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# THE PENNATE BENTHIC DIATOMS OF THE SAND BEACH OF KRUGLAYA BAY (THE BLACK SEA)

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**KEYWORDS**: diatoms, taxonomy, epipsammon, electronic scanning microscopy, Black Sea.

**ABSTRACT**

For the first time in the Kruglaya Bay of the Black Sea, 25 taxa of Bacillariophyta from 17 genera were found, three of them were new for the Crimea and the Black Sea *Halamphora tenerrima*, *Amphora tenuissima*, and *Navicula antonii*. Marine (40%), coastal-brackish (32%) and boreal-tropical (32%), arctic-boreal-tropical (24%), boreal and cosmopolitan (20% and 16%, respectively) prevailed. The morphological characteristics of the species in the SEM (scanning electronic microscope) and LM (light microscope), as well as the occurrence, ecology, phytogeography, and general distribution in various regions of the World Ocean are given.

**ZUSAMMENFASSUNG**: Die pennaten benthischen Diatomeen des Sandstrandes der Kruglaya-Bucht (Schwarzes Meer).

Erstmals wurden in der Kruglaya-Bucht des Schwarzen Meeres 25 Bacillariophyta-Taxa aus 17 Gattungen gefunden, drei davon neu für die Krim und das Schwarze Meer: *Halamphora tenerrima*, *Amphora tenuissima* und *Navicula antonii*. Marine (40%), küstenbrackig (32%) und boreal-tropisch (32%), arktisch-boreal-tropisch (24%), boreal und kosmopolitisch (20% bzw. 16%) überwogen. Die morphologischen Merkmale der Arten im SEM (Elektronisches Scan Mikroskop) und LM (Licht-Mikroskop) sowie das Vorkommen, die Ökologie, die Phytogeographie und die allgemeine Verbreitung in verschiedenen Regionen des Weltozeans werden angegeben.

**REZUMAT**: Diatomeele bentonice penate ale plajei de nisip din Golful Kruglaya (Marea Neagră).

Pentru prima dată în Golful Kruglaya al Mării Negre au fost găsiți 25 de taxoni de Bacillariophyta din 17 genuri, trei dintre aceștia fiind noi pentru Crimeea și Marea Neagră *Halamphora tenerrima*, *Amphora tenuissima* și *Navicula antonii*. Au predominat taxoni marini (40%), litoral-salmaștri (32%) și boreal-tropicali (32%), arctic-boreal-tropicali (24%), boreal și cosmopoliți (20% și respectiv 16%). Sunt prezentate caracteristicile morfologice ale speciilor în SEM (Microscop electronic cu baleiaj) și LM (Microscop optic), precum și apariția, ecologia, fitogeografia și distribuția generală în diferite regiuni ale Oceanului Mondial.

## INTRODUCTION

The diatoms epipsamon in shallow coastal waters of Kruglaya Bay are still poorly studied, including in SEM. However, the data from the study of diatoms in electronic scanning microscope (SEM) are important not only for species identification in general, but especially for cryptic ones, i.e. morphologically similar species. In addition to studying the morphological elements of diatoms, data on ecology and phytogeography are needed too.

The aim of this work is to study the species belonging of the epipsammon biraphid benthic diatoms of the Kruglaya Bay of the Black Sea, their morphology in SEM, size, structure, ecology, and phytogeography.

## MATERIAL AND METHODS

### Description of the study site

Kruglaya Bay (Omega) of the Black Sea is located five km southwest of the entrance to the Sevastopol (Fig. 1). Sampling from the sand beaches was carried out on October 30, 2016 in Kruglaya Bay from a depth of 0.3 m. At the time, water temperature was 13°C and water salinity 17.89‰.


Figure 1: Map of the sampling sites in Kruglaya Bay, Crimea, Black Sea.

### Sampling and laboratory study

Sample processing and preparation for analysis by scanning electron microscopy ("Sigma 300 VP" type, Great Britain) was carried out at the A. V. Zhirmunsky National Scientific Center of Marine Biology, Far Eastern Branch of the Russian Academy of Sciences.

We used the classification of benthic diatom taxa based on Round et al. (1990) with some later additions (Cox, 1988; Levkov, 2009). The morphometric (dimensions in SEM and LM), ecological (the relation of species to water salinity) and phytogeographical characteristics of diatoms were used from the literary sources. The SEM and LM examination of material from Kruglaya Bay reveals that diatom cell sizes are in accordance to our previous data and to the literature (Korotkevich, 1960; Proshkina-Lavrenko, 1963; Karayeva, 1972; Guslyakov et al., 1992; Ryabushko and Begun, 2016).

**RESULTS**

There are 25 species of Bacillariophyta representing to 17 genera and three species of *Halamphora tenerrima*, *Amphora tenuissima*, and *Navicula antonii* first indicated in the Black Sea (Tab. 1). From all species of marine (40%), marine-brackish (32%), boreal-tropical (32%), arctic-boreal-tropical (24%), boreal and cosmopolites (20% and 16% respectively) were dominated. But brackish, freshwater, indifferents and arctic-boreal marked with fewer (8% each), including notal species (12%), found in the southern hemisphere (Tab. 1).

Table 1: The occurrence of diatoms, their ecological (RS) and phytogeographycal (PhG) characteristics of epipsammon on Kruglaya Bay of the Black Sea; species are listed in alphabetical order; * – A new species for the Crimean coastal waters and the Black Sea; RS – the relation of species to the water salinity: M – marine species, FW – freshwater, MB – marine-brackish, B – brackish, ind – indifferents; PhG – phytogeographic elements: B – boreal species, AB – arctic-boreal, BT – boreal-tropical, ABT – arctic-boreal-tropical, C – cosmopolite, not – notal species, found in the southern hemisphere.

| Taxa | RS | PhG | Figs. |
|---|---|---|---|
| *Adlafia besarensis* (Giffen 1980) L. I. Ryabushko comb. nov. | M | BT | 7, a-c |
| *Amphora crassa* W. Gregory 1857 | M | ABT | 8, f-h |
| *Amphora tenuissima* Hustedt 1955 * | M | BT | 8, k-m |
| *Cylindrotheca closterium* (Ehrenberg) Reimer et Lewin 1964 | MB | C | 9, a-b |
| *Cymbella odessana* Guslaykov 1992 | B | B | 7, d-g |
| *Diploneis smithii* (Brèbesson) P. T. Cleve 1894 | MB | C | 2, a-h |
| *Entomoneis paludosa duplex* (Donkin) Czarnecki et Reinke 1982 | B | B | 12, d-e |
| *Gyrosigma attenatum* (Kützing) Rabenhorst 1853 | FW | ABT | 6, a-c, e |
| *Halamphora coffeiformis* (C. A. Agardh) Z. Levkov 2009 | MB | C | 8, a-b |
| *Halamphora tenerrima* (Aleem et Hustedt) Z. Levkov 2009 * | M | BT | 8, c-e |
| *Hantzschia spectabilis* (Ehrenberg) Hustedt 1959 | MB | B, not | 11, a-m |
| *Lyrella abrupta* (W. Gregory) D. G. Mann 1990 | M | BT | 4, b-d |
| *Lyrella atlantica* (W. Gregory) D. G. Mann 1990 | M | BT | 4 a |
| *Lyrella rudiformis* (Hustedt) Guslyakov et Karayeva, 1992 | M | B | 4, e-g |
| *Navicula antonii* Lange-Bertalot 2000 * | FW | BT, not | 3, f-k |
| *Navicula distans* (W. Smith) Ralfs 1861 | MB | ABT | 4, h-n |
| *Navicula palpebralis* Brébisson ex W. Smith 1853 | M | ABT, not | 3, a-e |
| *Nitzschia* cf. *angustata* (W. Smith) Grunow | ind | B | 9 f |
| *Nitzschia ovalis* Arnott 1880 | MB | AB | 9 c-e |
| *Plagiotropis lepidoptera* (W. Gregory) Kuntze 1898 | M | ABT | 6, d, f-k |
| *Pleurosigma cuspidatum* (P. T. Cleve) Peragallo 1891 | M | BT | 5 k-o |
| *Pleurosigma elongatum* W. Smith 1852 | MB | C | 5, a-h |
| *Pseudo-nitzschia pseudodelicatissima* (Hasle) Hasle 1993 | M | ABT | 10, a-g |
| *Surirella ovalis* Brébisson 1838 | ind | AB | 12, a-c |
| *Tryblionella coartata* (Grunow) D. G. Mann 1990 | MB | BT | 9, g-m |

Information on the taxonomic characteristics of diatoms identified in Kruglaya Bay, the Black Sea, their morphology and morphometric, ecology and phytogeography is presented below.

**Biraphid diatoms, Class Bacillariophyceae Haeckel 1878**
Order Naviculales Bessey 1907

Family Diploneidaceae Mann 1990
Genus *Diploneis* (Ehrenberg) P. T. Cleve 1894

***Diploneis smithii* (Brébisson) P. T. Cleve 1894. Fig. 2, a-h**

(Basionym: *Navicula smithii* Brébisson 1856; Synonyms: *Navicula elliptica* W. Smith 1853; *Pinnularia scutellum* O'Meara 1875; *Navicula scutelum* O'Meara 1875; *Navicula smithii* var. *laevis* Juhlin-Dannfelt 1882; *Navicula smithii* var. *borealis* Grunow 1884; *Navicula fusca* var. *permagna* Pantosek 1889; *Diploneis major* Cleve 1894; *Navicula smithii* var. *scutellum* Van Heurck 1896; *Navicula smithii* var. *permagna* Peragallo 1897; *Navicula gyrinida* A. Mann 1907; *Navicula smithii* var. *minor* West 1912; *Diploneis smithii* var. *permagna* Cleve 1915; *Diploneis gyrinida* Mills 1934).

Valve elliptical; central nodule not broad; furrows evenly curved on the outer edge, crossed by costae and double oblique rows of alveoli. Variable in size and in the curvature of the furrows. The size of the species varies depending on the geography of its distribution. Dimensions in SEM images: valve 19.4 µm length, 9.8 µm width, 14 ribs in 10 µm. Dimensions in LM images: valve 23-110 µm length, 13-40 µm width; frustule 35.3-50.4 µm width, 6-11 ribs in 10 µm with a double row of areoles reaching the longitudinal canals (Ryabushko and Begun, 2016); 48-60 µm length, 15-20 µm width, 10-11 ribs in 10 µm (Korotkevich, 1960; Karayeva, 1972); 46-54 µm length, 16-18 µm width, 9-10 striae in 10 µm (Al-Yamani and Saburova, 2011).

**Ecology, distribution, and phytogeography**: marine and brackish waters, benthic, euryhaline and eurythermal, littoral and sublittoral species, cosmopolite and ubiquiste. The species is indicated in the plankton of Amur Estuary, Arctic Ocean, Pechora, Laptev, Kara, Baltic, Barents, North, Norwegian, White, Caribbean, Mediterranean, Black, Azov, Caspian, Japan, East China seas and off the coast of Mexico, Greenland, Iceland, Spitsbergen, Finnmarken, Turkey, Kuwait, China, India, Japan, Northern America, Australia and New Zealand, the Arctic and Antarctic, the Islands of Sri Lanka (Ceylon), Madagascar, Java, Sumatra and Bahamas (Ryabushko and Begun, 2016).

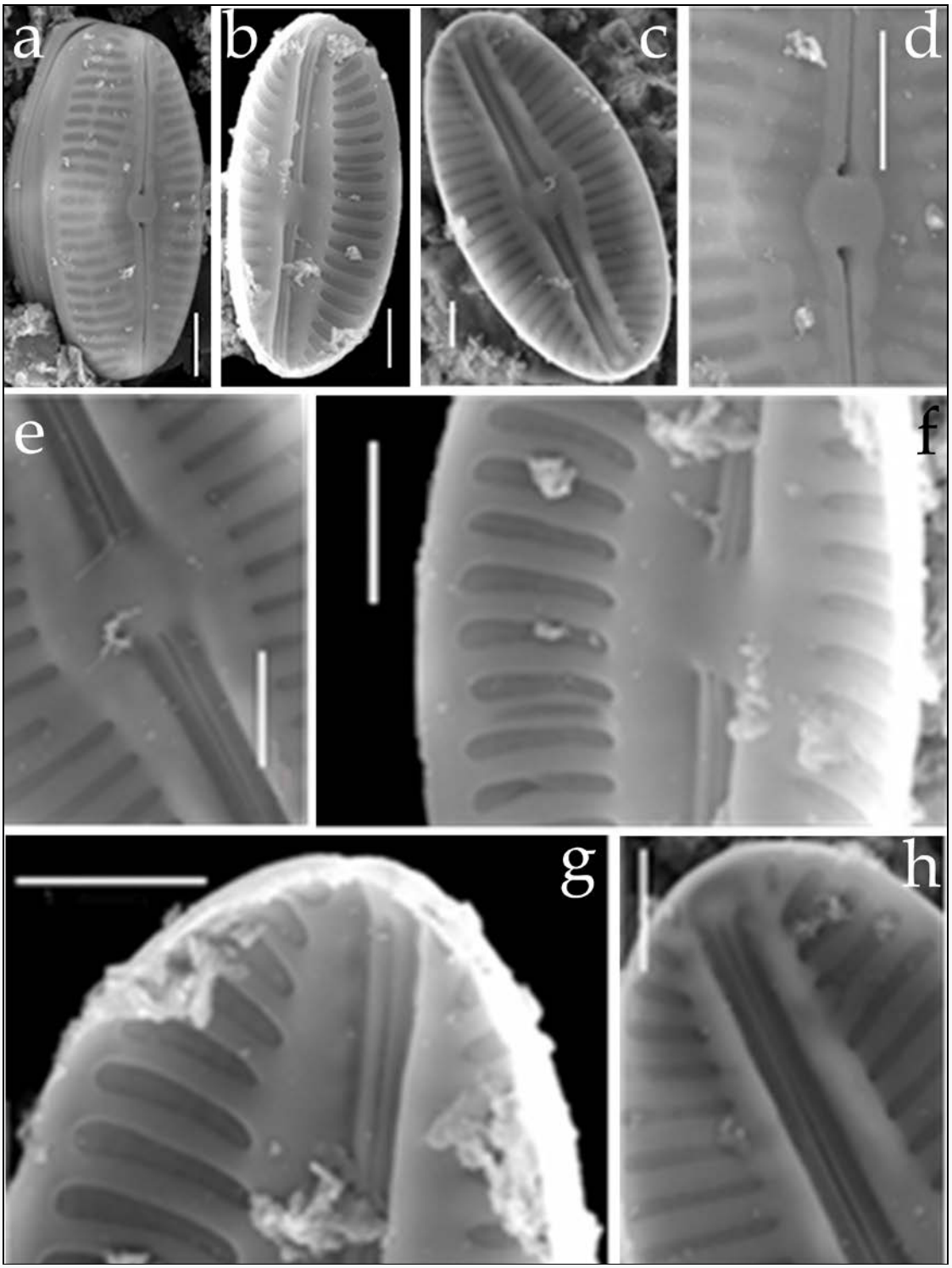


Figure 2: The valves of *Diploneis smithii* view (a-h), their fragments and structure (d-h); scale bar: 2 µm.

Family Naviculaceae Kützing 1844

Genus *Navicula* J. B. M. Bory de Saint-Vincent 1822 emend. E. J. Cox 1988

***Navicula antonii* H. Lange-Bertalot 2000. Fig. 3, f-k**

(Synonym: *Navicula menisculus* var. *grunowii* Lange-Bertalot 1993)

Dimensions in SEM images: valves 22 µm length, eight µm width, 20 punctae of areolae in 10 µm. Dimensions in LM images: valves 10-23.8 µm length, 4.2-7.3 µm width, 16-22 striae of areolae in 10 µm (Rumrich et al., 2000).

**Ecology, distribution and phytogeography**: freshwater, benthic, boreal-tropic and notal species. Occurrence in the Andes of Venezuela to Patagonia/Tierra del Fuego (Rumrich et al., 2000). This species was first discovered on the sand beach of Kruglaya Bay for the Crimean coastal waters of the Black Sea.

***Navicula distans* (W. Smith) Ralfs 1861. Fig. 4, h-n**

(Basionym: *Pinnularia distans* W. Smith, 1853; Synonym: *Navicula distans* (W. Smith) A. Schmidt 1874 nom. illeg., *N. distans* W. Smith, 1853)

Dimensions in SEM images: raphe valve 33-34.3 µm length, 7.5 µm wide, 13 radial striae in 10 µm. Dimensions in LM images: valves 27.5 µm length, 13-18 µm width, 6-7 striae and 20-21 areolaea in 10 µm (Proshkina-Lavrenko, 1963). 33.6-56 µm length, 14.4-29.7 µm width, 7-8 radial striae in 10 µm (Ryabushko, 1986).

**Ecology, distribution, and phytogeography**: benthic, sublittoral, marine and brackish water, arcto-boreal-tropical species. Occurrence in the ice of Franz Josef Land, the Laptev Sea, in the Chukchi, Bering, Norwegian, Barents, White, North, Black, East China and Caribbean seas, Arctic Ocean, off the coast of the North America, Greenland, Iceland, Svalbard, Finnmarken, Sweden, China, Canary, and Philippine Islands. In the Sea of Japan in Vostok Bay in the summer on rocky and sand beach at a depth of five m (Ryabushko 1986, 2014), in the periphyton of experimental plates made of plexiglass, asbestocement, high-alloy steel in Amur Bay, Uglovoe, and Golden Horn Bay in the epiphyton of the green alga *Cladophora stimpsonii* and sea flax of *Phyllospadix iwatensis*, the epizoon of the mussel *Mytilus trossulus*, and the barnacle of *Amphibalanus improvisus* (Begun, 2012; Ryabushko and Begun, 2016), as well as this species was found in Kraternaya Bight (Kuril Islands) (Ryabushko, 2020).

***Navicula palpebralis* Brébisson ex W. Smith 1853. Fig. 3, a-e**

(Basinonym: *Schizonema palpebrale* (Brébisson ex W. Smith) Kuntze 1898; Synonym: *Navicula palpebralis* var. *genuina* A. Cleve-Euler, 1953).

Cells biraphid, solitary, free living and motile. Dimensions in SEM images: valve 41.1 µm length, 12.9 µm width, 11 striae in 10 µm. Dimensios in LM images: valves 38-80 µm length, 13-16 µm width, 10 striae in 10 µm (Proschkina-Lavrenko, 1950; Ryabushko and Begun, 2016); 33-64 µm length; 10-26 µm width, 9-11 striae in 10 µm (Proshkina-Lavrenko, 1963); 44-51 µm length, 14-15 µm width, transapical striae radiate 11 in 10 µm (Al-Yamani and Saburova, 2011.

**Ecology, distribution, and phytogeography**: benthic, marine, arctic-boreal-tropical and notal species. Known in the North, Norwegian, Kara, Barents, Baltic, Mediterranean, Adriatic, Black, and Azov seas; in basins of Europe, Asia, America, the Arctic, Iceland, Norway, Sweden, England, Germany, Romania, Spain, France, New Zealand, the Canary and Galopagos Islands (Ryabushko and Begun, 2016), as well as off the coast of Kuwait (Al-Yamani and Saburova, 2011). In Kazachya Bay of the Black Sea was found on the red alga of *Gracilaria verrucosa* at a depth of 1-3 m at 5.7°C (Ryabushko, 1991) and on the epilithon of stony substrates of Vostok Bay of the Sea of Japan at a depth of 0.5 m (Ryabushko, 2014).

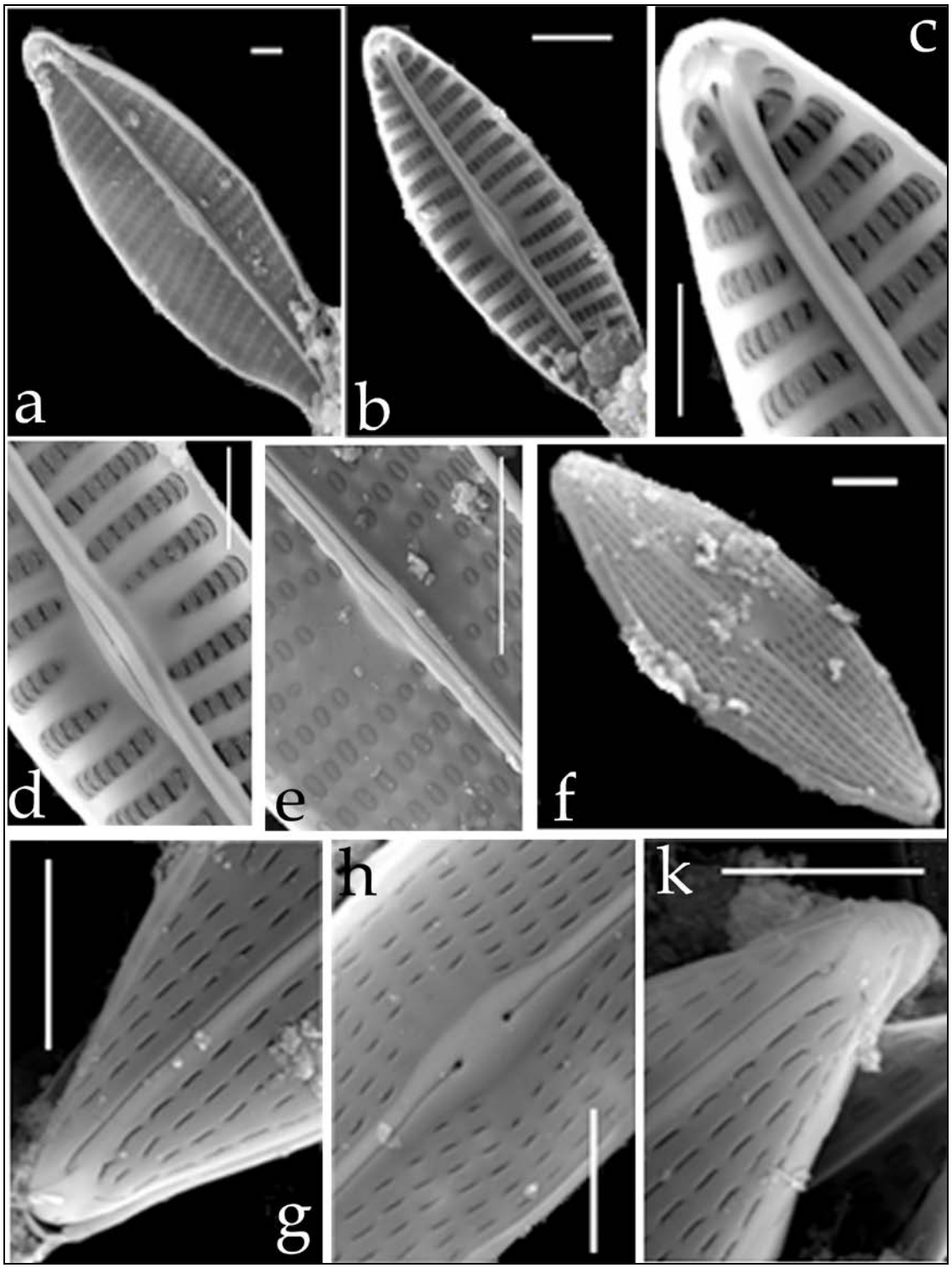


Figure 3: The valves of *Navicula palpebralis* (a-e) and *Navicula antonii* (f-k) view in different angles, with their fragments and structures; scale bar: 1 µm (a-e) and 2 µm (f-k).

Order Lyrellales D. G. Mann, 1990
Family Lyrellaceae D. G. Mann, 1990
Genus *Lyrella* N. I. Karayeva 1978

***Lyrella abrupta* (W. Gregory) D. G. Mann 1990. fig. 4, b-d**

(Basionym: *Navicula abrupta* (W. Gregory) Donkin 1870; Synonyms: *Navicula lyra* var. *abrupta* W. Gregory 1857)

Dimensions in SEM images: valve 27.7 µm length, 18.9 µm width, 10 striae and 25 puncta in 10 µm. Dimensions in LM images: valves 32-85 µm length, 19-35 µm width, 9-10 striae and 22-24 puncta in 10 µm (Proschkina-Lavrenko, 1950; Proshkina-Lavrenko, 1963); 29-46 µm length, 14-21 µm width, 12-14 striae in 10 µm (Al-Yamani and Saburova, 2011).

**Ecology, distribution, and phytogeography**: marine, eurythermal, littoral and sublittoral, boreal-tropical species. Found off the coast of Mexico, Turkey, Puerto Rico and Kuwait's marine sediments, in the Caribbean, Aegean, Adriatic, Black, Azov and Caspian seas; Canary and Philippine Islands, the Sea of Japan it is indicated in the summer in the sand beach of Vostok Bay at the depth of five m, in October at 10 m by 5.2ºC (Ryabushko, 1986, 2014).

***Lyrella atlantica* (A. W. F. Schmidt) D. G. Mann 1990. fig. 4a**

(Basionym: *Navicula atlantica* A. W. F. Schmidt 1874; Synonyms: *Navicula lyra* var. *atlantica* (Schmidt) Cleve 1895; *Lyrella lyra* var. *atlantica* (Schmidt) Karayeva 1988; *Lyrella lyra* var. *atlantica* (A. Sm.) Gusliakov et Karayeva 1992).

Dimensions in SEM images: valve 27.7 µm length, 18.9 µm width, 10 striae and 25 puncta in 10 µm. Dimensions in LM images: valves 32-85 µm length, 19-35 µm width, 9-10 striae and 22-24 puncta in 10 µm (Proschkina-Lavrenko, 1950; Proshkina-Lavrenko, 1963); 29-46 µm length, 14-21 µm width, 12-14 striae in 10 µm (Al-Yamani and Saburova, 2011).

**Ecology, distribution, and phytogeography**: marine, eurythermal, littoral and sublittoral, boreal-tropical species. Found off the coast of Mexico, Turkey, Puerto Rico and Kuwait's marine sediments, in the Caribbean, Aegean, Adriatic, Black, Azov and Caspian seas; Canary and Philippine Islands, the Sea of Japan it is indicated in the summer in the sand beach of Vostok Bay at the depth of five m, in October at 10 m by 5.2ºC (Ryabushko, 1986, 2014).

***Lyrella rudiformis* (Hustedt) Guslyakov et Karayeva, 1992. Fig. 4 e-g**

(Basionym: *Navicula rudiformis* Hustedt 1964)

Dimensions in SEM images: valve 30.4 µm length, 17.6 µm width, 10 striae in 10 µm. Dimensions in LM images: valve 28–36 µm length, 22–26 µm width, 10–11 striae in 10 µm (Guslyakov et al., 1992, page 38, table XLVII, figures 7, 8).

**Ecology, distribution, and phytogeography**: marine, littoral and sublittoral, boreal species. Indicated in fouling of macrophytic algae, as well as on silty-sandy ground in Tendrovsky and Dzharylgachsky gulfs (Guslyakov et al., 1992), as well as on the sand beach of Kruglaya Bay for the Crimea of the Black Sea.

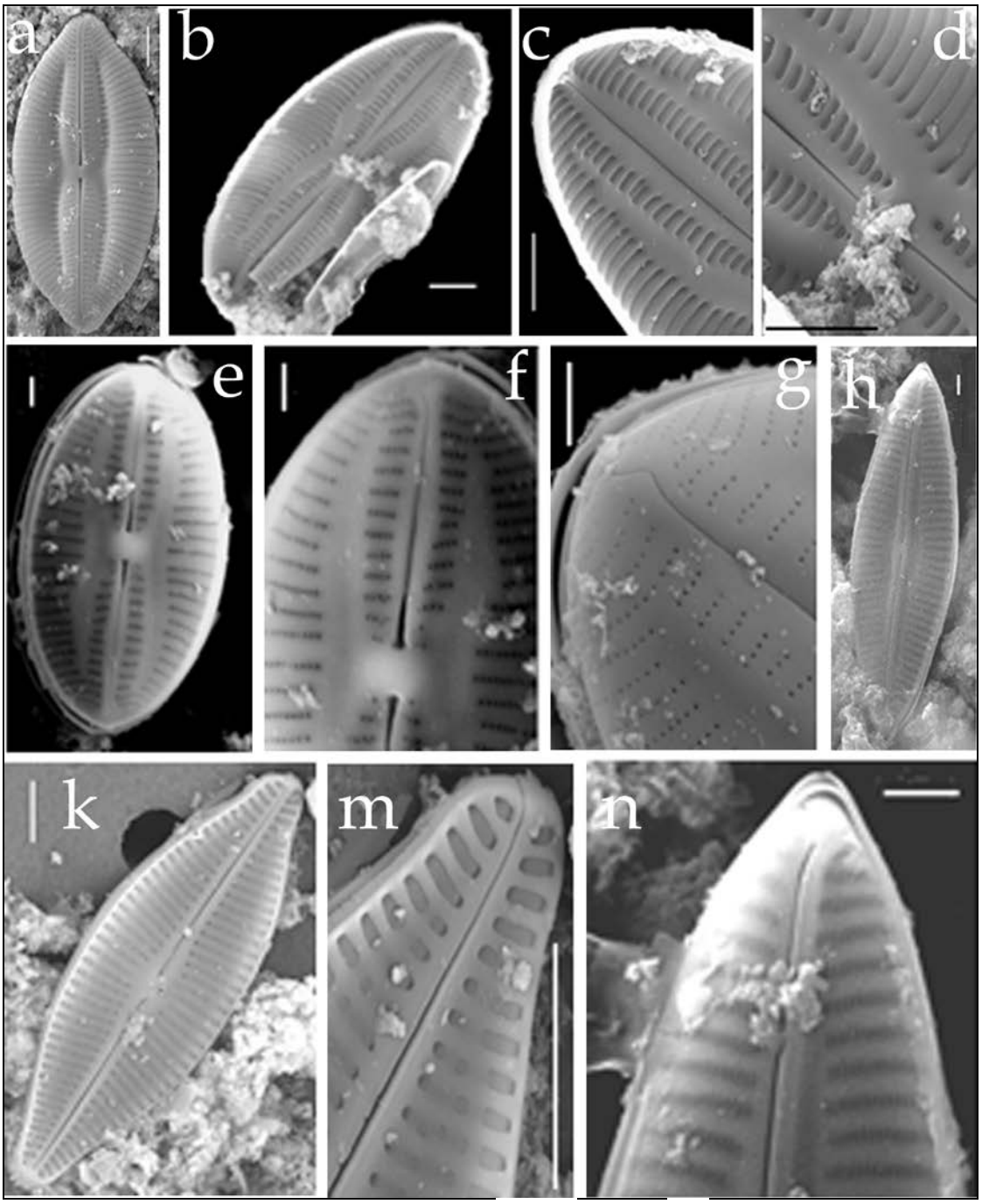


Figure 4: SEM images of the valves of *Lyrella atlantica* (a), *L. abrupta* (b-d), *L. rudiformis* (e-g) and *Navicula distans* (h-n) view, its fragments and structure. Scale bar: 5 µm (a-d) and 2 µm (e-n).

Family Pleurosigmataceae Mereschkowsky 1903
Genus *Pleurosigma* Smith 1852

***Pleurosigma cuspidatum* (Cleve) Peragallo 1891. Fig. 5, k-o**
(Synonym: *Pleurosigma lanceolatum* var. *cuspidatum* Cleve 1881)

Dimensions in SEM images: valves 76.3-86 µm length, 25.3-26.3 µm width, 25 transapical and 26 oblique striae in 10 µm. Dimensions in LM images: valves 85-148 µm length, 21-32 µm width, 19-21 transapical and 18-22 oblique striae in 10 µm (Al-Yamani, Saburova, 2011).

**Ecology, distribution, and phytogeography**: marine, littoral, sublittoral, boreal-tropical species, indicated in the Black Sea coast of Russia, Romania, also England, France, Sweden and Kuwait in siltflates, sandflates and epiphyton of macrophytes (Merezhkowsky, 1903; Hendey, 1964; Bodeanu, 1987-1988; Al-Kandari et al., 2009; Al-Yamani and Saburova, 2011).

***Pleurosigma elongatum* W. Smith 1852. Fig. 5, a-h**
(Synonym: *Pleurosigma maeoticum* Pantocsek 1902)

Dimensions in SEM images: valve 142 µm length, 20.5 µm width, 18 transapical and 19 oblique striae in 10 µm. Dimensions in LM images: valves 101-386 µm length, 17-65 µm width, 18-20 transapical and 17-19 oblique striae in 10 µm (Proshkina-Lavrenko, 1963).

**Ecology, distribution and phytogeography**: marine and brackish waters, littoral and sublittoral, eurythermal, $\beta$-mesosaprobes, cosmopolite, widespread in seas and continental ponds. First discovered in June 1849 and October 1850 off the coast of Britain (Smith, 1853). Occurrs in the ice of the Laptev Sea, in the White, Kara, Barents, Black, Azov, Caspian, East China Seas, off the coast of Romania, Bulgaria, Spain, England, Argentina, Brazil, China, Australia and New Zealand; in the Canary, Balearic and Hawaiian Islands, in ponds of Turkey (Aysel, 2005). The first discovered in the Sea of Japan in July 1921 and November 1923 (Skvortzow, 1932), on near Shikkoku Inland (Oshite, 1955). In the north-western part of the Sea of Japan, this species was found in the different bays and substrates and all seasons of the year, as well as in fouling of macrophytes (Ryabushko and Begun, 2016).

Genus *Gyrosigma* A.H. Hassall 1845

***Gyrosigma attenatum* (Kützing) Rabenhorst 1853. Fig. 6, a-c, e**
(Basionym: *Frustulia attenuata* Kützing 1834; Synonyms: *Sigmatella attenuata* (Kützing) Brébisson and Godey 1835; *Navicula attenuata* (Kützing) Kützing 1844; *Pleurosigma attenuatum* W. Smith 1852; *Scalptrum attenuatum* (Kützing) Kuntze 1891).

Dimensions in SEM images: valves 76.3-86 µm length, 25.3-26.3 µm width, 25 transapical and 26 oblique striae in 10 µm. Dimensions in LM images: valves 85-148 µm length, 21-32 µm width, 19-21 transapical and 18-22 oblique striae in 10 µm (Al-Yamani, Saburova, 2011).

**Ecology, distribution, and phytogeography**: marine and freshwater, arctic-boreal-tropic species. Occurs in Iberian Peninsula, Balearic Islands, Canary Islands, in the wetlands of Sweden, Iraq, Slovakia, Netherlands, Poland, Romania, Britain, France, Taiwan, Canada, Brazil, India, Pakistan, Tajikistan, Korea, Mongolia, Ireland, Portugal, Alaska, Laurentian Great Lakes, U.S.A., Mexico, Iceland, Albania, Italy, Russia, Ukraine, Spain, Ghana, Egypt, Taiwan, Iran, Turkey, Australia, New Zealand, and Baltic, Adriatic and Black seas (Guiry and Guiry, 2021). This species was first discovered on the sand beach of Kruglaya Bay and for the Crimean coastal waters of the Black Sea.

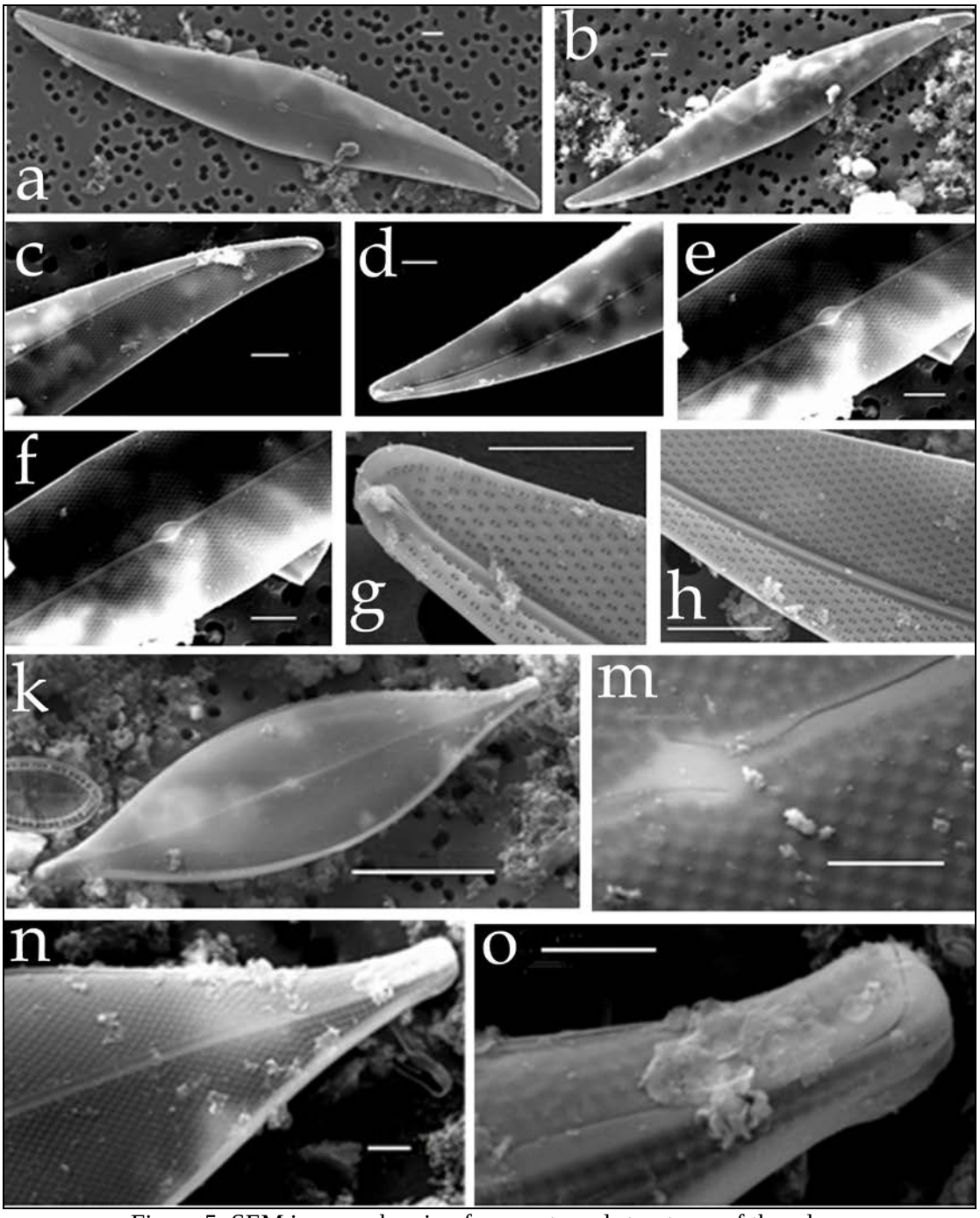


Figure 5: SEM images showing fragments and structures of thevalves of *Pleurosigma elongatum* (a-h), *Pleurosigma cuspidatum* (k-o) view, its fragments and structure; scale bar: 5 µm (a-d) and 2 µm (e-n).

Family Plagiotropidaceae D. G. Mann 1990
Genus *Plagiotropis* E. Pfitzer 1871

***Plagiotropis lepidoptera* (Gregory) Kuntze 1898. Fig. 6, d, f-k**

(Basionym: *Amphiprora lepidoptera* Gregory 1857; Synonyms: *Tropidoneis lepidoptera* (Gregory) Cleve 1894; *Orthotropis lepidoptera* (Gregory) Van Heurck 1896; *Plagiotropis lepidoptera* (Gregory) Poulin et Cardinal 1983).

Dimensions in SEM images: frustule 40 µm length, 10.4 µm width, 39 rows and 55 puncta in 10 µm. Dimensions in LM images: valves 120-200 µm length, 18-22 µm width, 20-21 striae in 10 µm (Proschkina-Lavrenko, 1950); valves 66-113 µm length, 14-18 µm width, 20-22 striae in 10 µm (Korotkevich, 1960; Proshkina-Lavrenko, 1963); valves 57-92 µm length, 9-18 µm wide and 23.8-27 µm width frustules, 20-21 rows of areolae in 10 µm, found in the summer in the sandflats and intestines of the Far Eastern sea cucumber in Vostok Bay, the Sea of Japan, at a depth of five m (Ryabushko, 1986, 2014).

**Ecology, distribution, and phytogeography**: marine, benthic, littoral and sublittoral, *β*-mesosaprobes species, arctic-boreal-tropic species. It is known in the Caribbean, Baltic, Barents, White, Black, Milk Estuary, Azov, Caspian, East China seas, off the coast of Europe, U.S.A., China, Kuwait, India, Bahamas and Canary Islands (Ryabushko and Begun, 2016).

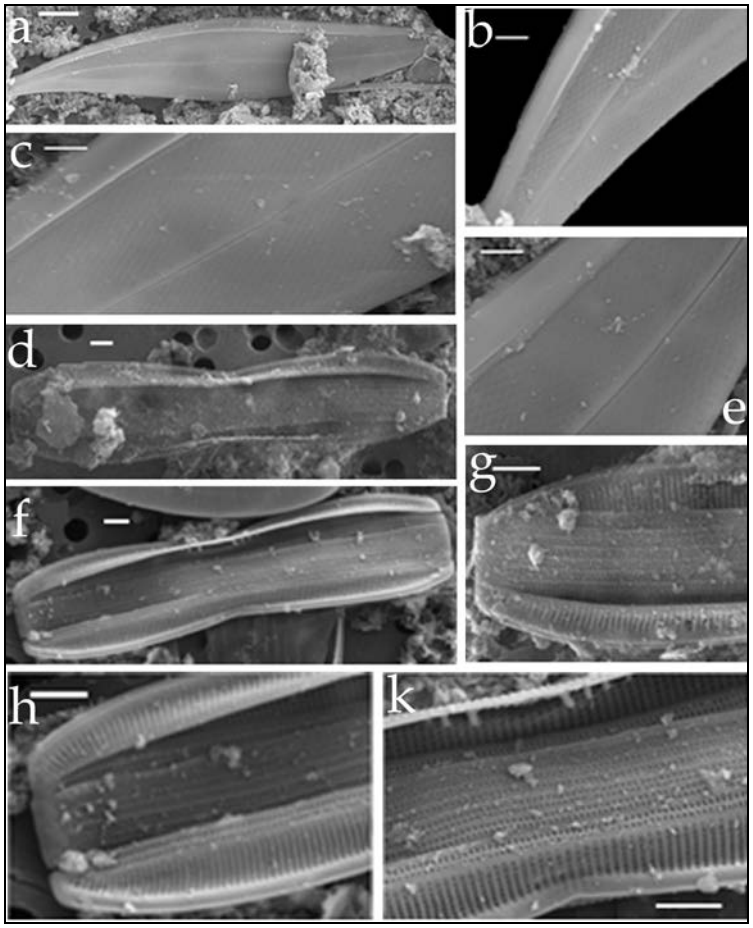


Figure 6: SEM images showing fragments and structures of the frustules of *Gyrosigma attenatum* (a-c, e) and *Plagiotropis lepidoptera* (d, f-k) view, its fragments and structure; scale bar: 5 µm (a-c, e) and 2 µm (d, f-k).

Order Cymbella Les D. G. Mann 1990
Family Anomoeoneidaceae D. G. Mann 1990
Genus *Adlafia* G. Moser, H. Lange-Bertalot et D. Metzeltin 1998

***Adlafia besarensis* (Giffen 1980) L.I. Ryabushko comb. nov**. **Fig. 7, a-c** (Synonym: *Navicula besarensis* Giffen 1980**)**

Dimensions in SEM images: lower raphe valve 35 µm length, 15 µm wide, 12 radial striae and 12 puncta in 10 µm. Dimensions in LM images: valve 34-35 µm length, 16-17 µm width, 12-14 radial striae and 12-15 puncta in 10 µm (Al-Yamani, Saburova, 2011). Valve 35 µm length, 15 µm width, 12 radial striae and 12 puncta in 10 µm (Witkowski et al., 2000).

**Ecology, distribution, and phytogeography**: marine, benthic, a rare and boreal-tropical species. Occurs also in the littoral of the Seychelles (Giffen, 1980), in the Indo-Western Pacific Ocean, Oman on the Arabian Sea, Poland and was noted in the sandflates of Kuwait (Al-Yamani and Saburova, 2011). Indicated for the first time off the coast of Karadag Reserve of the Crimean coastal waters (Nevrova, 2015) and now, for the first time, on the sand beach of Kruglaya Bay of the Black Sea.

Family Cymbellaceae Kützing 1844
Genus *Cymbella* C. Agardh 1830

***Cymbella odessana* Guslaykov 1992. Fig. 7, d-g**

Dimensions in SEM images: valves 13.4 µm length, 6.7 µm width, 20 rows areolae in 10 µm. Dimensions in LM images: valves 10-15 µm len*g*th, 2-4 µm width, 55 lionel and 20-24 rows areolae in 10 µm (Guslyakov et al., 1992).

**Ecology, distribution, and phytogeography**: brackish waters, benthic, littoral and sublittoral, boreal species. Occurred in the Ukraine in Odessky Gulf of the Black Sea on the rock and macrophytes in May at a depth of 0.5-4.0 m at a water temperature of 15°C with a salinity of 14 ‰ (Guslyakov et al., 1992). This is the first time when this species was found on the sand beach of Kruglaya Bay and for the Crimean coastal waters of the Black Sea.

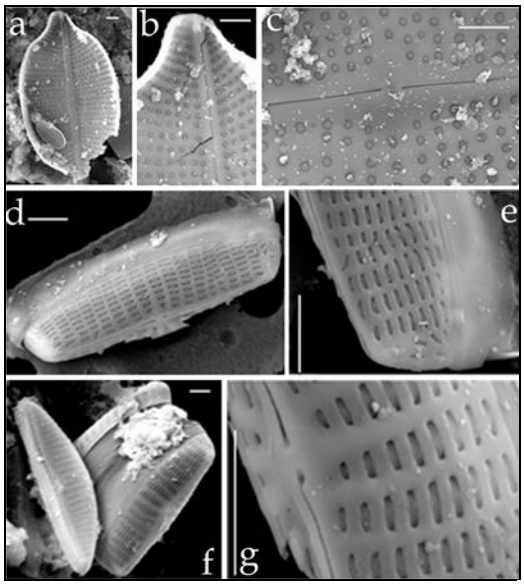


Figure 7: SEM images of fragments and structures of the valves of *Adlafia besarensis* (a-c) and *Cymbella odessana* (d-g); scale bar: 2 µm.

Order Thalassiophysales D. G. Mann 1990

Family Catenulaceae Mereschkowsky 1902

Genus *Halamphora* (Cleve) Mereschkowsky 1903

***Halamphora coffeiformis* (C. A. Agardh) Z. Levkov 2009. Fig. 8, a-b** (Bisyonym: *Frustulia coffeiformis* C. Agardh, 1827; Synonym: *Amphora coffeiformis* (C. A. Agardh) Kützing, 1844)

Dimensions in SEM images: frustule 35 µm length, 14.3 µm width, 12 band rims and 22 striae in 10 µm. Dimensions in LM images: frustules 18-42 µm long, 10-15 µm width, 12-14 band rims with 20-22 striae in 10 µm and 24 striae in 10 µm at the ends of the frustule (Proshkina-Lavrenko, 1963); valves 14-35 µm length, 4-6 µm width, 16-24 rows of areolae in 10 µm (Guslyakov et al., 1992); valves 16-30.8 µm length, 16.8 µm width, 12 striae in 10 µm (Ryabushko and Begun, 2016).

**Ecology, distribution, and phytogeography**: marine and brackish waters, littoral and sublittoral, euryhaline and eurythermal, cosmopolite. Occurrence in the Pechora, North, Kara, Barents, Baltic, Bering, Japan, Tyrrhenian, Caribbean, Mediterranean, Adriatic, Black, Azov, Caspian, Aral, East China and Dead seas, in Siavash, in the reservoirs of the Arctic, Canada, U.S.A., Iceland, Saxony, Poland, Austria, Greece, West India, South Africa, China, Syria, Iraq, Kuwait, Mongolia, Australia, off the Atlantic coast of the North America, in the Sandwich and Bahamas Islands. The species in summer on rocky and sand beach in Vostok Bay (Ryabushko, 1986), in the epiphyton of the red alga *Ahnfeltia tobuchiensis* (Kanne et Matsubara) Makijenko in Stark Strait, Bay of Peter the Great in August 2008 and 2009, in the periphyton of experimental plates of asbestos cement and the epiphyton of green macrophyte in Golden Horn Bay at 23°C and 24‰ were found (Ryabushko and Begun, 2016).

***Halamphora tenerrima* (Aleem et Hustedt) Z. Levkov 2009. Fig. 8, c-e** (Basionym: *Amphora tenerrima* Aleem et Hustedt; Synonym: *Amphora tenerrima* Aleem et Hustedt 1951)

Dimensions in SEM images: frustule 20 µm length, five µm width, 25 striae and 45 areolae in 10 µm. Dimensions in LM images: frustules 7-24 µm length, 3.5-8 µm width, 22-29 striae and 24-40 areolae in 10 µm (Clavero et al., 2000); valve 13.11-13.64 µm length and 3.02-3.11 µm width, 26 striae in 10 µm (Álvarez-Blanco and Blanco, 2014; Kaleli et al., 2017).

**Ecology, distribution, and phytogeography***:* marine, benthic species, boreal-tropical. Occurrence in the European Inland Waters and Comparable Habitats (Levkov, 2009), Baltic Sea (Snoeijs and Balashova, 1998), South Florida, U.S.A. (Wachnicka and Gaiser, 2007), British Islands (Hendey, 1964), Spain (Álvarez-Blanco and Blanco, 2014), England (Simonsen, 1987), and Turkey (Kaleli et al., 2017). Fist time to be observed in Kruglaya Bay and Crimean coastal waters of the Black Sea.

Genus *Amphora* Ehrenberg ex Kützing, 1844

***Amphora crassa* Gregory 1857. Fig. 8, f-h** (Synonym: *Amphora crassa punctata* A. Schmidt)

Dimensions in SEM images: frustule 40 µm length, 30 µm width, eight striae and 15 areolae in 10 µm. Dimensions in LM images: frustules 50-100 µm length, 20-30 µm width, 5-8 striae in 10 µm (Proschkina-Lavrenko, 1950); 45-136 µm length, 18-30 µm width; valves 8-17 µm width, five striae in 10 µm (Proshkina-Lavrenko, 1963); frustules 46-86 µm length, 20-30 µm width, 11-12 areolae in 10 µm (Ryabushko and Begun, 2016).

**Ecology, distribution, and phytogeography**: marine, benthic, arctic-boreal-tropical species. Occurs in Caribbean, North, Barents, White, Mediterranean, Adriatic, Black, Japan, East China seas, off the coast of Greenland, Spitsbergen, U.S.A., Finnmarken, England, Sweden, Finland, Kuwait, China, Sumatra, Philippines. It was found in the silflates of the Amur Bay, in the epilithon of stony and sandflats in winter and summer at a depth of 5-10 m at 18-19.6°C, in Posyet and Vostok bays of the Sea of Japan (Ryabushko and Begun, 2016).

***Amphora tenuissima* Hustedt 1955. Fig. 8, k-m**

Dimensions in SEM images: frustules 11.3-18.3 µm length, 3.5 µm width, 35 striae in 10 µm. Dimensions in LM images: frustules: 9.4-10.7 µm length, 2.2-3.1 µm width, 31-40 striae in 10 µm (Clavero et al., 2000); valves 8-10 µm length, 2-3 µm width, 35-45 striae in 10 µm. Recorded on siltflats and sandflats in the North-West of part the Black Sea (Guslayakov et al., 1992).

**Ecology, distribution, and phytogeography**: benthic, marine, boreal-tropic species. Observed for the first time in Kruglaya Bay of the Crimean coastal waters of the Black Sea.

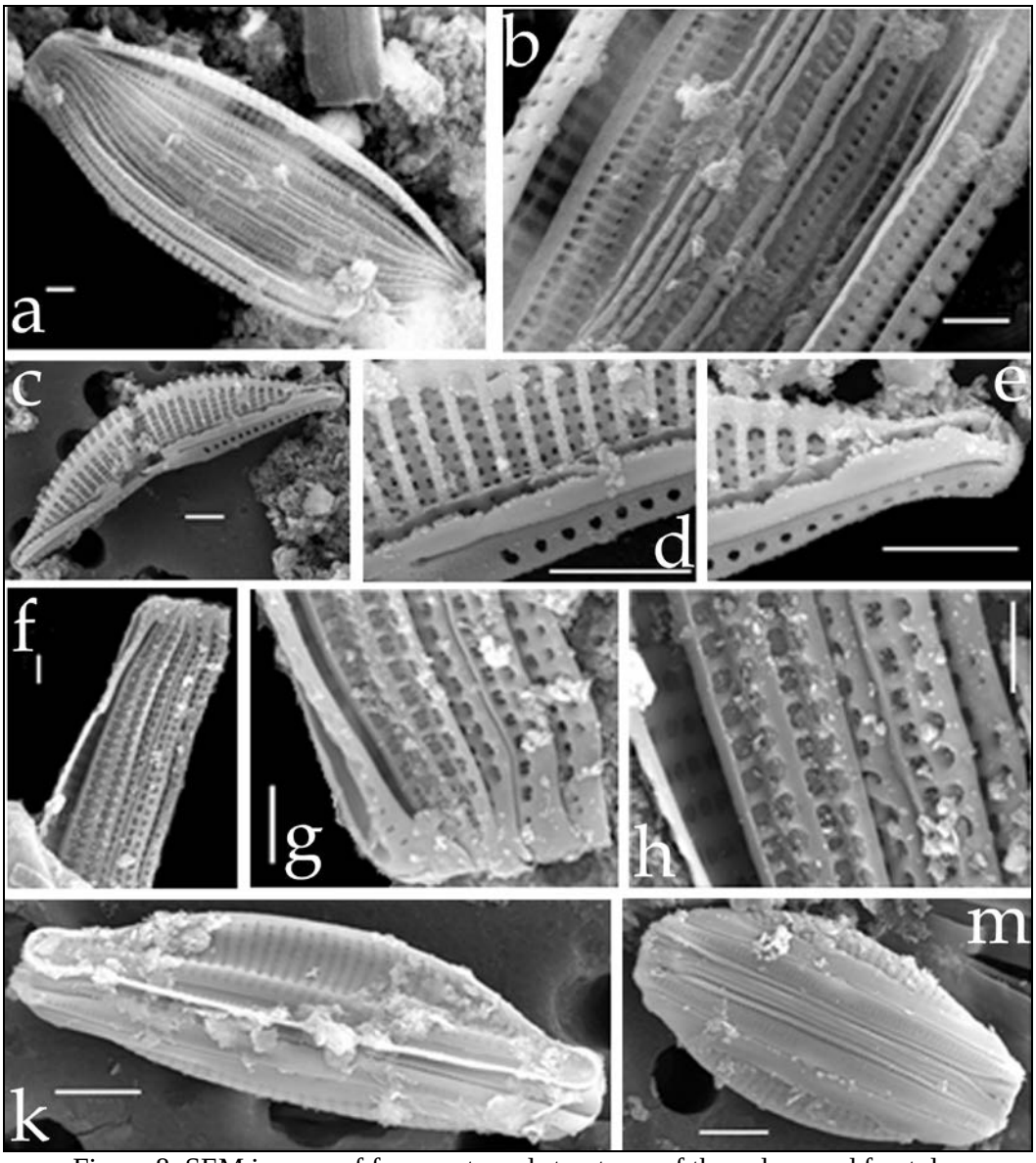


Figure 8: SEM images of fragments and structures of the valves and frustules of *Halamphora coffeiformis* (a-b), *H. tenerrima* (c-e), *Amphora crassa* (f-h), and *A. tenuissima* (k-m) view, fragments and structure; scale bar: 2 µm.

Order Bacillariales Hendey 1937

Family Bacillariaceae Ehrenberg 1831

Genus *Cylindrotheca* Rabenhorst 1859 emend. Reimann et Lewin 1964

***Cylindrotheca closterium* (Ehrenberg) Reimann et Lewin 1964. Fig. 9, a-b**

(Basionym: *Ceratoneis closterium* Ehrenberg 1839. Synonyms: *Nitzschia closterium* (Ehrenberg) W. Smith 1853; *N. reversa* W. Smith 1853; *N. closterium* var. *reversa* (W. Smith) Hauck; *Nitzschiella closterium* Rabenhorst 1864; *Nitzschia rostratum* Grunow 1880; *N. longissima* var. *closterium* (Ehrenberg) Van Heurck 1885; *N. curvirostris* var. *closterium* (Ehrenberg) De Toni 1892; *Nitzschiella longissima* var. *closterium* (Ehrenberg) Peragallo et Peragallo 1897; *Homoeocladia closterium* (Ehrenberg) Kuntze 1898; *Nitzschiella tenuirostris* Mereschk. 1901; *Nitzschia longissima* Gran 1930; *N. closterium* var. *recta* Gran 1931).

The species has a broad range of sizes. Dimensions in SEM images: valves 32.2-78.3 µm length, 2.6-5.7 µm width, 25 striae in 10 µm; valve 73.6 µm, 4.8 µm width. Dimensions in LM images: valves 32.5-260 µm length, 2-6 µm wide, striae are gentle, 12-16 keel points in 10 µm (Proschkina-Lavrenko, 1950); valves 42.5-217 µm length, 2.5-5 µm width, 12-16 keel points in 10 µm (Proshkina-Lavrenko, 1963); valves (SEM) 25-180 µm length, 1.5-8 µm width, 12-25 10 µm fibulae (Reimann and Lewin, 1964).

**Ecology, distribution, and phytogeography**: marine and brackish waters, euryhaline, littoral and sublittoral, benthos plankton species, cosmopolite, found in all geographic zones of the World Ocean. It was first discovered by W. Smith in May 1851 off the coast of England (Smith, 1853), in waters of Turkey (Aysel, 2005). Indicated in the ice of the Laptev Sea, North, Norwegian, Kara, Barents, White, Bering, Caribbean, Mediterranean, Adriatic, Aral, Caspian, Norwegian, Chukotka, Baltic, Black, Azov, East China seas and in the Amur Estuary, off the coast of Greenland, California, Spitsbergen, Brazil, Mexico, Finnmarken and Sweden, Spain, Croatia, Romania, Germany, Denmark, Kuwait, West India, Japan, Australia, New Zealand, Singapore, Sakhalin and Primorye, on the Hawaiian and Canary Islands (Ryabushko and Begun, 2016), as well as in the microphytobenthos of the Antarctic (Ryabushko, 2016).

Found in the Sea of Japan: in the Amur Gulf, Patrokl and Vityaz bays, Posyet Gulf, among fouling stones in Vostok Bay regularly on different substrates and in different seasons at depths of 0.5-10 m, in the stomachs of invertebrates and in the sandflate, fouling of brown alga *Saccharina japonica* in the Kit Bay, on the anthropogenic substrates, of different invertebrates and the epiphyton of macrophytes in the Amur Bay, Uglovoy, Ussuriysky, Rynda, Nakhodka, Slavyanka Gulfs, Tavrichansky Estuary, in Golden Horn and Severnaya bays, an artificial lagoon of Vladivostok (Ryabushko, Begun, 2016; Ryabushko et al., 2019).

Genus *Nitzschia* Hassall 1845

***Nitzschia* cf. *angustata* (W. Smith) Grunow 1880. Fig. 9f**

Dimensions in SEM images: valves 25.4 µm length, 2.8 µm width, in LM images: valves 32-55 µm length, 5-8 µm width, 13-16 rows of areolae in 10 µm (Guslayakov et al., 1992).

**Ecology, distribution, and phytogeography**: indifferent, $\alpha$-mesosaprobe, boreal species. Occurs very rare in epiphyton macrophytes and muddy bottom in the estuaries of the Dniestersky and Khadzhibeysky, Barents, Caspian, Aral, White, Red seas and reservoirs of Estonia, Belarus, Russia, Ukraine, France, Canada, U.S.A. and others (Guslayakov et al., 1992). The first listed for Kruglaya Bay of the Black Sea.

***Nitzschia ovalis* Arnott 1880. Fig. 9 c-e**

Dimensions in SEM images: valves 10.3 µm length, three µm width, 30 row in 10 µm; Dimensions in LM images: valves 10-14 µm length, 2.5-3 µm width, 13-14 keel points in 10 µm (Proshkina-Lavrenko, 1963; Guslyakov et al., 1992).

**Ecology, distribution and phytogeography**: benthic, indicated in macrophytes fouling, stones and silts, marine and brackish waters, arctic-boreal species. Occurrence in bays and estuaries of the northwestern part of the Black Sea and near the Karadag, as well as in the Sivash area (Guslyakov et al., 1992), in the salt water bodies of Germany, indicated in the Kara Sea (Cleve-Euler, 1953). The first listed for Kruglaya Bay of the Black Sea.

Genus *Tryblionella* W. Smith 1853

***Tryblionella coartata* (Grunow) D. G. Mann 1990. Fig. 9, g-m**

(Basionym: *Nitzschia coarctata* Grunow 1880; Synonym: *Nitzschia punctata* var. *coarctata* (Grunow) Hustedt 1921).

Dimensions in SEM images: valve 26.9 µm length, six µm width, in LM: valves 19-34 µm length, 7-13 µm width, 15 striae and 12-15 punctae in 10 µm (Proshkina-Lavrenko, 1963); valves 28-47.6 µm length, 10.2 µm wide, in the wide part 13.6-18 µm width, 8-10 keel punctae in 10 µm, striae in the middle of the valve not joined (Ryabushko, 1986).

**Ecology, distribution, and phytogeography***:* marine and brackish waters, eurythermal, sublittoral, boreal-tropical species, inhabits mainly in the seas of temperate latitudes. Occurs in the Caribbean, Baltic, White, Black, Azov, Aral, Mediterranean, Aegean, Sea of Japan, off the coast of the Atlantic and Pacific oceans, Brazil, Sweden, Romania, Turkey, Kuwait, Korea, Japan (Ryabushko and Begun, 2016). In the Sea of Japan is indicated in the summer in the sandflats and epiphyton the macrophytes of Vostok Bay at a depth of 0.5-5.0 m (Ryabushko, 1986). The first listed for the Kruglaya Bay of the Black Sea.

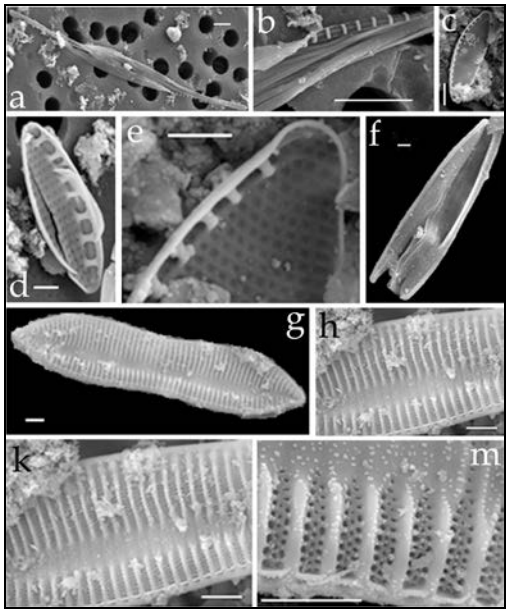


Figure 9: SEM images of fragments and structures of the valves and frustules of *Cylindrotheca closterium* (a-b), *Nitzschia* cf. *angustata* (f), *N. ovalis* (c-e) and *Tryblionella coartata* (g-m) view, its fragments and structure; scale bar: 2 µm, 1 µm (c-e).

Genus *Pseudo-nitzschia* H. Peragallo ex M. Peragallo 1900

***Pseudo-nitzschia pseudodelicatissima* (Hasle) Hasle 1993. Fig. 10, a-g**

(Basionym: *Nitzschia pseudodelicatissima* Hasle 1976; Synonyms: *Nitzschia delicatula* Hasle 1965, *Nitzschia haslea* Schoeman 1982).

Dimensions in LM images: valves 59-140 µm length, 1.5-2.5 µm width, more 30 striae and 16-26 fibules in 10 µm (Hasle and Syvertsen, 1997).

**Ecology, distribution, and phytogeography**: marine, planktonic, arctic-boreal-tropic species. Widespread in the coastal waters of Denmark, Norway, Spain, England, off the coast of eastern Canada, South Brazil, Argentina, Chile, Australia, New Zealand, China, Mexico and Saint-Laurent Gulfs, French, Portugal and Greek coastal waters, Japan, Adriatic seas (Hasle, 2002) and also in the Baltic Sea (Snoeijs and Balashova, 1998), in the ice of the Laptev Sea (Usachev, 1946), phytoplankton of the Black Sea and estuaries Sea of Azov (Ryabushko, 2003). This species causes the water blooms leading to production of domoic acid, which in turn causes amnesic shellfish poisoning (ASP) in humans (Martin et al., 1990; Lundholm et al., 2003; Ryabushko, 2003). The first listed for Kruglaya Bay of the Black Sea.

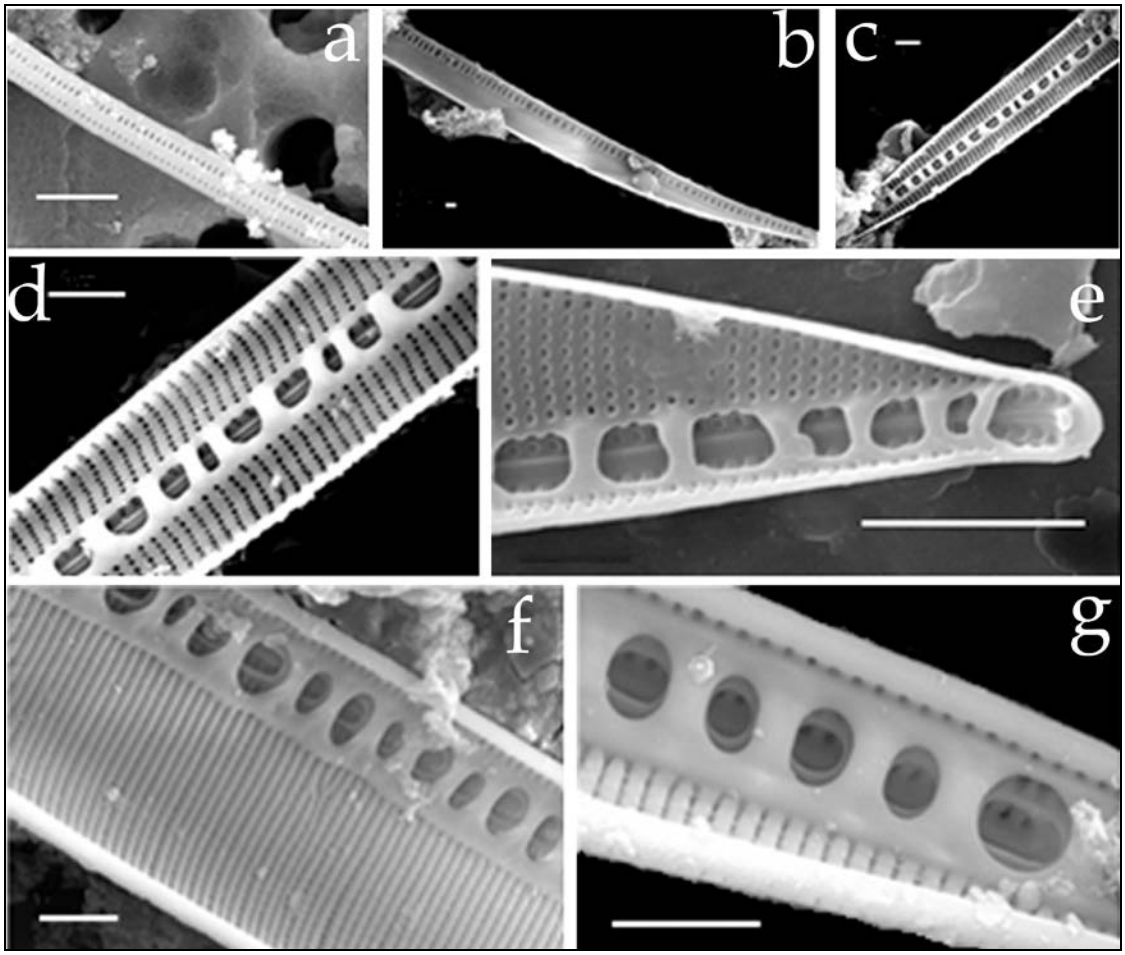


Figure 10: SEM images of fragments and structures of the valves and frustules of *Pseudo-nitzschia pseudodelicatissima* (a-g) view, its fragments and structure; scale bar: 2 µm.

Genus *Hantzschia* Grunow 1877

***Hantzschia spectabilis* (Ehrenberg) Hustedt 1959. Fig. 11, a-m**

(Basionym: *Synedra spectabilis* Ehrenberg 1841)

Dimensions in SEM images: valves 58.2-87.0 µm length, 5.4-7.8 µm width, 10 striae in 10 µm. Dimensions in LM images: frustules 67.9-103 µm length, 13,8 µm width, valve six µm width, nine striae in 10 µm (Ryabushko and Begun, 2016).

**Ecology, distribution, phytogeography**: benthoplanktonic, marine and brackish water, boreal and notal species. Known in the water bodies of the U.S.A., Germany, Britain, Spain, the Far East, and New Zealand (Guiry and Guiry, 2021). Occurs in the Baltic Sea (Snoeijs and Balashova, 1998). In the Japan Sea was first found in March 2014 on the red alga *Mastocarpus stellatus* in Troitsa Bay of Posyet Gulf at depth of 3-6 m at a water temperature of about –1.5°C (Ryabushko and Begun, 2016). The first listed for the Black Sea Kruglaya Bay.

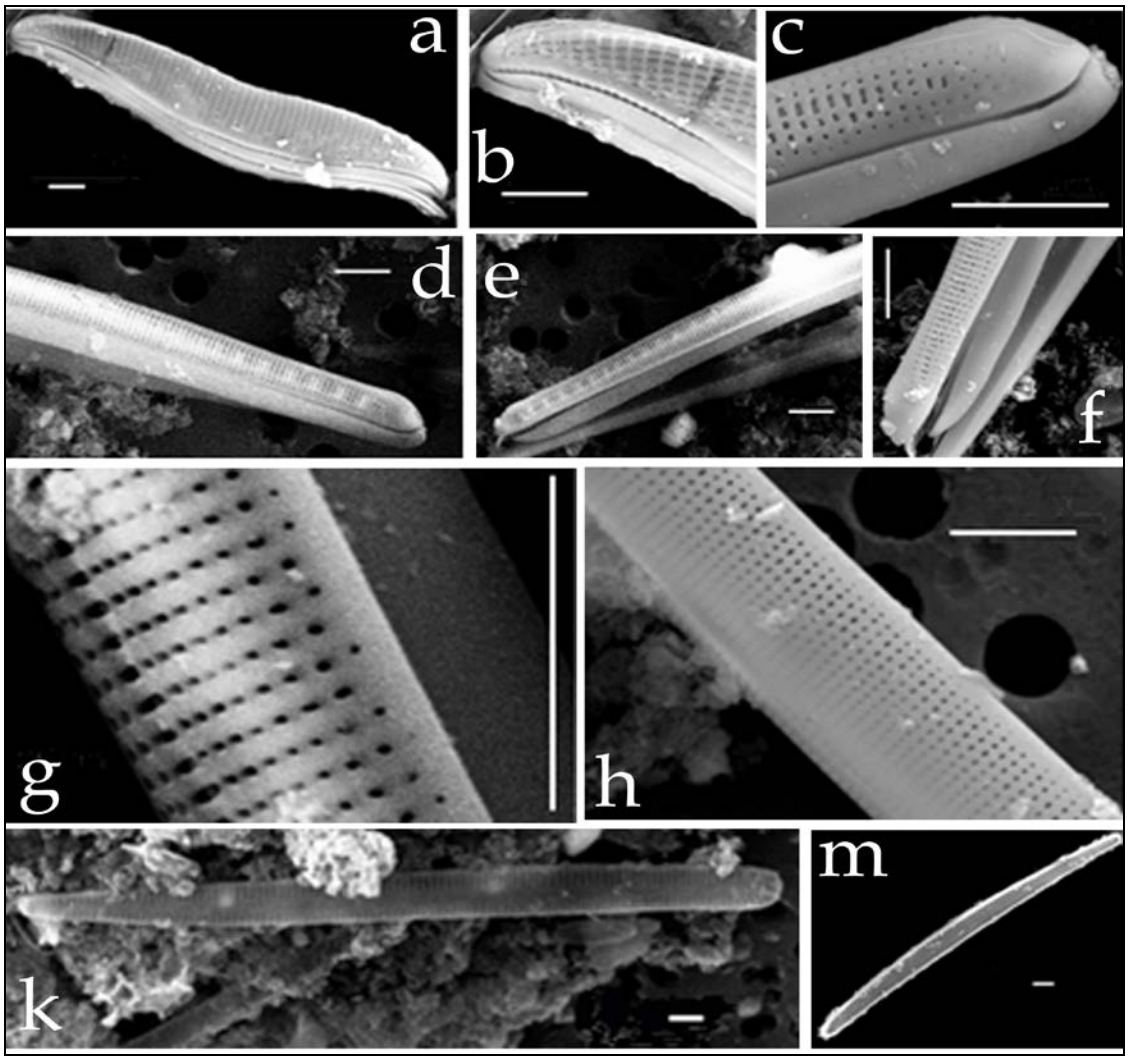


Figure 11: SEM images of fragments and structures of the valves and frustules of *Hantzschia spectabilis* (a-m) view, its fragments and structure; scale bar: 3 µm.

Order Surirellales D. G. Mann 1990
Family Surirellaceae Kützing 1844

Genus *Surirella* Turpin 1828
***Surirella ovalis* Brébisson 1838. Fig. 12, a-c**
(Basinonym: *Surirella ovata* var. *ovalis* (Brébisson) Kirchner 1878; Synonyms: *Surirella ovalis* (Brébisson) Pfitzer 1871; *Surirella ovalis* var. *ovata* (Kützing) Van Heurck 1885, *Surirella ovalis* f. *typica* A. Mayer, *Surirella lanceolata* H. P. Gandhi 1955)

Dimensions in SEM images: valve 26.3 µm length, 15 µm width, 15 rows areolarea in 10 µm. Dimensions in LM images: valves 30-37 µm length, 13-17 µm width, 15-17 rows areolarea in 10 µm (Guslyakov et al., 1992).

**Ecology, distribution, and phytogeography**: indifferent, benthic, *β*-mesosaprobes, arctic-boreal species. Recorded in epiphyton of macrophytes, epilithon of stones, on siltflates, sandflates and on the surface of mollusk shells, artificial substrates off the coast of the Crimea in Karadag Reverse (Roshchin, 1989) and in the north-western part of the Black, Azov, Baltic, Northern, Barents, White, Kara, Laptev, Japan, Mediterranean, Tyrrhenian, Caspian, Aral seas; Amur Estuary, in the waters of Russia, Ukraine, the Caucasus, Central Asia, as well as off the coast of Greenland, England (Hendey, 1964), Norway, Sweden, Finland, Germany, Belgium, Poland, France, Greece, Turkey, Iraq, China, South Africa, Canada, U.S.A., Colombia (Guslyakov et al., 1992), near of Iberian Peninsula, in Balearic and Canary Islands (Guiry and Guiry, 2021).

Family Entomoneidaceae Reimer 1975
Genus *Entomoneis* (Ehrenberg) C. G. Ehrenberg 1845
***Entomoneis paludosa* var. *duplex* (Donkin) Czarnecki et Reinke 1982. Fig. 12, d-e**
(Basionym: *Amphiprora paludosa* var. *duplex* Donkin 1880; Synonyms: *Amphiprora duplex* Donkin 1858; *Entomoneis paludosa* (W. Smith) Reimer 1975.

Dimensions in SEM images: frustule 30 µm length. Dimensions in LM images: valves 16-24 µm length, 7-13 µm width in the middle (Proshkina-Lavrenko, 1963).

**Ecology, distribution, and phycology**: brackish waters, littoral, sublittoral, rare boreal species. Occurs in the Black Sea in the northwestern part and in the Crimean coast near Karadag Reserve, as well as in the North, in the Bothnia Gulf of the Baltic Sea (Proshkina-Lavrenko, 1963; Guslyakov et al., 1992; Roshchin et al., 1992). This species was first noted in the Black Sea Kruglaya Bay.

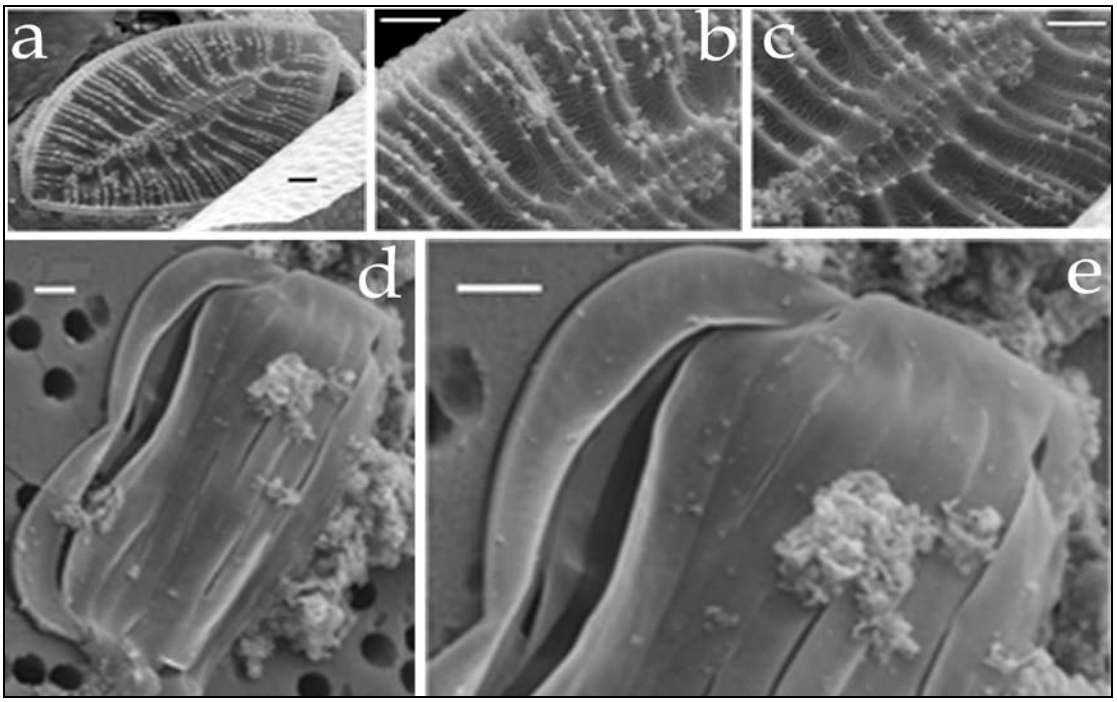


Figure 12: SEM images of fragments and structures of the valve and frustules of *Surirella ovalis* (a-c) and *Entomoneis paludosa* var. *duplex* (d-e) view; scale bar: 2 µm.

**DISCUSSION**

This is a study of the taxonomic composition of the diatoms of Kruglaya Bay, characterized by the use of SEM. The results show that there is a high biodiversity with a prevalence of the biraphid species. This result is typical for the microphytobenthos of the coastal waters of the Black, Azov, and Japan seas (Ryabushko, 2013; Balycheva, 2014; Ryabushko and Begun, 2015, 2016; Bondarenko, 2017; Barinova et al., 2019). The species composition of diatoms of sand has a rich flora and in some species similar to other ecotopes of the sea. The temperature, light and hydrochemical regimes at the shallow waters of the Black Sea are very favorable for microalgae vegetation. Many of the observed species form different communities on both natural and anthropogenic substrates (Ryabushko, 2009, 2013). We observed some typical species of epipsammon, such as representatives of the genera *Amphora, Halamphora, Lyrella, Diploneis, Hantzschia*, etc. Among them there were three species first recorded in the Crimean coastal waters and the Black Sea. The current study investigated the species of diatoms found on 16 species of brown, red, and green macroalgae epiphyton at a depth of 0-20 m. This study was carried out in May and August 1990 near Cape Omega of Kruglaya Bay (Ryabushko, 1996). In May on 10 species of macrophytes was found 36 species of diatoms, in August on 6 species of macrophytes – 31, from them 15 were biraphid algae. In addition, in February-March 1989, in the closed part of Kruglaya Bay, 100 m from the sand beach, 10 species diatoms were noted in the periphyton of synthetic materials (Ryabushko, 2013). In general, pennate algae predominated, which differed in species composition depending on the ecotope of habitat and on the sandy substrates of the Kruglaya Bay.

## CONCLUSIONS

This is the first study conducted on diatoms from the sand beach of Kruglaya Bay of the Black Sea, accomplished in just one day, 30th of September 2016 and analyzed by scanning electron microscopy (SEM). We found 25 taxa to biraphid of Bacillariophyta representing 17 genera. Three new species: *Halamphora tenerrima*, *Amphora tenuissima*, and *Navicula antonii*, were reported for the first time in the Crimea and the Black Sea. The most dominant species were: marine (40%), marine-brackish (32%) and of boreal-tropical (32%), arctic-boreal-tropical (24%), boreal and cosmopolites (20% and 16% respectively) while brackish, freshwater, indifferent, and arctic-boreal were less well represented (8% each), including notal species (12%), found in the southern hemisphere. The morphological characteristics of species in the SEM and LM are given based on original and published data on the variability of the valve and frustule sizes, occurrence, ecology, phytogeography, and the general distribution in different areas of the World Ocean.

**ACKNOWLEDGEMENTS**

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