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A Last Interglacial record of environmental changes from the Sulmona Basin (central Italy)

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A R T I C L E   I N F O

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A B S T R A C T

Here we present a multiproxy record ($\delta^{13}C$, $\delta^{18}O$, major and minor element composition, mineralogy, and low-resolution biogenic silica content) from a lacustrine succession in the Sulmona Basin, central Italy. Based on previous tephrochronological constraints and a new $^{40}Ar/^{39}Ar$ dating of a tephra matching the widespread X-6 tephra, the record spans the ca. 129–92 ka period and documents at sub-orbital scale the climatic and environmental changes over the Last Interglacial and its transition to the Last Glacial period. The $\delta^{18}O$ composition is interpreted as a proxy for the amount and seasonality of local precipitation, whereas variations in elemental and mineralogical composition are inferred to reflect climatic-driven changes in clastic sediment input. The observed variations are consistent among the different proxies, and indicate that periods of reduced precipitation were marked by enhanced catchment erosion, probably due to a reduction in vegetation cover. The first part of the Last Interglacial shows the most negative $\delta^{18}O$ values. Comparison with pollen records from the Mediterranean suggests a greater seasonality of the precipitation at this time. At millennial-to-centennial time scales, comparison of the Sulmona record with speleothem $\delta^{18}O$ records from central Italy highlights a highly coherent pattern of hydrological evolution, with enhanced variability and similar events of reduced precipitation consistently recorded by each isotope record. The observed intra-interglacial variability can potentially be linked, within the uncertainties associated with each age model, to similar variations observed in sea-surface temperature records from the Mediterranean and the North Atlantic, suggesting a link between Mediterranean hydrology and North Atlantic temperature and circulation patterns that persists during periods of low ice volume.

1. Introduction

The climate of the Last Interglacial (LIG), roughly corresponding to marine isotope stage (MIS) 5e and the Eemian interglacial in the European pollen stratigraphy (Govin et al., 2015 and references therein), has many features in common with model projections of future climate, because during this period much of the Earth experienced a climate warmer than present (e.g. Kukla et al., 2002). Although orbital parameters for MIS5e are quite different from that of the Holocene (e.g. Berger and Loutre, 1991), the LIG is a potential analog for projected future global warming and is thus an interesting study case for evaluating the climate and environmental responses during periods characterized by an excess of warmth. From this perspective, of particular interest are intra-interglacial millennial-scale climate changes. Evidence of abrupt climatic variations are well documented in several LIG records from North Atlantic marine sediments and Greenland ice (e.g. Oppo et al., 2001, 2006; Galaasen et al., 2014; Pol et al., 2014) and some seem to have propagated into the Mediterranean basin (Sáñchez-Goñi et al., 1999; Martrat et al., 2004, 2014; Sprovieri et al., 2006; Kandiano et al., 2014). Potential expressions of this oceanic driven instability have also been recognized in central Europe (e.g. Sirocko et al., 2005; Seelos and Sirocko, 2007; Seelos et al., 2009), as well as in the Mediterranean

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region (e.g. Tzedakis et al., 2003; Brauer et al., 2007; Drysdale et al., 2007; Couchoud et al., 2009; Milner et al., 2013, 2016; Regattieri et al., 2014a, 2016a; Vogel et al., 2010; Lézine et al., 2010; Zanchetta et al., 2016a). However, the effects of such changes on climate and ecosystems of the European continent are still poorly known and understood (Galaasen et al., 2014; Govin et al., 2015). Identification, correlation and evaluation of the climatic expressions of LIG millennial-scale variability outside the North Atlantic region remain unclear or largely based on postulated temporal phase relations. Addressing these issues requires the compilation of regionally representative, high-resolution and independently dated paleoclimatic records. Lacustrine successions deposited in tectonic basins of the Apennines are capable of fulfilling these requirements (Giaccio et al., 2015a, 2015b; Regattieri et al., 2015, 2016b; Russo-Ermolli et al., 2010) due to the high sensitivity of the local sediment properties, and particularly of the oxygen stable isotope composition of authigenic carbonates ($\delta^{18}O$), to hydrological and environmental changes. Moreover, these archives offer the possibility to develop independent age models based on the $^{40}Ar/^{39}Ar$ geochronometer, that can be directly or indirectly applied to the volcanic ash layers (tephra). These tephra layers, deriving from the intense activity of Quaternary peri-Tyrrhenian explosive volcanism, are systematically found in the lacustrine sediments of the Apennine intermountain basins (e.g. Giaccio et al., 2012; Petrosino et al., 2014; Giaccio et al., 2017).

Of the central Italian continental basins, Sulmona has already been recognized as a promising archive. The sedimentary record is underpinned by a robust tephrochronological framework (Giaccio et al., 2012, 2013a, 2013b), and provides important insights into climate and environmental evolution of the central Mediterranean and the linkages with extra-regional climate variability (Giaccio et al., 2015a; Regattieri et al., 2015, 2016b). In particular, the stable isotope profiles ($\delta^{18}O$ and $\delta^{13}C$), $CaCO_3$ content and tephrostratigraphy of the Popoli section (POP hereafter), documenting Early Last Glacial climate fluctuations (from ca. 115 to ca. 90 ka), highlight strong Mediterranean–North Atlantic climate teleconnections as well as the influence of low-latitude circulation patterns (Regattieri et al., 2015). In order to explore the environmental-hydrological changes over the entire early-to-middle MIS 5 (MIS 5e to MIS 5c, ca. 129–92 ka), and in particular the intra-LIG millennial scale variability, in this study we extended through a multiproxy approach ($\delta^{18}O$ and $\delta^{13}C$ analysis, $CaCO_3$ content, biogenic silica content, XRF major and minor element composition, XRD-based bulk mineralogy and $^{40}Ar/^{39}Ar$ geochronology) the investigation of the POP section back to ca.129 ka. The results provide a longer and richer multi-proxy record, which allows a detailed reconstruction of local environmental change and give insights on potential relations with the extra-regional millennial-scale variability during the full LIG and at the LIG/Last Glacial transition.

2. Study site

2.1. Geological and stratigraphic setting

An up-dating stratigraphic framework of the Sulmona Basin (Fig. 1) is provided in Giaccio et al. (2009 with amendments in Giaccio et al., 2013a; 2012), Galli et al. (2015) and Regattieri et al. (2015, 2016b), to which the reader is referred for integrating the information summarized here. The Sulmona Basin (Fig. 1) is a block-faulted intermontane depression which accumulated lacustrine sediments discontinuously during the Quaternary (e.g. Cavinato et al., 1994; Cavinato and Miccadei, 1995, 2000; Miccadei et al., 1998; Giaccio et al., 2012, 2013a). The exposed Pleistocene succession in the Sulmona basin is composed of three main unconformity-bound, alluvial-fluvial-lacustrine units (SUL 6, SUL 5 and SUL 4-3), chronologically constrained by magnetostratigraphy and tephrochronology (Giaccio et al., 2012, 2013a, 2013b, 2015a; Sagnotti et al., 2014, 2016). The interval investigated here (POP section) corresponds to the lowermost part of the SUL 4-3 unit (ca. 110–14 ka, Fig. 1). The outcropping portion of the POP section (~19 m from the top of the lacustrine deposits; Fig. 1) has been described by Giaccio et al. (2012), with particular attention to its tephrostratigraphy, and by Regattieri et al. (2015), who presented the stable isotope results ($\delta^{13}C$ and $\delta^{18}O$) from the lacustrine carbonates and extended the tephrostratigraphic investigation down to ~27 m of the outcrop depth (Fig. 1) by means of a trench and a borehole (Fig. 1).

Six tephras were previously recognized in the POP section, named from top to the base POP1, POP2, POP2a, POP2b, POP3 and POP4 (Figs. 1 and 2). Descriptions, tephrostratigraphic correlations with other archives and ages for these tephras have been provided by Giaccio et al. (2012) and Regattieri et al. (2015) and are summarized in Table 1. Here, we present a new $^{40}Ar/^{39}Ar$ age for tephra POP4, which chemically matches the X-6 tephra (Regattieri et al., 2015) of the marine tephrostratigraphic schemes of Keller et al. (1978). This tephra shows a large dispersal area covering the central Mediterranean and the Balkans (Bourne et al., 2015; Donato et al., 2016, Insinga et al., 2014, Iorio et al., 2014; Leicher et al., 2016; Lézine et al., 2010; Petrosino et al., 2016; Sulpizio et al., 2010; Vogel et al., 2010).

2.2. Climatic and hydrological settings

The Sulmona Basin is located in the central Apennines (Fig. 1) at a mean elevation of ~400 m a.s.l. The current mean annual temperature is 13.7 °C and the mean annual rainfall is 870 mm (data from the Sulmona meteorological station). About 60% of the region's precipitation has a North Atlantic origin, especially during winter, whereas the other 40% is mainly sourced from the western Mediterranean (Bard et al., 2002). The present hydrology of the basin is dominated by large perennial springs fed by the extensive karst systems hosted in the mountains surrounding the basin, where precipitation reaches values of about 1200 mm/year at the summits. These springs are mainly fed by recharge at 1200–1500 m a.s.l. with minor input from higher altitudes (up to 2900 m a.s.l., Barbieri et al., 2005; Desiderio et al., 2005a, 2005b). Because they are recharged at higher altitude, the springs have a $\delta^{18}O$ composition lower than local precipitation (which is ~−7.13‰, data from L'Aquila station, Longinelli and Selmo, 2003). Discharge is higher during early spring due to snowmelt, lowering further the average $\delta^{18}O$ isotopic values of water recharging the basin (Falcone et al., 2008). Waters also have a higher $\delta^{13}C$ of dissolved inorganic carbon (DIC) compared with that of the more superficial springs due to longer water residence times and rock-water interactions within the karst (Falcone et al., 2008). These springs represented the main source also for the studied paleo-lake and, likely, hydrological conditions of the high-altitude catchment area dominated its recharge, both during drier and wetter periods (Regattieri et al., 2015, 2016b; Giaccio et al., 2015a).

3. Material and methods

3.1. Stratigraphy, sampling and stable isotope analyses

In the current study we present new results from a ~13.1 m-thick lacustrine interval recovered in the upper part of the ~60 m borehole described by Regattieri et al. (2015), which extends to ~40 m of the outcrop depth of the previous investigation (Fig. 1). At this depth (corresponding to ~23 m in core, Fig. 1), the lacustrine succession is interrupted by a hydromorphic paleosol with an upper Histic horizon, which marks the lowermost horizon investigated here. Below this peodogenic horizon (~1 m deep), the sedimentary succession continues, first with a thin layer of gravel and then, continuously to the core bottom, with greyish-greenish lacustrine-palustrine marls (Fig. 1). However, there are no chronological constraints to allow us to define either the length of the sedimentary hiatus (represented by a paleosol and gravel) or the age of the underlying lacustrine-palustrine