Thalassiosira kozyrenkoae sp. nov. (Bacillariophyta) from the outcrops on the Taman Peninsula (Russia)

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Abstract. A study of the Upper Miocene deposits on the Taman Peninsula revealed a new centric diatom *Thalassiosira kozyrenkoae* Kovaleva et Gogorev. The absence of findings of this species in the modern diatom flora suggests that it is extinct. The species was likely endemic for the Sea of Azov – the Black Sea basin. Single findings of valve fragments in the New Azov layers make it possible to use *T. kozyrenkoae* as a stratigraphic marker and to estimate the distribution extent of the Neogene sediments from the outcrops. This study will contribute to the more precise identification of the origin of the redeposited fossil diatoms in the Quaternary sediments from the Sea of Azov.
Keywords: *Biddulphia tuomeyi*, *Thalassiosira,* diatoms, Miocene, morphology, taxonomy.

Thalassiosira kozyrenkoae sp. nov. (Bacillariophyta) из обнажений на Таманском полуострове (Россия)

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Резюме. Приводится описание нового для науки вида диатомовых водорослей — *Thalassiosira kozyrenkoae* Kovaleva et Gogorev. из верхнемиоценовых отложений Таманского полуострова. Отсутствие находок этого вида в современной флоре дает основание считать описанный таксон вымершим. Вероятно, этот вид был эндемиком Азово-Черноморского бассейна. Находки обломков створок этого вида в новоазовских слоях позволяют использовать *T. kozyrenkoae* в качестве стратиграфического маркера, который поможет оценить масштабы разноса неогеновых осадков из обнажений и уточнить происхождение переотложенных ископаемых диатомовых в четвертичных осадках Азовского моря.
Ключевые слова: *Biddulphia tuomeyi*, *Thalassiosira*, диатомовые водоросли, миоцен, морфология, таксономия.

A vast marine basin in the Neogene, the Paratethys, stretched from the Alps to the Aral Sea and included the Pannonian, Dacian and Euxinian-Caspian water bodies linked by straits (Rostovtseva, 2009a). The Paratethys diminished in size in the Middle Sarmatian, resulting in the isolation and emergence of the Pannonian Sea. During the Maeotian Stage, the Paratethys continued to be separated into the Pannonian and Dacian-Euxinian-Caspian (the Eastern Paratethys) basins, completely isolated from each other. While the Pannonian Sea during that period was a brackish-water body with an endemic fauna of molluscs, the Dacian-Euxinian-Caspian basin was a semi-marine reservoir in the early Maeotian and a brackish one in the late Maeotian Regional Stage (Rostovtseva, 2009b).

The exposures of the Neogene deposits of the Taman Trough are well-known and have been thoroughly studied (Neveskaya *et al.,* 2004). Beginning with the Middle Miocene, they were well-exposed on the Black Sea coast of the Taman Peninsula. The more ancient deposits are exposed only in the kernels of diaper folds and registered on the Sea of Azov coast, where they are broken by landslides. A light, denser alternation cluster of clays and marls, which is of marker value, is well-distinguished in the Middle Sarmatian deposits. Deepwater facies with diatomite interlayers comprise the Upper Miocene deposits (to the Upper Maeotian), and typical facies of valencienneside clays comprise the Pontian ones. Clayey deposits (the Lower Cimmerian) comprise the Pliocene layers in the lower parts of transects and shallow-water deposits, and lenses of brown ironstones (the Kamysh-Burun layers of the Cimmerian) comprise the upper ones. The brackish shallow water deposits of supra-ore thickness, overlain with a cluster of semi-marine Akchagyl deposits, comprise the top layers of the Late Pliocene–Lower Pleistocene deposits (Neveskaya *et al.,* 2004).

Studies by D. Pantochek, A. S. Savchenko, A. B. Missuna, A. P. Zhuze, A. I. Proschkina-Lavrenko, I. V. Makarova, T. F. Kozyrenko, A. P. Ol'shtynskaya, E. P. Rodionova, and others have provided detailed descriptions of fossil diatom complexes of the Neogene from the Taman and Kerch peninsulas. A detailed review of these studies has been given earlier (Makarova, 1960, 1965; Makarova, Kozyrenko, 1966; Kozyrenko, Makarova, 1968; Rostovtseva, Kozyrenko, 2006).

Studying the Sea of Azov Quaternary deposits, especially from the southern part of the sea, we regularly register poorly preserved fragments of diatom valves and try to identify these redeposited forms. It is important to determine the age and origin of redeposited valves to interpret the presence of these forms in the Ancient and New Azov layers of the Sea of Azov deposits more precisely. When we identified the fragments of valves of *Thalassiosira* species in one of the cores sampled in the Northern Kerch Strait, their morphology indicated that they did not correspond to any of *Thalassiosira* species previously registered in the Sea of Azov (Gogorev, Kovaleva, 2017). A comparison of the redeposited fragments with the earlier results showed that they are similar to a *Thalassiosira* species, registered in a sample of diatomite from the exposures on Cape Panagia (the Taman Peninsula). A thorough study of the species morphology using scanning electronic microscopy allowed the description of a new species, *Thalassiosira kozyrenkoae* Kovaleva et Gogorev.

Material and Methods

We sampled the exposures on Cape Panagia in June 2006 during the expedition of the Southern Scientific Centre of the Russian Academy of Sciences (SSC RAS). Cape Panagia (45°08′26.0″N, 36°38′00.5″E), located in the Temryuk District of Krasnodar

Territory, is in the south-west of the Taman Peninsula, 12 km from the stanitsa (Cossack village) of Taman (Fig. 1). This is the eastern entry cape to the Kerch Strait from the Black Sea. The specimen was sampled in the upper part of the open exposure, 150 m north of the tip of Cape Panagia (Fig. 1). We discovered the outcrop of diatomite in the upper part of the sampling site (Fig. 2).

Part of the sample of diatomite (approximately 3 g) was boiled in distilled water with several drops of 32% hydrogen peroxide in the laboratory. After rock disintegration, the sample was rinsed several times with distilled water and centrifuged (Elmi SM-6M; 3000 rpm). An aliquot of the rinsed sample was examined with a light microscope (LM) Leica DME (× 1000); permanent slides were made with the highly refractive *Naphrax* medium (refractive index of 1.73). The sample was then examined with a Carl Zeiss EVO 40 XVP (covered Au/Pd; accelerating voltage 15–25 kV; working distance 7.5–10.5 mm) scanning electronic microscope (SEM) (Centre of Collective Usage of Facilities of the Southern Scientific Centre RAS, No. 501994). The names of taxa of higher rank are according to Round *et al.* (1990) and Cox (2015).

Results and Discussion

The Miocene diatoms on the coast of the Taman Peninsula have been thoroughly studied along the transects on Capes Tuzla, Popov Kamen' and Zheleznyi Rog near the stanitsa of Taman (Makarova, Kozyrenko, 1966; Kozyrenko, Makarova, 1968; Rostovtseva, Kozyrenko, 2006). As for the diatom flora from the transects on Cape Panagia, the results of studying a series of specimens from the coastal exposures are given

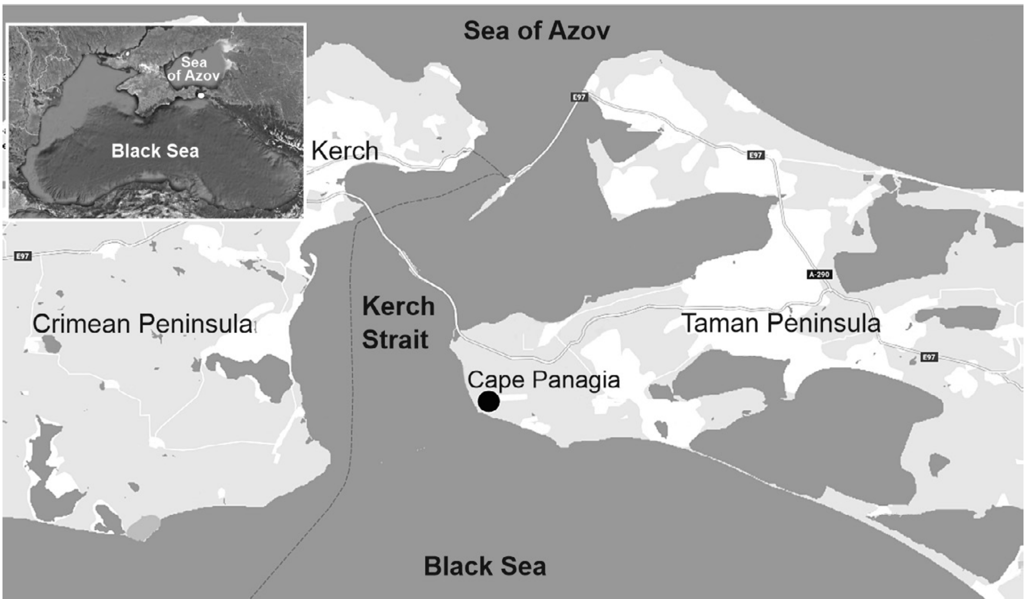

Fig. 1. Map with the sampling site at Cape Panagia.

Fig. 2. Sampling site at the coastal exposure at Cape Panagia.
1 — general view of exposure; 2 — Cape Panagia's tip; 3 — enlarged view of diatomite outcrop; the arrow indicates the sample site.

by Makarova (Milovanova, 1955; Makarova, 1960), the author who first described the diatom complexes of the Middle and Late Sarmatian and Maeotian in this region. These data were subsequently generalized and extended in joint publications with Kozyrenko (Makarova, Kozyrenko, 1966; Kozyrenko, Makarova, 1968).

According to these, abundant development of *Biddulphia tuomeyi* (Bailey) Roper var. *tuomeyi* [= *Biddulphia tridens* (Ehrenb.) Ehrenb.] and var. *tridentata* (Ehrenb.) Jousé was a typical feature of the Late Miocene diatom flora. In their opinion, the valve thickness of this species is typical of the Late Sarmatian–Early Maeotian Regional Stages. They registered *B. tuomeyi* in the upper layers of the Upper Sarmatian Period on the Taman Peninsula (Makarova, 1960) and the lower layers of the Maeotian in the North-Eastern Crimea (Makarova, Kozyrenko, 1966). The presence of this

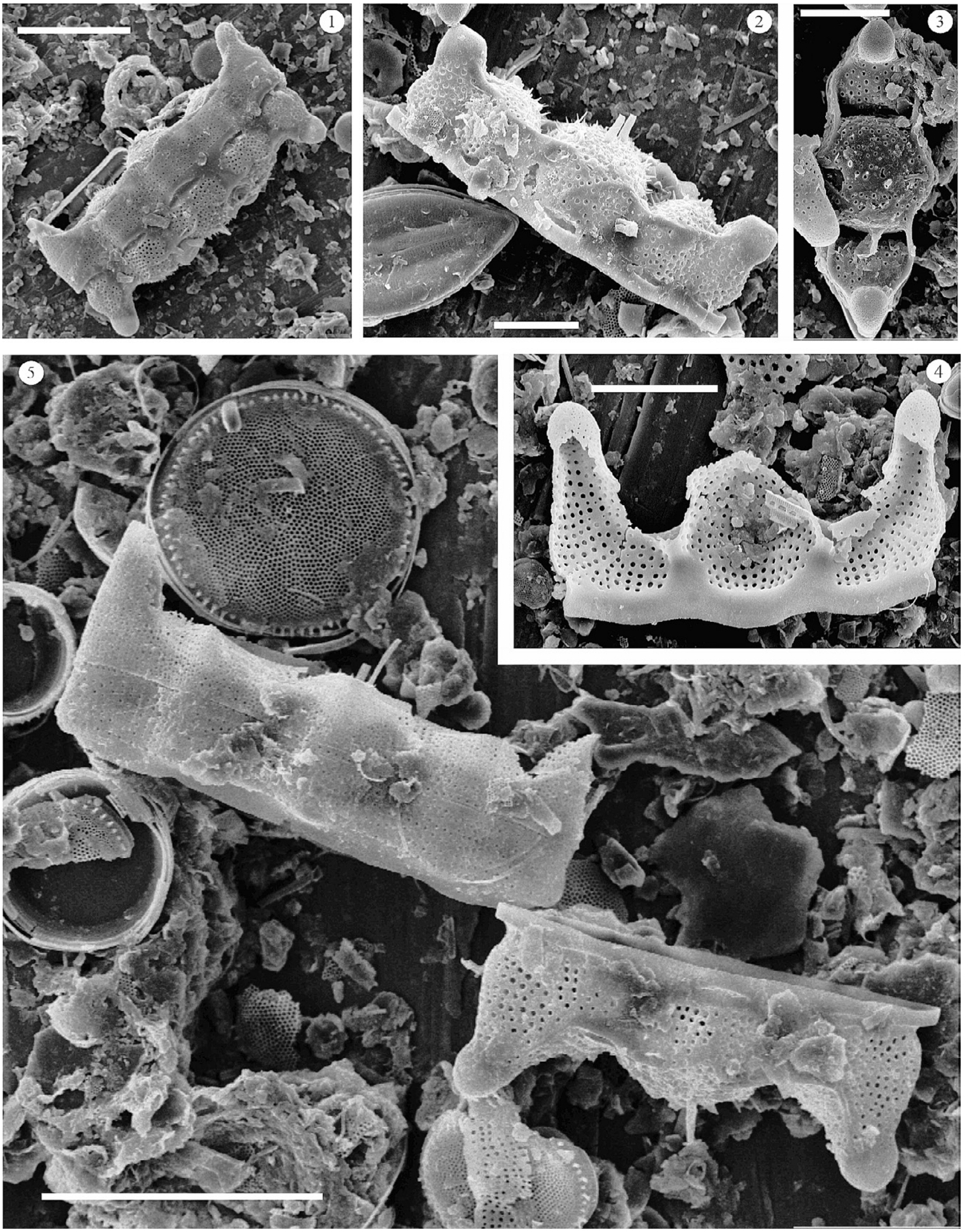

Plate I. Diatom complex from diatomite outcrop at Cape Panagia.
1–2 — *Biddulphia tuomeyi* var. *tuomeyi*; 3–4 — *B. tuomeyi* var. *tridentata*; 5 — valve of *Thalassiosira kozyrenkoae* (top), *B. tuomeyi* var. *tuomeyi* (middle), and *B. tuomeyi* var. *tridentata* (bottom).
Scale bars: 1, 5 — 50 µm; 2–4 — 20 µm.

species-marker (Plate I) in our diatomite specimen allowed us to relate the examined deposits to the Late Sarmatian–Early Maeotian (the Late Miocene).

Makarova and Kozyrenko (1966) also stated that neritic species belonging to the genus *Thalassiosira*, such as *T. variabilis* I. V. Makarova, *T. tenera* Proshk.-Lavr., *T. delicatissima* Proshk.-Lavr., *T. subsalina* Proshk.-Lavr., *T. maeotica* Proshk.-Lavr. and *T. coronifera* Proshk.-Lavr., often accompanied the diatom complex with *Biddulphia tuomeyi* var. *tuomeyi* and var. *tridentata*. Because they had at their disposal only a LM, we assume that they misidentified the species under the name of *T. coronifera*. When studied using LM, the valves of *T. kozyrenkoae* are very similar to *T. coronifera*; however, the use of SEM for a detailed study of valve structure allowed us to determine significant differences between them (Table 1). The species diagnosis is given below.

Phylum **BACILLARIOPHYTA**
Class **MEDIOPHYCEAE** Medlin et Kaczmarska
Order **THALASSIOSIRALES** Glezer et I. V. Makarova
Family **Thalassiosiraceae** M. Lebour

Thalassiosira kozyrenkoae Kovaleva et Gogorev, sp. nov. (Plates II–V)

Valves flat, slightly concave in center, 20–61 µm in diam., with a rather high mantle. Areolae pattern radial and fasciculated, 12–13 (rarely 14) areolae in 10 µm, 26–30 areolae in 10 µm on valve mantle. Foramina of areolae big, round in center. Rarely, foramina are smaller, slit-like, tri- or quadrangular near the margin. Cribrum round to elongated ellipsoid with 18–24 cribrum pores in 1 µm (n = 23) (Plate V: 2, 3, 5, 6).

One central strutted process with 5 satellite pores, with external short tube (Plate III: 6; IV: 4) and usually surrounded by 1–2 larger areolae (Plate V: 6). Marginal strutted processes with 4 satellite pores in a ring, 6 in 10 µm (Plate V: 3, 5); rarely 4–5 in 10 µm on great valves (45–60 µm in diam.). External marginal processes with rather long tubes, sometimes surrounded by extension (coil) at the end (Plate IV: 7) and with internal very short tubes inside the valve (Plate V). Single rimoportula between two marginal strutted processes, on external surface with external tube longer than in marginal processes (Plate III: 1, 3, 7; Plate IV: 3), 1.9–2.7 µm long (Plate IV: 3); internal slit of labiate process about 1 µm long, located radially (Plate V: 2, 5, 7).

H o l o t y p e : The specimen on slide No. 7, stored at the Southern Scientific Centre RAS, Rostov-on-Don (Russia), illustrated at Plate II: 4. I s o t y p e : Slide LE A0000299 (No. 716).

T y p e l o c a l i t y : Russia, Taman Peninsula, Cape Panagia, 45°08′26.0″N, 36°38′00.5″E, Late Miocene deposits, VI 2006, *G. V. Kovaleva*.

D i s t r i b u t i o n . Fossil species, frequently registered in the Late Miocene deposits (from the layers of the Late Sarmatian to the Early Maeotian Regional Stages); single finds registered in the Quaternary sediments from the Sea of Azov as redeposited valves.

Etymology. The specific epithet was chosen in honor of the Russian diatomologist Tatiana Fedorovna Kozyrenko who studied the Miocene diatoms of the Taman Peninsula for many years.

Differentiation. *Thalassiosira kozyrenkoae* is morphologically similar to both *T. coronifera* and *T. punctigera* (Castrac.) Hasle in valve size and areolae pattern. *Thalassiosira kozyrenkoae* differs from the first description of *T. coronifera* (Proschkina-Lavrenko, 1955) by a greater density of areolae and marginal processes. In the emended diagnosis of *T. coronifera* (Genkal, Terenko, 2009), the areolae density is within a wider range (Table 1), but the density of marginal processes is also less when compared to *T. kozyrenkoae*. Moreover, Genkal, Terenko (2009) indicated up to three central strutted processes and also observed a long external tube of labiate process, which differs from our data (2–5 µm in length, unlike 1.8–2.7). In addition, according to other data (Diatomovye..., 1988), the *T. coronifera*'s central strutted processes on the external surface has only aperture, unlike *T. kozyrenkoae* that has an external tube. *Thalassiosira kozyrenkoae*, *T. angulata* (W. Greg.) Hasle, and *T. tenera* are similar in morphology by the density of areolae and differ by the external valve view and areolae pattern. The main morphological differences between *T. kozyrenkoae* and the compared species are in the different density of the marginal processes and the different number of satellite pores of the central strutted process (Table 1).

Acknowledgments

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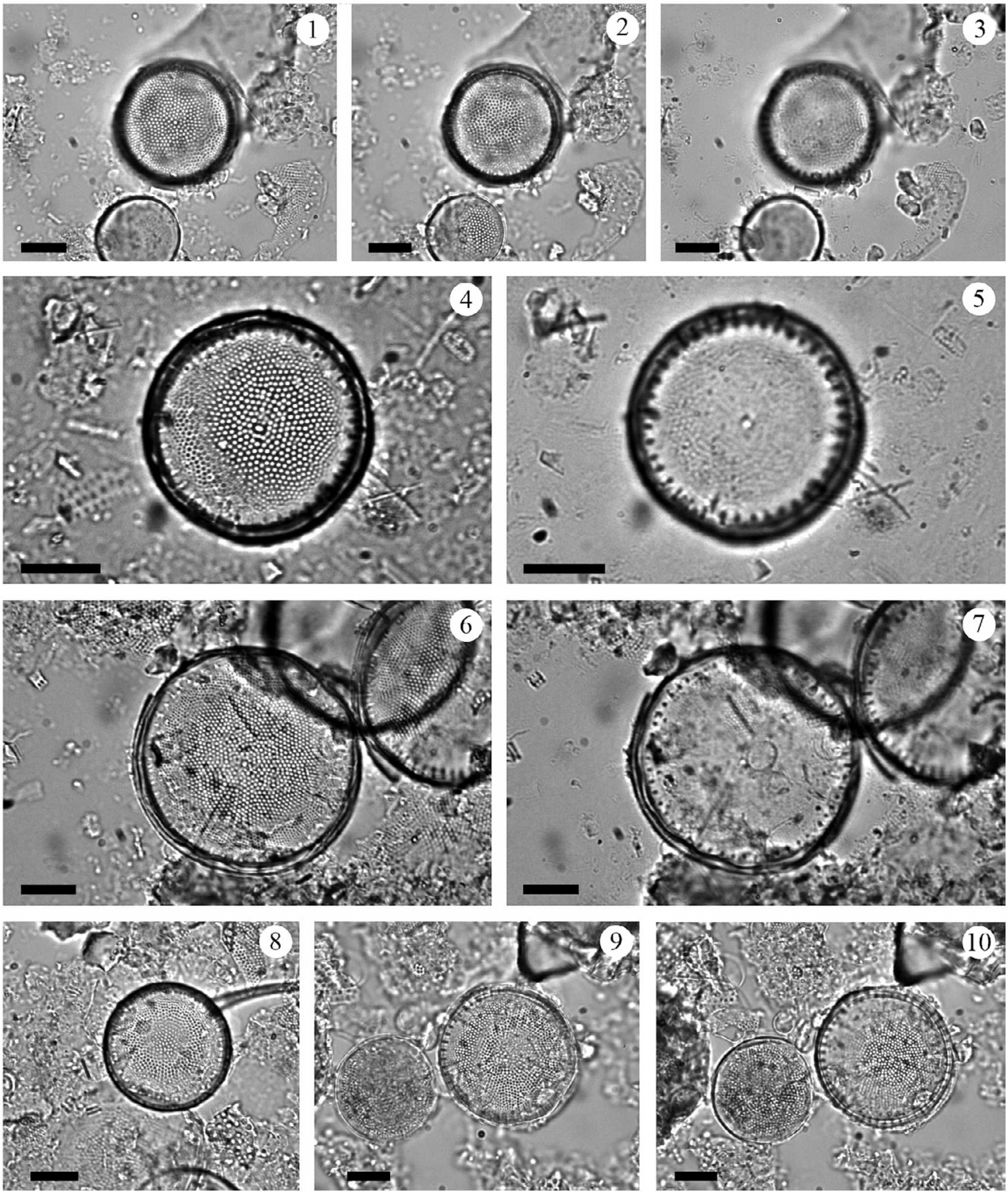

Plate II. *Thalassiosira kozyrenkoae* from the sample of diatomite, LM.
1–10 — valve: 4 — holotype of *T. kozyrenkoae*, slide No. 7.
Scale bars: 10 µm.

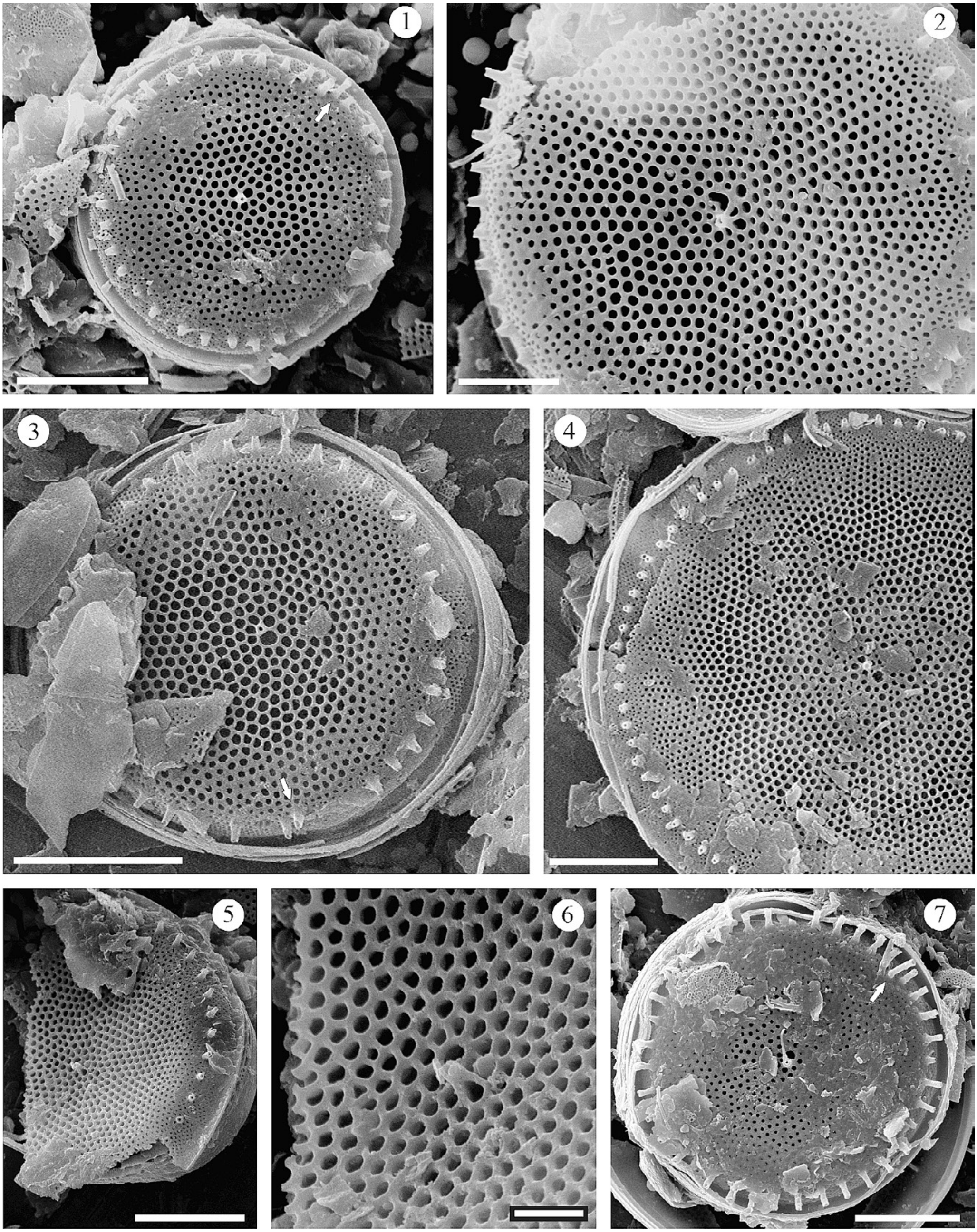

Plate III. *Thalassiosira kozyrenkoae* (external valve surface) from the sample of diatomite, SEM.
1, 3, 7 — external valve surface (external tube of rimoportula marked with arrows);
2, 4–6 — part of exterior valve: 6 — central strutted process.
Scale bars: 1, 3–5, 7 — 10 µm; 2 — 5 µm; 6 — 2 µm.

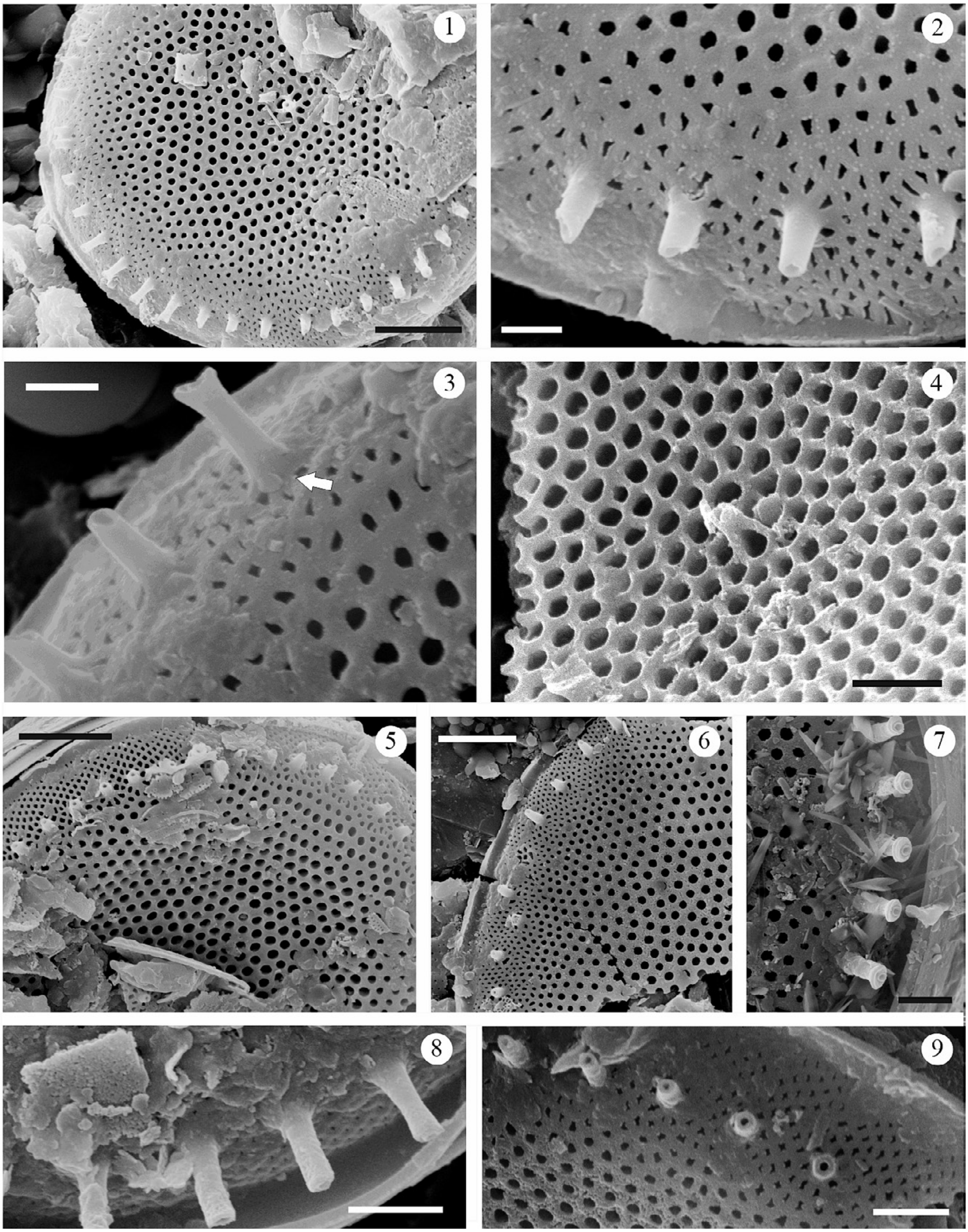

Plate IV. *Thalassiosira kozyrenkoae* (external valve surface) from the sample of diatomite, SEM.
1–3, 5–9 — margin of valve, several marginal strutted processes,
rimoportula (3) marked with arrow; 4 — central strutted process.
Scale bars: 1, 5, 6 — 5 µm; 2, 3 — 1 µm; 4, 7–9 — 2 µm.

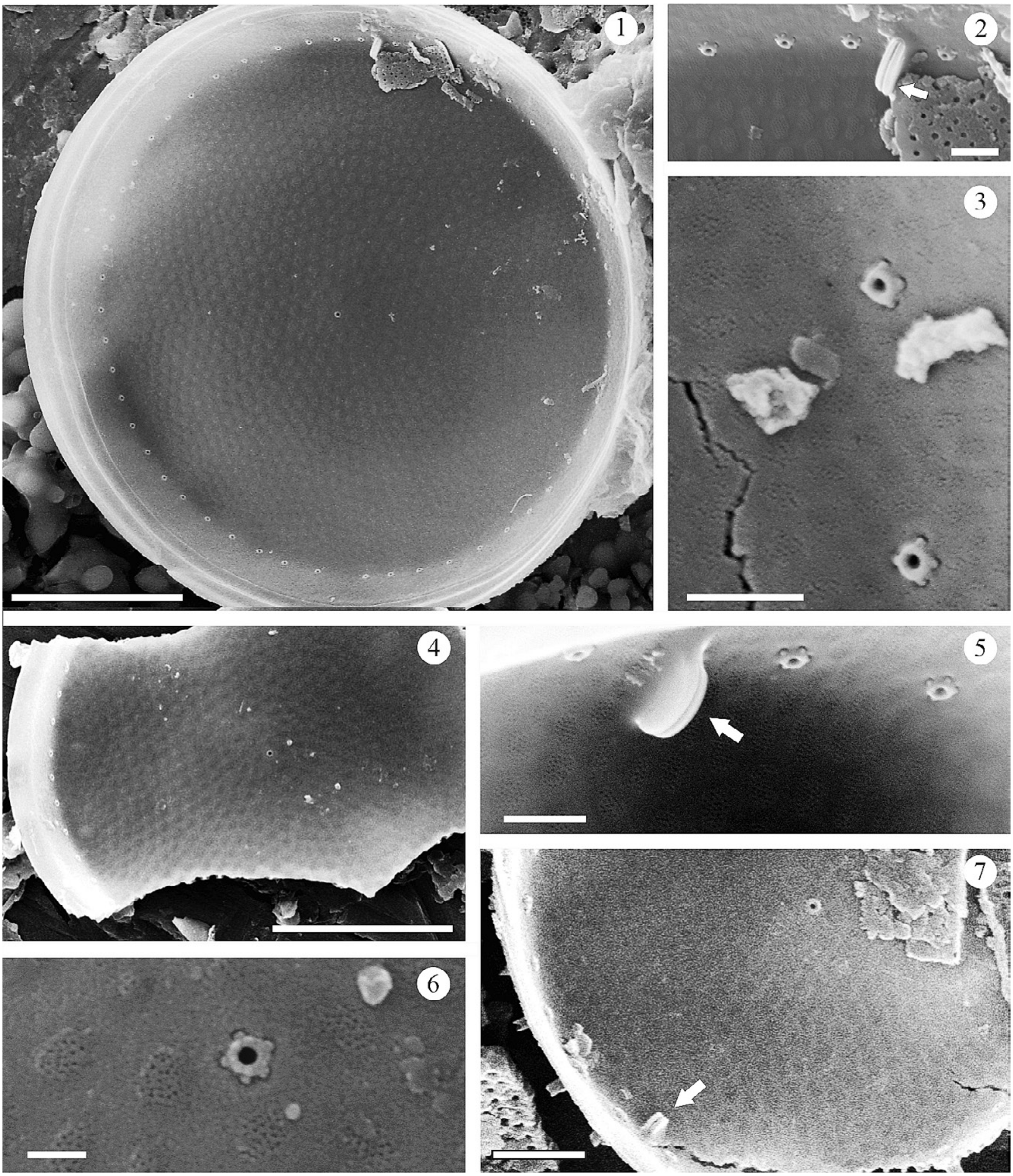

Plate V. *Thalassiosira kozyrenkoae* (internal valve surface) from the sample of diatomite, SEM. 1 — internal valve surface; 2–7 — part of interior valve with marginal strutted processes, rimoportula (2, 5, 7 — arrows), central strutted process (6). Scale bars: 1, 4 — 10 µm; 2, 3, 5 — 1 µm; 6 — 0.5 µm; 7 — 2 µm.

Table 1

Morphological features of *Thalassiosira kozyrenkoae* sp. nov. and similar species

	Valve diameter, µm	Number of areolae in 10 µm			Areolae pattern	Number of CF	Number of MF in 10 µm	Number and size of rimoportula	References*
		Center	Margin	Mantle					
T. kozyrenkoae sp. nov.	20–61	12–13	14	26–30	radial, in fascicles	1	6 (rarely 4–5)	1, 1.8–2.7 µm	[1]
T. aestivalis Gran	20–32	18		20–22	radial, in fascicles	1	3–5	1	[2]
	14–56	18		>20		1	4	1	[3]
	14–56	>20			in fascicles	1	4	1	[4]
T. angulata	17–40	8–12	12–15	16–20	tangential	1	3	1, 2.6–2.7 µm	[2]
	12–39	8–18		14–24	tangential	1	3 (2–4)	1	[3]
	11–39	14–24			tangential, in fascicles	1	4	1	[4]
T. coronifera	16–48	10	16–17	-	tangential, radial, in fascicles	1	3–4	1	[5]** Black Sea
	11–18	8–10	15–16	-	tangential-radial, in fascicles	1	3–5	1	[6] Caspian Sea
	11–48	8–10	15–17	16–17	tangential, radial	1	4–5	1, approximately 2 µm	[2]
	17–41	9–14	11–16	15–20		1 (rarely 2–3)	3–5	1, 2.8–5 µm	[7] Black Sea
T. decipiens (Grunow) E.G. Jørg.	12–42	6–8	10–17		tangential		3–5		[8]
	9–28	8–12		10–15	tangential, radial	1	4–7	1	[9]
	9–40	8–12		10–15	tangential	1	4–6	1	[2]
	9–40	8–12		10–15	tangential	1	4–6	1	[3]
	10–30	8–10	13	15	tangential	1	4–5	1	[10]
	8–32(40)	10–15			tangential	1	4–6	1	[4]

	Valve diameter, µm	Number of areolae in 10 µm			Areolae pattern	Number of CF	Number of MF in 10 µm	Number and size of rimoportula	References*
		Center	Margin	Mantle					
T. maeotica	11–45	16	18–20	20–22	radial, in fascicles	1	7–8	-	[11]
	11–45	16	18–20	20–22	radial, in fascicles	1?	7–8	1	[2]
T. punctigera	50–130	13–16		10–12	radial, in fascicles	1	5–6	1	[2]
	40–186	10–23		10–23	in fascicles	1	4–5	1	[3]
	24–80 (40–186)	10–23			in fascicles	1	4–5	1	[4]
T. tenera	6.5–15	12–13	15	23–26	tangen-tial-linear	1	4–6	-	[12]
	6.5–15	12–13	15	23–26	tangen-tial-linear	1	4–6	1	[2]
	10–29	(9)10–16	10–16	20–24	tangen-tial-linear	1	3–5	1	[3]
	7–18	16	40	24–30	linear	1	5	1	[10]
	10–46 (10–29)	10–16			linear	1	3–5	1	[4]
T. variabilis	16–23	9–10	11–12	14–15 (18–20)	tangential	1	4–8 per valve		[13] Caspian Sea
	16–31	9–10	11–12	14–15 (18–20)	tangential		4–8 per valve		[8] Sea of Azov
	10–37	9–10	11–12	18–20	tangen-tial-radial		4–8 per valve		[6] Caspian Sea

Note. CF — central strutted processes; MF — marginal strutted processes.

* References: [1] — This study; [2] — Diatomovye ..., 1988; [3] — Hasle, Syvertsen, 1996; [4] — Hoppenrath *et al.*, 2007; [5] — Proschkina-Lavrenko, 1955; [6] — Proschkina-Lavrenko, Makarova, 1968; [7] — Genkal, Terenko, 2009; [8] — Proschkina-Lavrenko, 1963; [9] — Hasle, 1979; [10] — Ake-Castillo *et al.*, 1999; [11] — Proschkina-Lavrenko, 1960; [12] — Proschkina-Lavrenko, 1961; [13] — Makarova, 1959.

** — given as *T. coronata*.

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