Quaternary Science Reviews 152 (2016) 80–92

Contents lists available at ScienceDirect

Quaternary Science Reviews

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

Environmental variability between the penultimate deglaciation and the mid Eemian: Insights from Tana che Urla (central Italy) speleothem trace element record

Eleonora Regattieri [a, c, *], Giovanni Zanchetta [b, c, d], Russell N. Drysdale [e, f], Ilaria Isola [d], Jon D. Woodhead [g], John C. Hellstrom [g], Biagio Giaccio [a], Alan Greig [g], Ilaria Baneschi [c], Elissavet Dotsika [h]

[a] Istituto di Geologia Ambientale e Geoingegneria, IGAG-CNR, Via Salaria Km. 29.300 Monterotondo, Rome, Italy
[b] Dipartimento di Scienze della Terra, Via S. Maria 53, 56126 Pisa, Italy
[c] Istituto di Geoscienze e Georisorse IGG-CNR, Via Moruzzi 1, 56100 Pisa, Italy
[d] Istituto Nazionale di Geofisica e Vulcanologia INGV, Via della Faggiola 32, Pisa, Italy
[e] School of Geography, University of Melbourne, Victoria 3010, Australia
[f] EDYTEM, UMR CNRS 5204, Université de Savoie-Mont Blanc, 73376 Le Bourget du Lac Cedex, France
[g] School of Earth Sciences, University of Melbourne, Victoria 3010, Australia
[h] National Center for Scientific Research Demokritos, Athens, Greece

A R T I C L E I N F O

Article history:
Received 6 May 2016
Received in revised form
23 September 2016
Accepted 24 September 2016

Keywords:
Speleothem
Trace elements
Penultimate deglaciation
Last Interglacial
Central Italy

A B S T R A C T

A trace element record (Mg, Sr, Ba, Al, Si, P, Y, Zn) covering the ca. 133 ka to ca. 124 ka time interval was acquired from a flowstone core from Tana che Urla Cave (central Italy). It was compared with stable isotope data to investigate the environmental evolution in response to regional and extra-regional climate changes in the period corresponding to the latter part of the Penultimate Deglaciation and the first part of the Last Interglacial (Eemian). Trace element geochemical changes on centennial and millennial time scales responded to changes in hydrological input, variations in the supply and transport of catchment erosion products to the cave, including those linked to intense rainfall events, and to the state of the overlying soil and vegetation. Abrupt increases in precipitation and the progressive development of soil and vegetation occurred at ca. 132 ka, in response to the development of the global deglacial phase. The major changes in trace element composition are coherent with the previous hydrological interpretation of speleothem oxygen stable isotope composition ($\delta^{18}O$) as predominantly a rainfall-amount proxy. However, reduced growth rate persisted until ca. 130 ka, suggesting still depressed temperatures. An abrupt event of climatic deterioration, with marked decrease in precipitation and soil degradation, is apparent between ca. 131 and 130 ka. Cool-wet conditions between ca. 132 and 131 ka and the subsequent dry period may represent the local hydrological response to an interval of North Atlantic cooling and ice-rafted-debris (IRD) deposition known as Heinrich event 11 (H11). After 129.6 ka there was a rapid recovery according to all of the studied speleothem properties, indicating the onset of full interglacial conditions. A minor amplitude event of reduced precipitation is recorded within the LIG at ca. 127 ka. The record highlights the growing regional evidence for a complex penultimate deglacial climate involving major reorganization of oceanic and atmospheric patterns.

1. Introduction

Investigations of the climate and environmental dynamics associated with deglaciations and the onset of interglacial periods are important for addressing key issues regarding the effects of rapid warming, as is expected in the near future. The Penultimate Deglaciation, corresponding to Termination II (TII) in the marine

* Corresponding author. Now at Institute of Geology and Mineralogy, University of Cologne, Zülpicher Str. 49a, Cologne, Germany.
E-mail address: eleonora.regattieri@dst.unipi.it (E. Regattieri).

http://dx.doi.org/10.1016/j.quascirev.2016.09.027
0277-3791/

record (Lisiecki and Raymo, 2005), and the following warm stage, the Last Interglacial (LIG or Eemian interglacial in the European pollen stratigraphy), spanning the period ca. 140–110 ka, are among the best documented in the geological record. They have been the subject of a number of paleoclimate studies for over a century (e.g. Govin et al., 2015; Kukla et al., 2002; Shackleton et al., 2003). However, discrepancies still exist regarding timing and internal variability, as well as on the expression of this variability in the marine and in the terrestrial realms (e.g. Drysdale et al., 2009; Marino et al., 2015; Martrat et al., 2014). In particular, within TII, the timing and expression on land of Heinrich event 11 (H11), i.e., the millennial-scale episode of North Atlantic cooling and ice-rafted-debris (IRD) recorded in marine records from the sub-polar to the western Mediterranean between ca. 134 and 130 ka (e.g. Martrat et al., 2014; Jiménez-Amat and Zahn, 2015; Marino et al., 2015), are still matter of debate. Due to the scarcity of absolute age constraints in most archives covering TII and the LIG, various stratigraphic alignments to different reference chronologies have been used to link ice core, marine and terrestrial records (e.g. Govin et al., 2015; Zanchetta et al., 2016a). However, each of those approaches relies on different paleoclimate assumptions. They often regard synchronicity between climatic events recognized in marine records and those in terrestrial archives, and the paleoclimatic meaning of the compared proxies. This makes difficult to evaluate the climatic feedback mechanisms and the sequence of events over this time period (e.g. Masson-Delmotte et al., 2010; Landais et al., 2013; Zanchetta et al., 2016a). A detailed understanding of environmental parameters controlling the proxies selected for alignment among records is definitely of paramount importance.

Speleothems record palaeoenvironmental changes via a suite of geochemical properties that can be anchored to a robust radiometric U-Th chronology (Dorale et al., 2004). As a consequence of the development of high-resolution, well-dated speleothem records covering the TII-LIG period (e.g. Wang et al., 2001; Drysdale et al., 2009), several attempts have been made to refine the chronologies of marine sediments and ice cores by using climatic alignments to the most common tracer measured on speleothems, the oxygen stable isotope composition of the calcite $\delta^{18}O$ (e.g. Drysdale et al., 2009; Barker et al., 2011; Jiménez-Amat and Zahn, 2015; Marino et al., 2015). Changes in temperature, rainfall amount and rain sources are considered the dominant drivers of $\delta^{18}O$ (e.g. Lachniet, 2009; McDermott, 2004). However, these changes are often interconnected and the dominant climatic parameter differ from one region to another, making it difficult to forcefully argue the “climatic” link between $\delta^{18}O$ and the climate-sensitive properties measured in other archives (Govin et al., 2015). To overcome this issue and disentangle the different drivers of the $\delta^{18}O$ changes, the assessment of the paleoclimatic meaning of additional proxies measured in speleothems and the extent to which they agree with the $\delta^{18}O$ series, is of paramount importance. One widely exploited proxy is the stable isotope composition of carbon ($\delta^{13}C$), which has been used to infer local pedogenic, hydrological and/or cave ventilation processes (Genty et al., 2001a, 2003; Spötl et al., 2005). Another speleothem property is growth rate, which is mainly controlled by the supply of CO_2 in the seepage water, drip discharge and temperature (Hellstrom and McCulloch, 2000; Genty et al., 2001b; Borsato et al., 2015). A third source of information is trace element composition. Interpretations of speleothem trace element records are usually more challenging than other properties, because the elemental variability arises from complex interactions between atmospheric inputs, vegetation/soil, karstic aquifer, primary speleothem crystal growth and post-deposition processes (Fairchild and Treble, 2009). However, the integration of information on local environmental features from elemental records in the wider paleoclimatic framework provided by stable isotopes can provide a robust multi-proxy basis by which to unravel the response of the local palaeoenvironment to regional- and wider-scale climatic changes. This also helps to shed light on environmental and climate parameters driving changes in the $\delta^{18}O$ composition.

In this paper we investigate trace element changes (Mg, Sr, Ba, Al, Si, Zn, Y, P) from a flowstone core (TCUD4) from Tana che Urla Cave (TCU) in central Italy (Fig. 1) for the interval ca.133 ka to ca.124 ka. The $\delta^{18}O$ and $\delta^{13}C$ profiles of TCUD4 for the period ca.159 ka to ca.121 ka have already been discussed by Regattieri et al. (2014a). In this new work, we explore the factors driving trace element geochemical changes on centennial and millennial time scales. Then we compare the trace element results with the pre-existing stable isotope record and with the broader environmental changes inferred from previous studies from the region (e.g. Brauer et al., 2007; Couchoud et al., 2009; Drysdale et al., 2005, 2009; Milner et al., 2013; Tzedakis et al., 2003). This multiproxy approach allows us to assess in detail the changing environmental evolution at the TCU cave site during the period encompassing most of the Penultimate Deglaciation and the first part of the LIG. It also provides insights into the factors leading $\delta^{18}O$ variability and on their links to regional and extra-regional climate changes.

2. Site and sample description

TCU is a sub-horizontal spring cave that opens at 620 m a.s.l. on the south-eastern side of the Apuan Alps, central Italy (Fig. 1). The cave characteristics have been discussed in previous studies (Regattieri et al., 2012, 2014a) and are only briefly summarized here. The cave has developed at the contact between meta-siliciclastics (Fornovolasco schist formation, Pandeli et al., 2004) and Triassic meta-dolomite (Grezzoni formations), and is crossed by a permanent stream. The cave temperature is ca. 10.7 ± 0.5 °C and the catchment is covered by a relatively deep soil that sustains a well-developed forest of cultivated chestnut (*Castanea sativa*) and beech (*Fagus sylvatica*). Regional climatic settings are described in previous studies on TCU (Regattieri et al., 2012, 2014a) and on the nearby Antro del Corchia Cave (Baneschi et al., 2011; Drysdale et al., 2004; Piccini et al., 2008). Briefly, mean annual precipitation is high at the cave (about 2500 mm/yr, Piccini et al., 1999) due to the strong orographic effect exerted by the Apuan Alps chain, which is located only ca. 20 km away from the Tyrrhenian Sea. This chain traps eastward-moving moisture sourced from the western Mediterranean and the North Atlantic. Precipitation is distributed throughout the year, with higher amounts during spring and autumn, when it

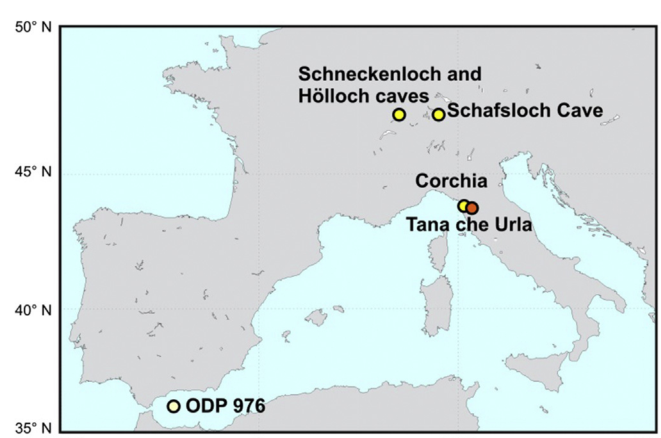

Fig. 1. Location of TCU site and of other sites mentioned in the text.