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Palynology of the Last Interglacial Complex at Lake Ohrid: palaeoenvironmental and palaeoclimatic inferences

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ABSTRACT

In this article, we present new, high-resolution, pollen results obtained from the DEEP site sequence recovered from Lake Ohrid (Albania/FYROM) for the Last Interglacial Complex (LIC), corresponding to Marine Isotope Stage 5 (MIS 5) of the marine isotope stratigraphy. LIC covers the period between 130 and 70 ka and includes the Eemian (Last Interglacial, LI) and the succession of stadial and interstadial phases of the Early Last Glacial.

During the LIC, the pollen record shows an alternation of periods characterized by forest and open vegetation, clearly resembling the well-known vegetational succession of other European records. Our results reveal three key phases for the LI: a first period (128-125 ka) with a rapid increase in temperature and precipitation, a central phase (125–118.5 ka) characterized by a slight cooling, and a late phase (118.5–112 ka), with a decline both in temperatures and precipitation. Besides the LI, we identify four more forested periods dominated by mesophilous trees and intercalated by colder and drier steppe phases, during which, however, most arboreal taxa never disappear.

During the Early Last Glacial we also identify several abrupt events that can be correlated to the succession of cold events recorded in the Greenland ice core records, associated to a weakening of the North Atlantic Meridional Overturning Circulation.

The new high-resolution record indicates that Lake Ohrid is an important site to understand the response of vegetation to fluctuations in regional moisture availability and temperature changes, and thus provides new evidence for the connection between the Mediterranean Region and Northern Hemisphere climate oscillations.

1. Introduction

To evaluate past environmental natural changes and to hypothesize future climate scenarios, the close correlation between plant populations and climate change is used since the last century (Fægri and Iversen, 1989; Birks et al., 2016). Pollen rain, preserved in anoxic sediments, reflects past vegetation and is an invaluable tool for studying the evolution of the environment over time and for following the succession of climatic events.

The Last Interglacial Complex (LIC, 130–80 ka, Govin et al., 2015; Turon, 1984 and references therein), the terrestrial equivalent to Marine Isotope Stage 5 (MIS 5) of the marine benthic isotope stratigraphy (Shackleton et al., 2003), provides interesting hints to interpret the present-day environment and to infer its potential future changes. In particular during the Last Interglacial (LI, or Eemian in the European pollen stratigraphy, Turner, 2002; ca. 130-110 ka), the majority of the Earth experienced a climate warmer than present (e.g. Kukla et al., 2002). Thus, it is considered as a

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possible analogue for the projected global warming, although global climate boundary conditions differ from the current interglacial (Brewer et al., 2008 and references therein). Moreover, unlike the Holocene, the global environmental change that occurred during LI was surely not influenced by long-term impacts due to human-induced CO_2 emission (Ruddiman and Thomson, 2001; Ruddiman, 2003; Ruddiman et al., 2005, 2016), allowing unraveling the background of natural variability during period of "excess" warmth. Besides the Eemian interglacial, the terrestrial stratigraphy of the LIC comprises a succession of stadial and interstadial periods, which constitute the Early Last Glacial (commonly named Early Weichselian in Europe). Several pollen records from continental Europe, Mediterranean and Near East (see Fig. 1) show coherent general trends at the orbital scale for the LIC, particularly for the onset of the main interstadial (i.e., forested) periods. Instead, latitudinal gradients between central and southern Europe are apparent and concern especially the end of the Eemian phase, with interglacial conditions lasting longer in the south (Sánchez-Goñi et al., 2005). However, only few of these records have sufficient temporal resolution to resolve short-term climatic oscillations within the LI and the onset of the Last Glacial. A pervasive short-term (i.e., centennial to millennial scale) climatic variability during the LIC is indeed apparent from a wealth of high-resolution marine and continental records from the North Atlantic and the Mediterranean, especially during the Early Last Glacial but also within the LI, although the latter characterized by lower intensity (e.g. Drysdale et al., 2007; Klotz et al., 2004; Milner et al., 2016; Mokeddem et al., 2014; Regattieri et al., 2014, 2015, 2016a, 2017).

However correlations among different records and definitions of the timing and of the regional expression of these events is still problematic, primarily due to the lack of independent and robust chronologies (e.g. Govin et al., 2015; Zanchetta et al., 2016).

In this article, we present a detailed high-resolution pollen analysis of the LIC (128-70 ka) at Lake Ohrid (LO), which is located at the border between Albania and the Former Yugoslav Republic of Macedonia (FYROM, southern Balkans). LO is an important archive of environmental and climate evolution. A detailed multiproxy biogeochemical record (Wagner et al., 2017 and references therein) is available for the last 640 ka, including low-resolution pollen analyses (Bertini et al., 2016; Sadori et al., 2016) for the last 500 ka. Noteworthy, the LO chronology is based on independent tephrochronology and orbital tuning (Francke et al., 2016). Thus the vegetational changes observed in our record can significantly improve the available knowledge on the timing and patterns of vegetational evolution during the LIC in southern Europe, both on orbital- and on millennial/centennial-scale. Moreover, through direct comparison with the other biogeochemical proxies available from the LO, our record would provide a more comprehensive view of environmental changes during the studied period. This would allow a stronger correlation between changes at the site and variations in regional hydrological patterns and temperature variability known from other records covering the same time span. The new record will also shed light on the role that LO played as glacial refugium for the Balkans and Southern Europe.

2. General setting

2.1. Geographic and geological settings

Lake Ohrid (LO, 40°54′ to 41°10′ N and 20°38′ to 20°48′ E; Fig. 1) is located at 693 m above sea level (a.s.l.) at the southern Balkan Peninsula. It is located within the Dinarides–Albanides–Hellenides mountain chain, a fold and thrust belt formed in the tertiary during the final phase of Alpine orogenesis. Geological studies suggest that the lake has a tectonic origin (Lindhorst et al., 2015). The lake graben structure was formed ca. 2–10 Ma (Lindhorst et al., 2015; Trajanovski et al., 2010). The modern lake basin is tub-shaped, with a N-S orientation. It is 30.3 km long and 15.6 km wide, and thus it is one of the largest existent lakes in Europe. The lake is surrounded by several, N-S oriented mountain ranges, i.e. the Mokra mountains (maximum altitude 1514 m a.s.l.) and Jablanica (maximum altitude 1945 m a.s.l.) to the west, the Mali Thatë to the south (maximum altitude 2028 m a.s.l.), and the Galičica mountains to the east (maximum altitude 2265 m a.s.l.). LO has a volume of ca. 55 km^3 and an average water depth of 164 m, with a maximum depth of 293 m. The water body is mainly fed by karstic inflow, rivers and direct precipitation; while water leaves the lake through the river Crni Drim and by evaporation. LO is also hydrologically connected through underground karst channels with the nearby Lake Prespa, LP (849 m a.s.l., Matzinger et al., 2006; Watzin et al., 2002, Fig. 1). Today LO is oligotrophic. Surface water temperature varies between 6 °C and 26 °C, while bottom water temperatures are fairly constant at 5–6 °C (Popovska and Bonacci, 2007).

2.2. Local climate

The climate of the Ohrid region is characterized by Mediterranean-type conditions, with hot and dry summers and cold and mild winters, but it is also affected by continental influences (Panagiotopoulos et al., 2014). Moisture availability is linked to the penetration of westerly storm tracks across southern Europe, especially during winter, and to Mediterranean cyclogenesis (Dünkeloh and Jacobeit, 2003; Ulbrich et al., 2012). Warm and dryness in summer are related to the expansion of the Azores High (Xoplaki et al., 2003). In addition, local meteorology is influenced by the proximity of the Adriatic Sea, by the local topography and by the lake thermal capacity (Watzin et al., 2002).

The pluviometric regime is Mediterranean, with highest precipitation during November (ca. 144 mm) and the lowest in July (ca. 42 mm). The mean annual precipitation ranges from ca. 700 mm at the altitude of the lake to 1200 mm on the surrounding mountains ridges. The temperatures range between ca. 2 and 6 °C during winter and between 10 and 22 °C during summer. The mean annual temperature equals 11.5 °C (Popovska and Bonacci, 2007).

The wind regime is influenced by the morphology of the lake basin. Winds are characterized by a prevailing North provenience during winter, while during spring and summer, wind direction is mostly from South to South-East (Bordon, 2008; Hoffmann et al., 2012; Matzinger et al., 2006; Wagner et al., 2009).

2.3. Present day vegetation

LO is one of the largest water-reserve in the Balkans situated at the border between two biogeographical regions (Mediterranean and Alpine, Fig. 1), and an important site for studies on past evolution and speciation mechanisms connected to climatic and environmental changes (e.g. Albrecht et al., 2006; Föller et al., 2015; Stankovic, 1960; Wagner et al., 2008). Indeed, LO hosts a high number of relic and endemic species. Concerning the vegetation, Mediterranean and Balkan elements dominate, but several central European species are also widespread in the area. The vegetation is organized in altitudinal belts, developed from the lake level at 693 m a.s.l. to the top of the surrounding mountains at up to 2200 m a.s.l. (Matevski et al., 2011).

In riparian forests, willows (*Salix alba* L.) are dominant. Extrazonal elements of Mediterranean vegetation are present at lower elevations, while most forests are formed by deciduous elements. Below 1200 m a.s.l. deciduous and semi-deciduous oaks (*Quercus cerris* L., *Quercus frainetto* Ten., *Quercus petraea* (Matt.) Liebl., *Quercus pubescens* Willd., and *Quercus trojana* Webb) form mixed