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Vegetation responses to abrupt climatic changes during the Last Interglacial Complex (Marine Isotope Stage 5) at Tenaghi Philippon, NE Greece

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ABSTRACT

The discovery that climate variability during the Last Glacial shifted rapidly between climate states has intensified efforts to understand the distribution, timing and impact of abrupt climate change under a wide range of boundary conditions. In contribution to this, we investigate the nature of abrupt environmental changes in terrestrial settings of the Mediterranean region during the Last Interglacial Complex (Marine Isotope Stage [MIS] 5) and explore the relationships of these changes to high-latitude climate events. We present a new, temporally highly resolved (mean: 170 years) pollen record for the Last Interglacial Complex from Tenaghi Philippon, north-east Greece. The new pollen record, which spans the interval from 130,000 to 65,000 years ago, forms part of an exceptionally long polleniferous sediment archive covering the last 1.35 million years.

The pollen data reveal an interglacial followed by alternating forest and steppe phases representing the interstadials and stadials of the Early Glacial. Superimposed on these millennial-scale changes is evidence of persistent sub-millennial-scale variability. We identify ten high-amplitude abrupt events in the pollen record, characterised by rapid contractions of closed forest to open steppe environment and interpreted to indicate major changes in moisture availability and temperature. The contractions in forest cover on millennial timescales appear associated with cooling events in the Mediterranean Sea, North Atlantic and Greenland regions, linked to the Dansgaard-Oeschger (DO) cycles of the Early Glacial. On sub-millennial timescales, the pattern of changes in forest cover at Tenaghi Philippon display a structure similar to the pattern of short-lived precursor and rebound-type events detected in the Greenland ice-core record. Our findings indicate that persistent, high-amplitude environmental variability occurred throughout the Early Glacial, on both millennial and submillennial timescales. Furthermore, the similarity of the pattern of change between Tenaghi Philippon and Greenland on sub-millennial timescales suggests that teleconnections between the high-latitudes and the Mediterranean region operate on sub-millennial timescales and that some terrestrial archives, such as Tenaghi Philippon, are particularly sensitive recorders of these abrupt climate changes.

1. Introduction

The late Pleistocene is an ideal interval to decipher the expressions, mechanisms and feedbacks of climate change because of the relatively high abundance of accessible palaeoclimate archives and the existence of pronounced climate fluctuations under both glacial and interglacial boundary conditions. Certain intervals during the late Pleistocene have been the focal point of much research: the peak warmth of the Last Interglacial (Marine Isotope

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Stage [MIS] 5e) (e.g. CAPE-Last Interglacial Project Members, 2006), rapid climate variability of MIS 4 to 2 (e.g. Fletcher et al., 2010; Müller et al., 2011), the Last Glacial Maximum (e.g. Harrison and Prentice, 2003; Clark et al., 2009) and the Last Glacial-Holocene transition (e.g. Clark et al., 2012; Muschitiello and Wohlfarth, 2015). Although these extreme intervals are important for our understanding of the climate system, they do not provide a complete representation of the range of boundary conditions of an interglacial-glacial cycle. The focus of our paper, therefore, is the Last Interglacial Complex from 130,000 to 70,000 thousand years before present (130–70 ka), including the Last Interglacial (MIS 5e) and Early Glacial (MIS 5d-a) interval and occurring before the onset of the well-studied climate variability of MIS 4 to 2. The Early Glacial (the Early Weichselian in Europe) is characterised by increasing global ice volume and two stadials and interstadials, equivalent to MIS 5d and 5b, and 5c and 5a, respectively (Shackleton, 1969; Shackleton et al., 2003). The broad climate characteristics of the Early Glacial interval of MIS 5 are relatively well-established from a large number of marine, terrestrial and ice-core proxy datasets from different archives across Europe and the North Atlantic region (e.g. Sánchez-Goñi et al., 1999; NGRIP-Members, 2004; Helmens, 2014). However, what is particularly interesting about the Early Glacial are the abrupt climate events that have been detected in temporally more highly resolved proxy datasets (e.g. Drysdale et al., 2007; Capron et al., 2010; Incarbona et al., 2010; Boch et al., 2011), which to date have received less research focus than the Dansgaard-Oeschger (DO) cycles and the Heinrich events of the Last Glacial (MIS 4 to 2) (Dansgaard et al., 1993; Grootes et al., 1993).

Since the discovery of DO cycles for the Last Glacial period there has been a proliferation of studies investigating the nature and causes of abrupt climate change (e.g. Sánchez-Goñi and Harrison, 2010, and references therein). The language used to describe and define abrupt climate change can, however, cause confusion, which prompts the need to standardise the terms applied. In the review by Alley et al. (2002), abrupt climate change is described to occur “when the climate system is forced to cross some threshold, triggering a transition to a new state at a rate determined by the climate system itself and faster than the cause”. This definition, which was later adopted by the Intergovernmental Panel on Climate Change (Meehl et al., 2007) and is widely followed in the description of abrupt events of the Last Glacial (e.g. Sánchez-Goñi and Harrison, 2010), is therefore also used in this paper.

Evidence from the Greenland ice cores indicates that the Early Glacial was characterised by lower-frequency DO events followed by long interstadials (NGRIP-Members, 2004). In addition, sub-millennial variability characterised by abrupt warming prior to DO events (so-called “precursor events” (Capron et al., 2010)), warming events towards the end of interstadials (“rebound events” (Capron et al., 2010)), and abrupt cooling episodes within interstadials are detected in the ice core records (Capron et al., 2010). DO cycles have been detected in Early Glacial terrestrial records throughout Europe (e.g. Allen et al., 2000) but few of these records have a temporal resolution sufficient to resolve the sub-millennial features detected in the Greenland ice cores. An exception is a radiometrically-dated composite speleothem record from the northern rim of the Alps (Switzerland and Austria) that provides a fragmented, but high-resolution $\delta^{18}O$ record for 118–64 ka (Boch et al., 2011). This record exhibits a similarity to the DO cycles known from Greenland in terms of timing, duration and relative amplitude of the cycles as well as in the presence of sub-millennial features. The similarity between the two records presents a strong case for synchronous climate between Greenland and central Europe during the Early Glacial, within the limits of dating uncertainties (Boch et al., 2011). Whether the sub-millennial features of the Early Glacial DO cycles are present in other European terrestrial archives is yet unclear due to a lack of suitably high-resolution, continuous records. The waxing and waning of Pleistocene ice sheets mean that terrestrial records, particularly in northern and central Europe, are often fragmentary due to the erosive action of ice sheets (de Beaulieu et al., 2001; Müller et al., 2003). With relatively ice-free conditions persisting even during glacial intervals at low altitudes in southern Europe, archives from these regions can provide continuous records of environmental change through the full range of climatic boundary conditions (e.g. Wijmstra, 1969; Tzedakis et al., 1997; Brauer et al., 2007; Roucoux et al., 2008; Sadori et al., 2016).

One such archive is Tenaghi Philippon, north-east Greece, which has yielded a polleniferous sequence spanning the last 1.35 million years (Tzedakis et al., 2006; Pross et al., 2015). The enormous potential of this site for palynological research was first demonstrated by T.A. Wijmstra and colleagues in the 1960s–80s when they generated an orbital-scale-resolution pollen dataset for the entire sequence (Wijmstra, 1969; Wijmstra and Smit, 1976; van der Wiel and Wijmstra, 1987a,b). The resulting record of vegetation change, which was found to exhibit a close correspondence with deep-sea records (Wijmstra and Groenhart, 1983), highlighted the stratigraphical completeness of the Tenaghi Philippon archive. The relatively low temporal resolution of this seminal record precludes the detection of abrupt changes, but centennial-scale analyses of new core material recovered in 2005 and 2009 (Pross et al., 2007, 2015) demonstrate that the vegetation at Tenaghi Philippon was highly sensitive to millennial-, centennial-, and decadal-scale climate change during both glacials and interglacials (Pross et al., 2009; Fletcher et al., 2013; Milner et al., 2013). The close fidelity between vegetation changes at Tenaghi Philippon and DO events in Greenland ice cores (Müller et al., 2011) highlights the potential of the Tenaghi Philippon archive to detect abrupt variability seen in North Atlantic, higher-latitude climate records, and therefore to test for climatic teleconnections between the higher and lower latitudes.

This paper: i) investigates the characteristics of abrupt climate change during the Early Glacial in north-east Greece by reconstructing a centennial-scale record of vegetation change at Tenaghi Philippon, and ii) examines how the changes in the vegetation record relate to high-latitude climate events, such as the sub-millennial features identified in the DO cycles. Selected pollen data for the Last Interglacial from this site were previously presented by Milner et al. (2012, 2013). The complete pollen dataset for the Last Interglacial underlying these papers together with the previously unpublished Early Glacial data presented here creates a new high-resolution pollen record for the entire Last Interglacial Complex (MIS 5) from Tenaghi Philippon.

2. Regional setting

Tenaghi Philippon (42 m a.s.l., Fig. 1) is a 55 km^2 large sub-basin of the Drama Basin, an intermontane tectonic graben in the western part of the Rhodope Massif. Whereas marine and deltaic sediments were deposited during the Pliocene when the graben was connected to the Parathethys Sea, fluvial and lacustrine sediments were deposited during the Early Pleistocene across large parts of the Drama Basin. The lake shallowed and was replaced by marshes (Filippidis et al., 1996), which marks the start of the formation of peat in the Tenaghi Philippon sub-basin from 1.35 Ma (van der Wiel and Wijmstra, 1987b; Tzedakis et al., 2006), including the core interval presented in this paper. The peat from Tenaghi Philippon is predominantly formed from Cyperaceae and continued accumulating, with intercalated lake sediments, until the area was drained for agricultural use between 1931 and 1944. A detailed review of