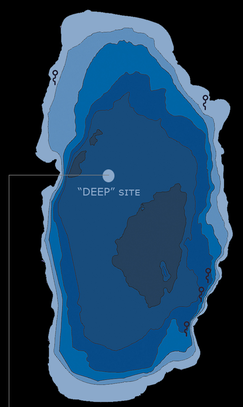
Unravelling the drivers of diatom evolution in ancient Lake Ohrid: ecosystem resilience and species resistance; a link between geology and biology

Cvetkoska, A.[1]; Jovanovska, E.[2]; Levkov, Z.[3]; Reed, J.M.[4]; Wagner, B.[5]; Donders, T.H.[1]; Wagner-Cremer, F.[1]

[1]Utrecht University, Palaeoecology, Department of Physical Geography, Utrecht, The Netherlands (acvetkoska@yahoo.com; t.h.donders@uu.nl; f.wagner@uu.nl)
[2] Justus Liebig University, Department of Animal Ecology and Systematics, Giessen, Germany (jovanovska.eci@gmail.com)
[3]University Ss Cyril and Methodius, Institute of Biology, Skopje, Macedonia (zlevkov@yahoo.com)
[4]Department of Geography, Environment and Earth Sciences, University of Hull, Hull, UK (j.m.reed@hull.ac.uk)
[5]University of Cologne, Institute of Geology and Mineralogy, Cologne, Germany (wagnerb@uni-koeln.de)



Property	Unit	Lake Ohrid
Altitude	m asl	693
Catchment area	km^2	2610
Lake surface area	km^2	358
Maximum depth	m	288
Mean depth	m	155
Volume	km^3	55.4
Hydraulic residence time	yr	~70
Average phosphorus TP concentration	mg P m^{-3}	4.5
Average summer air temperature	°C	26
Average winter air temperature	°C	-1
Average annual precipitation	mm yr^{-1}	750
Number of endemic species		300
Number of diatom species		~800
Number of endemic diatoms		132
Drill site "DEEP" water depth	m	243
Length of composite record	m	544.88
Estimated age of the record	Ma	>1.2

A ~600 m long continuous sediment sequence retrieved from Europe's oldest lake, Lake Ohrid (Macedonia, Albania) as part of the ICDP deep drilling campaign, Scientific Collaboration on Past Speciation Conditions in Lake Ohrid, is unique in the preservation of diatoms (Bacillariophyceae) over the last ~2 million years. Here, we present the first results of diatom analysis of the complete sequence at a resolution of ca. 1500 years, comparing with geochemical data to assess the influence of environmental change on evolution of the dominant diatom lineages.The bio(geological) data indicate cold, arid conditions and a lake-level low-stand of ~60 m bellow the present water-level of Lake Ohrid occurred during the penultimate glacial. Under the third hypothesis, the high morphological plasticity can be further related to high species adaptability, which may promote its resistance to climate and environmental change. This scenario is further supported by the bio(geological) data which shows high ecosystem stability during the last interglacial-glacial period, demonstrating Lake Ohrid's high resilience may be important in mitigating external disturbances, and ultimately, maintaining its biodiversity. Further analyses of the complete sequence are needed to test the hypothesis for the role of high species resistance and ecosystem resilience in preventing major extinction events in Lake Ohrid.

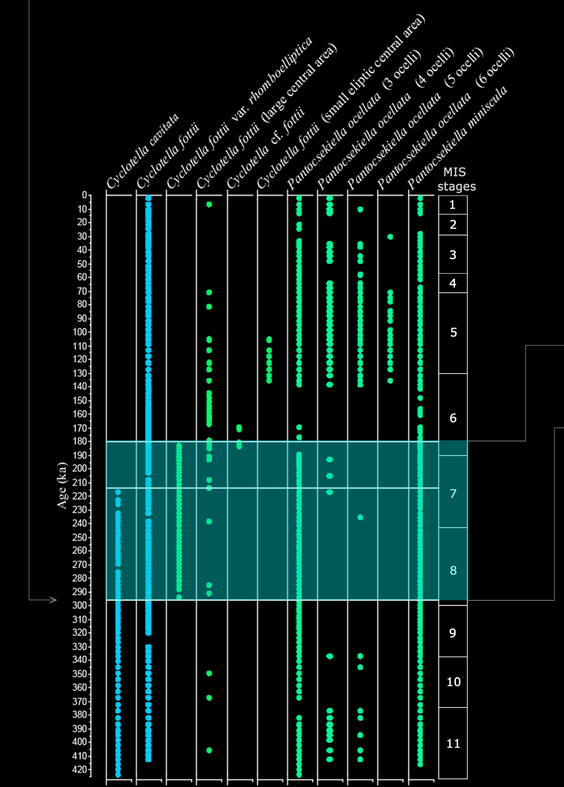


Figure: Biostratigraphic presence of selected diatom species in Lake Ohrid "DEEP" site core. Marine Isotope Stages (MIS) after Lisiecki & Raymo (2005).

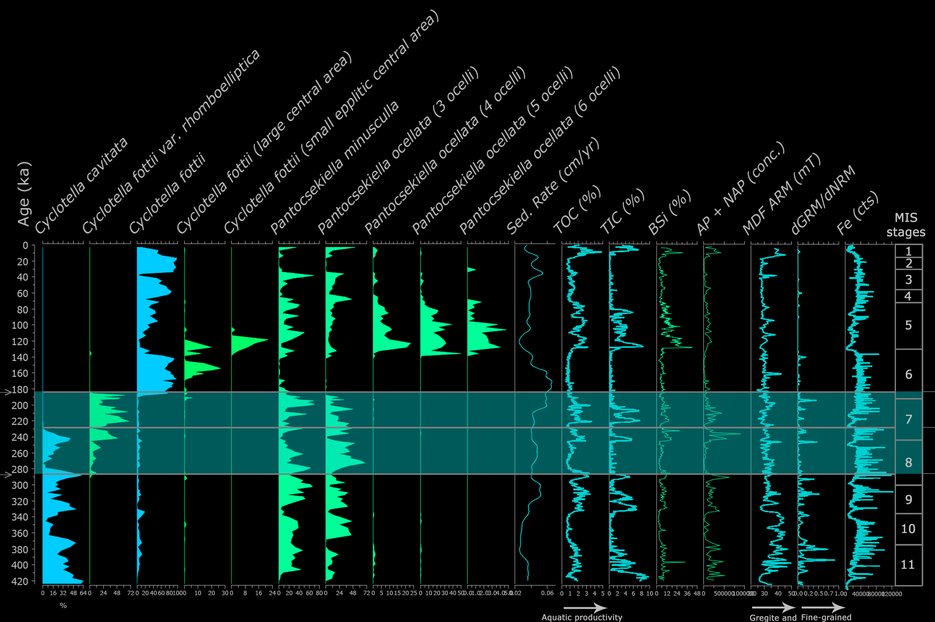
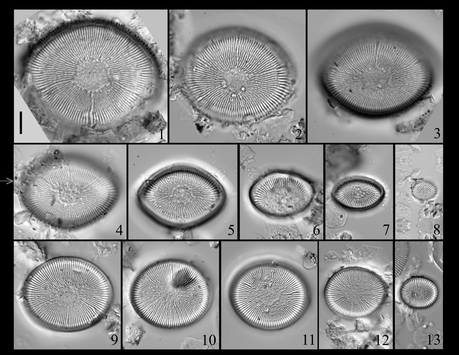


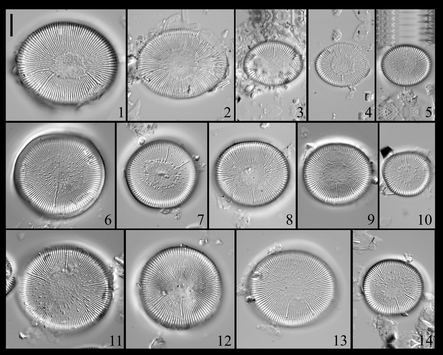
Figure: Relative abundance (%) of selected diatom speceies in Lake Ohrid "DEEP" site core compared to selected (bio)geochemistry data; TOC - total organic carbonates; TIC - total inorganic carbon; BSi - biogenic silica; AP- arboreal + NAP - non-arboreal pollen concentrations, MDF - median destructive field; GRM - gyro-remanent magnetization of gregite; NRM - natural remanent magnetization; Fe - iron counts. Marine Isotope Stages (MIS) after Lisiecki & Raymo (2005).

i) Speciation? ii) Extinction? iii) Eco-phenotypes?

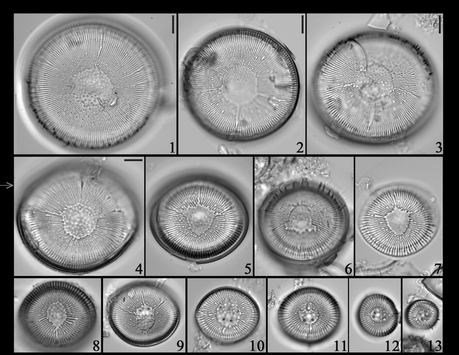
"Species resistance" + "Ecosystem resilience" → "No catastrophic events" → "Cradle of evolution"



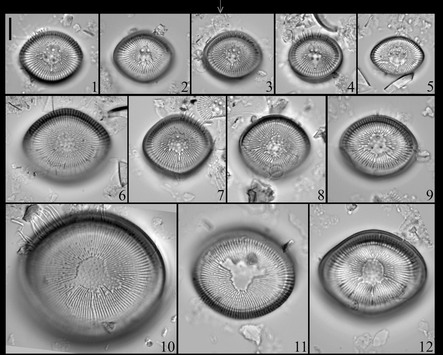
Figs 1–8 (x1500). *Cyclotella fottii* var. *rhomboelliptica*. Figs 9–13 (x1500). *Cyclotella fottii* var. *rhomboelliptica*? Figs 1–8. Lake Ohrid "DEEP" site core, 80.1–79.5 m core depth, 189.5–188.4 ka. Figs 9–12. 79.3 m, 188.1. Fig. 13. 78.9, 187.5 ka. Scale bar: 10µm.



Figs 1–5 (x1500). *Cyclotella fottii* var. *rhomboelliptica*? Figs 6–14 (x1500). *Cyclotella fottii*? Figs 1, 5, 8, 10. 79.2 m core depth, 187.8 ka; Figs 2–4. 79.3 m, 188 ka. Figs 6, 11, 12. 78.7 m, 187 ka. Figs 7, 9, 13, 14. 78.5 m, 186.7 ka. Scale bar: 10µm.



Figs 1–3 (x1200). *Cyclotella fottii*. Figs 4–7 (x1500). *Cyclotella fottii* var. *rhomboelliptica*. Figs 8–13 (x1500). *Cyclotella cavitata*. Figs 1-13. Lake Ohrid "DEEP' core, 125.2–124.8 m core depth; 288.2–286.9 ka; MIS 8. Scale bar: 10 µm.



Figs 1–9 (x1500). *Cyclotella cavitata*? Figs 10–12. *Cyclotella fottii* var. *rhomboelliptica*. Figs 1–12. Lake Ohrid "DEEP" site core, 100.3 m core depth, 230.8 ka; MIS 7. Scale bar: 10 µm.

ACKNOWLEDGEMENTS: The SCOPSCO Lake Ohrid drilling campaign was funded by ICDP, the German Ministry of Higher Education and Research, the German Research Foundation, the University of Cologne, the British Geological Survey, the INGV and CNR (both Italy), and the governments of the Republics of Macedonia and Albania. Logistic support was provided by the Hydrobiological Institute in Ohrid. Drilling was carried out by Drilling, Observation and Sampling of the Earth's (I) Continental Crust's (DOSECC) and using the Deep Lake Drilling System (DLDS). A.C. would like to thank Jan van Tongeren for technical assistance.