Quaternary Science Reviews 132 (2016) 129–145

Contents lists available at ScienceDirect

Quaternary Science Reviews

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

A multi-proxy record of MIS 11–12 deglaciation and glacial MIS 12 instability from the Sulmona basin (central Italy)

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ARTICLE INFO

Article history:
Received 31 July 2015
Received in revised form
19 November 2015
Accepted 20 November 2015
Available online 10 December 2015

Keywords:
Stable isotope
Lacustrine succession
MIS 12–11
Tephrostratigraphy
Central Italy

ABSTRACT

A multi-proxy record (lithology, XRF, $CaCO_3$ content, carbonate $\delta^{18}O$ and $\delta^{13}C$) was acquired from a sediment core drilled in the intermountain Sulmona basin (central Italy). Tephrostratigraphic analyses of three volcanic ash layers ascribe the investigated succession to the MIS 12-MIS 11 period, spanning the interval ca. 500–410 ka. Litho-pedo facies assemblage indicates predominant lacustrine deposition, interrupted by a minor sub-aerial and lake low stand episode. Variations in major and minor elements concentrations are related to changes in the clastic input to the lake. The oxygen isotopic composition of carbonate ($\delta^{18}O_c$) intervals is interpreted mainly as a proxy for the amount of precipitation in the high-altitude catchment of the karst recharge system. The record shows pronounced hydrological variability at orbital and millennial time-scales, which appears closely related to the Northern Hemisphere summer insolation pattern and replicates North Atlantic and west Mediterranean Sea Surface Temperature (SST) fluctuations. The MIS 12 glacial inception is marked by an abrupt reduction of precipitation, lowering of the lake level and enhanced catchment erosion. A well-defined and isotopically prominent interstadial with increased precipitation maybe related to insolation maxima-precession minima at ca. 465 ka. This interstadial ends abruptly at ca. 457 ka and it is followed by a phase of strong short-term instability. Drastic lake-level lowering and enhanced clastic flux characterized the MIS 12 glacial maximum. Lacustrine deposition restarted about 440 ka ago. The MIS 12–MIS 11 transition is characterized by a rapid increase in the precipitation, lake-level rise and reduction in the clastic input, interrupted by a short and abrupt return to drier conditions. Comparison with marine records from the Iberian margin and western Mediterranean suggests that major events of ice rafted debris deposition, related to southward migrations of the polar front, match the harshest periods in central Italy. This indicates strong teleconnections between Northern hemisphere ice sheet dynamics, North Atlantic oceanic conditions and Mediterranean continental hydrology.

1. Introduction

The marine isotope stage (MIS) 12–11 interval (460–380 ka, Railsback et al., 2015) encompasses the most extreme conditions of the last half million years of Earth's climate history, and occurred at a time when orbital configuration was similar to the most recent glacial-interglacial cycle (i.e., similar amount of solar radiation due to similar orbital eccentricity, Healey and Thunell, 2004). In particular, the glacial MIS 12 stands out as one of the most severe periods of the Late Quaternary, based on both marine (e.g., Shackleton, 1987; Raymo, 1997; Rohling et al., 1998; Poli et al., 2000; Bauch and Erlenkeuser, 2003; Toucanne et al., 2009; Billups et al., 2006; Lambert et al., 2012; Bard and Rickaby, 2009; Stein et al., 2009; Lang and Wolff, 2011; Girone et al., 2013; Naafs

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http://dx.doi.org/10.1016/j.quascirev.2015.11.015
0277-3791/

et al., 2013, 2014; Vásquez-Riveiros et al., 2013; Rohling et al., 2014) and continental archives (e.g. Tzedakis et al., 2003; Hughes et al., 2006, 2007, 2010; Russo-Ermolli et al., 2010), as well as in the Antarctica ice cores (Masson-Delmotte et al., 2010). Global ice volume was ~15% greater than during the last glacial maximum (LGM; ~30–20 ka), resulting in sea-level about 140 m below present one (e.g. Shackleton, 1987; Rohling et al., 1998, 2014; Lisiecki and Raymo, 2005). On the contrary, during the MIS 11, sea level is estimated to have been much higher than the current sea level. Even if sea level estimates are difficult to reconstruct, it has been suggested that during MIS 11 it may have reached 20 m above that of the present day (e.g. Hearty et al., 1999; Rohling et al., 2014), implying that ice caps were significantly smaller than during Holocene. Thus, glacial Termination V represents the highest-amplitude climatic shift since 600 ka (e.g. Howard, 1997; Healey and Thunell, 2004). Paradoxically, this large glacial/interglacial change took place during a period when insolation changes were relatively small and precessional forcing was low (Imbrie and Imbrie, 1980; Raymo, 1997).

Evidence for millennial-scale instability during MIS 12 has been provided from both high latitude and sub-tropical North Atlantic marine records (e.g. Oppo et al., 1998; McManus et al., 1999; Poli et al., 2000; Chaisson et al., 2002; Haley and Thunell, 2004; Billups et al., 2006; Stein et al., 2009; Voelker et al., 2010; Rodrigues et al., 2011; Vásquez-Riveiros et al., 2013; Naafs et al., 2013, 2014). The periodic occurrence of major ice-rafting events, analogous to the Heinrich Events during MIS 4-2 (e.g. Hemming, 2004), is observed within MIS 12 in high latitude North Atlantic marine cores (e.g. Oppo et al., 1998; McManus et al., 1999; Hodell et al., 2008; Vásquez-Riveiros et al., 2013). Major ice-rafted debris (IRD) peaks were recognized also in the eastern and western mid-latitude North Atlantic (e.g. Stein et al., 2009; Voelker et al., 2010; Naafs et al., 2014) as far as south 34°N (Poli et al., 2000). This suggests that, because of the large ice-volume, the polar front would have migrated further south compared with the Last Glacial, directly influencing the mid-latitude North Atlantic (e.g. Poli et al., 2000; Billups et al., 2006; Naafs et al., 2014) and the Mediterranean sea hydrography (Girone et al., 2013), with an overall imprint on the global climate (Naafs et al., 2014). However, paleoclimatic reconstructions for MIS 12 outside the North Atlantic region are scarce and mostly confined to the marine realm (e.g. Lourens, 2004, Bard and Rickaby, 2009; Maiorano et al., 2013; Girone et al., 2013), making it difficult to evaluate the extra-regional expressions of MIS 12 climate variability. In particular, only few studies document climatic changes during this time interval in the Mediterranean region, especially from continental archives (e.g. Tzedakis et al., 2003, 2006; Hughes et al., 2006, 2007; Russo-Ermolli et al., 2010; Blain et al., 2012). Nevertheless, these data suggest that the MIS 12 maximum was particularly harsh in this region, with several small ice caps over the Balkans (Hughes et al., 2006) and major reductions in the arboreal vegetation of southern Europe (e.g. Tzedakis et al., 2003, 2006; Russo-Ermolli et al., 2010).

Many paleoclimatic records in the Mediterranean have highlighted that changes in North Atlantic oceanic conditions were expressed in the region mainly as hydrological variations, with cold North Atlantic events and weakened Meridional Overturning Circulation (MOC) coinciding with drier conditions in the basin (e.g. Tzedakis et al., 2003; Drysdale et al., 2005, 2007, 2009; Regattieri et al., 2014a,b; 2015). This applies to both long-term glacial-interglacial changes and millennial-scale variability. Specifically, the sensitivity of the central Mediterranean hydrology to North Atlantic conditions is well documented for the Holocene (e.g. Zanchetta et al., 2007a, 2014; Regattieri et al., 2014a), the Last Interglacial complex, i.e., the MIS 5 (e.g. Drysdale et al., 2005, 2007, 2009; Milner et al., 2012, 2013; Leng et al., 2013; Regattieri et al., 2014b, 2015) and the MIS 19 (Giaccio et al., 2015). However, the relationships between high-latitude climate and hydrological variability in the Mediterranean are still poorly known for the Lower-Middle Pleistocene (e.g. Tzedakis et al., 2003; Girone et al., 2013). With the aim to extend our knowledge on the North Atlantic-Mediterranean climatic teleconnections for the Middle Pleistocene period, we have assembled a multiproxy record (carbonate $\delta^{18}O$ and $\delta^{13}C$, $CaCO_3$ content and XRF data) of hydrological and environmental variability from a lacustrine sedimentary succession in the Sulmona basin (central Italy, Fig. 1), tephrochronologically constrained to the MIS 12–11 interval. The sequence has allowed us to reconstruct regional hydrological changes occurring at the orbital scale (i.e., glacial/interglacial transition), to investigate the occurrence of millennial-scale variability during MIS 12, and to explore teleconnections between Mediterranean hydrological variability and North Atlantic oceanic conditions during glacial inception, full glacial and deglaciation times.

2. Site description

2.1. Tectonic and stratigraphic setting

The Sulmona basin (Fig. 1) is a block-faulted intermontane depression formed during the Plio-Quaternary extensional tectonic phase (e.g. D'Agostino et al., 2001) and presently bounded by the active Mount Morrone, NW-SE-trending fault system (Gori et al., 2011; Galli et al., 2015) (Fig. 1). During the late Early-Upper Pleistocene, the basin was filled by a thick lacustrine-fluvial succession (e.g. Cavinato et al., 1994; Cavinato and Miccadei, 1995, 2000; Miccadei et al., 1998; Giaccio et al., 2012, 2013a). Lacustrine environment is documented until the Late Pleistocene (Giaccio et al., 2012; Regattieri et al., 2015), followed by alluvial-fan deposits of the Last Glacial (Gori et al., 2011) and minor Holocene colluvial and alluvial-fan episodes (Giaccio et al., 2012; Galli et al., 2015) (Fig. 1). The whole sedimentary infill of the Sulmona basin is very rich in tephra layers, which document the history of Italian explosive volcanoes and, through radiometric dating, allow a precise chronology of the successions to be established (e.g. Giaccio et al., 2012, 2013b, 2015; Sagnotti et al., 2014; Galli et al., 2015; Regattieri et al., 2015). Three main unconformity-bounded units compose the Sulmona Pleistocene succession, each chronologically constrained by magnetostratigraphy, tephrostratigraphy and an $^{40}Ar/^{39}Ar$ chronology to the intervals of ~814->530 ka (unit SUL6), ~530-<457 ka (unit SUL5), and ~110–14 ka (unit SUL4-3) (Giaccio et al., 2012, 2013a,2013b; Sagnotti et al., 2014; Regattieri et al., 2015) (Fig. 1). The succession investigated in the present study belongs to unit SUL5, which was briefly described by Giaccio et al. (2009). For the present study, we investigated the ca. 12.5 m-thick interval of the SUL5 unit recovered in the upper part of a borehole (SC1, Giaccio et al., 2013a; Sagnotti et al., 2014) drilled throughout the SUL5 and SUL6 units. Unit SUL5 is characterized by the occurrence of several tephras (Fig. 1), such as: the Tufo di Bagni Albule (~527 ka), the Ash Fall-a (~517 ka) and the Pozzolane Rosse (~457 ka) marker layers from the Colli Albani caldera (Freda et al., 2011; Giaccio et al., 2013b) and the Fall A tephra (~500 ka) from the Sabatini volcanic complex (Giaccio et al., 2014; Galli et al., 2015). The SUL5 unit is separated from the SUL6 unit by an unconformity that, according to the local paleo-geomorphological setting, can be represented by an erosional surface and/or a reddish-brownish paleosol.

2.2. Climatic and hydrological settings

The Apennines represent a natural barrier in the central Mediterranean which traps eastward moving moisture sourced from the Atlantic and the western Mediterranean. At present, about 60% of