = 2.5  $\mu$ m. (B) Side view showing part of valve interior and exterior. Scale bar = 2.5  $\mu$ m. (C) Valve view of interior showing ringleiste. Scale bar = 2.5  $\mu$ m. (D) High magnification view of single areola showing fine hymenate occlusion over opening. Scale bar = 0.3  $\mu$ m. (E) Side view showing part of the valve interior and exterior. Scale bar = 2.5  $\mu$ m.

#### 4. Discussion

Many species of *Aulacoseira* have only a few areolae scattered across the valve face (e.g., *A. pusilla* (F.Meister) Tuji and Houki; [16,17]) or concentrated around the periphery (e.g., *A. lirata* (Ehrenberg) R.Ross in Hartley; [11,18,19]). *Aulacoseira wyomingensis* is among the *Aulacoseira* species with areolae across the entire valve face. In Table 1, *A. wyomingensis* is compared and contrasted with other species of the genus having the valve face covered with areolae. In short, the few, large areolae on the valve face, shield-like, small spines that do not interdigitate with opposing valves (and thus lack of a filamentous growth habit), lack of rimoportulae and the disorganized nature of the striae on the valve mantle all distinguish this new species from other, previously described taxa. *Aulacoseira wyomingensis* does share the feature of not forming filaments with taxa such as *A. singulara* Bennett and

Kociolek [14] and *A. tenella* (Nygaard) Simonsen [20], *A. chockii* Siver [9] among others, but differs from these taxa in the other features described above.

**Table 1.** Comparison of morphometric data of some *Aulacoseira* species with valve face covered with areolae.

Taxon	Diameter ( $\mu\text{m}$ )	Valve Mantle Height ( $\mu\text{m}$ )	Striae/10 $\mu\text{m}$	Areolae/10 $\mu\text{m}$	References
<i>A. brasiliensis</i>	8–24	4–10	10–16	10–15	[21]
<i>A. tenella</i>	5–12	2–5	20–24 (face) ca. 20 (mantle)		[22]
<i>A. humilis</i>	5–9	2–5	12–20	17 (face) 24–40 (mantle)	[23]
<i>A. nivalis</i>	6–18	2.5–6.0	12–16	9–10 (mantle) 7–14 (face)	[22,24]
<i>A. nivaloides</i>	4–11	4–6	16–22	15–21 (mantle) ca. 18	[22]
<i>A. islandica</i>	3–28	4–21	11–16	12–15	[25,26]
<i>A. minuscula</i>	3.0–4.5	2.0–3.5	16–20	No data	[27]
<i>A. imparis</i>	7–13	7–10	23–25	No data	[13]
<i>A. lancea</i>	7–15	5–10	22–25	No data	[13]
<i>A. occulata</i>	7–17	7–10	22–25	No data	[13]
<i>A. perglabra</i>	8–17	2–4	20–28	28–80	[25]
<i>A. pfaffiana</i>	4–23	3.0–10.5	12–15	16–18	[25]
<i>A. delicatula</i>	3–6	2–3	No data	No data	[14]
<i>A. singularia</i>	2.0–5.5	1–2	13–15	20	[14]
<i>A. wyomingensis</i>	6–15	3–7	4–6 (face) 9–12 (mantle)	12–16 (mantle)	This Study

*Aulacoseira wyomingensis* sp. nov. was the dominant taxon in the sample from which it is described, having a relative abundance of 57.8%. Other common taxa in the sample include *Epithemia* cf. *adnata* (11.0%), *Denticula kuetzingii* Grunow (7.8%), *D. valida* (Pedicino) Grunow (7.2%), *Encyonopsis microcephala* (Grunow) Krammer (4.2%), *Adlafia bryophila* (J.B.Petersen) Moser et al. (3.2%), *Staurosirella* sp. (2.7%) and *Epithemia* cf. *sorex* (2.5%). Other ecological data for this sample are wanting. To date, it has only been found in this Recent collection.

We assign *A. wyomingensis* to *Aulacoseira*, based on its expanded valve mantle and that it lacks features of most of the genera currently in Aulacoseiraceae. For example, *A. wyomingensis* lacks the diagnostic features of internal struts found in *Miosira* and *Alveolophora* [3,4,28] and lacks the long spathulate spines found in *Eosira* [2]. Within *Aulacoseira*, five groups can be recognized (according to [15] using a total evidence approach for understanding phylogenetic relationships. Synapomorphies for these different groups have not been recognized, so it is difficult to align their phylogenetic relationships with specific morphological features. Species of *Aulacoseira* that have the valve face covered in areolae occur in three of their five groups, including *A. pfaffiana* in group 1 (with *A. crenulata* (Ehrenberg) Thwaites, the generitype), *A. perglabra* in group 4 (with *A. subarctica* and allies) and *A. islandica* in group 5. The tremendous morphological diversity seen amongst taxa currently assigned to *Aulacoseira*, both Recent and fossil [9,25,29,30], suggests further research and, perhaps, an analysis of the phylogenetic relationships of the genus as well as the family is warranted.

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## References

1. Round, F.E.; Crawford, R.M.; Mann, D.G. *The Diatoms. Biology and Morphology of the Genera*; Cambridge University Press: Cambridge, UK, 1990; 747p.
2. Wolfe, A.P.; Edlund, M.B. Taxonomy, phylogeny, and paleoecology of *Eoseira wilsonii* gen. et sp. nov., a Middle Eocene diatom (Bacillariophyceae: Aulacoseiraceae) from lake sediments at Horsefly, British Columbia, Canada. *Can. J. Earth Sci.* **2005**, *42*, 243–257. [CrossRef]
3. Krammer, K.; Lange-Bertalot, H.; Schiller, W. *Miosira rhoenana* n. gen. n. sp. (Bacillariophyceae) from Miocene limnic sediments of the Rhoen mountains in comparison with other centric diatoms. *Paläontologische Z.* **1997**, *71*, 5–18. [CrossRef]
4. Usoltseva, M.; Kociolek, J.P.; Khursevich, G.K. Three new species of *Alveolophora* (Aulacoseiraceae) from Miocene fossil deposits in western North America. *Phycologia* **2013**, *52*, 109–117. [CrossRef]
5. Khursevich, G.K.; Kociolek, J.P. A Preliminary, Worldwide Inventory of the Extinct, Freshwater Fossil Diatoms from the Orders Thalassiosirales, Stephanodiscales, Paraliales, Aulacoseirales, Melosirales, Coscinodiscales, and Biddulphiales. *Nova Hedwig. Beih.* **2012**, *141*, 315–364.
6. Houk, V.; Klee, R.; Tanaka, H. Atlas of freshwater centric diatoms with a brief key and descriptions. Second emended edition of Part I and II. Melosiraceae, Liparogyraceae, Paraliaceae and Aulacoseiraceae. *Fottea* **2007**, *1* (Suppl. S17), 1–616.
7. Siver, P.A.; Velez, M.; Cliveti, M.; Binda, P. Early freshwater diatoms from the Upper Cretaceous Battle Formation in western Canada. *Palaios* **2018**, *33*, 525–534. [CrossRef]
8. Krebs, W.N.; Bradbury, J.P.; Theriot, E.C. Neogene and Quaternary lacustrine diatom biochronology, Western USA. *Palaios* **1987**, *2*, 505–513. [CrossRef]
9. Siver, P.A. *Aulacoseira chockii* sp. nov., an early freshwater centric diatom from the Eocene bearing a unique morphology. *Diatom Res.* **2021**, *36*, 253–263. [CrossRef]
10. Moisseeva, A.I.; Nevretdinova, T.L. Novye semeistvo i rod presnovodnykh diatomovykh vodoroslei (Bacillariophyta). *Bot. Zhurnal* **1990**, *75*, 539–544.
11. Camburn, K.E.; Kingston, J.C. The genus *Melosira* from soft-water lakes with special reference to northern Michigan, Wisconsin and Minnesota. In *Diatoms and Lake Acidity*; Smol, J.P., Battarbee, R.W., Davis, R.B., Meriläinen, J., Eds.; Dr. W. Junk Publishers: Dordrecht, The Netherlands, 1986; pp. 17–34.
12. Camburn, K.E.; Charles, D.F. *Diatoms of Low-Alkalinity Lakes in the Northeastern United States*. (Academy of Natural Sciences of Philadelphia Special Publication); Academy of Natural Sciences: Philadelphia, PA, USA, 2000; Volume 18, pp. 1–152.
13. Siver, P.A.; Hamilton, P.B. The Diatoms of North America: The Freshwater Flora of Waterbodies on the Atlantic Coastal Plain. *Iconogr. Diatomol.* **2011**, *22*, 1–916.
14. Kociolek, J.P.; Laslandes, B.; Bennett, D.; Thomas, E.; Brady, M.; Graeff, C. Diatoms of the United States 1: Taxonomy, Ultrastructure and Descriptions of New Species and Other Rarely Reported Taxa from Lake Sediments in the Western, U.S.A. *Bibl. Diatomol.* **2014**, *61*, 1–188.
15. Edgar, S.M.; Theriot, E.C. Phylogeny of *Aulacoseira* (Bacillariophyta) based on molecules and morphology. *J. Phycol.* **2004**, *40*, 772–788. [CrossRef]
16. Tuji, A.; Houki, A. Taxonomy, ultrastructure, and biogeography of the *Aulacoseira subarctica* species complex. *Bull. Natl. Sci. Mus. Ser. B* **2004**, *30*, 35–55.
17. Tuji, A.; Williams, D.M. Type examination of the freshwater centric diatom *Aulacoseira pusilla* (F. Meister) Tuji et Houki. *Diatom* **2006**, *22*, 70–73.
18. Florin, M.-B. The taxonomy of some *Melosira* species, a comparative morphological study. II. In Proceedings of the 6th Symposium on Recent and Fossil Diatoms, Budapest, Hungary, 1–5 September 1980; International Society of Diatoms: Koeltz, Germany; Koenigstein, Germany, 1981; pp. 43–74.
19. Krammer, K. Morphology and taxonomy of some taxa in the genus *Aulacoseira* Thwaites (Bacillariophyceae). I. *Aulacoseira distans* and similar taxa. *Nova Hedwig.* **1991**, *52*, 89–112.
20. Potapova, M. *Aulacoseira tenella*. Diatoms of North America. 2010. Available online: [https://diatoms.org/species/aulacoseira\\_tenella](https://diatoms.org/species/aulacoseira_tenella) (accessed on 5 May 2022).
21. Tremarin, P.I.; Ludwig, T.A.V.; Torgan, L.C. Ultrastructure of *Aulacoseira brasiliensis* sp. nov. (Coscinodiscophyceae) and comparison with related species. *Fottea* **2012**, *12*, 171–188. [CrossRef]

22. English, J.; Potapova, M. *Aulacoseira pardata* sp. nov., *A. nivalis* comb. nov., *A. nivaloides* comb. nov. et stat. nov., and their occurrences in western North America. *Proc. Acad. Nat. Sci. Phila.* **2009**, *158*, 37–48. [[CrossRef](#)]
23. English, J.; Potapova, M. *Aulacoseira humilis*. *Diatoms of North America*. 2010. Available online: [https://diatoms.org/species/aulacoseira\\_humilis](https://diatoms.org/species/aulacoseira_humilis) (accessed on 5 May 2022).
24. Tuji, A. Examination of type material of *Melosira nivalis* W.Sm. (Bacillariophyceae) and its synonymy with *Aulacoseira pfaffiana* (Reinsch) Krammer. *Bull. Natl. Mus. Nat. Sci. Ser. B* **2010**, *36*, 161–164.
25. Krammer, K.; Lange-Bertalot, H. Bacillariophyceae, 3 Teil, Centrales, Fragilariaceae, Eunotiaceae. In *Süßwasserflora von Mitteleuropa, Band 2*; Ettl, H., Gerloff, J., Heynig, H., Mollenhauer, D., Eds.; Gustav Fischer: Stuttgart/Jena, Germany, 1991; pp. 1–576.
26. Genkal, S.I.; Poposkaya, G.I. New data on the diatom morphology of *Aulacoseira islandica* (Bacillariophyta). *Diatom Res.* **1991**, *6*, 255–266. [[CrossRef](#)]
27. Tremarin, P.I.; Ludwig, T.A.V.; Torgan, L.C. Four new *Aulacoseira* species (Coscinodiscophyceae) from Matogrossense Pantanal, Brazil. *Diatom Res.* **2014**, *29*, 183–199. [[CrossRef](#)]
28. Usoltseva, M. Morphological variability of *Alveolophora jouseana* (Bacillariophyta) from type material. *Phytotaxa* **2022**, *533*, 194–204. [[CrossRef](#)]
29. Lee, Y.; Yoon, S.-K. Morphologic accounts of the diatom genus *Aulacoseira*, the dominant of the Han River. *Korean J. Phycol.* **1994**, *9*, 135–143.
30. Houk, V. *Aulacoseira hibschi* (Reichel) Houk comb. nov. (Bacillariophyceae, Centrales) from the type locality in Varnsdorf (Czech Republic). *Bull. Geosci.* **2007**, *82*, 419–428. [[CrossRef](#)]