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Vegetation and environmental changes during the last interglacial in eastern Anatolia (Turkey): a new high-resolution pollen record from Lake Van

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ABSTRACT

A high-resolution multi-proxy record from Lake Van, eastern Anatolia, derived from a lacustrine sequence cored at the 357 m deep Ahlat Ridge (AR), allows a comprehensive view of paleoclimate and environmental history in the continental Near East during the last interglacial (LI). We combined paleovegetation (pollen), stable oxygen isotope ($\delta^{18}O_{bulk}$) and XRF data from the same sedimentary sequence, showing distinct variations during the period from 135 to 110 ka ago leading into and out of full interglacial conditions. The last interglacial plateau, as defined by the presence of thermophilous steppe-forest communities, lasted ca. 13.5 ka, from ~129.1–115.6 ka BP.
The detailed palynological sequence at Lake Van documents a vegetation succession with several climatic phases: (I) the *Pistacia* zone (ca. 131.2–129.1 ka BP) indicates summer dryness and mild winter conditions during the initial warming, (II) the *Quercus-Ulmus* zone (ca. 129.1–127.2 ka BP) occurred during warm and humid climate conditions with enhanced evaporation, (III) the *Carpinus* zone (ca. 127.2–124.1 ka BP) suggest increasingly cooler and wetter conditions, and (IV) the expansion of *Pinus* at ~124.1 ka BP marks the onset of a colder/drier environment that extended into the interval of global ice growth. Pollen data suggest migration of thermophilous trees from refugial areas at the beginning of the last interglacial. Analogous to the current interglacial, the migration documents a time lag between the onset of climatic amelioration and the establishment of an oak steppe-forest, spanning 2.1 ka. Hence, the major difference between the last interglacial compared to the current interglacial (Holocene) is the abundance of *Pinus* as well as the decrease of deciduous broad-leaved trees, indicating higher continentality during the last interglacial. Finally, our results demonstrate intra-interglacial variability in the low mid-latitudes and suggest a close connection with the high-frequency climate variability recorded in Greenland ice cores.

1. Introduction

The last interglacial (LI) plateau (128–116 ka BP, Shackleton et al., 2002), equivalent to the Marine Isotope Stage (MIS) 5e (132–115 ka BP; Shackleton et al., 2002), is often considered as a possible analogue for natural climate variability and vegetation changes to the current interglacial, the Holocene, and potentially, for future changes. However, unlike the Holocene, the global environment during LI was not influenced by human activity which may have widespread and long-term impacts upon the climate system.

The last interglacial has been intensively studied from locations in northern and southern Europe (Aalbersberg and Litt, 1998; Frogley et al., 1999; Sánchez Goñi et al., 1999, 2005; Tzedakis, 2000; Klotz et al., 2003; Kühl and Litt, 2003; Müller et al., 2003, 2011; Tzedakis et al., 2006; Brauer et al., 2007; Djamali et al., 2008; Allen and Huntley, 2009; Milner et al., 2013), providing insights into climate patterns that corroborate global variability. Based on continental and marine deposits, the LI is traditionally defined as a period of climatic amelioration that is generally as warm or warmer than today (Jessen and Milthers, 1928; Fairbridge, 1972; Kukla et al., 2002; NGRIP, 2004; Rohling et al., 2008). Similar to the present interglacial, the LI climate conditions have been described as relatively stable (Litt et al., 1996; Kukla et al., 2002), however, short-term intra-interglacial instability, characteristic for the North Atlantic region, was observed in a variety of high-resolution marine and continental archives (e.g. Sánchez Goñi et al., 1999; Bond et al., 2001; Müller et al., 2005; Oppo et al., 2006; Couchoud et al., 2009). Of special research interests are uncertainties regarding the length of interglacial conditions on land, the timing and

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nature of vegetation changes and the effects of climate on vegetation due to global ice growth towards the end of the LI (e.g. Allen and Huntley, 2009; Brauer et al., 2007; Djamali et al., 2008; Klotz et al., 2003; Kukla et al., 1997, 2002; Milner et al., 2013; Müller et al., 2003, 2011; Sánchez Goñi et al., 1999, 2005; Shackleton et al., 2002, 2003; Tzedakis, 2000, 2003; Tzedakis et al., 2002, 2004a, 2004b, 2006). Due to challenges with precise dating of continental records, inferred vegetation changes are difficult to place within a global framework of ice-volume and sea-level changes. However, European variability in vegetation and climate during the last interglacial can be correlated with orbital forcing of insolation (Berger, 1978; Berger et al., 2007; Rohling et al., 2008) and with oscillations in North Atlantic circulation pattern (Dansgaard et al., 1993; McManus et al., 1994, 1999; Müller and Kukla, 2004). Various sequences from the adjacent Mediterranean region have been analysed for pollen and stable isotopes encompassing several interglacial phases, e.g. Lago Grande di Monticchio (Italy, e.g. Allen and Huntley, 2009; Brauer et al., 2007), Tenaghi Philippon and Ioannina (Greece, e.g. Milner et al., 2013; Tzedakis et al., 2002, 2004a, 2004b). Long continental and high-resolution records in southern Europe suggest that warm-temperate forest usually extends into the interval of global ice growth (e.g. Tzedakis, 2005; Allen and Huntley, 2009; Milner et al., 2013).

Compared to the well-studied European region, the LI in the Near East is poorly known due to the lack of long continental records of vegetation and environmental history. The low-resolution pollen sequence of Lake Urmia (NW Iran, Fig. 1) is available for this time period (Van Zeist and Bottema, 1977; Bottema, 1986; Djamali et al., 2008; Stevens et al., 2012) and only recently, the publications of Shumilovskikh et al. (2012, 2013) have complemented the last interglacial picture in northern Anatolia based on cores from the Black Sea. In light of the scarcity of long continental archives in the Near East, Lake Van is in a key position to clarify regional paleoclimate evolution (Litt et al., 2012). The robust chronology of the Lake Van sedimentary profile (Stockhecke et al., 2014a) extends over the last 600 ka. Initial low-resolution studies (Kwiecien et al., 2014; Litt et al., 2014; Randlett et al., 2014) revealed that Lake Van sediments document with unprecedented detail environmental changes and thus contribute to the understanding of regional response to climate variability of the last six glacial-interglacial cycles.

Here we present a first high-resolution multi-proxy investigation of the Lake Van sedimentary record, integrating palynological, microscopic charcoal, stable oxygen isotope and X-ray fluorescence (XRF) measurements. It allows a systematic comparison of different independent indicators throughout the penultimate late glacial, last interglacial, and the succeeding glacial inception at a centennial-to-millennial time-scale (between ~100 and 800 years). Furthermore, we compare our results with long-term paleoclimate sequences from the Near East and Mediterranean region to evaluate the timing and length of the last interglacial period in relation to the Lake Van record and to examine vegetation differences between these locations.

2. Regional setting

Lake Van (38°6′N, 42°8′E) is located on the eastern Anatolian high plateau, Turkey, where the Afro/Arabian Plate from the south meets the Eurasian Plate from the north and east (Fig. 1). The lake, at an altitude of 1649 m above sea level (asl) and a maximum water depth of ~450 m, is situated in the eastern continuation of the active Muş graben (Kempe et al., 1978) in direct vicinity of two active volcanoes (Nemrut 2948 m asl; Süphan 4058 m asl; Fig. 2). With a surface area of 3574 km^2 and volume of ~607 km^3, Lake Van is the fourth largest terminal lake on earth. It is also the largest soda lake in the world (pH 9.8; salinity 21.4‰; Kadioğlu, 1997; Kempe et al., 1991).

The regional climate at Lake Van has a continental character, with large diurnal and seasonal variations in temperature and humidity. It is controlled by alternation in position and strength of the following atmospheric components: (a) the mid-latitude westerlies, (b) the sub-tropical high-pressure system and (c) the Siberian high-pressure system (Türkeş, 1996; Akçar and Schlüchter, 2005). During summer, the extension of the subtropical high-pressure system strongly affects the tracks of the North Atlantic westerlies. Warm and dry air reach the interior plateau of

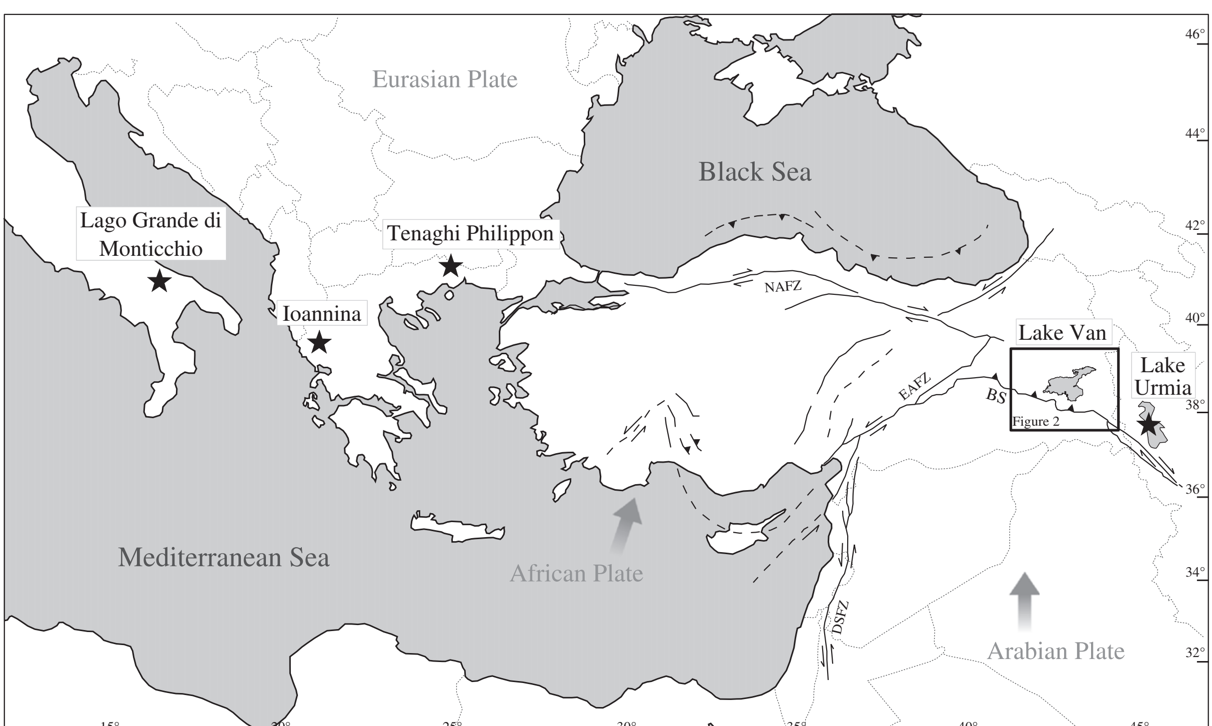

Fig. 1. Map of the central and eastern Mediterranean region with geological setting of the Lake Van (black rectangle, see Fig. 2, modified from Karaoğlu et al., 2005) region as well as the locations of the most important Mediterranean pollen records (black stars) as mentioned in the discussion; NAFZ: North Anatolian Fault Zone; EAFZ: East Anatolian Fault Zone; BS: Bitlis Suture; DSFZ: Dead Sea Fault Zone.