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Diatom-based evidence for abrupt climate changes during the Late Glacial in the Southern Carpathian Mountains

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A high-resolution paleolimnological record from Lake Brazi (TDB-1; 45°23'47"N, 22°54'06"E, 1740 m a.s.l.), a small, glacial lake in the Retezat (South Carpathian Mountains, Romania) provides a sensitive record of the impacts of late glacial climatic change on siliceous algal assemblages. The sequence, ranging from 15,700 cal yr BP to 9500 cal yr BP, suggests that the most significant changes in diatom assemblages took place at 12,800 and 10,400 cal yr BP, when alkaliphilous fragilarioid taxa were replaced by acidophilous diatoms. Altogether eight zones were distinguished with sharp and rapid changes of diatom assemblages. The paper discusses the application of siliceous algae in multi-proxy paleolimnological analyses, demonstrates the advantages and disadvantages of this proxy and presents the story of floristic discovery of unique diatom assemblages, the closest recent analogs of which are found in the arctic region.

Key words: diatoms, glacial lakes, oligotrophy, Retezat Mountains, paleolimnology

Introduction

Recent concern over the effects of climate change has focused scientific and public attention on sensitive paleoenvironmental records worldwide, including extreme environments, such as the High Arctic and Antarctica, as well as pristine,

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remote alpine regions (Pienitz et al. 1995; Stoermer and Smol 1999; Schmidt et al. 2004, 2006; Antoniades et al. 2008). Cold, sparsely inhabited regions provide favorable conditions for cryptogams and small-sized animals, but these groups are rarely the objectives of taxonomical studies, while for instance vascular plants are much better studied. Nevertheless, resistant body parts of algae, mosses, macro-invertebrates and sponges are preserved in lake sediments (so-called biotic proxies), providing excellent possibilities for better understanding the functioning of natural systems, as well as being useful for making environmental reconstructions (Smol 2008). Their remnants in lake sediments open a time window for short (a couple of years, decades or hundreds of years) or long-term (thousand to million years) histories of lake ecosystems. The rich biotic evidence preserved in lake sediments of remote alpine lakes plays a distinguished role in the reconstruction of past ecosystem reactions including abrupt climate changes (Lotter et al. 1997, 1998; Schmidt et al. 2004, 2006).

The quality of reconstruction increases with the number of proxies applied. Each proxy reflects environmental change at its own scale and has advantages and disadvantages (Lotter 2003). Siliceous algae (diatoms and crysophycean statospores) are one of the most often studied biotic proxies. Scientists agree and emphasize that, although many inference models have recently been developed for fine paleoenvironmental reconstructions (so-called transfer functions), only little attention has been paid to the quality of the primary data on which the reconstructions are based (Mackay et al. 2005; Antoniades et al. 2008; Ryves et al. 2009).

In this paper we introduce the reader to the advantages and disadvantages of diatom-based reconstructions, to show the difficulties and uncertainties but also the beauties of diatoms in the example of a glacial lake in the Retezat Mts. We present our attempts, carried out since 2007, to build the best database for paleoenvironmental reconstruction. Our work can be regarded as if we were zooming in on a subject. While moving from a low-resolution analysis to a high-resolution analysis, we refined the amplitude and spanning of changes along the time scale and then improved our knowledge of mountain diatom taxa, permitting a more precise reconstruction.

Diatom analyses of the sediments of Lake Brazi

In order to become familiar with the diatom flora of Lake Brazi, a low-resolution study of the diatom samples was carried out in 2008 (at 8–12 cm resolution, representing 500 to 1000-year steps) and detailed photo documentation was made. It became rapidly clear that some small-celled taxa were present in the sediments which are very similar under the light microscope (LM). Our first impression was that there is a sharp difference between the Late Glacial and Holocene sequences, the first one being dominated by fragilaroid taxa and the second one by the *Aulacoseira* species. This recognition was followed by some work to clear up the taxonomic diversity of this dominant group (Buczkó et al. 2010).

The second part of the analysis of Lake Brazi took place in the fall and winter of 2008 and the beginning of 2009, when species-level identifications were made every 4–8 cm (representing a time resolution of 300–600 years). During the counting procedure it was realized that LM is insufficient for correct identifications at species level, so groupings were made on generic level during the first analysis. Three zones were differentiated with 2–5 sub-zones on the basis of the generic level diatom analyses. The most characteristic changes were found at ca. 10,150 and 5800 cal yr BP. Below 588 cm (14,266 cal yr BP) no diatoms were found (Buczkó et al. 2009). Our results were in agreement with the traditionally accepted view, as the Holocene (encompassing the last 11,500 years) is a stable period in terms of climatic conditions, especially when compared with the abrupt climate changes of the Late Glacial period. Further division into sub-zones resulted in additional zone boundaries at ca. 12,350, 10,800 and 9,800 cal yr BP.

This finding highlighted the need for high-resolution analysis in the Late Glacial and Early Holocene parts of the section (approximately between 15,755 – 9500 cal yr BP). As a third step therefore, every centimeter was sampled, and counted using LM as well as SEM (in this way we obtained a record from every 16 to 104 years). By the end of 2009 it became clear that several insufficiently described or new species are in the section. The material published in this study was made on the basis of species-level identifications. It must, however, be emphasized that we are far from completing the diatom study of Lake Brazi. Taking into account the results of other proxies (chironomids, cladoceran remains) that inferred lake stage even before 14,510 cal yr BP (588 cm), we very carefully scanned the deepest layers searching for siliceous remains. After days-long scanning of the slides some remains were actually found. In this paper we present the results of high-resolution analysis from the Late Glacial part of the cored section.

Material and Methods

Study site

The Retezat is the wettest massif in the Romanian Carpathians, due to Mediterranean and oceanic influences. As a result the effects of the last glaciations have been more significant here than elsewhere in the South Carpathians. Numerous glacial lakes were formed as a result of the retreat of the ice in the subalpine and alpine belts, mainly during the Late Glacial (Reuther et al. 2007). Diatom assemblages from these lakes and their sediments were first studied by Péterfi (1974). Recently diatoms of pre-industrial times and the present day were compared in order to show biological and limnological changes within five lakes of the district (Clarke et al. 2005). More information on the studied lakes and the aim of the PROLONGE (Providing long environmental records of Late Quaternary climatic oscillations in the Retezat Mountains) project can be found in Magyari et al. (this issue).

Methods

A 490-cm long sediment core was taken in 2007 with a Livingston piston corer from the deepest part of the shallow lake (1 meter average water depth). Water depth at the coring point was 110 cm; the base of the core is thus at 600 cm below lake surface level. Sampling and boundary depths hereafter are given in depths below the surface of the lake, not from the top of the sedimentary column. For sub-sampling, the plastic tubes containing the sediment were cut into halves and sub-samples were taken at 1–4 cm intervals for multi-proxy analyses, including pollen, macrofossils, cladocera, chironomid, geochemical properties and siliceous algae (Magyari et al., this issue). For analyses of siliceous algae, samples were prepared using standard digestion procedures (Batterbee 1986). Aliquot-evaporated suspensions were embedded in Zrax (refractive index 1.7). At least 300 valves were counted in 87 samples using a light microscope (LEICA DM LB2 with 100 HCX PLAN APO). Diatom stratigraphies were zoned using CONISS as implemented in the Psimpoll 3.00 software (Bennett 2005). To confirm the validity of the quantitative zonation by CONISS, diatom zones were also delimited using binary splitting by sums-of-squares. The two methods gave very similar result; therefore the CONISS zones were kept.

Loss-on-ignition (LOI) analysis was used to determine the organic content of the sediment. It was carried out on 1 cm^3 samples at 550 °C following the recommendations of Heiri et al. (2001). LOI was measured at 1 cm intervals.

Biogenic silica was extracted from a 20 mg homogenized dry sample using 10 cm^3 0.2 mol dm^{-3} sodium hydroxide at 90 °C for 2 hours. Measurement of silica and aluminum were made by ICP-OES. Dissolution of minerogenic silicates was negligible; thus alumina correction was not applied. Biogenic silica was expressed as percentage of dry weight.

Results

More than 150 taxa were distinguished in 87 samples that were suitable for quantitative analysis. Several taxonomical questions remained open and require a more detailed study. Consequently the number of taxa may either increase or decrease in the future. Many similar, small-celled species were found in the Late Glacial part of the core. The most characteristic diatoms are presented in Plates 1–4, in the sequence of diatom assemblage zones.

Late Glacial diatom assemblage zones of Lake Brazi

Eight zones were differentiated on the basis of the 31 most abundant taxa (Fig. 1). The most significant diatom assemblage changes were found at ca. 10,400 and 12,800 cal yr BP.

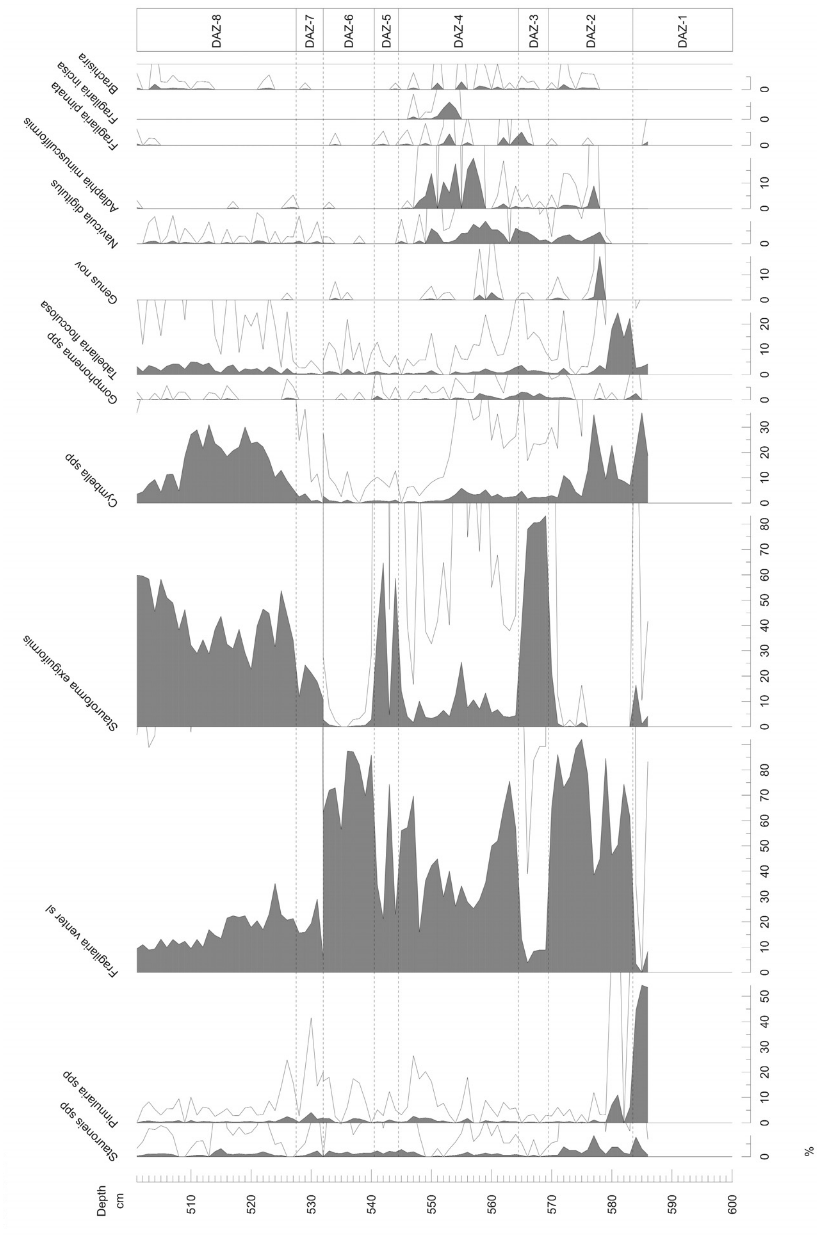


Fig. 1
Relative frequency diagram of the most important 31 diatom species/group in TDB-1, Lake Brazi. Diatom relative frequencies are expressed as percentage of total diatoms. DAZ: diatom assemblage zones. Lines without filling are exaggerated (× 10)

Diatom assemblage zone – DAZ-1
600–583.5 cm (15,755–14,067 cal yr BP) Plate 1 – Figs 1–24

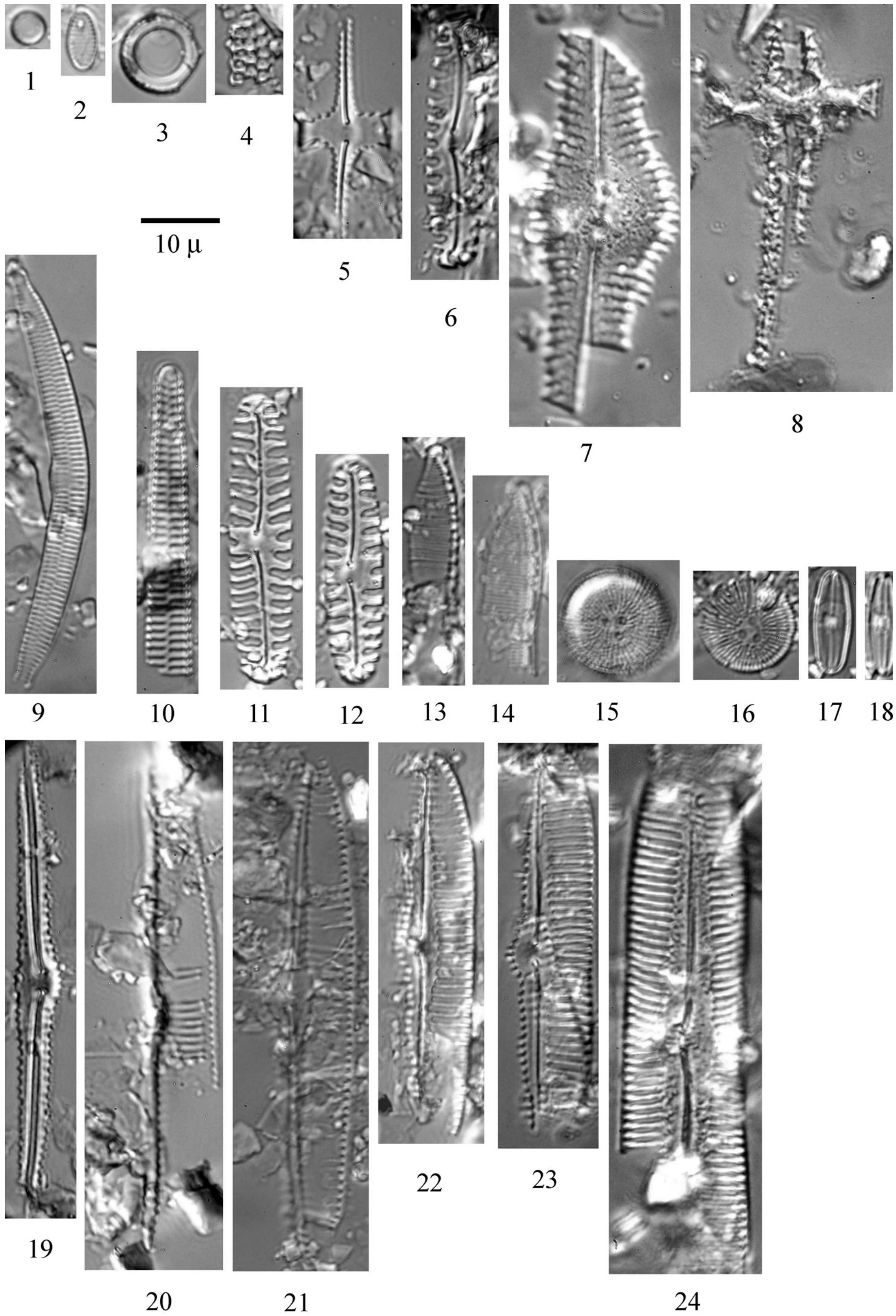
The first diatom assemblage zone can be divided into two significantly different sub-zones: in the first one, the occurrences of siliceous algae are sporadic (600–586.5 cm; ca. 15,755–14,364 cal yr BP), while in the second subzone (586.5–583.5 cm / 14,364–14,067 cal yr BP) more remains were found (Plate 1).

There were not enough valves in the deepest part of the core for statistical analysis, but with careful scanning some dissolved remains of siliceous algae were detected. Already the first samples bore some chrysophyceaen cysts, and fragmented, dissolved diatoms (Plate 1 – Figs 1–7). The preserved parts of the valves (so-called sternums; Plate 1 – Figs 5, 7, 8 and the inner ring of *Aulacosiera* taxa, the so-called ringleiste = Fig. 3) are the strongest and most resistant parts of the frustules where the expressed silicification was detected. These findings suggest that in this very early stage of the lake development several diatom taxa were already present. Not only small-celled species (< 10 μm), but also large, heavy diatom taxa inhabited barren surfaces on the lakeshore, and the open water of the glacial lake. *Pinnularia borealis* (Fig. 6) is known as an aerophytic species, but in Fig. 5 a *Stauroneis sternum* and in Fig. 7 central area of a cymbelloid species can also be recognized. These diatoms live in water and thus support lake conditions with at least a short partial ice-free period.

At 596 cm some lotic (taxa living in running water) forms were found (*Hannea arcus* (Ehr.) Patrick, Plate 1 – Fig. 10), indicative of flowing water. Small brooklets likely flowed into the lake. The diatom assemblages at 587 cm were rich in aerophytic taxa, e.g. *Pinnularia borealis* Ehr., *Hantzschia amphyoxis* (Ehr.) Grunow, *Orthoseira roseana* (Rabenhorst) O'Meara, *Diadesmis* sp. (Plate 1 – Figs 11–18). These diatoms live on bare stone surfaces, cliffs, and likely indicate a small water body that did not support a diverse aquatic diatom assemblage, but where several terrestrial species were washed into it. In Plate 1 (Figs 19–24) we present a photo series demonstrating the different phases of dissolution. In Fig 19, only the strongest, central part of the valves can be observed, while in Figs 20–21 the striation of *Pinnularia* species is also visible, but the edge of the valves (where the valves are thicker) is better recognizable. In this phase, the characteristic features of species are sufficient for species-level identification; the identity of *Pinnularia microstauron* s.l. is clear in Figs 22–23, and especially in Fig. 24.

Plate 1 →

Figures 1–24. Siliceous remains obtained from the DAZ-1 of Lake Brazi. Fig. 1. *Crysophyceaen statospora*, Fig. 2. *Staurosira veneta*, Fig. 3. *Aulacoseira* sp., Ringleiste, Fig. 4. probable *Aulacoseira* mantle view, Fig. 5. *Stauroneis sternum*, Fig. 6. *Pinnularia borealis*, Fig. 7. sternum of a cymbelloid species, Fig. 8. *Stauroneis sternum*, Fig. 9. *Hannea arcus*, Fig. 10. *Ulnaria ulna*, Figs 11–12. *Pinnularia borealis*. Figs 13–14. *Hantzschia amphyoxis*, Figs 15–16. *Orthoseira roseana*, Figs 17–18. *Diadesmis* sp. Figs 19–24. series of the corosion of *Pinnularia* species. Fig. 9. reofil indicator, prefers flowing water. Figs 11–18. aerophytic species. Figs 1–7. TDB-1 600 cm, Figs 8–10. TDB-1 596 cm, Figs 11–24. TDB-1 587 cm, Scale bar = 10 μm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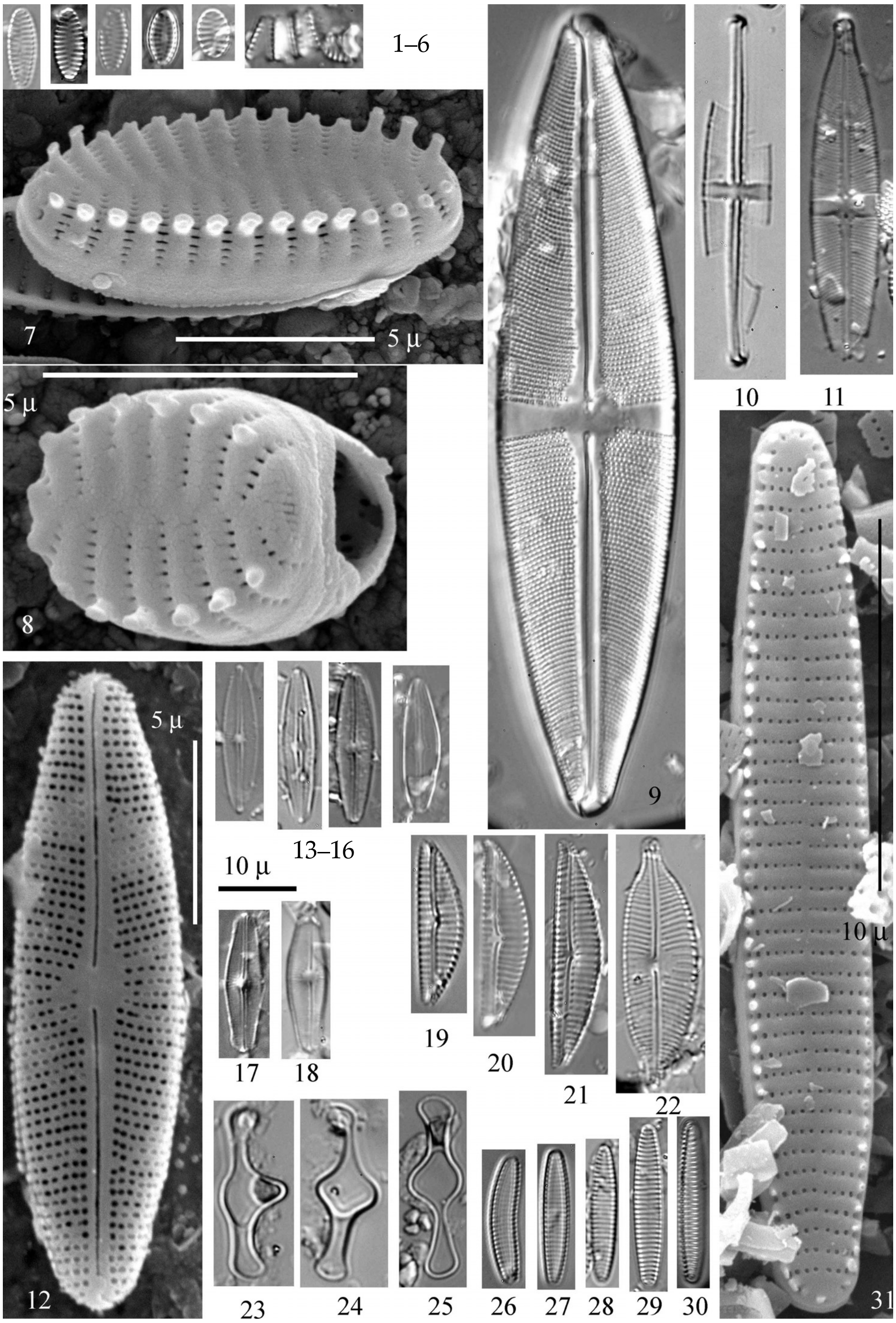
In the second sub-zone (586.5–583.5 cm / 14,364–14,067 cal yr BP) valves are more abundant and thus samples were suitable for counting. Nonetheless the high portion of sternum suggests poor preservation. Notable is the high abundance of *Encyonema* species [*E. silesiaca* (Bleisch) Mann (Plate 2 – Figs 19–21); *Cymbopleura amphicephala* Krammer (Plate 2 – Fig. 22)]. The relative frequency of chrysophyceaen cysts is also high in this zone, but they were probably found more often because of their resistant, round shape, and the easily identifiable resting spores. This siliceous algae assemblage suggests a permanent water body with increasing planktonic habitats and poor nutrient availability.

Diatom assemblage zone – DAZ-2
583.5–569.5 cm (14,067–12,781 cal yr BP) Plate 2 – Figs 1–25

From 14,067 cal yr BP the diatom record indicates the dominance of small, fragilaroid taxa. The most abundant species in this zone is a small-celled, more or less elliptical form, *Staurosira venter* s.l. (Ehr.) Cleve and Moeller (Plate 2 – Figs 1–8). It is one of the most often reported species that can colonize newly-formed lakes. It can form chains that lead to the multiplication of its size. Cymbelloid species are also well represented in the diatom vegetation. The most abundant representative of this group is *Encyonema silesiaca*, but *Cymbopleura amphicephala* is also a constant member of the assemblage. Both species have a pH optimum around 8 (Antoniades et al. 2008) suggesting alkali-rich water conditions. Several Stauroneis taxa (Plate 2 – Figs 9–11) contribute to the diverse flora of DAZ-2. A small but characteristic relative frequency peak was detected at ca. 13,500 cal yr BP, when a peculiar, small, asymmetric diatom was recognized with a special raphe pattern (Fig. 12, bottom). It seems that this form has not been found elsewhere, and thus requires detailed taxonomical study, which could result in a new genus for science (Plate 2 – Figs 12–18). High abundance of *Tabellaria flocculosa* (Roth) Kütz. is also characteristic for this zone. The diatom assemblage in this and the previous zone represents the Bølling/Allerød interstadial (GI-1) that commenced ca. 14,500 cal yr BP (Björck et al. 1998). The diatom assemblages suggest that true aquatic conditions were only developed since ca. 14,100 cal yr BP in Lake Brazi, when the increasing dominance of *Staurosira venter* s.l. indicates benthic diatom abundance and silty lake bottom substrate. Cymbelloid taxa furthermore suggest the presence of thelmatophytes or mosses either on the

Plate 2 →
Figures 1–31. Diatoms from the DAZ-2 (Figs 1–25) and DAZ-3 (Figs 26–31) of Lake Brazi. Figs 1–8. *Staurosira venter* s.l. (Ehrenberg) Cleve and Moeller 1881. Figs 9–11. *Stauronei*s spp. Figs 12–18. Unknown diatom, probably new to science referred to as *Genus* sp. in Fig. 1. Figs 19–21. *Encyonema silesiaca,* Fig. 22. *Cymbopleura amphicephala,* Figs 23–25. terratological forms of *Tabellaria flocculosa,* Figs 26–31. S*tauroforma exiguiformis.* Scale bar = 10 μm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lakeshore or in the water. Note however that macrofossils of aquatic plants and lakeshore mosses were not found in the sediment (Magyari et al., in prep).

The end of DAZ-2 (cc. 12,781 cal yr BP) is very near to the climatic event around 12,800 cal yr BP, known as the Younger Dryas climatic reversal (GS-1; Björck et al. 1998).

Diatom assemblage zone – DAZ-3
569.5–564.5 cm (12,781–12,331 cal yr BP) Plate 2 – Figs 26–31

This zone is characterized by the dominance of *Stauroforma exiguiformis* (Lange-Bertalot) Flower (Plate 2 – Figs 26–31), *Staurosira venter*, and *Navicula digituloides* Lange-Bertalot. Cymbelloid taxa were also found, but their relative frequencies are low. Organic matter and biogenic silica content is slightly lower in this phase, and these proxies altogether suggest decreasing in-lake productivity.

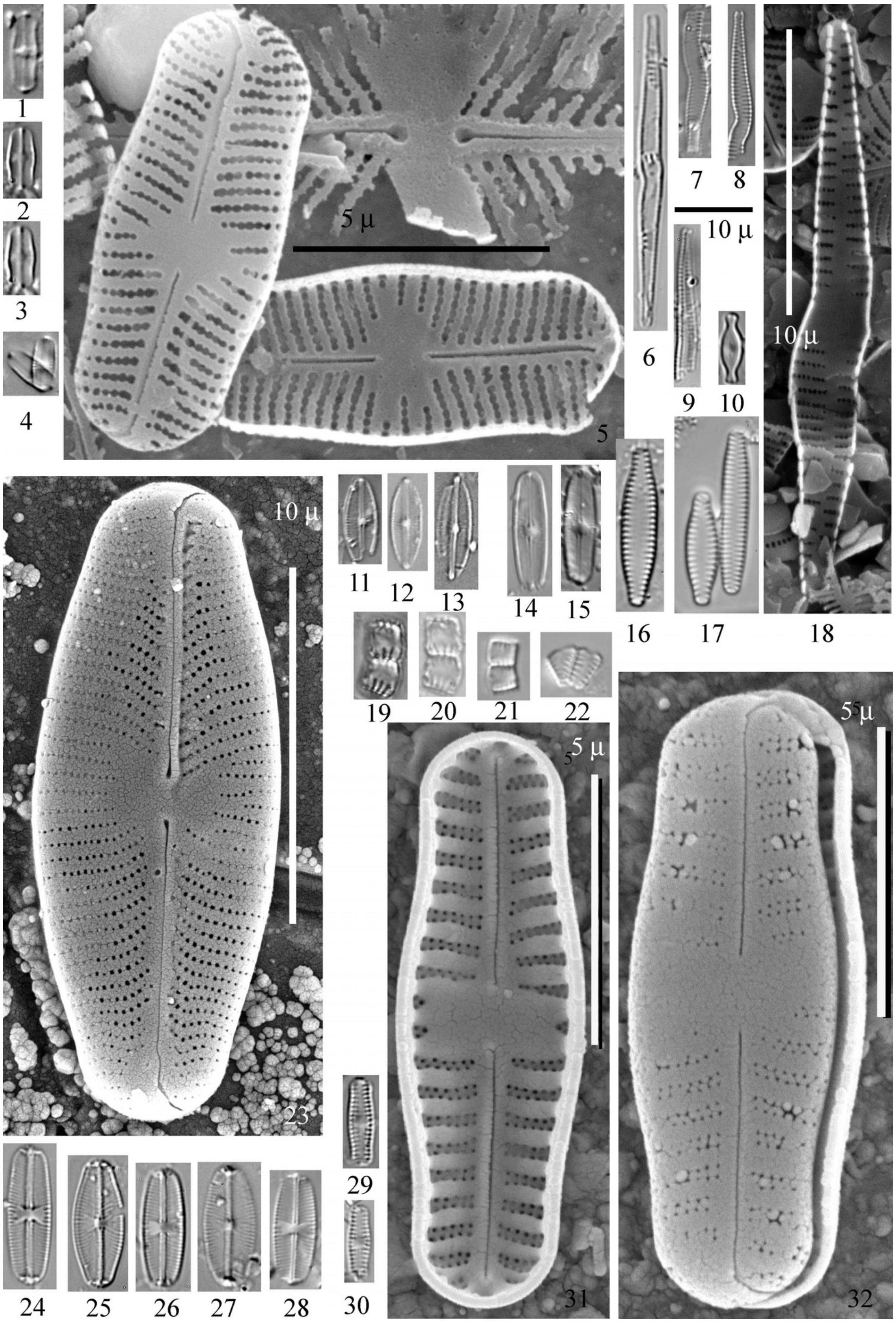
Diatom assemblage zone – DAZ-4
564.5–544.5 cm (12,331–11,052 cal yr BP) Plate 3 – Figs 1–32

This zone is characterized by a diverse diatom flora with several small forms. The small-celled forms caused difficulties during the counting procedure, since the size-uniformity hides an extremely rich taxonomical diversity. Most of the dominant taxa presented on Plate 3 are <10 μm, while the diatom valves >20 μm can be regarded as exceptions. The abundant taxa were: *Adlaphia minuscula* (Grunow) Lange-Bertalot, *Navicula digituloides* (Plate 3 – Figs 14–15), *Navicula elorantana* Lange-Bertalot (Plate 3 – Figs 29–32), *Navicula schmassmannii* Hustedt, *Sellaphora* spp. (Plate 3 – Figs 1–5, 23–28), *Pseudostaurosira* cf. *brevistriata* (Grunow in Van Heurck) D.M. Williams et Round (Plate 3 – Figs 19–22), small-round fragilaroid species (Plate 3 – Figs 19–22), *Navicula* cf. *notha* Wallace, *Brachysira* sp. Noteworthy is the unusual shape of *Fragilaria incisa* (C.S. Boyer) Lange-Bertalot (Plate 3 – Figs 6–9, 18) that at first sight can be regarded as a teratological form of *Fragilaria capucina* Desm. It is known from acidic waters.

Diatom assemblage zone – DAZ-5
544.5–540.5 cm (11,052–10,901 cal yr BP)

Zone 5 is characterized by the recurring dominance of the slightly acidophilous *Stauroforma exiguiformis* (Plate 2 – Figs 26–31) that outgrew other diatoms for five

Plate 3 →
Figures 1–32. Main diatom species of DAZ-4 of Lake Brazi. Figs 1–5. *Sellaphora* sp. (planned to be published as *S. rosenstockiiformis* nova sp.), Figs 6–9, 18. *Fragilaria incisa*, Fig. 10. *Navicula schmassmannii,* Figs 11–13. *Adlafia minuscula,* Figs 14–15. *Navicula digituloides*, Figs 16, 17. *Pseudostaurosira* cf. *brevistriata*, Figs 19–22. "Fragilaria round" indet, small fragilaroid taxa, Figs 23–28. *Sellaphora pupula* group, Figs 29–32. *Navicula(dicta) elorantana.* Scale bar = 10 μm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centuries. The dominance of *S. exiguiformis* coincides with a slight increase in biogenic silica content and suggests that lake productivity increased from ca. 11,050 cal yr BP, as is also indicated by the increase of green algae (*Botryococcus*, *Pediastrum boryanum* (Turpin) Meneghini, *P. integrum* Nägeli, *P. alternans* Nygaard).

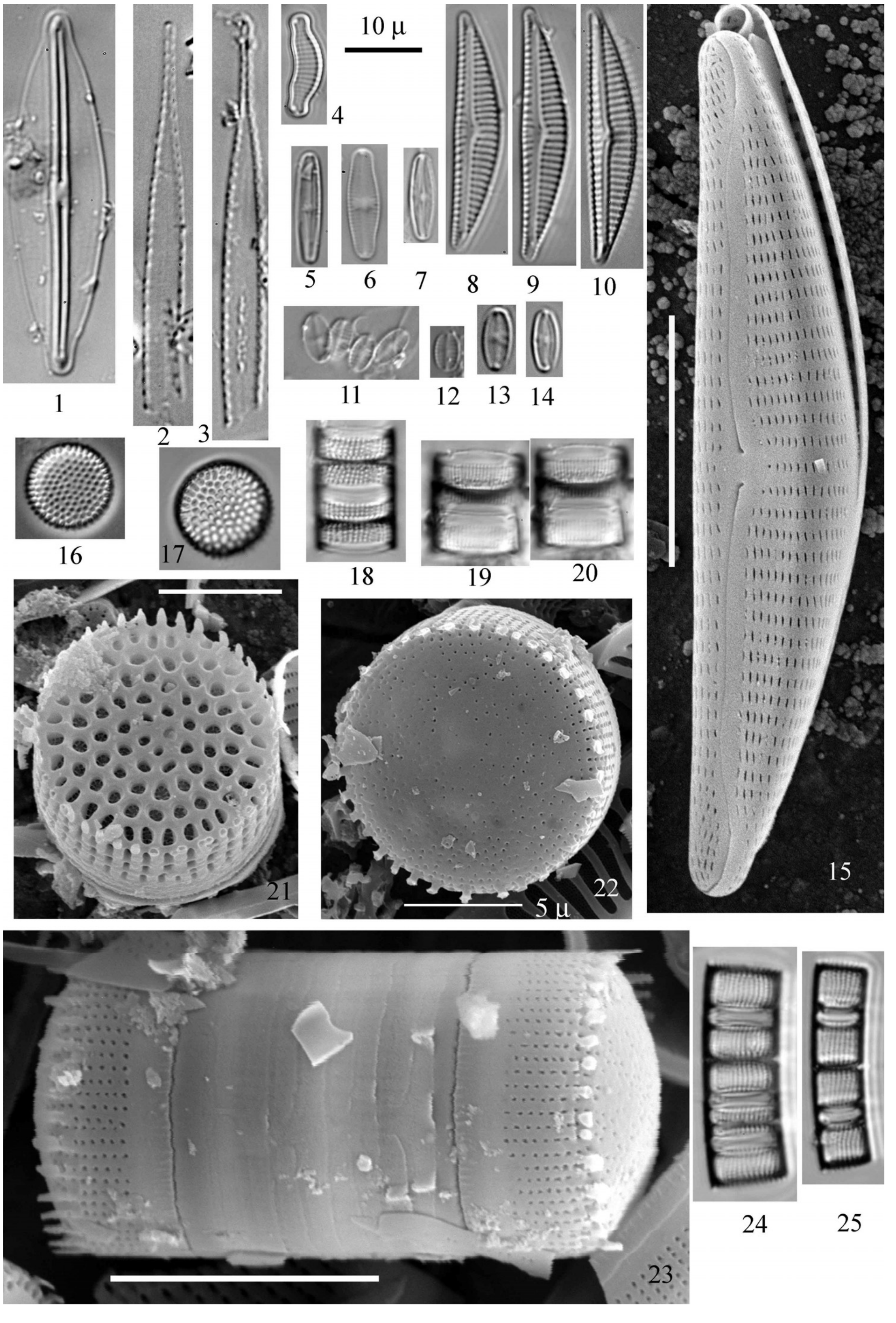
Diatom assemblage zone – DAZ-6
540.5–532 cm (10,901–10,514 cal yr BP)

The small-celled *Staurosira venter* is dominant, and only another small-celled diatom contributed significantly to the assemblage, an unidentified *Navicula* form that is very similar to *Navicula elorantana*, but significantly larger. Diatom diversity was low, but the biogenic silica content increased. During additional scanning of the slides to check diatom diversity we detected the presence of some very large diatom valves in the samples, but during the standard counting procedure these large-celled diatoms were not encountered, or were only occasionally recorded. Some *Pinnularia* species, as long as 300 μm and with heavily silicified valves, flourished in this period with *Neidium amphigomphus* s.l. (Ehr.) Pfitz. The biogenic silica content of a large valve can be thousandfold higher than that of a small, weak, fragile one.

Diatom assemblage zone – DAZ-7,
532–527.5 cm (10,514–10,387 cal yr BP) Plate 4 – Figs 5–7

DAZ-7 covers ca. 130 years and is characterized by a gradual increase of the slightly acidophilous *Stauroforma exiguiformis* and the dominance of a small *Sellaphora* species, which is very similar to *S. seminulum* (Grunow) D.G. Mann; however, the identity of this taxon requires further SEM study. However, the genus *Sellaphora* has become a model system for studies of species concept, as its identification is problematic. Several different small-celled forms were identified in this study as *Sellaphora*. In the history of diatom taxonomy these simply-structured, bilaterally symmetrical, raphid diatoms were usually classified in the genus *Navicula*. There is nothing particularly unusual about the structure in *Sellaphora* that sets it apart from all other "naviculoid" diatoms (Mann et al. 2008), but the chloroplast morphology (single plastid, H-shaped, lying with its center against the epivalve) and the reproductive characteristics separate the genus. In

Plate 4 →
Figures 1–32. Characteristic diatom species of DAZ-7 – DAZ-8 of Lake Brazi. Fig. 1. *Frustulia saxonica*, Fig. 2. *Stenopterobia delicatissima*, Fig. 4. *Eunotia exigua*, Figs 5–7. *Achnathidium* cf. *minutissimum*, Figs 8–10, 15. *Encyonema gracilis*, Figs 11–14. *Sellaphora seminulum* group, Figs 16–18, 21, 24–25. *Aulacoseira nivalis* (W. Smith) English and Potapova, Figs 19, 20, 22, 23. *Aulacoseira laevissima* (Grunow) Krammer. Scale bar = 10 μm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fossil samples neither the chloroplasts nor the reproductive phases can be observed, so the only feature that we can take into consideration is the structure of poroids that are small and round (Plate 3 – Fig. 5, Fig. 23). *Sellaphora* species often occurred in the sediment-derived epipelon.

Diatom assemblage zone – DAZ-8
527.5–501 cm (10,387–9956 cal yr BP) Plate 4 – Figs 1–4, 8–25

DAZ-8 represents a time of significant and basic changes in the diatom assemblages. After the continuous and virtual competition between the two most dominant species, the alkalophilous *Staurosira venter* and slightly acidophilous *Stauroforma exiguiformi*s, it seems that the second species expanded successfully. The return of *Tabelleria flocculosa*, together with bog-diatoms, e.g. *Frustulia saxonica* Rabenhorst (Plate 4 – Fig. 1), *Stenopterobia delicatissima* (Lewis) Brébisson ex Van Heurck (Plate 4 – Figs 2), and *Eunotia exigua* (Bréb.) Rabenh. (Plate 4 – Fig. 4) point to the acidification of the lake water and the establishment of *Sphagnum* species around the lake. Rapid increase of *Encyonema* species (Plate 4 – Figs 8–10) is also a sign of the diversifying habitats. Meso-eutrotraphenic *Nitzschia* species with *Achnathidium minutissimum* (Kützing) Czarnecki indicate more mesotrophic lake conditions. In this zone the sharp increase of *Aulacoseira* taxa (Plate 4 – Figs 16–25) point to increasing water level.

Discussion

The aim of the multi-proxy analyses of the sediment of Lake Brazi is to provide a high-resolution environmental reconstruction for periods that show abrupt and/or rapid climate change. We use the term "abrupt change" following the recommended definition by the Committee on Abrupt Climate Change" (2002), namely "An abrupt climate change occurs when the climate system is forced to transition to a new state at a rate that is determined by the climate system itself, and which is more rapid than the rate of change of the external forcing". The distinction between rapid and abrupt changes in our dataset is not possible at this time, but it is the main aim of our multi-proxy study. On the basis of earlier published paleolimnological studies in this region, rapid climate changes are expected around 12,800 (Younger Dryas) and 11,500 cal yr BP (Late Glacial/Holocene boundary). Partly concordant with these ages, partly contrary to them, the siliceous algae record from TDB-1 showed the most remarkable changes in the aquatic ecosystem at ca. 12,800 and 10,400 cal yr BP. While the Younger Dryas reversal is explicit in our record, the beginning of the Holocene is not well marked.

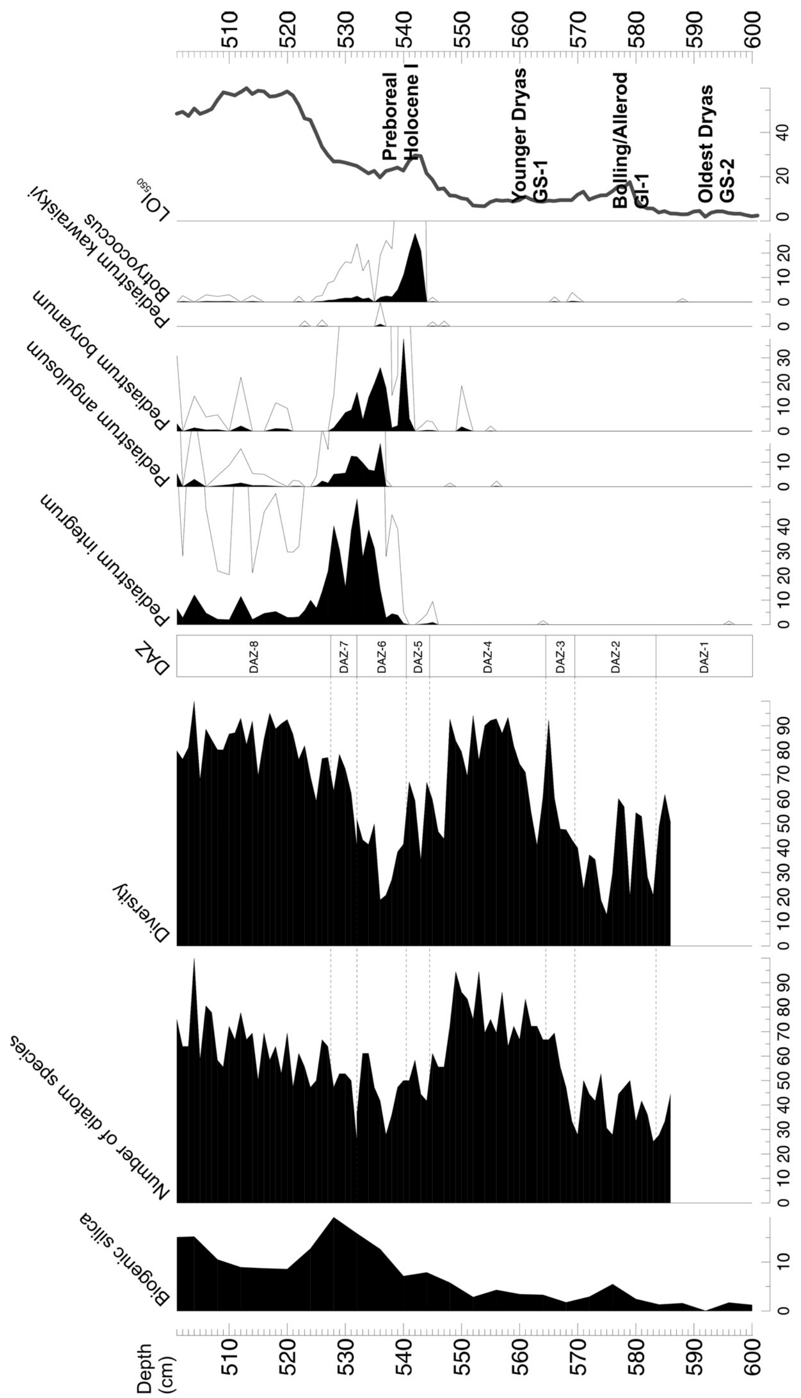

Fig. 2
Biogenic silica, number of diatom species, diversity of diatoms, selected green algae relative frequencies and the Loss Of Ignition (LOI) from TDB-1 Lake Brazi. Lines without filling are exaggerated (× 10)

The Late Glacial history of Lake Brazi based on diatoms

A high-resolution diatom study from Lake Brazi pointed to pronounced, decadal to centennial scale fluctuation in the lake environment during the Late Glacial and the Early Holocene.

The first phase of lake development cannot be reconstructed by diatoms, because of poor preservation, but some eroded remains of large-celled diatoms infer the presence of a shallow lake, directly after the retreat of the Capra-Judele glacier from the Gales-valley, during the Oldest Dryas (GS-2; Björck et al. 1998). High relative frequency of aerophilic taxa indicated a high influx of allochthonous material during this period.

Between ca. 14,000 and 12,900 cal yr BP, small alkalophilous diatoms were dominant that usually inhabit the sediment surface and indicate shallow lake conditions. The lake diatom assemblage signaled an abrupt change at ca. 12,900–12,800 cal yr BP, when a slightly acidophilous diatom assemblage overgrew the alkalophilous taxa. There are several possible explanations for this change. Probably the sharp change of the diatom assemblage was caused by cooling during the Younger Dryas with extended winter ice cover. In a cooling scenario, prolonged ice cover prevents the escape of dissolved CO_2 to the atmosphere, in addition to inhibiting light penetration and thus the drawdown of CO_2 through photosynthetic activity. The resultant increase in the concentration of CO_2 in the lake causes a decline in pH through the production of carbonic acid, or H_2CO_3 (Wolfe 2002), providing conditions more favorable for the slightly acidophilous to circumneutral diatom taxa. Another plausible explanation is connected to soil development that began with considerable delay during the Bølling/Allerød interstadial and likely led to soil leaching and podzol formation by the onset of the Younger Dryas; locally this did not result in the extirpation of the coniferous tree population (Magyari et al. this issue) and local ecosystem productivity did not decrease considerably, according to the organic content measurements (Magyari et al., this issue). Humic acids washed into the lake may have caused acidification of the lake water. A third, possible scenario for the short-term (500 years) lake water acidification is increased fire intensity with the onset of the Younger Dryas. This was recorded by the microcharcoal accumulation rate curve (Magyari et al.. in prep).

Between 12,781–12,300 cal yr BP the diatom species replace each other quite often, suggesting that the environment was unstable or unpredictable, and the competition could have been strong for the available resources. In the ecology the so-called "r strategists" or r-selection have a small body-size. The diversity and number of taxa (Fig. 2) are also high in this zone. The reduced cell-size corresponds with low biogenic silica content in DAZ-4. We infer cold, slightly alkaline shallow pond conditions. Note that this zone corresponds to the second part of the Younger Dryas, but also extends to the Early Holocene (from ca. 11,500 cal yr BP). The observed frequent changes in the diatom flora may bear a relationship to the high amplitude warming in this period, which in the lake water triggered changes, but with a delay, most probably due to the increased input of glacier melt water and consequently subsistent cold lake water conditions (lake water in such cases is in disequilibrium with air temperature). A similar phenomenon was found in the Swiss Alps, where the Late Glacial and Early Holocene chironomid assemblages suggested persistent cold-water conditions for centuries even after the regional vegetation already pointed to warming (Ilyashuk et al. 2009).

Between 12,300 and 11,050 cal yr BP rich diatom assemblages were detected, suggesting a stable environment in which abiotic stress was reduced and the biotic interfaces could regulate the assemblages – as shown by the high taxa-richness and diversity.

Between 10,901–10,514 cal yr BP the green algae probably responded to increasing lake water temperature in the growing season and accelerated nutrient input with the increase of soil temperatures. Planktonic habitats also increased, probably reflecting gradually increasing lake level in this zone.

For a better interpretation of the main changes in this period further analyses are needed, such as biomass calculation and selective counting of the large valves. The high biogenic silica content with the presence of large-body-sized, so-called 'k-strategist' diatoms probably responded to increasing lake water temperature in the growing season and/or the longer vegetation period.

Between 11,050 and 10,050 the productivity of the lake gradually increased, as can be inferred not only from the biogenic silica content that measures siliceous algae abundance, but also from the increasing abundance of green algae (*Pediastrum* spp. and *Botryococcus* sp.). From 10,050 cal yr BP the water of the lake became more acidic, and a peat-bog, probably similar to the recent floating *Sphagnum* carpet, grew along the shore of the lake.

Biogenic silica

Biogenic silica content reflects the biomass of diatoms and cysts that is a simple indicator of past siliceous algal production. In our study, the biogenic silica content was low during the Late Glacial, increased in the Pre-Boreal, peaked in the Early Holocene (in DAZ-7 and DAZ-8), but remained less than 10% during the studied period. The flourish of siliceous algae occurred during the Middle and Late Holocene (see Magyari et al. in this issue).

Diatom diversity

In this stage of our study, the most adventurous and most problematic part of the paleoenvironmental reconstruction was the taxonomical difficulty, especially in the older layers in the case of glacial lakes of Retezat. Above we have presented some examples for the difficulties that partly derived from the climate-driven floristic changes of the diatom assemblages. Analogies to the Late Glacial flora of

Lake Brazi can be found in arctic regions which, although they have been intensively studied recently, can be regarded as poorly-known regions (Fallu et al. 2000; Siver et al. 2005; Antoniades et al. 2008). While the investigation of diatoms has a history of more than 200 years in Europe, arctic diatoms have been the focus of interest for only 20–30 years. This intensive research resulted in many new taxa as well as monographs (Fallu et al. 2000; Antoniades et al. 2008; Esposito et al. 2008) proving that solving taxonomical problems require further effort for a long time. This extremely high taxonomic diversity relates to the problem of distribution of diatoms. Species that are generalists have broad ecological tolerance and consequently wide distribution, while species that are specialists have more exacting requirements and as a consequence they can occur only at a few locations (Poulickova et al. 2008). It seems that we must accept the indicator values and tolerance levels of the arctic species in our reconstruction, because most of the diatom taxa recorded in the Late Glacial part of Lake Brazi did not survive in the Retezat Mountains during the Holocene.

The growing database of the arctic region gives us a chance for diatom-based climate reconstruction. In this paper we focused on the Late Glacial part of the core, but naturally we plan the detailed analysis of siliceous remains of the Holocene deposits. For the last 10–11 thousand years paleoenvironmental reconstruction can be further refined by applying a calibration set obtained from glacier lakes and mires of the Retezat Mts. The calibration set is essential for the quantitative reconstruction. To build a detailed calibration set, collecting samples from surface sediments, mosses, rocks and other habitats of glacial lakes in Retezat Mountains is needed not only for diatoms, but also for chironomids, Cladocera, other algal groups.

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