Palaeogeography, Palaeoclimatology, Palaeoecology 406 (2014) 22–32

Contents lists available at ScienceDirect

Palaeogeography, Palaeoclimatology, Palaeoecology

journal homepage: www.elsevier.com/locate/palaeo

# Late Glacial to Holocene climate change and human impact in the Mediterranean: The last ca. 17 ka diatom record of Lake Prespa (Macedonia/Albania/Greece)

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ARTICLE INFO

*Article history:*
Received 22 October 2013
Received in revised form 5 April 2014
Accepted 8 April 2014
Available online 24 April 2014

*Keywords:*
Lake Prespa
Diatoms
Lake level
Productivity
Mediterranean
Palaeoclimate

ABSTRACT

Lake Prespa (Macedonia/Albania/Greece) occupies an important location between Mediterranean and central European climate zones. Although previous multi-proxy research on the Late Glacial to Holocene sequence, core Co1215 (320 cm; ca. 17 cal ka BP to present), has demonstrated its great value as an archive of Quaternary palaeoclimate data, some uncertainty remains in the interpretation of climate change. With the exception of oxygen stable isotope data, previous palaeolimnological interpretation has relied largely on proxies for productivity. Here, existing interpretation is strengthened by the addition of diatom data. Results demonstrate that shifts in diatom assemblage composition are driven primarily by lake-level changes and thus permit more confident interpretation of shifts in moisture availability over time, while corroborating previous interpretation of catchment- and climate-induced productivity shifts. An inferred cold, arid shallow lake phase between ca. 17.1 and 15.7 cal ka BP is not only followed by a high-productivity phase from ca. 15.7 cal ka BP with Late Glacial warming, but also is the first evidence for a gradual increase in lake level, in line with other regional records. Clear evidence for a Younger Dryas climate reversal between ca. 13.1 and 12.3 cal ka BP is followed by an unusually gradual transition to the Holocene and deeper, oligotrophic–mesotrophic lake conditions are reached by ca. 11.0 cal ka BP. In contrast to the arid episode from ca. 10.0 to 8.0 ka inferred from positive $^{18}\delta O_{calcite}$ values, rapid diatom-inferred lake-level increase after the start of the Holocene suggests high moisture availability, in line with palynological evidence, but with only very subtle evidence for the impact of an 8.2 ka cold event. The maintenance of high lake levels until 1.9 cal ka BP, and the peak of inferred humidity from ca. 7.9 to 6.0 cal ka BP, matches the oxygen stable isotope profile and confirms that the latter is driven primarily by evaporative concentration rather than reflecting regional shifts in precipitation sources over time. During the Late Holocene progressive eutrophication is inferred between 1.9 and present. Two shallow phases at ca. 1.0 cal ka BP and at ca. 100 years ago probably represent an aridity response which is added to increase human impact in the catchment. Overall, the study is important in confirming previous tentative inferences that Late Glacial to Holocene moisture availability has strong affinity with other sites in the Eastern Mediterranean. It also tracks the pattern of North Atlantic forcing.



## 1. Introduction

The Mediterranean is a region of high climatic spatial variability. Although Late Quaternary palaeoclimate data have improved substantially over the last decade (e.g. González-Sampériz et al., 2006; Kotthoff et al., 2011; Fletcher and Zielhofer, 2013), we still require improved understanding of spatial variability in climate over time in order to understand the underlying climatic mechanisms (Tzedakis, 2007). A prime example is the ongoing debate concerning the spatial distribution of moisture availability during the Holocene (Magny et al., 2012).

Balkan Lake Prespa is an ancient tectonic lake which probably formed >2 Ma ago and is hydrologically connected through the mountain range Galicica with Lake Ohrid (Stankovic, 1960). Both lakes are renowned for their extraordinary biodiversity and high endemism (Albrecht and Wilke, 2008). They are also located at an important junction between Mediterranean and continental European climate zones (Hollis and Stevenson, 1997; Wagner et al., 2008). While Lake Ohrid is deep and oligotrophic, significant water level oscillations occur naturally in Lake Prespa (Sibinoviç, 1987), offering contrasting potential for palaeolimnological climate reconstruction.

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http://dx.doi.org/10.1016/j.palaeo.2014.04.010
0031-0182/

Previous multi-proxy research on the Late Glacial to Holocene sequence of core Co1215 (320 cm; ca. 17 cal ka BP to present) has focused largely on productivity indicators, linked to palynological evidence for catchment changes (Aufgebauer et al., 2012; Panagiotopoulos et al., 2013), with palaeohydrological data confined to oxygen stable isotope analysis (Leng et al., 2010, 2013). Although these studies demonstrate the great value of Lake Prespa as an archive of Quaternary palaeoclimate data, the interpretation of climate change is still uncertain. Diatoms (single-celled algae; Bacillariophyceae) are abundant, diverse and sensitive to a wide range of limnological variables, and can provide strong proxy evidence both for productivity and lake-level changes. Here, existing interpretation of Late Glacial to Holocene climate change in Lake Prespa is strengthened by the addition of diatom data, to address a key area of uncertainty in Mediterranean palaeoclimate reconstruction.

## 2. The study area

Lake Prespa (40° 46′–41° 00′ N, 20° 54′–21° 07′ E, or Macro Prespa, Fig. 1) is located in the Western-Macedonian geotectonic zone of the Dinarides at an altitude of 849 m a.s.l. The transboundary catchment (Macedonia, Albania and Greece) also contains the smaller lake, Micro Prespa. The two were formerly joined as a single lake basin; in 1969/1970, an artificial dam was constructed between the lakes to manage the water level of Lake Micro Prespa (Hollis and Stevenson, 1997). Both lakes are part of a former lake complex called the Dessarets (Stankovic, 1960), which includes Lake Ohrid and Lake Maliq (Korca basin). According to Radoman (1985) these tectonic basins are Tethys derivates formed during Alpine orogeny in the Late Tertiary. Cvijic (1911) suggested that the Dessarets have belonged to an Adriatic group of lakes which is isolated from the Aegean limnetic group. However, Bourcart (1922) suggested that there may have been some hydrological connection through the Korca depression and the Transaegean valley.

Lake Prespa currently has a surface area of 254 km$^2$, mean water depth of ca. 14 m, maximum water depth of ca. 48 m and a total volume of 3.6 km$^3$. The estimated hydraulic residence time is ca. 11 years. The water balance is controlled by the input/output ratio. The water input depends on surface input from river inflow, catchment runoff, direct precipitation, Lake Micro Prespa inflow and groundwater input (no data available for the latter). The output is via surface evaporation, water abstraction for irrigation and subsurface outflow through the karstic aquifers of Galicica Mountain into Lake Ohrid (Matzinger et al., 2006). The climate may be described as Mediterranean in the southern and continental in the northern part of the catchment area, with sub-alpine character below 1650 m altitude and alpine character above this altitude. Annual temperature fluctuates from 1 °C in winter to 21 °C in summer, and annual precipitation varies between 720 and 1200 mm yr$^{-1}$ in the lake's valley and the surrounding mountain ranges, respectively (Hollis and Stevenson, 1997). Major recent lake level fluctuations have occurred, with a decline of almost 10 m in between 1950 and 2009. The location of historical settlements and palaeo-shorelines around the lake indicates that Lake Prespa also experienced major lake-level fluctuations in the past (Sibinoviç, 1987). Recent accelerated anthropogenic eutrophication has occurred, with an increase in total phosphorus (TP) input from a historic mean of ca. 20 to 31 mg P m$^{-3}$ in 2003 (Matzinger et al., 2006).

## 3. Material and methods

### 3.1. Core recovery and chronology

The sediment core Co1215 was recovered in autumn 2009 at a water depth of 14 m in the central northern part of Lake Prespa (Wagner et al., 2012) from a floating platform equipped with gravity and piston corers (UWITEC Corp. Austria). Correlation of gravity and up to 3 m long piston core sections resulted in a 1575 cm long composite sequence with

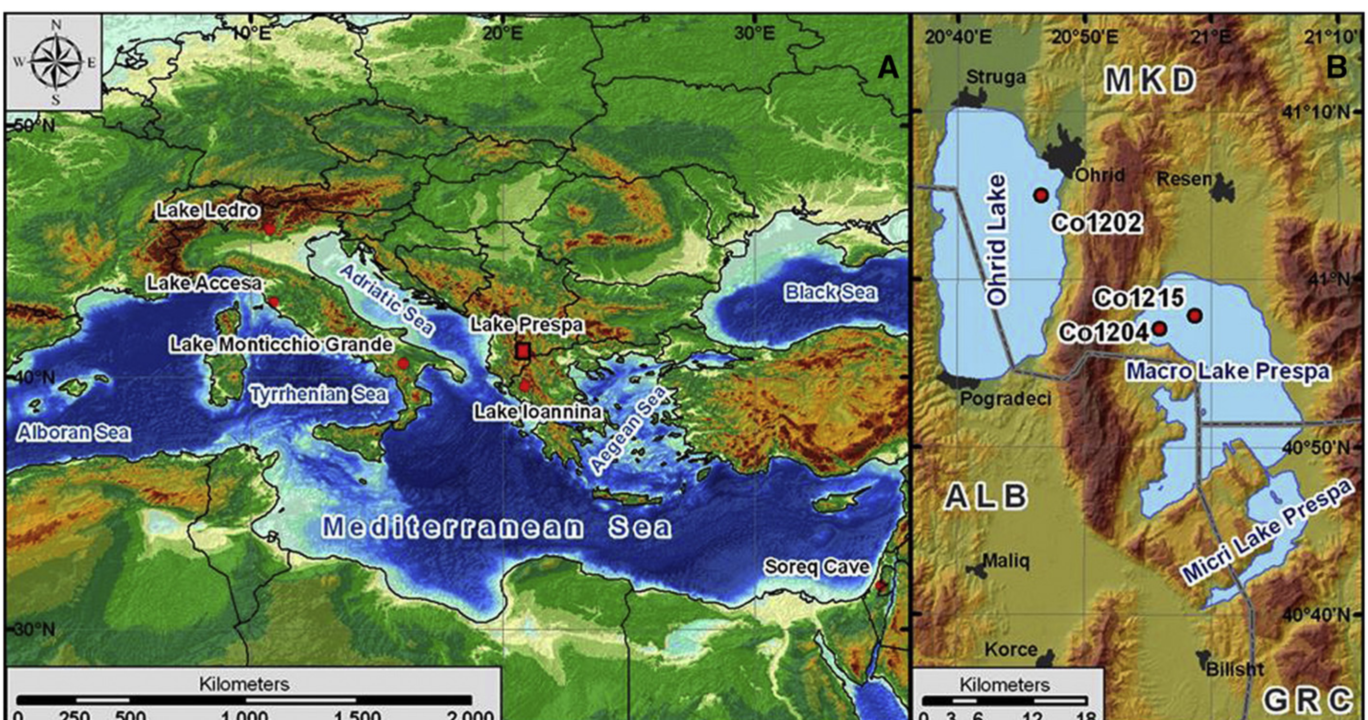


**Fig. 1.** Map of the Mediterranean region (A) showing the location of lakes Prespa and Ohrid (red rectangle) and palaeoreconstruction sites used for comparison and referred to in the text: Alboran Sea (Cacho et al., 2002), Tyrrhenian Sea (Cacho et al., 2001), Lago Grande di Monticchio (Allen et al., 1999), Lake Accesa (Magny et al., 2009), Lake Ledro (Magny et al., 2012), Adriatic Sea (Giunta et al., 2001), Lake Ioannina (Wilson et al., 2008), Aegean Sea (Rohling et al., 2002), and Soreq Cave (Bar-Matthews et al., 2003). Map of lakes Ohrid and Prespa (B) showing location of core Co1215 and other coring sites referred to in the text: Lake Prespa Co1204 (Wagner et al., 2010) and Lake Ohrid Co1202 (Reed et al., 2010; Vogel et al., 2010; Wagner et al., 2010; Cvetkoska et al., 2012).