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The cryptotephra record of the Marine Isotope Stage 12 to 10 interval (460–335 ka) at Tenaghi Philippon, Greece: Exploring chronological markers for the Middle Pleistocene of the Mediterranean region

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ABSTRACT

Precise chronologies that allow direct correlation of paleoclimate archives are a prerequisite for deciphering the spatiotemporal characteristics of short-term climate variability. Such chronologies can be established through the analysis of tephra layers that are preserved in the respective sedimentary archives. Here we explore the yet untapped tephrochronological potential of the Eastern Mediterranean region for the Middle Pleistocene, specifically for the interval spanning Marine Isotope Stages (MIS) 12–10 (460–335 ka). High-resolution cryptotephra analysis was carried out on peat cores spanning the MIS 12–10 interval that have been recovered from the iconic climate archive of Tenaghi Philippon, NE Greece. Eighteen primary cryptotephras were identified, and major- and trace-element analyses of single glass shards from all cryptotephras were performed in order to correlate them with their eruptive sources. The results suggest origins from both Italian and Aegean Arc volcanoes. Specifically, one cryptotephra layer could be firmly correlated with the Cape Therma 1 eruption from Santorini, which makes it the first distal tephra finding for this eruptive event. While eight further cryptotephras could be tentatively correlated with their volcanic or even eruptive sources, the provenance of another nine cryptotephras as yet remains unknown. The relatively large number of cryptotephras that could not be assigned to specific volcanic sources and eruptive events reflects the still considerable knowledge gap regarding the geochronology and geochemistry of proximal tephra deposits from the Middle Pleistocene of the Central and Eastern Mediterranean regions. Due to the lack of well-dated Middle Pleistocene eruptions, we provide age estimates for all cryptotephra layers identified in the MIS 12–10 interval at Tenaghi Philippon based on high-resolution pollen data from the same cores. While eight of the identified cryptotephras were deposited within MIS 12 (~438–427 ka), one cryptotephra was deposited at the onset of MIS 11 (~419 ka), five cryptotephras during the younger part of MIS 11 (~391–367 ka), and four cryptotephras during MIS 10 (~359–336 ka). The high number of cryptotephras from multiple sources as recorded in the MIS 12–10 interval at Tenaghi Philippon highlights the key role of this archive for linking tephrostratigraphic lattices for the Middle Pleistocene of the Central and Eastern Mediterranean regions.

1. Introduction

The Middle Pleistocene period, spanning Marine Isotope Stages (MIS) 19 to 6 (c. 781–126 ka; Cohen et al., 2013), contains some of the arguably most interesting episodes of Quaternary climate

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evolution. It includes interglacials that represent the two best orbital analogues for the Holocene (i.e., MIS 11 and 19) and as such allow insight into the natural evolution of the present interglacial without human influence (e.g., Past Interglacials Working Group of Pages, 2016). At the same time, it comprises the two strongest glaciations of the past 800 ka (i.e., MIS 12 and 16; Lisiecki and Raymo, 2005).

Over the past decades, Middle Pleistocene climate dynamics have been studied in a number of proxy records from marine (e.g., Barker et al., 2015; Herbert et al., 2010), terrestrial (e.g., Cheng et al., 2016; Melles et al., 2012) and ice-core (e.g., Jouzel et al., 2007; Loulergue et al., 2008) archives that comprise multiple glacial/interglacial cycles. The synchronization of the datasets from these archives is a prerequisite for a mechanistic understanding of short-term climate variability, notably for the quantification of leads and lags between different components of the climate system. This is, however, hindered by the often considerable uncertainties in the age models that exist for the individual archives (Bronk Ramsey et al., 2015; Lowe et al., 2015).

An interesting avenue for the direct synchronization of geological archives is provided by tracing, dating and fingerprinting of tephra layers (Lowe, 2011; Lowe et al., 2015). Tephra layers represent time-sensitive marker horizons because of their geologically instantaneous eruption and deposition. They circumvent chronological uncertainties as they are intrinsically connected to the application of absolute dating techniques. The geochemical composition of tephra glass shards represents their connection to a source volcano/individual eruption. Therefore, once a particular tephra layer has been geochemically characterized, it can be used to link, synchronize and potentially date sedimentary archives where it has been found. Ideally, a tephra layer can be dated via correlation to a previously dated eruptive event. Alternatively, it can be dated directly by K-Ar, Ar-Ar, U-series, and fission-track methods, or indirectly via dating of the host sediments (Bronk Ramsey et al., 2015). Identification of non-visible ash layers (i.e., cryptotephras) in distal localities has greatly extended the geographical area over which some eruptions can be traced (e.g., Davies, 2015). This approach has greatly boosted the establishment of tephrostratigraphic frameworks for the Late Pleistocene and Holocene in many parts of the world.

The Eastern Mediterranean is a key region for paleoenvironmental research. Due to its intermediate position between the climate systems of the higher and lower latitudes, it exhibits particularly high climatic and environmental variability (Lionello et al., 2012). At the same time, it has particular relevance for paleoanthropological, protohistorical and archeological research. It can help shed light on the dispersal dynamics of archaic and modern humans from Africa into Eurasia (e.g., Lowe et al., 2012; Müller et al., 2011; Zanchetta et al., 2018), and at the same time it represents the cradle of ancient civilizations (Freeman, 2014).

Although the Eastern Mediterranean region has yielded long sedimentary archives both from the marine (e.g., ODP Sites 964, 967, and 968 – e.g., Grant et al., 2017; Lourens, 2004, Fig. 1) and the terrestrial realm (e.g., Tenaghi Philippon – Pross et al., 2015; Lake Ohrid – Wagner et al., 2017; Lake Van – Litt et al., 2014) that cover the Middle Pleistocene, the precise correlation of these archives has remained challenging. For such efforts, the massive explosive volcanism in the Eastern Mediterranean region as it has occurred from the Eocene onwards (Peccerillo, 2017) has great potential via the generation of a tephrostratigraphic lattice (Keller et al., 1978). However, the tephrostratigraphic framework for the Eastern Mediterranean region as available today does not extend beyond the past ~200 ka (e.g., Aksu et al., 2008; Wulf et al., 2018), and the vast majority of the Middle Pleistocene has yet remained unexplored

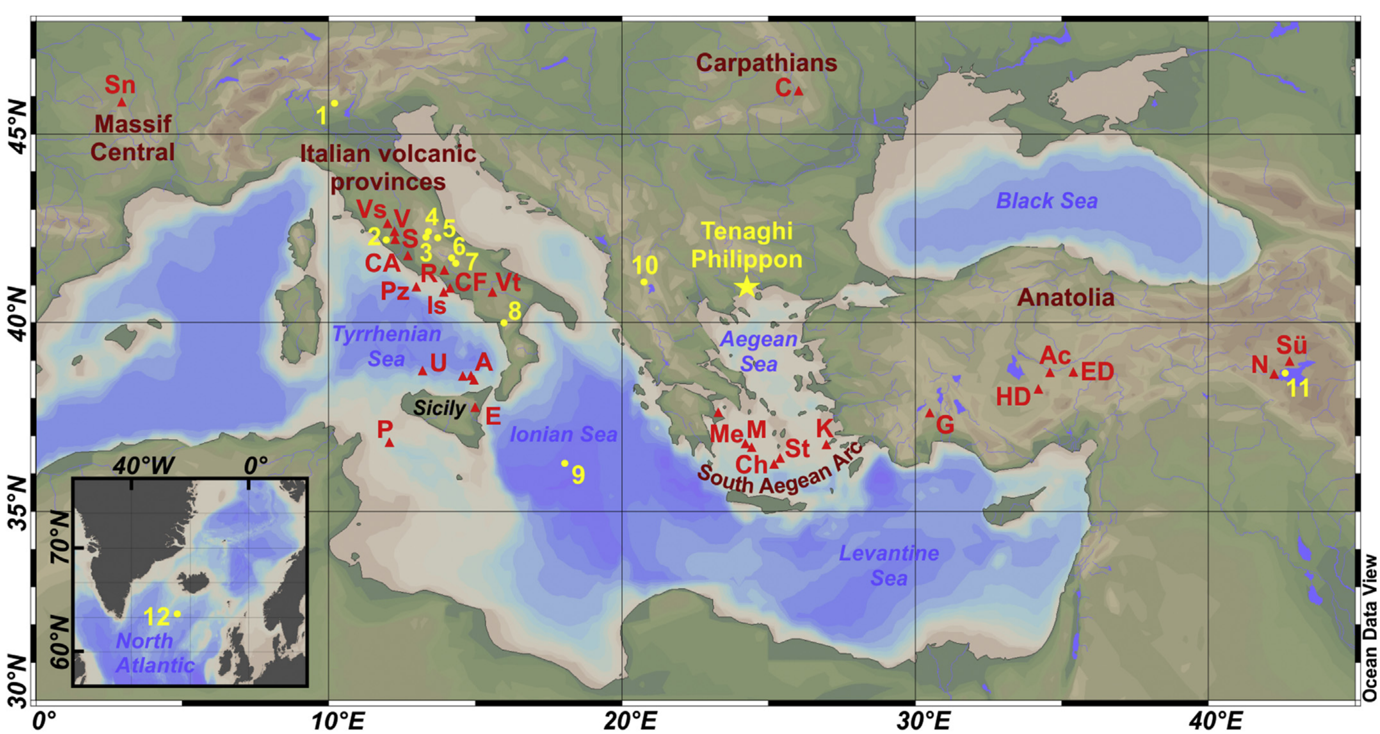

Fig. 1. Map of the Central and Eastern Mediterranean regions showing the location of Tenaghi Philippon and other Middle Pleistocene tephra archives considered in this study: 1 – Piánico paleolake; 2 – Ficoncella site; 3 – Campo Felice basin; 4 – Paganica-San Demetrio-Castelnuovo basin; 5 – Sulmona basin; 6 – Sessano basin; 7 – Boiano basin; 8 – Mercure basin; 9 – ODP Site 964; 10 – Lake Ohrid; 11 – Lake Van. The main volcanic centers active (or possibly active) during MIS 12–10 are also marked: A, Aeolian Islands; Ac, Acigöl; C, Ciomadul; CA, Colli Albani; CF, Campi Flegrei; Ch, Christiana Islands; E, Etna; ED, Erciyes Dagi; G, Gölcük; HD, Hasan Dagi; Is, Ischia; K, Kos; M, Milos and Antimilos; Me, Methana; N, Nemrut; P, Pantelleria; Pz, Ponza Island; R, Roccamonfina; S, Sabatini; Sn, Sancy; St, Santorini; Sü, Süphan; U, Ustica; V, Vico; Vs, Vulsini; Vt, Monte Vulture. The inset map shows the location of ODP Site 983 (12) in the North Atlantic.