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PALEOECOLOGY OF HOLOCENE DIATOMS FROM SPHAGNUM PEAT BOGS IN THE CENTRAL SREDNA GORA MOUNTAINS (BULGARIA)

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Abstract: The fossil record from three sphagnum peat bogs situated at altitudes of 1400–1550 m in the Central Sredna Gora Mts (Bulgaria), consisting of 115 Diatomaceea species, 15 varieties and 2 forms, represents four diatom zones covering the time span of the last 10 ky. The diatom flora in the peat bogs emerged 8 ky ago. The fluctuating development of diatom communities was controlled by unstable water level, affected by local humidity and other climatic changes.

Key words: Holocene, Bulgaria, paleoecology, peat bogs, diatoms, quantitative pollen analysis.

Introduction

The first data on diatoms from Holocene sediments in Bulgaria have been so far reported for the Beloslav and Dourankoulak lakes on the Bulgarian Black Sea Coast (Temniskova & Dojceva 1989; Temniskova & Atanassova 1996), the Sozopol Bay (Ognjanova-Rumenova 1995; Ognjanova-Rumenova & Zaprjanova 1998). The Holocene history of the development of the two coastal lakes has marked three periods of salinization of their waters. A marine transgression, which had affected the composition of the diatom flora in the two lakes, was traced out at about 4000 BC for Dourankoulak and at about 4170±150 BC for Beloslav lake. Ognjanova-Rumenova (2001a,b) studied the diatom flora of Quaternary sediments from the subalpine lake Dulgoto in the Northern Pirin Mts. Five diatom biozones have been differentiated and the local paleoecologial conditions have been reconstructed. The first studies of Holocene diatoms from the peat bogs relate to the species composition of diatom flora from the Barierata stratigraphic profile in the Central Sredna Gora Mts (Stancheva 2001a,b). It was taken from inundated meadows in the deforested areas at 1000 m a.s.l., where *Sphagnum* spp. were missing in the vegetation cover. This makes a significant difference when compared to the sphagnum peat bogs situated at higher altitudes in the region. Stancheva (2001c) published only the taxonomical composition of the diatom flora from the Shiligarka sphagnum peat bog.

For the Central Sredna Gora Mts, four forest succession phases have been established in the 10,025±225 BP period, and light has been thrown on the development of vegetation and the main climatic changes until the formation of the contemporary beech forests (Petrov & Filipovitch 1987; Filipovitch 1992, 1996, 1998; Filipovitch et al. 1998; Stefanova & Filipovitch 1997).

The purpose of the present study is to establish the succession of the diatom community in the sediments of the investigated peat bogs and to reconstruct the paleoecological conditions in the last 10,000 years by interpreting the available data on autochthonous siliceous microfossils.

Study area

The Sredna Gora Mts lies to the south of the Balkan Range and Rearbalkan valleys, with a predominantly West-East orientation. Morphographically, the Sredna Gora Mts has a highly variable relief comprising hill-and-valley, lower and higher mountain stretches. Geologically and petrographically, most of that region is formed of anticlinal folds, with cores of Early Paleozoic (Hercynian) granites and pre-Paleozoic and Paleozoic metamorphic rock complexes (gneisses, micaceous schists, amphibole schists, etc.) (Georgiev 1991). The physicogeographical region of the objects of study extends to the southernmost part of the Temperate Continental and to the northern part of the Transitory Continental Climatic Zone. Winter is cold and comparatively dry, summer is warm, with maximum precipitations in May and June (Mishev 1989).

The Central Sredna Gora Mts falls into the European Deciduous Forests Zone, the Balkan (Illyrian) Province, Sredna Gora region. Beech and oak forests dominate, with an occasional thin hornbeam forest and secondary communities of *Corylus, Carpinus orientalis*, with artificial afforestations of *Pinus sylvestris* in some places (Bondev 1991, 1997).

The investigated sphagnum peat bogs are located in the Central Sredna Gora Mts (Fig. 1). Shiligarka and Bogdan-3 peat bogs lie above the upper tree line, at an altitude of 1500–1550 m, between peaks Bogdan (1604 m a.s.l.) and Malak Bogdan (1532 m a.s.l.). Bogdan-3 peat bog is situated on a southern slope of the mountain crest, while Shiligarka peat bog is neighbouring a beech forest. Bogdan-6 peat bog lies in the beech belt, at an altitude of 1400 m. The investigated peat bogs vary in area from several square meters to 10,000–20,000 m^2 and have various slope gradients. The fontinal peat bogs represent heterotrophotypic complexes of mosaically ar-

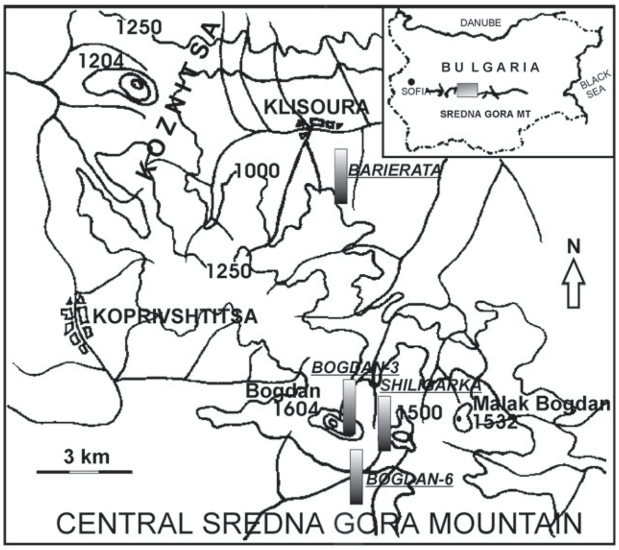

Fig. 1. Location map of the studied peat bogs in the Central Sredna Gora Mts.

ranged eutrophic and oligotrophic plant communities, depending on terrain lowering (Filipovitch et al. 1998). The following species prevail in the vegetation cover of the sphagnum peat bogs: *Eriophorum vaginatum* L., *E. latifolium* Hoppe., *Carex flava* L., *C. leporina* L., *C. echinata* Murr., *Juncus effusus* L., *J. thomassi* Ten., *Parnasia palustris* L., *Pinguicula vulgaris* L., *Drosera rotundifolia* L., *Orchis maculatus* L., *Epilobium palustre* L., *Deschampsia caespitosa* P.B., *Potentilla erecta* (L.) Rausch., *Galium palustre* L., *Myosotis scorpioides* L., *Equisetum hiemale* L., *E. palustre* L., *E. arvense* L., *Geum coccineum* S.S., *Vaccinium vitis-idaea* L., *V. uliginosum* L., *Caltha palustris* L., *Hieratium pilosella* L., *Epilobium angustifolium* L., *Ajuga genevensis* L., *Athyrium filix-femina* (L.) Roth. The peat bogs in higher locations are surrounded by mountain meadow communities, dominated by *Nardus stricta* L., *Juniperus communis* L. and *Bruckenthalia spiculifolia* (Salisb.) Rchb.

Material and methods

The material studied was obtained from three cores retrieved from each peat bog. The cores were of the following length: Bogdan-3 (150 cm), Bogdan-6 (80 cm) and Shiligarka (70 cm). The sampling was done by means of a manual, Dachnowsky-type corer, with camera diameter of 2 cm (Filipovitch et al. 1998). Lithological composition of the studied cores was detailed as follows:

Bogdan-3: 0–31 cm — peat with plant remains; 31–82 cm — dark, strongly humified peat, with five consecutive layers; 82–145 cm — humified brown peat with plant remains; 145–150 cm — coarse clay with sand.

Bogdan-6: 0–40 cm — brown peat; 40–70 cm — black peat; 70–75 cm — peat with plant remains; 75–80 cm — coarse clay with abundant of sand.

Shiligarka: 0–60 cm — peat with plant remains; 60–65 cm — peat with plant remains and fine sand; 65–70 cm — peat with phyto-remains and gravel (Stancheva 2001c).

Radiocarbon dating of the sediments from Bogdan-3, Bogdan-6 and Shiligarka cores was carried out at the ^{14}C und ^{3}H Laboratorium, Niedersächisches Landesamt für Bodenforschung in Hannover, Germany. The results of the dating are presented in Table 1 (acc. to Filipovitch et al. 1998).

A total of 156 samples for diatom analysis were extruded at 1–5 cm intervals, next to the samples for pollen analysis. Laboratory processing followed the technique of Hasle & Fryxell (1970), as modified by Ognjanova-Rumenova (1991). Microscopic slides for LM were prepared according to Gleser et al. (1974), and for SEM according to Loseva (1982), with a gold coating. Light microscopic investigation was carried out by means of an Amplival light microscope with oil immersion objective ×100. Jeol JSM-T 300 and Jeol JSM-5300 scanning electron microscope were used for the identification and documentation of the problematic taxa. Quantitative analysis followed the standard percentage counting technique of Battarbee (1986), with 500 valves counted in each slide. For the diatom taxa with known autecology, ecological spectra were determined in accordance with Abbott & Van Landingham (1972). They were based on literary sources with comparable data by various authors (Kolbe 1927; Hustedt 1937–1939; Lowe 1974; Krammer & Lange-Bertalot 1986–1991; Denys 1991; Foged 1993; Häkansson 1993; Vos & De Wolf 1993; Van Dam et al. 1994; Van de Vijver et al. 1998; etc.).

They featured water salinity after Hustedt (1957), active water reaction after Hustedt (1937–1939), trophic status after Naumann (1921, cit. acc. to Van Dam et al. 1994), specific habitats according to the definition of Vos & De Wolf 1993, and geographical distribution. The percentage ratio of diatom frustules/chrysophycean stomatocysts was determined after Smol (1985). This reflected the changes in trophic and hydrological status of paleobasins.

In this paper pH reconstruction uses the categories of Hustedt (1937–1939) and is based on Index B (Renberg & Hellberg 1982). It was applied to two equations expressing the ratio between pH and log Index B.

Index B based on data from lakes in Bohuslän (Renberg & Hellberg 1982) was:

$$pH = 6.40–0.85 \log \text{Index B } (r^2 = 0.91; \text{S.E.} = \pm 0.30).$$

Index B based on data from 33 lakes in Galloway (Flower 1986) was:

$$pH = 6.30–0.865 \log \text{Index B } (r^2 = 0.82; P < 0.001; \text{S.E.} = \pm 0.36).$$

Ecological analysis and pH reconstruction were applied only to samples with 500 counted diatom valves.

Diatoms were identified using the floras of Germain (1981), Krammer & Lange-Bertalot (1986, 1988, 1991, 1991a) etc. For nomenclature refer to Krammer & Lange-Bertalot (1986, 1988, 1991, 1991a) and Round et al. (1990).

Results

A total of 115 diatom species, 15 varieties and two forms belonging to 28 genera (see Appendix) were identified. Eight taxa were identified to the generic level. One hundred and

Table 1: Radiocarbon datings (Filipovitch et al. 1998).

Locality	Depth (cm)	Lab. №	^{14}C Dates Age BP
Bogdan-3	100–105	Hv 6722	7145±95
Bogdan-3	125–135	Hv 6723	8115±100
Shiligarka	55–60	Hv 21662	5285±180
Bogdan-6	35–40	Hv 21663	5060±165
Bogdan-6	65–70	Hv 21664	7835±445
Bogdan-6	70–80	Hv 21665	10025±225

eight taxa were found in the sediments of the Shiligarka sampling site, 76 in Bogdan-6 and only 41 in Bogdan-3 peat bogs. The identified diatom flora consisted entirely of recent species.

Diatom biostratigraphy

The stratigraphic distribution pattern and relative abundance of the most frequently occurring diatoms and the values of the diatom frustules/chrysophycean stomatocysts ratio in the three cores are presented on Figs. 2, 3 and 4. The diagrams include all diatom species that exceeded 2 % of the total numbers found within each of the samples. Definition of the biostratigraphic diatom zones and their correlation are based on the total fossil record of diatoms (Salvador 1994; Nikolov & Sapunov 2002). Changes in the diatom species composition enabled us to distinguish four diatom assemblage zones, representing different ecological conditions:

DAZ A (Bogdan-3: 140–120 cm, Bogdan-6: 70–65 cm, corresponding to the beginning of PAZ SG 2 of Filipovitch et al. (1998)

This zone was characterized by a low number of taxa and low abundance of diatoms. The highest species diversity was recorded in *Pinnularia* (6 species) and *Eunotia* (5 species). *Eunotia glacialis* Meister, *E. monodon* Ehrenberg (Fig. 5.16,17), *E. praerupta* Ehrenberg, *Pinnularia borealis* Ehrenberg (Fig. 6.5), *P. lata* (Bréb.) W. Smith (Fig. 6.6,7), and *P. maior* (Kütz.) Rabenhorst were the most frequently occurring species. The remaining taxa were represented by single specimens. *Fragilaria ulna* (Nitz.) Lange-Bertalot and *Navicula radiosa* Kützing occurred only in the sediments of Bogdan-6 peat bog on that level. Abundantly occurring chrysophycean stomatocysts have also been observed in great numbers.

DAZ B (Bogdan-3: 120–55 cm, Bogdan-6: 65–40 cm, corresponding to the end of PAZ SG 2, PAZ SG 3a of Filipovitch et al. (1998)

In DAZ B diatom flora is represented by very low number of taxa and the diatom record is incomplete. Sediment samples taken from 108–100, 95–90, 85–80 cm (Bogdan-3) and 64–61, 55–52 cm (Bogdan-6) depth intervals were barren. In other levels *Eunotia glacialis, E. monodon, Gomphonema angustatum* (Kütz.) Rabenhorst*, Meridion circulare* var. *constrictum* (Ralfs) Van Heurck*, Stauroneis anceps* Ehrenberg, and *Pinnularia maior, Pinnularia* sp. were identified. The valves were poorly preserved and the large valves of *Eunotia monodon* and *Pinnularia* sp. were fragmented. Representation of *Eunotia* sp. and *Navicula* sp. were small and, owing to partial dissolution, their determination was impossible. Rarely occurring chrysophycean stomatocysts were identified in some of the samples.

DAZ C (Bogdan-3: 53–13 cm, Bogdan-6: 40–18 cm, Shiligarka: 60–20 cm, corresponding to PAZ SG 3, and the beginning of PAZ SG 4 of Filipovitch et al. (1998)

A species-rich diatom community has been identified in the lowermost part of the sediments of Shiligarka peat bog, as well as increased relative abundance of single taxa in the sediments of Bogdan-3 and Bogdan-6 peat bogs. Chrysophycean stomatocysts considerably dominated over diatoms through-

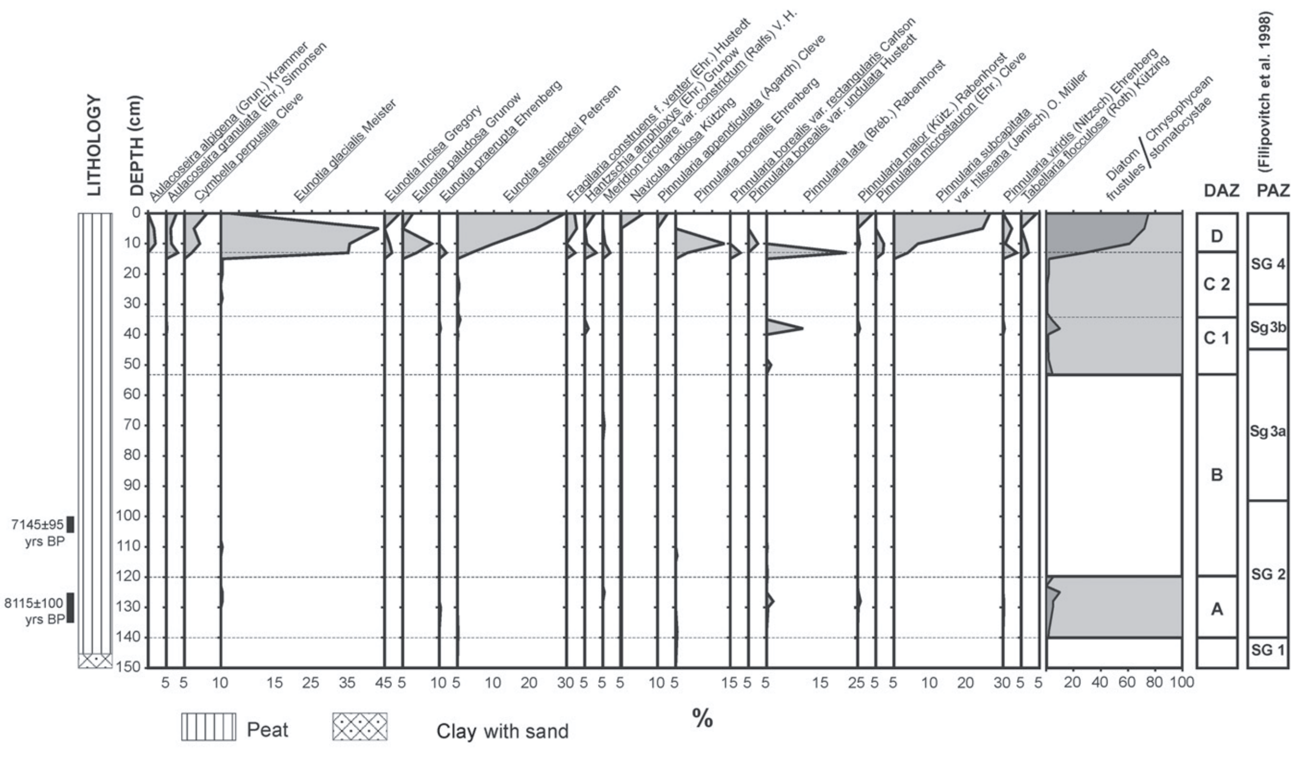

Fig. 2. Diatom frequency diagram of the most common diatoms and percentage ratio of diatom frustules/chrysophycean stomatocysts in the sediments of Bogdan-3 peat bog.

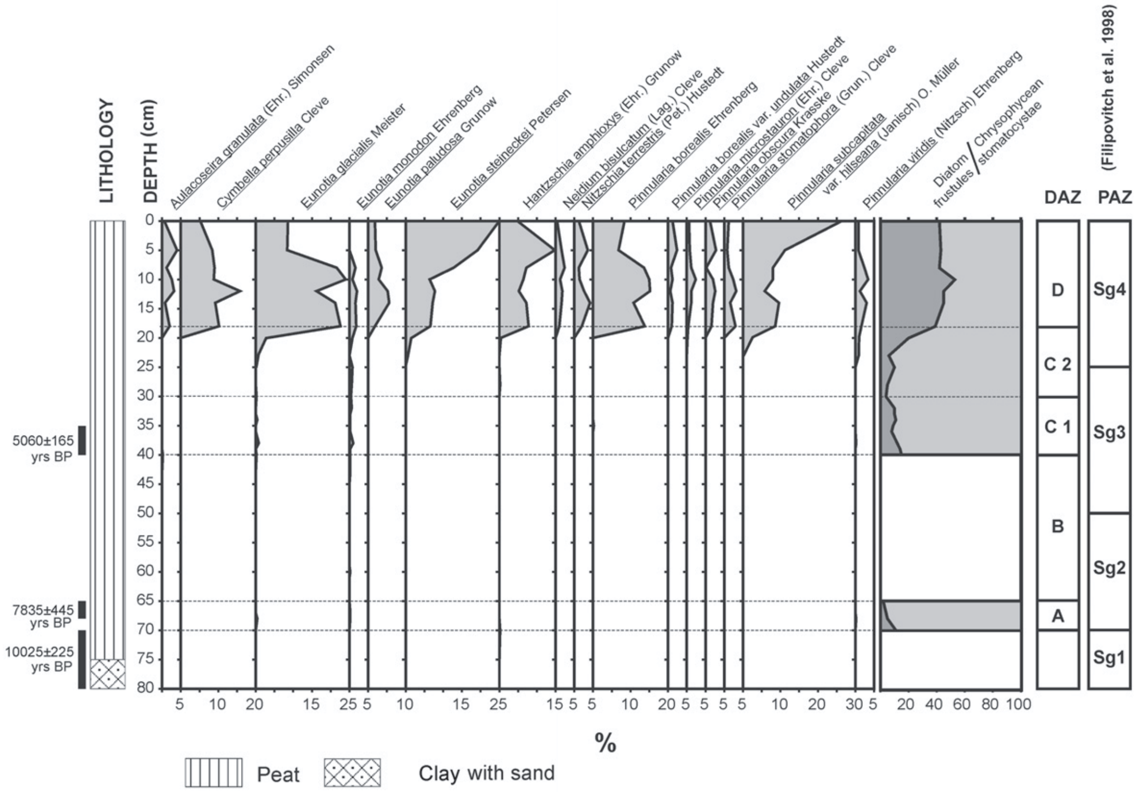

Fig. 3. Diatom frequency diagram of the most common diatoms and percentage ratio of diatom frustules/chrysophycean stomatocysts in the sediments of Bogdan-6 peat bog.

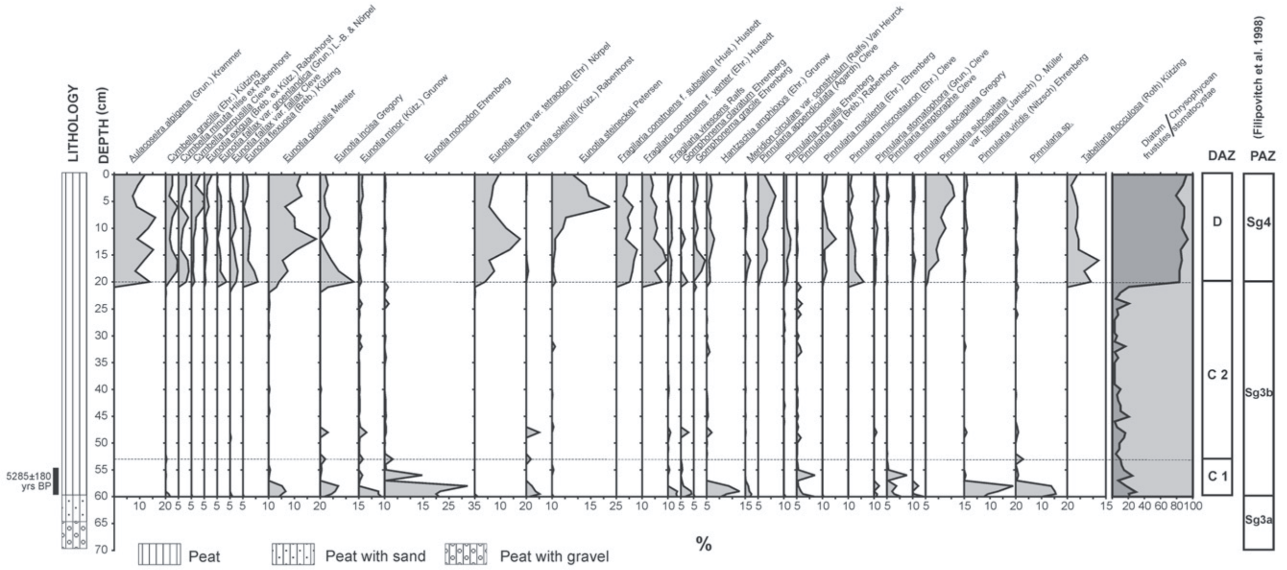

Fig. 4. Diatom frequency diagram of the most common diatoms and percentage ratio of diatom frustules/chrysophycean stomatocysts in the sediments of Shiligarka peat bog.

out the entire zone. Changes in the diatom species composition allowed us to distinguish two subzones (DAZ C1 and DAZ C2) within DAZ C.

DAZ C1 (Bogdan-3: 53–35 cm, Bogdan-6: 40–30 cm, Shiligarka: 60–52 cm, corresponding to PAZ SG 3, PAZ SG 3b of Filipovitch et al. (1998)

This subzone was characterized by a diatom flora rich in taxa. *Eunotia monodon* (32.2 %), *E. minor* (Kütz.) Grunow (8.8 %) (Fig. 5.10), *Hantzschia amphioxys* (Ehr.) Grunow (12.8 %), *Pinnularia viridis* (Nitz.) Ehrenberg (19 %), *Pinnularia* sp. (15.6 %), *P. streptoraphe* Cleve (7.8 %) and *P. lata* (7 %) showed high relative abundance in the sediments of Shiligarka peat bog and reached their highest relative abundance in this subzone. *Aulacoseira granulata* (Ehr.) Simonsen and *A. subarctica* (O. Müller) Haworth, *Fragilaria capucina* var. *rumpens* (Kütz.) Lange-Bertalot, *F. virescens* Ralfs, and *Melosira varians* Agardh appeared for the first time. The lowermost part of the subzone is characterized by occurrence of

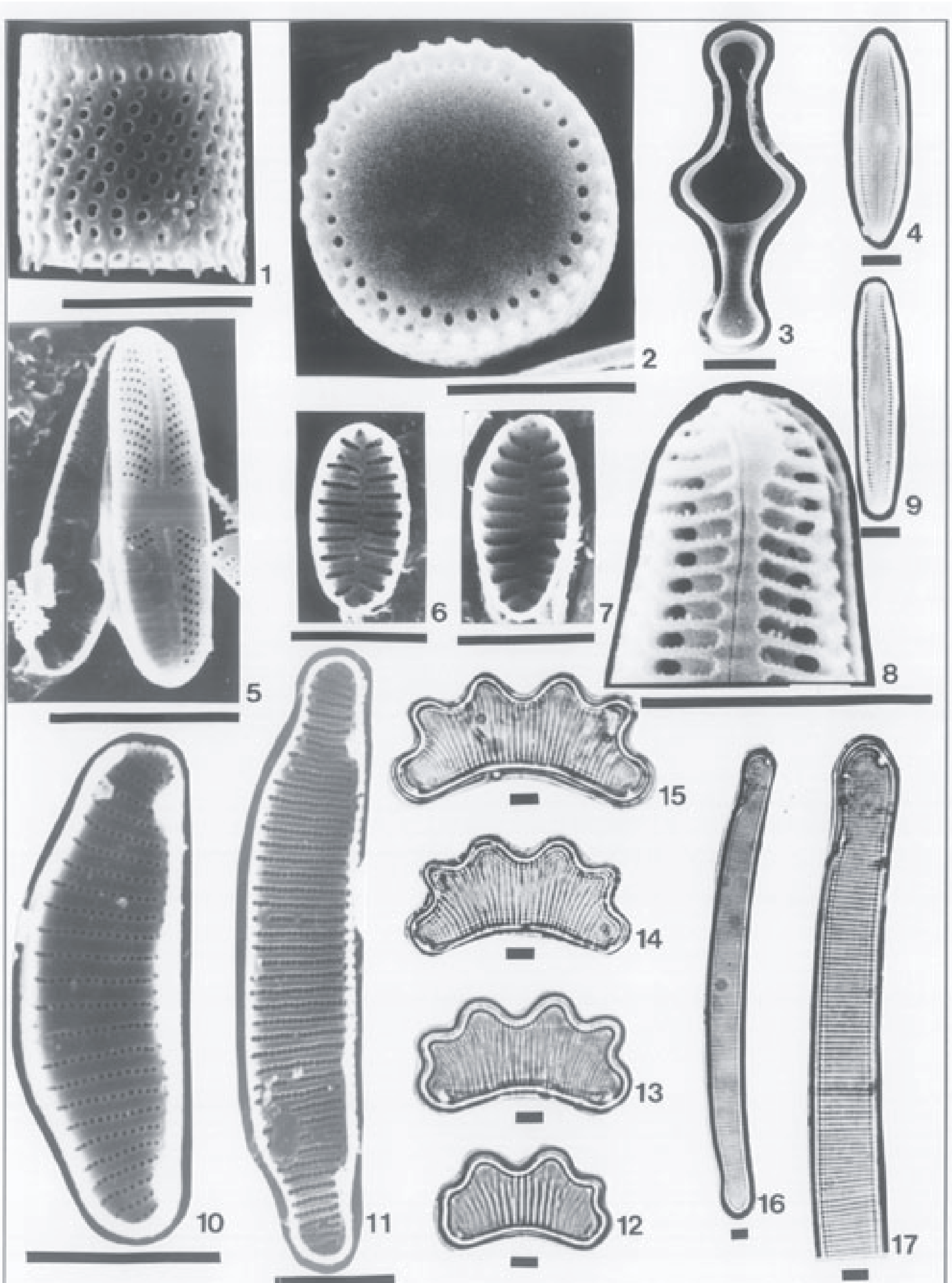

Fig. 5. **1.** *Aulacoseira alpigena* (Grunow) Krammer — valve mantle, SEM. **2.** *Aulacoseira alpigena* (Grunow) Krammer — valve face, SEM. **3.** *Tabellaria flocculosa* (Roth) Kützing — septum, SEM. **4.** *Caloneis bacillum* (Grunow) Cleve, SEM. **5.** *Achnanthes petersenii* Hustedt, SEM. **6.** *Fragilaria construens* f. *venter* (Ehrenberg) Hustedt — valve exterior, SEM. **7.** *Fragilaria construens* f. *venter* (Ehrenberg) Hustedt — valve interior, SEM. **8.** *Caloneis tenuis* (Gregory) Krammer — detail, SEM. **9.** *Caloneis tenuis* (Gregory) Krammer, SEM. **10.** *Eunotia minor* (Kützing) Grunow, SEM. **11.** *Eunotia incisa* Gregory, SEM. **12–15.** *Eunotia serra* var. *tetraodon* (Ehrenberg) Nörpel, LM. **16–17.** *Eunotia monodon* Ehrenberg, LM. Scale bars = 5 µm.

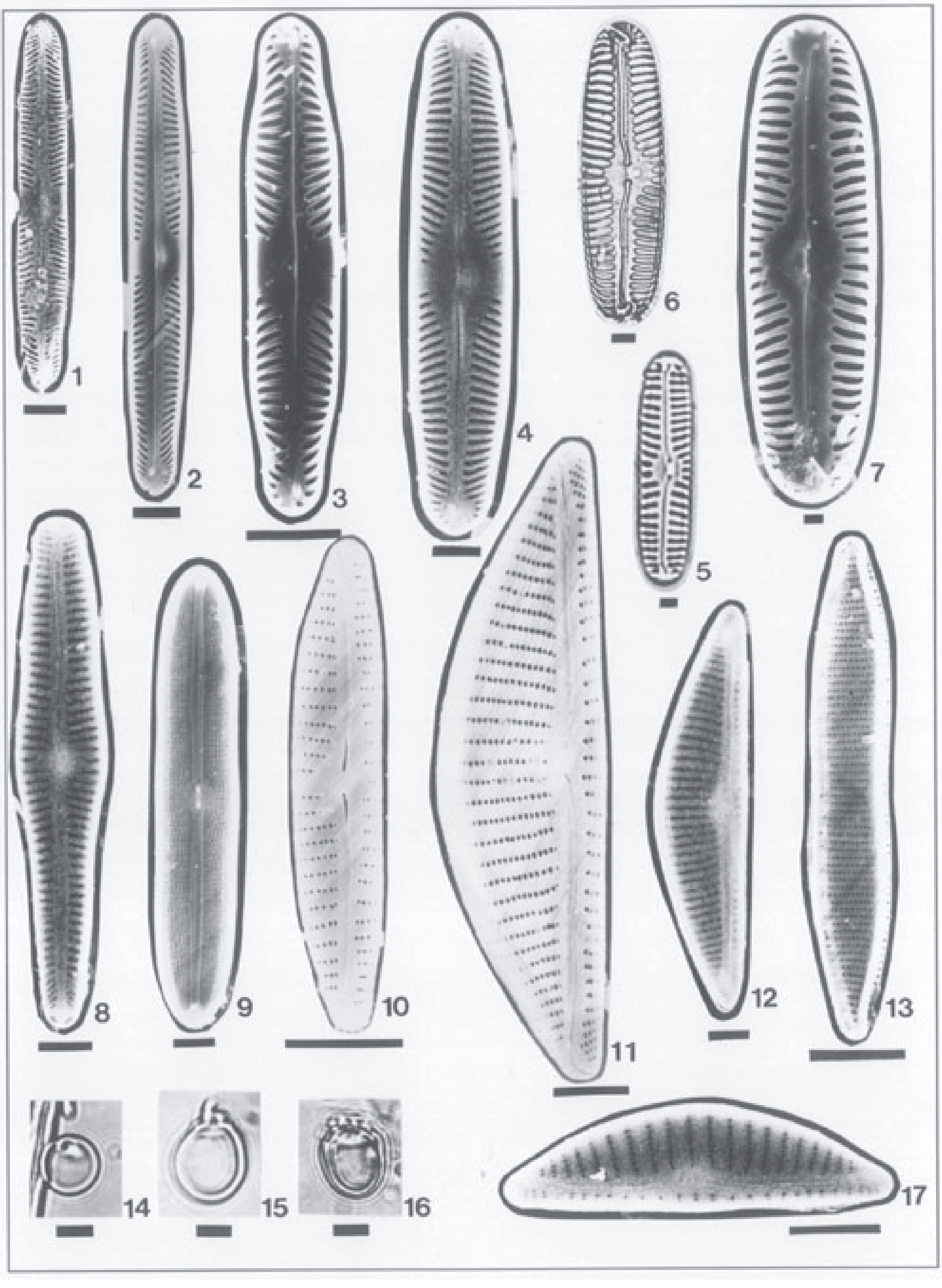

Fig. 6. **1.** *Pinnularia subcapitata* Gregory — valve exterior, SEM. **2.** *Pinnularia subcapitata* Gregory — valve interior, SEM. **3.** *Pinnularia appendiculata* (Agardh) Cleve, SEM. **4.** *Pinnularia microstauron* (Ehrenberg) Cleve, SEM. **5.** *Pinnularia borealis* Ehrenberg, LM. **6.** *Pinnularia lata* (Brébisson) Rabenhorst, LM. **7.** *Pinnularia lata* (Brébisson) Rabenhorst, SEM. **8.** *Gomphonema clavatum* Ehrenberg, SEM. **9.** *Neidium bisulcatum* (Lagerstedt) Cleve, SEM. **10.** *Cymbella perpusilla* Cleve, SEM. **11.** *Cymbella silesiaca* Bleisch, SEM. **12.** *Cymbella mesiana* Cholnoky, SEM. **13.** *Nitzschia hantzschiana* Rabenhorst, SEM. **14.–16.** Chrysophycean stomatocyst, LM. **17.** *Cymbella minuta* Hilse, SEM. Scale bars = 5 μm.

Eunotia soleirolii (Kütz.) Rabenhorst. It represented by vegetative cells and valves possessing internal resting spores. Towards the end of the Subzone C1, relative abundance of dominant species has gradually decreased and the number of taxa was reduced. The diatom frustules/chrysophycean stomatocysts ratio ranged from 2 to 28 %.

DAZ C2 (Bogdan-3: 35–13 cm, Bogdan-6: 30–18 cm, Shiligarka: 52–20 cm, corresponding to the end of PAZ SG 3, PAZ SG 3b, and the beginning of PAZ SG 4 of Filipovitch et al. (1998)

Diatoms of this subzone are characterized by a low number of taxa which were also recorded in the preceding subzone, e.g. *Eunotia steineckei* Petersen*, E. monodon, E. minor, Pinnularia lata,* and *P. viridis*. They were represented by single specimens, some with traces of fragmentation and dissolution of the valves. Mass occurrence of chrysophycean stomatocysts dominating over diatoms was recorded in this subzone.

DAZ D (Bogdan-3: 13–0 cm, Bogdan-6: 18–0 cm, Shiligarka: 20–0 cm, corresponding to PAZ SG 4 of Filipovitch et al. (1998)

This zone was characterized by a diatom assemblage typical for peat-bog habitats. In the sediments from all three peat bogs studied *Cymbella perpusilla* Cleve (Fig. 6.10)*, Eunotia glacialis, E. steineckei, Hantzschia amphioxys, Pinnularia microstauron* (Ehr.) Cleve (Fig. 6.4)*, P. subcapitata* var. *hilseana* (Janisch) O. Müller*, P. borealis* and *P. viridis* dominated.

The rich and diverse diatom flora identified in this zone was predominantly composed of different representatives of the genera *Eunotia, Pinnularia, Frustulia,* and *Stenopterobia,* described by Patrick & Reimer (1966) as closely specialized species, suited to live in progressively developed peat bogs. A group of acidobiontic taxa such as *Eunotia paludosa* Grunow, *Navicula subtilissima* Cleve and *Pinnularia subcapitata* var. *hilseana* attained higher frequencies in this zone. In the sediments of Bogdan-6 peat bog *Orthoseira roeseana* (Rab.) O'Meara and *Stenopterobia delicatissima* (Lewis) Brébisson were most characteristic, while the north-alpine diatom species *Frustulia rhomboides* var. *crassinervia* (Bréb.) Ross, *Achnanthes petersenii* Hustedt (Fig. 5.5) and *Caloneis lauta* Carter et Bailey-Watts were more frequent in Shiligarka peat bog. Diatoms dominated in over chrysophycean stomatocysts.

Ecological analysis of the diatom flora

Only 8.4 % of the identified diatom taxa have unknown ecology.

The ecological composition of the diatom flora from Bogdan-3 was generally characteristic with dominance of oligohalobous-indifferent (54 %), acidophilous (37 %), oligotrophic (33 %), epiphytic (40 %), and cosmopolite (78 %) diatoms. In the sediments of Bogdan-6 the diatoms were represented by oligohalobous-indifferents (57 %), pH indifferents (36 %), oligotrophs (30 %), epiphytes (32 %), and cosmopolites (70 %). Oligohalobous-indifferent and halophobous diatoms (49 % each), acidophilous (36 %), oligotrophic (37 %), and cosmopolite (69 %) species prevailed in the diatom flora of the Shiligarka peat bog.

The diatom flora in the peat bogs emerged 8000 BP ago (DAZ A). Halophobous and oligohalobous-indifferent diatom species prevailed. Acidophilous and oligotrophic species developed, followed by indifferents and oligo- to mesotrophic species. All identified species were benthic: epiphytes or aerophilous, with the exception of *Fragilaria ulna.*

In the Middle Holocene the development of diatom community gradually abated (DAZ B, 7145±95 BP for Bogdan-3). Sediments of strongly humified black peat with several alternating layers have preserved single, fragmented valves, usually chemically eroded in the smaller specimens. This impeded the ecological analysis of the diatom flora of that period.

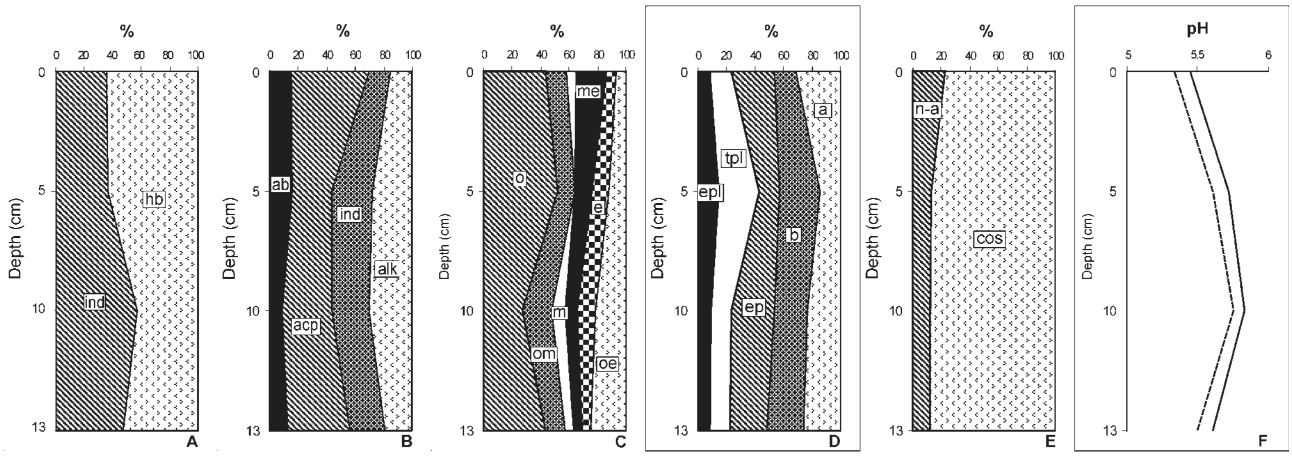

Fig. 7. Relative abundance of the diatom ecological groups and diatom-inferred pH values in the sediments of Bogdan-3 peat bog. *Legend:* **A.** Halobion diatom groups (hl — oligohalobous-halophilous, ind — oligohalobous-indifferent, hb — oligohalobous-halophobous); **B.** pH diatom groups (ab — acidobiontic, acp — acidophilous, ind — indifferent, alk — alkaliphilous); **C.** Trophic diatom groups (o — oligotrophic, om — oligo-mesotrophic, m — mesotrophic, me — meso-eutrophic, eu — eutrophic, oe — oligo- to eutrophic); **D.** "Habitat" diatom groups (epl — euplanktonic, tpl — tychoplanktonic, ep — epiphytic, b — benthic, a — aerophilous); **E.** Geographic distribution (bor — boreal, n-a — north-alpine, cos — cosmopolitan); **F.** Diatom-inferred pH values (- - index B (Flower 1986), — index B (Renberg & Hellberg 1982)).

About 5285 BP (DAZ C) such favourable conditions in peat bog Shiligarka encouraged the rapid formation of a species-rich diatom community, with prevalence of oligohalobous (halophobous and indifferent); acidophilous, oligotrophic and oligo- to mesotrophic species (Fig. 9). The active water reaction values obtained by application of Index B (Fig. 9E) for the sediments from Shiligarka peat bog varied between 5.2–5.9 in the 60–55 cm interval.

During the latest period of existence of the peat bogs (DAZ D), the percentage shares of the different ecological groups of diatoms in the peat bogs of Shiligarka and Bogdan-6 were rather similar. In terms of salinity, only oligohalobous species have been identified, with prevalence of halophobes and indifferents over halophiles (0–4 %) (Figs. 8A, 9A). In terms of active water reaction, acidophilous and indifferent species showed more significant relative abundance. Acidobionts varied between 6 % and 10 %, and alkaliphilous species were between 18 % and 30 % (Figs. 8B, 9B). In terms of trophic conditions, the groups of oligo- and oligo- to mesotrophic species were best represented, followed by oligo- to eutrophic and eutrophic species. A minimum presence of meso- and meso-eutrophic species was registered (Figs. 8C, 9C). According to their specific habitats, benthic diatoms dominated, with almost equal percentage shares of epiphytes, aerophilous and benthos (sensu lato). Euplanktonic species formed from 3 % to 10 %, and tychoplanktonic species varied in the different peat bogs as follows: 13–22 % in Shiligarka, and from 3 % to 7 % in Bogdan-6 (Figs. 8D, 9D). The low proportion of the euplanktonic group is quite legitimate for the acid lakes, where contrary to benthos, diatom plankton is often poorly developed (Battarbee et al. 1999). During that stage of development of Shiligarka and Bogdan-6 peat bogs the active water reaction in both sites varied between 5.6–5.9 (Figs. 8E, 9E). In the Bogdan-3 peat bog active water reaction registered a reduction from 5.9 to 5.3 towards the surface (Fig. 7E). Another important feature of the diatom community in Bogdan-3 peat bog was the absence of halophilous species and the higher percentage of acidobiontic (up to 16 %) and oligotrophic (up to 52 %) diatom algae (Fig. 7). The low values of active water reaction probably related to the processes of natural acidification established in other water basins by the same methods (Jones et al. 1989).

Discussion

Clayey sediments of the Early Holocene (10,025±225 BP for Bogdan-6) did not contain siliceous microfossils (diatoms and chrysophyceans). Apparently, the harsh environmental conditions were unfavourable for the development of algal flora in the early stage of peat-bog formation in Bogdan-3 and Bogdan-6 core sites situated on the mountain crest. During that period 10,000–8000 BP (PAZ SG 1) the mountain slopes were fully clad by grassy communities, while paleoclimatic conditions were characterized by low temperatures, deficient humidity and poor soils (Filipovitch et al. 1998).

At ca. 8000 BP (DAZ A), pioneer algal flora emerged in Bogdan-3 (8115±100 BP) and Bogdan-6 (7835±445 BP) peat bogs. The diatom assemblage was species poor and frequency was low. The benthic character of the diatom community shows that during that period water level was low. Water in the peat bog had acid reaction and was poor in nutrients. Temperatures were still low, which encouraged the development of oligothermic species *Pinnularia borealis* and the oligo- to mesothermic species *Fragilaria ulna* and *Navicula radiosa* (Lowe 1974). Quantitative predominance of chrysophycean stomatocysts over diatoms indicated that initially the conditions were rather unfavourable for the development of algal flora. Smol (1983, 1985) explained the great abundance of chrysophycean stomatocysts in post-glacial sediments by the oligotrophic conditions and late beginning of the vegetation season. That period (PAZ SG 2) witnessed the afforestation of

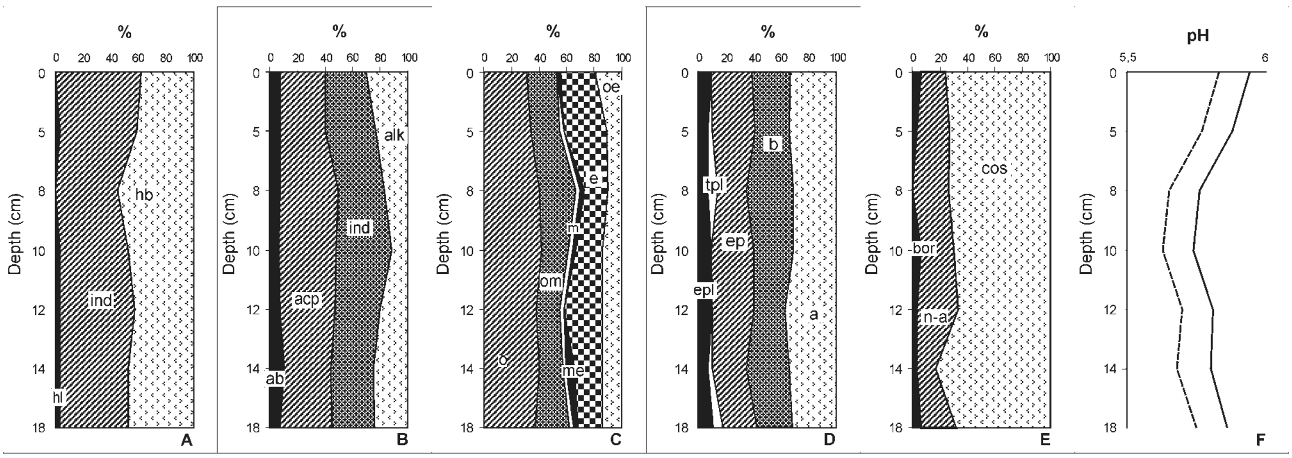

Fig. 8. Relative abundance of the diatom ecological groups and diatom-inferred pH values in the sediments of Bogdan-6 peat bog. *Legend:* **A.** Halobion diatom groups (hl — oligohalobous-halophilous, ind — oligohalobous-indifferent, hb — oligohalobous-halophobous); **B.** pH diatom groups (ab — acidobiontic, acp — acidophilous, ind — indifferent, alk — alkaliphilous); **C.** Trophic diatom groups (o — oligotrophic, om — oligo-mesotrophic, m — mesotrophic, me — meso-eutrophic, eu — eutrophic, oe — oligo- to eutrophic); **D.** "Habitat" diatom groups (epl — euplanktonic, tpl — tychoplanktonic, ep — epiphytic, b — benthic, a — aerophilous); **E.** Geographic distribution (bor — boreal, n-a — north-alpine, cos — cosmopolitan); **F.** Diatom-inferred pH values (- - index B (Flower 1986), — index B (Renberg & Hellberg 1982)).

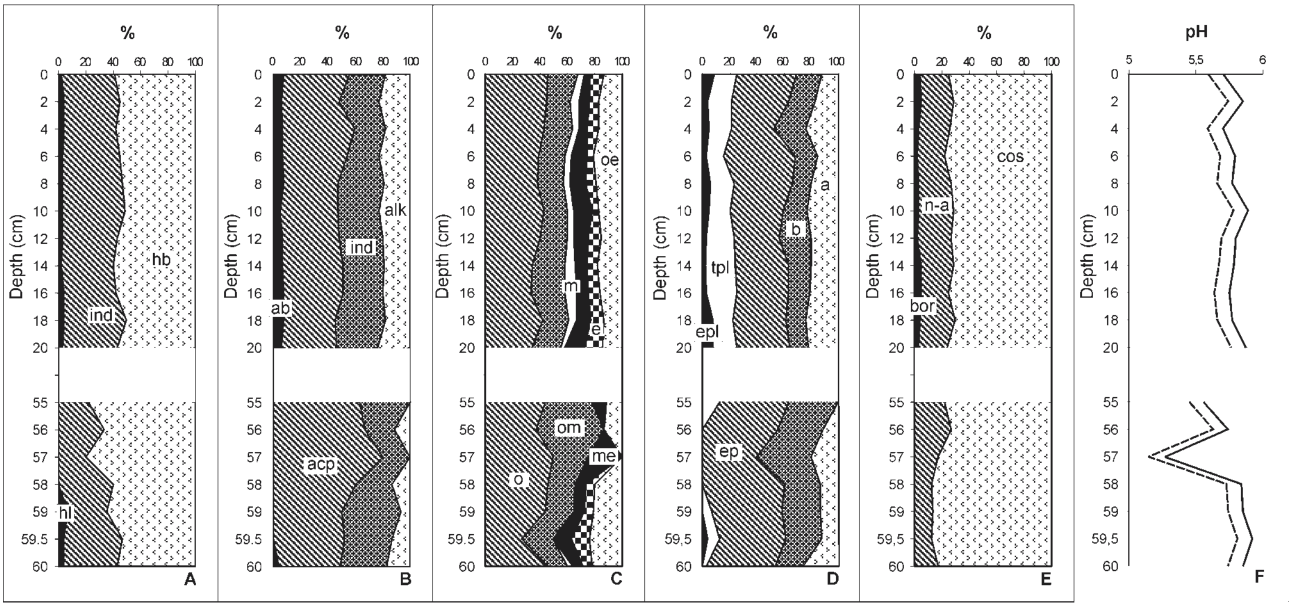

Fig. 9. Relative abundance of the diatom ecological groups and diatom-inferred pH values in the sediments of Shiligarka peat bog. *Legend:* **A.** Halobion diatom groups (hl — oligohalobous-halophilous, ind — oligohalobous-indifferent, hb — oligohalobous-halophobous); **B.** pH diatom groups (ab — acidobiontic, acp — acidophilous, ind — indifferent, alk — alkaliphilous); **C.** Trophic diatom groups (o — oligotrophic, om — oligo-mesotrophic, m — mesotrophic, me — meso-eutrophic, eu — eutrophic, oe — oligo- to eutrophic); **D.** "Habitat" diatom groups (epl — euplanktonic, tpl — tychoplanktonic, ep — epiphytic, b — benthic, a — aerophilous); **E.** Geographical distribution (bor — boreal, n-a — north-alpine, cos — cosmopolitan); **F.** Diatom-inferred pH values (- - index B (Flower 1986), — index B (Renberg & Hellberg 1982)).

mountain slopes, dominated by *Pinus* and *Betula*, which signalled an improvement of climatic conditions and development of soils (Filipovitch et al. 1998). The interval 9000–8000 BP witnessed one of the most dynamic processes in the vegetation cover formation of low-altitude mountains in Bulgaria (Tonkov & Bozilova 1995).

In the Middle Holocene (DAZ B), within the range of 7145 BP for Bogdan-3 and up to 5060 BP for Bogdan-6, diatom remnants in peat-bog sediments were scanty and poorly preserved. Straub (1993) explained analogical findings in lacustrine sediments by sedimentological discontinuities or changes in climatic conditions. Another possible explanation could be sought in average annual temperature rises in the 8000–7000 BP period (Tonkov & Bozilova 1995), which repeatedly caused the peat bogs to dry out, as well as in the greater access of oxygen to the peat and the latter's stepped-up humification. Poor preservation under acid condition seems to be related to oxidation of the sediments (Round 1964). The climate during the Late Atlantic (6000–5000 BP) was determined by the transport of air masses from the Atlantic Ocean eastwards far inside Eurasia more than in the preceding and subsequent periods (Tonkov & Bozilova 1995). This zone corresponded to PAZ SG 3a, which witnessed the development of mixed deciduous forests of *Ulmus, Tilia* and *Quercus.* The wide distribution of *Ulmus* and *Tilia* and considerably poorer participation of *Quercus* promted the assumption of a stronger expressed mesophilic character of these woods (Filipovitch et al. 1998).

Shiligarka peat bog emerged about 5285±180 BP (DAZ C1) as a result of intensive seepage of underground waters. The water in the peat bog had low salinity and nutrient content. The pH of the water showed distinct decrease from its maximum value of 5.92 (at 52 cm) to the lowest value in the entire history of the peat bog development of 5.28 (at 57 cm). This resulted in another change on the same depth level: reduction and disappearance of the eutrophic and oligo- to eutrophic taxa. The initially higher mineral content of water in the peat bog has gradually decreased. This corresponded well to the fact that *Eunotia soleirolii* developed intensively only at the beginning of this level. Contrary to other representatives of the genus identified in the sediments, that species was indifferent with respect to pH. This invites the assumption that initially there were totally water-covered patches in the peat bog, with open water surfaces, where the euplanktonic species *Aulacoseira granulata* and *A. subarctica* used to develop, as well as the tychoplanktonic species *Melosira varians, Fragilaria capucina* and *F. virescens.* In the high-altitude mountains of Southwest Bulgaria, Rila and Pririn, Tonkov & Bozilova (1995) found out that after 5500 BP peat had increased in area and accumulation in the fontinal peat bogs.

The same, but less pronounced trends have been observed in the sediments from Bogdan-3 and Bogdan-6 sites. In addition to *Aulacoseira granulata,* another euplanktonic species — *Aulacoseira islandica* — developed characteristically in the sediments of Bogdan-6 peat bog. Generally for DAZ C1, Shiligarka and Bogdan-3 marked the peak development of the north-alpine acidophilous species, *Pinnularia lata.* Towards the end of this subzone the peat bogs once again gradually dried out. This phenomenon was much more strongly developed in Bogdan-3 and milder for Bogdan-6.

Sediments from the three peat bogs of DAZ C2 showed few diatom species and of low abundance. Chrysophycean stomatocysts occurred abundantly and maintained a relative index of 85–99 % as compared to diatoms. A certain analogy with DAZ B could be seen, but DAZ C2 did not dry out as strongly and the siliceous microfossils were generally better preserved.

The latest stages of the investigated peat bogs are characterized by a specific diatom assemblage, typical of the peat bogs. It was rich in various species of high abundance, inhabiting nutrient-poor waters with increased content of humic substances and low active pH. Battarbee et al. (1999) pointed out that such waters inhabited by diverse diatom flora are often unproductive. The specific hydrological conditions in the peat bogs were the reason for the diatom algae to thrive, owing to which the latter considerably exceeded in percentage share the chrysophycean stomatocysts.

The latest changes in vegetation (PAZ SG 4) were characterized by the development of beech as the main tree species on the mountain slopes, related to a slight drop in temperatures (Filipovitch 1996; Filipovitch et al. 1998). About 4500–4000 cal. BP, beech began to play an important part in the forest cover of all Bulgarian mountains (Bozilova & Tonkov 2000). According to Huntley et al. (1989), climatic changes were determinant for the distribution of *Fagus* in Europe and North America. Palynological data has shown a rise in humidity between 4000 and 2000 BP, which led to formation of many peat bogs in the Sredna Gora Mts (Filipovitch 1996). A combination of higher humidity and lower temperatures had a favourable effect on diatom flora in the three mountain peat bogs, which then reached its maximum species diversity. Shiligarka peat bog offered the most favourable conditions for the development of a rich diatom flora, followed by Bogdan-6. This related to the higher water level in these peat bogs and patches of open surface water in them. The favourable hydrological regime of the Shiligarka peat bog was due to ample inflow of fontinal waters and its situation in a concave relief. This created conditions for *Aulacoseira alpigena* (Grun.) Krammer (Figs. 5.1,2) to reach considerable numbers only in that peat bog. This species develops in waters with pH 6.2–6.7 and, apart from plankton habitats, it could occur in benthic communities (Haworth 1988). Both peat bogs are located in close proximity to the forest border. In comparison, Bogdan-3 site had a lower water level, with a lower active water reaction and was poorer in biogenic elements. These local conditions in the latter peat bog were unfavourable to diatoms, which maintained low diversity there. Shortage of water in Bogdan-3 peat bog was most probably due to the fact that it was considerably distanced from the forest as a result of anthropogenic impact in the last 2000 years in the investigated region (Filipovitch et al. 1998).

Conclusion

Analysis of the fossil diatom community identified in the sediments of the three investigated mountain peat bogs enable us to distinguish four diatom assemblage zones. A pioneer diatom flora emerged about 8000 BP. The peat bogs dried up in the Middle Holocene. About 5000 BP, humidity increased. A diatom assemblage formed, limited once again by another, slighter drought. At the end of the Holocene temperatures dropped slightly, a richer and more diverse diatom flora emerged in the sphagnum peat bogs. Their water level remained inconstant and sensitive to climatic changes. Water salinity in the peat bogs varied from 0.01 to 0.3 g/l and their active water reaction was between 5.2–5.9. The water was poor in biogenic substances and mild to low in temperature.

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Appendix

Taxonomical composition of the diatom flora from the invesigated peat-bog sediments and ecological spectra of the diatoms. Legend: **B-3** — core Bogdan-3; **B-6** — core Bogdan-6; **Shil** — core Shiligarka; **1.** Halobion diatom groups (hl — oligohalobous-halophilous, ind — oligohalobous-indifferent, hb — oligohalobous-halophobous); **2.** pH diatom groups (ab — acidobiontic, acp — acidophilous, ind — indifferent, alk — alkaliphilous); **3.** Trophic diatom groups (o — oligotrophic, om — oligo-mesotrophic, m — mesotrophic, me — meso-eutrophic, eu — eutrophic, oe — oligo- to eutrophic); **4.** "Habitat" diatom groups (epl — euplanktonic, tpl — tychoplanktonic, ep — epiphytic, b — benthic, a — aerophilous); **5.** Geographical distribution (bor — boreal, n-a — north-alpine, cos — cosmopolitan).

TAXONOMICAL LIST	**ECOLOGICAL SPECTRA**					**CORES**		
	1	**2**	**3**	**4**	**5**	**B-3**	**B-6**	**Shil**
Achnanthes *biasolettiana* Grunow, 1880	ind	alk	m	ep	bor			+
A. lanceolata (Bréb.) Grunow, 1880	ind	alk	eu	ep	cos		+	+
A. minutissima Kützing, 1833	ind	alk	oe	ep	cos		+	+
A. nodosa Cleve, 1900			o		n-a			+
A. petersenii Hustedt, 1937	ind	ind	o	ep	n-a			+
Aulacoseira *alpigena* (Grun.) Krammer, 1990	hb	acp	o	tpl	n-a	+	+	+
A. ambigua (Grun.) Simonsen, 1979	ind	ind	eu	epl	cos			+
A. distans (Ehr.) Simonsen, 1979	hb	acp	o	tpl	n-a			+
A. distans var. *nivalis* (W. Sm.) Haworth, 1988	hb	acp	o	tpl	n-a			+
A. granulata (Ehr.) Simonsen, 1979	ind	alk	eu	epl	cos	+	+	+
A. granulata var. *angustissima* (O. Müller) Simonsen, 1979	ind	alk	eu	epl	cos	+	+	+
A. islandica (O. Müller) Simonsen, 1979	ind	alk	oe	epl	n-a		+	+
A. laevissima(Grun.) Krammer, 1990								+
A. muzzanensis (Mest.) Krammer, 1991	ind	alk	eu	epl	cos			+
A. pfaffiana (Reinsch) Krammer, 1990	hb	acp	o	tpl	cos			+
A. subarctica (O. Müller) Haworth, 1988	hb	acp	om	epl	n-a		+	+
A. tenuior (Grun.) Krammer, 1990						+		
Brachysira *brebissonii* Ross, 1986	hb	acp	o	b	cos			+
Caloneis *bacillum* (Grun.) Cleve, 1894	ind	alk	me	b	cos			+
C. lauta Carter & Bailey-Watts, 1981	hb		o		n-a		+	+
C. silicula (Ehr.) Cleve, 1894	ind	alk	me	b	cos		+	
C. tenuis (Greg.) Krammer, 1985	ind	ind	m	a	cos			+
Cocconeis *placentula* var. *euglypta* (Ehr.) Grunow, 1884	ind	alk	eu	ep	cos		+	+
Cyclotella *meneghiniana* Kützing, 1844	ind	alk	eu	tpl	cos		+	+
Cymbella *elginensis* Krammer, 1981			o	ep	n-a		+	+
C. gracilis (Ehr.) Kützing, 1844	hb	acp	om	ep	n-a	+	+	+
C. helvetica Kützing, 1844	ind	alk	m	epl	bor			+
C. mesiana Cholnoky, 1955	ind	alk		ep	cos			+
C. minuta Hilse, 1862	ind	ind		ep	cos		+	+
C. norvegica var. *lapponica* Cleve-Euler, 1951	ind	ind	o		n-a			+
C. perpusilla Cleve, 1895	hb	acp	o	a	cos	+	+	+
C. silesiaca Bleisch, 1864	ind	ind	oe	ep	cos		+	+
Cymbella sp.								+
Diatoma *anceps* (Ehr.) Kirchner, 1878	hb	alk	oe	tpl	n-a			+
D. mesodon (Ehr.) Kützing, 1844	hb	alk	m	tpl	n-a			+
Diploneis *ovalis* (Hilse) Cleve, 1891	ind	alk		a	cos	+	+	
Epithemia *adnata* (Kütz.) Brébisson, 1838	ind	alk	me	ep	cos	+	+	+
Eunotia *arculus* (Grun.) L.-B. et Nörpel, 1991	hb	acp	om		bor			+
E. exigua (Bréb.) Rabenhorst, 1864	hb	ab	oe	a	cos			+
E. fallax Cleve, 1895	hb	acp	o	ep	cos			+
E. fallax var. *groenlandica* (Grun.) L.-B. et Nörpel, 1991	hb	acp	o	a	cos			+
E. flexuosa (Bréb.) Kützing, 1849	hb	acp	om	ep			+	+
E. glacialis Meister, 1912	hb	acp	om	ep	cos	+	+	+
E. incisa Gregory, 1854	hb	acp	o	ep	n-a	+	+	+
E. meisteri Hustedt, 1930	hb	acp	o	a	cos			+
E. minor (Kütz.) Grunow, 1881	hb	acp	om	a	cos	+	+	+
E. monodon Ehrenberg, 1843	hb	acp	o	ep	cos	+	+	+
E. naegelii Migula, 1907	hb	acp	o	ep	cos		+	+
E. nymanniana Grunow, 1881	hb	acp	o		n-a			+
E. paludosa Grunow, 1862	hb	ab	o	a	cos	+	+	+
E. praerupta Ehrenberg, 1843	hb	acp	o	ep	cos	+		+
E. praerupta var. *bidens* Grunow, 1880	hb	acp	o	ep	cos			+
E. serra var. *tetraodon* (Ehr.) Nörpel, 1991	hb	acp	o	ep	n-a	+	+	+
E. soleirolii (Kütz.) Rabenhorst, 1864	hb	ind	o	ep	cos			+
E. steineckei Petersen, 1950	hb		o			+	+	+
E. sudetica O. Müller, 1898	hb	acp	om	ep	cos			+
E. tenella (Grun.) Hustedt, 1913	hb	acp	o	ep	cos			+
Eunotia sp.						+		
Fragilaria *brevistriata* Grunow, 1885	ind	alk	oe	tpl	cos			+
F. capucina var. *rumpens* (Kütz.) L.-B., 1991	ind	ind	om	ep	cos			+
F. construens f. *subsalina* (Hust.) Hustedt, 1957	hl	alk	me	tpl	cos			+
F. construens f. *venter* (Ehr.) Hustedt, 1957	ind	alk	me	tpl	cos	+	+	+
F. pinnata Ehrenberg, 1843	ind	alk	oe	tpl	cos			+
F. ulna (Nitzsch) L.-B., 1980	ind	alk	oe	ep	cos	+	+	
F. virescens Ralfs, 1843	hb	ind	om	tpl	cos	+	+	+
Frustulia *rhomboides* var. *crassinervia* (Bréb.) Ross, 1947	hb	acp	o	b	n-a			+
Gomphonema *angustatum* (Kütz.) Rabenhorst, 1864	ind	alk	eu	ep	bor		+	+
G. clavatum Ehrenberg, 1832	ind	ind	me	ep	cos	+	+	+
G. gracile Ehrenberg, 1838	ind	ind	m	ep	cos	+	+	+
G. parvulum (Kütz.) Kützing, 1849	ind	ind	me	ep	cos			+
Hantzschia *amphioxys* (Ehr.) Grunow, 1880	ind	ind	oe	a	cos	+	+	+
Luticola *cohnii* (Hilse) D.G. Mann, 1990	ind	ind	eu	b	cos		+	
L. goeppertiana (Bleisch) D.G. Mann, 1990	ind	ind	eu	a	cos		+	
L. mutica (Kütz.) D.G. Mann, 1990	hl	ind	eu	a	cos		+	+
Melosira *varians* Agardh, 1827	ind	alk	eu	tpl	cos			+
Meridion *circulare* var. *constrictum* (Ralfs) Van Heurck, 1880	ind	alk	oe	ep	cos	+	+	+
Navicula *cocconeiformis* Gregory ex Greville, 1856	hb	ind	om	b	n-a			+
N. contenta Grunow, 1885	ind	ind	oe	a	cos			+
N. difficillima Hustedt, 1950	hb	acp	om	b				+
N. elginensis (Greg.) Ralfs, 1861	ind	alk	eu	b	cos		+	
N. elginensis var. *cuneata* (Møll. ex Foged) L.-B., 1985	ind	alk	eu	b	cos	+	+	+
N. hambergii Hustedt, 1924		acp		a	cos		+	
N. lenzii Hustedt, 1936	ind	alk						+
N. radiosa Kützing, 1844	ind	ind	me	ep	cos	+	+	
N. soehrensis Krasske, 1923	hb	acp	o	a	cos		+	
N. subtilissima Cleve, 1891	hb	ab	o	b	bor		+	+
Navicula sp. 1							+	
Navicula sp. 2						+		
Neidium *ampliatum* (Ehr.) Krammer, 1985	ind	ind	om	b	bor			+
N. bisulcatum (Lagerst.) Cleve, 1894	ind	ind	o	b	n-a		+	+
N. iridis (Ehr.) Cleve, 1894	hb	ind	m	b	cos			+
Nitzschia *amphibia* Grunow, 1862	ind	alk	eu	epl	cos			+
N. hantzschiana Rabenhorst, 1860	hb	ind	m	a	bor		+	
N. paleaceae (Grun.) Grunow, 1881	ind	alk	eu	ep	cos			+
N. perminuta (Grun.) M. Peragallo, 1903	ind	alk	om	ep	cos	+	+	+
N. terrestris (Pet.) Hustedt, 1934	ind	ind		a			+	
Nitzschia sp.							+	
Orthoseira *roeseana* (Rab.) O'Meara, 1875	ind	alk		b	cos		+	
Pinnularia *acrosphaeria* Rabenhorst, 1853	hb	ind	om	b	cos		+	
P. appendiculata (Ag.) Cleve, 1895	hb	acp	om	a	n-a	+	+	+
P. borealis Ehrenberg, 1843	ind	ind	om	a	cos	+	+	+
P. borealis var. *rectangularis* Carlson, 1913	ind	ind			cos	+	+	+
P. borealis var. *undulata* Hustedt, 1934					n-a	+	+	+
P. brevicostata Cleve, 1891	hb	acp	o	b	bor		+	+
P. gibba Ehrenberg, 1841	ind	acp	oe	b	cos		+	+
P. gibba var. *linearis* Hustedt, 1930	hb	acp	oe	b	cos			+
P. hemiptera (Kütz.) Rabenhorst, 1853	ind	ind	o	b	n-a			+
P. interrupta W. Smith, 1853	hb	ind	om	b	bor		+	
P. lapponica Hustedt, 1942								+
P. lata (Bréb.) Rabenhorst, 1853	hb	acp	o	b	n-a	+	+	+
P. macilenta (Ehr.) Ehrenberg, 1843	ind				cos	+	+	+
P. maior (Kütz.) Rabenhorst, 1853	ind	acp	me	b	cos	+	+	
P. microstauron (Ehr.) Cleve, 1891	ind	acp	oe	b	cos	+	+	+
P. obscura Krasske, 1932	ind	ind	o	a	n-a		+	+
P. pulchra Østrup, 1897	hb	ind	o	b	bor			+
P. rupestris Hantzsch, 1861	hb	ind	o	a	n-a	+	+	
P. stomatophora (Grun.) Cleve, 1895	hb	acp	o	a	cos		+	+
P. streptoraphe Cleve, 1891	hb	acp	om	b	cos		+	+
P. streptoraphe var. *minor* (Cl.) Cleve, 1895	hb	acp	o	b	cos			+
P. subcapitata Gregory, 1856	ind	acp	om	b	cos			+
P. subcapitata var. *hilseana* (Janisch) O. Müller, 1898	hb	ab	o	b	cos	+	+	+
P. viridis (Nitz.) Ehrenberg, 1843	ind	ind	oe	b	cos	+	+	+
Pinnularia sp. 1							+	+
Pinnularia sp. 2							+	
Sellaphora *laevissima* (Kütz.) D.G. Mann, 1989	hb	ind	m	b	cos			+
Stauroneis *anceps* Ehrenberg, 1843	ind	ind	me	b	cos		+	+
S. phoenicenteron (Nitz.) Ehrenberg, 1843	ind	ind	me	b	cos		+	+
Stephanodiscus *medius* Håkansson, 1986		alk	eu					+
S. minutulus (Kütz.) Cleve et Möller, 1878	ind	alk	eu	epl	cos		+	+
Stephanodiscus sp.						+	+	
Stenopterobia *delicatissima* (Hust.) Krammer, 1987	hb	acp	o		cos		+	
Tabellaria *flocculosa* (Roth) Kützing 1844	hb	acp	m	tpl	cos	+		+