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THE SO-CALLED “4.2 EVENT” IN THE CENTRAL MEDITERRANEAN AND ITS CLIMATIC TELECONNECTIONS

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ABSTRACT**:** High-resolution isotopic analyses were performed on RL4 flowstone from Renella Cave (Alpi Apuane, central Italy), a speleothem studied previously at low resolution. The new data are discussed together with recently obtained data from Corchia and other localities in the central Mediterranean, to elucidate the possible origin and regional articulation of a climatic event centred at ca. 4.0 ka. This analyses indicates that central to southern Italy between ca 3.8 and 4.3 ka was characterized by drier conditions, whereas in Northern Italy the event seems less expressed or, as within the Alps, marked by cooler and wetter conditions. Several lines of evidence suggest that this event could be characterized by longer summer drought and possibly by little impact on precipitation during winter, even if this aspect needs to be explored in more detail. However, the event is particularly prominent in the northern sector of the African Monsoon domain, which has been robustly linked to southward shifts in the ITCZ; whereas its occurrence is uncertain on northern European latitudes. However, many proxies indicate that there aridification probably started some centuries earlier and culminated at ca. 4.0 ka. Taken as a whole, these data can be used to clarify the regional articulation of this event, but interpretations based on general circulation are still elusive.

Keywords: 4.2 event, speleothem, Mediterranean, Renella Cave

1. INTRODUCTION

The mid-Holocene was a time of profound worldwide climatic and cultural transformation in the human societies of the old world, particularly within the low latitudes (e.g. Roberts et al., 2011; Staubwasser and Weiss, 2006). The end of the mid-Holocene is often considered to be characterized by a widespread climatic event at around 4000 cal. yr BP, and it is used as formal boundary between Middle and Late Holocene (Walker et al., 2012). Evidence for this climatic deterioration (also known as the “4.2 ka event”) has been widely recognized from the Northern Hemisphere (e.g. Cullen et al., 2000; Marchant & Hooghiemstra, 2004; Booth et al., 2005; Drysdale et al., 2006). There is an increasing number of data supporting the notion that this climatic event also played an important role in the “collapse” of major ancient civilizations in India, China, Egypt, Mesopotamia and the Mediterranean (e.g. Weiss & Bradley, 2001; Staubwasser and Weiss, 2006; Zanchetta et al., 2013; Dixit et al., 2014; Welc & Marks, 2014; and references therein). For instance, catastrophic floods seem to have occurred in the Yellow River reaches, accompanied by severe drought that impacted local late Neolithic settlements (Liu & Feng, 2012; Huang et al., 2010, 2011), whereas a dramatic reduction in Nile discharge and drought may have produced severe conditions in ancient Egypt (e.g. Welc & Marks, 2014 and references therein). The change in Nile flow and the channeling and drainage of the delta for agricultural purposes produced a shift from a river-dominated to a more wave-influenced delta, chronologically placed at ca. 4000 yr cal BP (Anthony et al., 2014). More classical is the idea of the “collapse” of the “Akkadian empire” as related to drought at this time (Weiss et al., 1993; Cullen et al., 2000).

In this paper we discuss the climatic changes that occurred at around 4 ka in the frame of new evidence recently collected in the Central Mediterranean and new high-resolution isotopic data from Renella Cave (Apuan Alps, Northern Tuscany, Fig. 1). At Renella, a low-resolution multiproxy record (Drysdale et al., 2006) has already indicated an important phase of decrease cave recharge at ca. 4 ka. Thanks to new high resolution data from Renella and recently published multiproxy data from nearby Corchia Cave (Regattieri et al., 2014a), we explore the possible correlations with high- and low-latitude proxy records for understanding the mechanisms behind the climatic changes at ca. 4 ka and their impact over the Central Mediterranean.

2. SITE DESCRIPTION

Renella Cave (44° 05’42’’ N, 10° 11’01’’ E) is a small, shallow cave located at the confluence of Canale Regolo and the Frigido River in the Alpi Apuane (central Italy, Fig. 1). The cave, which opens at 275 m a.s.l., has a predominantly horizontal development, for a total

Fig. 1 - Reference map. a) Location of palaeoclimatic records discussed in the text. b) Geological sketch of the Apuan Alps.

length of ca. 200 m (Fig. 2a). It has formed in Triassic metadolomite (Grezzoni Formation), close to the contact with the Palaeozoic phyllitic basement. The metadolomite beds dip almost vertically, and cave development follows WSW direction of the strike (Fig. 2a).

The region experiences a Mediterranean climate, with a predominantly North Atlantic influence as for most of the Apennines (López-Moreno et al., 2011), and a mean annual precipitation of ca. 2000 mm (Piccini et al., 2008). The mean annual temperature is ca. 13°C while mean monthly temperatures range from 23.1°C in July to 7.4°C in January (detailed information on internal cave stratigraphy can be found in Zhornyak et al., 2011).

3. MATERIAL AND METHODS

The flowstone RL4 (Fig. 2b), collected in the upper level of the Renella cave (Fig. 2b) and previously studied at low resolution by Drysdale et al. (2006), was micromilled at 200 μm increments using a micro-milling method (Drysdale et al., 2012). The stable isotope composition of the powders was measured on CO_2 gas released by reaction with 105% H_3PO_4 at 70°C, which was measured using an AP2003 mass spectrometer at the University of Newcastle, Australia. Isotopic results are reported using the conventional δ-notation in *per mille* (‰), with reference to the Vienna Pee Dee Belemnite (V-PDB) standard. Long-term analytical reproducibility ($\pm 1\sigma$) was ±0.05‰ and ±0.10‰ for carbon and oxygen,

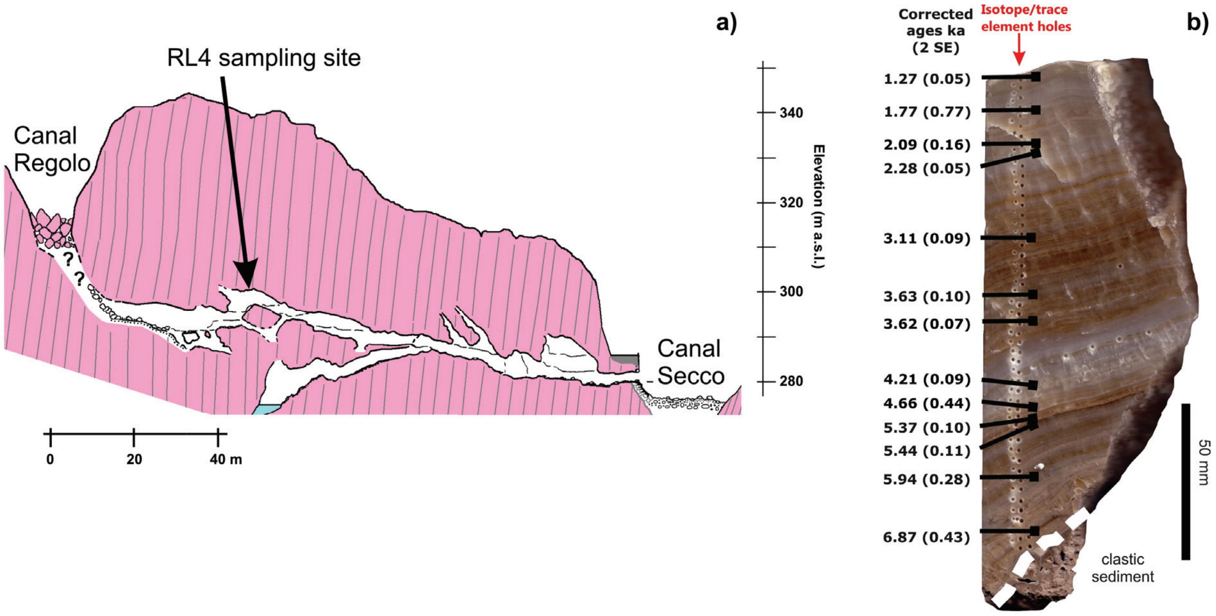

Fig. 2 - a) Geological section of the Renella cave. The RL4 position is also shown; b) RL4 section with U/Th dating position (Drysdale et al., 2006; Zhornyak et al., 2011).

respectively. Data are shown in Fig. 3.

An age model was obtained by interpolation between the previously published, low resolution, age model (Drysdale et al., 2006) and the new, high resolution, depth series. More details on dating are available on Drysdale et al. (2006) and Zhornyak et al. (2011), including age correction for clastic contamination.

For data comparison all records discussed in the text are reported to AD 2000. When discussing of the event at “4.2”, we generally intend the occurrence of a clear century-scale change in the proxy considered (i.e. prominent respect to the general trend) between ca. 3.8 and 4.2 ka, basically the range of ages of this event inferred from Renella Cave (see below).

Following the study by Drysdale et al. (2006), a discontinuous monitoring program was undertaken in the cave including cave water samples (drips, pools) for isotopic analyses. Preliminary data that are relevant for the purpose of the present study are also presented. The stable isotopic composition of water samples was determined at the IGG-CNR stable isotope laboratory in Pisa. The $\delta^{18}O$ of the water was determined after equilibration with CO_2 (Epstein and Mayeda, 1953). The isotopic measurements were made on a ThermoFinnigan MAT-252 mass-spectrometer. The iso-

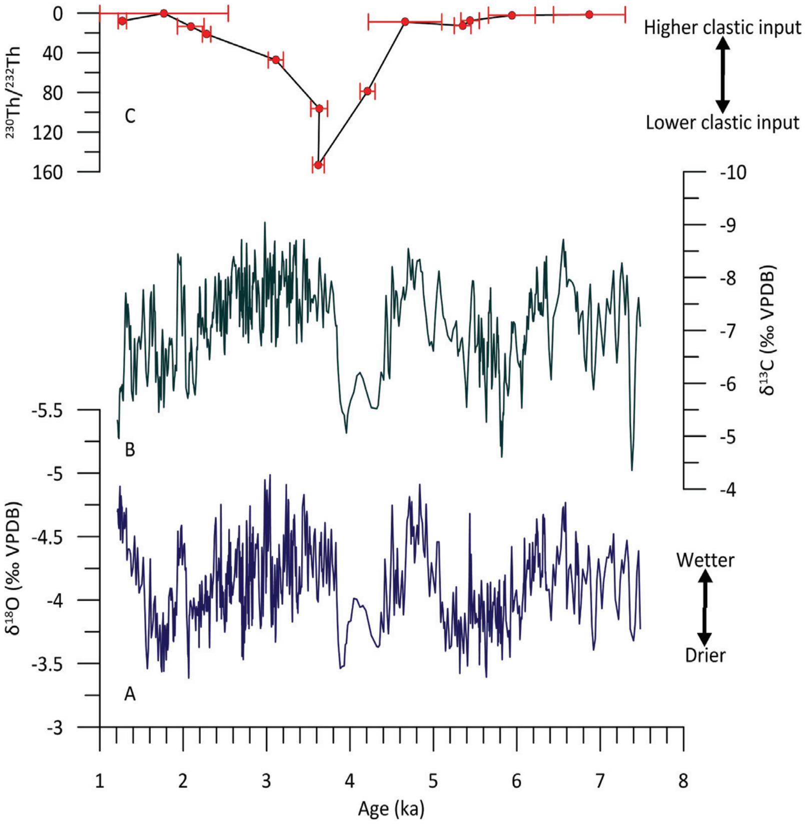

Fig. 3 - A) Carbon isotope composition of RL4 vs age; B) Oxygen isotope composition vs age; C) [$^{230}Th/^{232}Th$] measured in RL4 (Drysdale et al., 2006).

topic composition of hydrogen (δ^2H) was determined by means of the H_2 generated by hydrolysis of water using Zn (modified after Coleman et al., 1982) and analysed by a Geo20-20 mass-spectrometer (Europa Scientific). Results are reported as δ values in units of parts per thousand (‰) relative to the V-SMOW (Vienna- SMOW) standard. Data are reported in Fig. 4 and Table 1.

4. RESULTS AND PROXIES INTERPRETATION

Figure 3 shows the new high-resolution $\delta^{18}O$ and $\delta^{13}C$ record from RL4 flowstone. $\delta^{13}C$ and $\delta^{18}O$ show some correlation (r^2=0.33). In Fig. 3 the [$^{230}Th/^{232}Th$] activity ratio is also shown (Drysdale et al., 2006; Zhornyak et al. 2011). The ratio between radiogenic and detrital Th indicates that ages around 4 ka has the lowest amount of clastic contamination. This shows that ages around this period have low correction and can be considered particularly precise and accurate. In addition it suggests a decrease of transport of clastic material from the catchment to the cave.

The new record shows a prominent increase in the $\delta^{18}O$ centered at ca. 4 ka and lasting ca. 0.5 ka, accompanied by a concurrent increase in $\delta^{13}C$. Higher $\delta^{18}O$ on the Apuan Alps calcite speleothem, in absence of large changes in the water composition of the oceans, are interpreted as due to decrease in precipitation (Drysdale et al., 2007; Zanchetta et al., 2007; Regattieri et al., 2014a, b). Interpretations of speleothem $\delta^{13}C$ records are more challenging because of the complex reactions involving soil CO_2, bedrock dissolution, and the reaction kinetics in the CO_2-H_2O-$CaCO_3$ system (e.g. Fairchild and Baker, 2012). Many processes, however, tend to drive the final $\delta^{13}C$ of speleothem in the same direction, at least in the middle latitudes. Elevated values of speleothems can be due to a decrease in soil-CO_2 productivity (e.g. Genty et al., 2003), usually associated with a reduction in rainfall and cooler climate. Reduction in recharge can also produce degassing along the fracture paths, with enhanced calcite precipitation occurring before drip waters reach the cave (e.g. Baker et al., 1997). Other effects can occur, like changes in the rate in the mineralization of labile vs. recalcitrant organic matter into the soil (Rudzka et al., 2011).

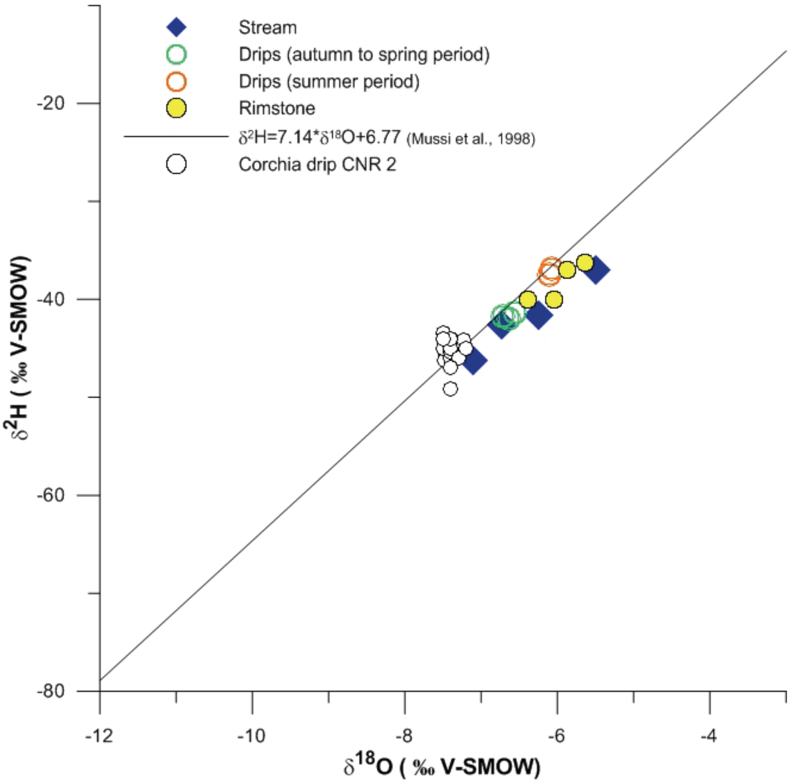

Fig. 4 - Isotopic composition (Hydrogen and Oxygen) of Renella Cave waters. The regional meteoric water line is also reported (Mussi et al., 1998)

Sampling site	date/period of sampling	$\delta^{18}O$ (‰V-SMOW)	δ^2H (‰V-SMOW)
Stream	05/06/2009	-5.5	-37
Stream	09/11/2009	-7.1	-46
Stream	22/07/2010	-6.7	-43
Stream	04/01/2013	-6.2	-42
Rimstone	05/06/2009	-5.6	-36
Rimstone	09/11/2009	-5.9	-37
Rimstone	22/07/2010	-6.4	-40
Rimstone	04/01/2013	-6.1	-40
Drip RLW-1	autumn 2009 - spring 2010	-6.6	-41
Drip RLW-2	autumn 2009 - spring 2010	-6.6	-42
Drip RLW-3	autumn 2009 - spring 2010	-6.7	-42
Drip RLW-1	summer 2010	-6.1	-37
Drip RLW-2	summer 2011	-6.1	-38

Tab. 1 - Isotopic data for waters collected in the Renella Cave.

5. DISCUSSION

Regional expression of the 4.2 event

Figure 5 shows the comparison with the Corchia mean anomaly record (Regattieri et al., 2014a), obtained by combining trace elements (Mg/Ca molar ratio) and stable isotopes results into an indicator of moisture levels in the cave recharge system. Both records indicate a clear decrease in the cave recharge starting at ca. 4.3 and ending at ca. 3.8 ka, therefore, lasting ca. 500 yr. The $\delta^{18}O$ from RL4 seems to indicate that drying may have started ca. 2 centuries earlier (ca. 4.5 ka), ending abruptly at 3.8 ka. At Corchia the tendency is less evident, and there is no evidence of the abrupt termination (Fig. 5). This would be due to the extremely different cave settings, with deep and large Corchia Cave system slowly responding, compared to smaller and shallower caves like Renella, a fact also noted comparing Corchia record with that from another small cavity on the Apuan Alps, the Tana che Urla Cave (Regattieri et al., 2014b). Interestingly, the event centered at 4 ka is not clearly expressed in the oxygen isotopic composition of CC26, but appears more prominent in the trace element data (Regattieri et al., 2014a), a point to which we return later.

Regionally, the lake record from Accesa (southern Tuscany, Fig. 1, Magny et al., 2007) shows a dramatic increase of lake level at ca. 4.6 ka, culminating at ca. 4.2 ka, followed by a short event of lake level drop between ca. 4-4.1 ka (Fig. 5). It is worth noting that the age model of Accesa record was partly based on tephrochronology (Magny et al., 2007). In particular, the Pomici di Avellino tephra, from Vesuvius, was recognized and an age of 4.3 ka was attributed to it. However, considering the current well established age for Pomici di Avellino eruption, i.e., ca. 3.8 ka (Passariello et al. 2009, Zanchetta et al., 2011; Sevink et al., 2011), a shift of the prominent low lake level centered at ca. 4.6-4.7 ka in the original age model (Magny et al., 2007) to ca. 4.1 ka, is required. With this new chronology, the Accesa record would show a prominent lake level lowering within the range of age of Corchia and Renella reduction in cave recharge (Fig. 5).

Several Italian pollens succession also record a distinct opening of the forest around this time (Sadori & Nar-

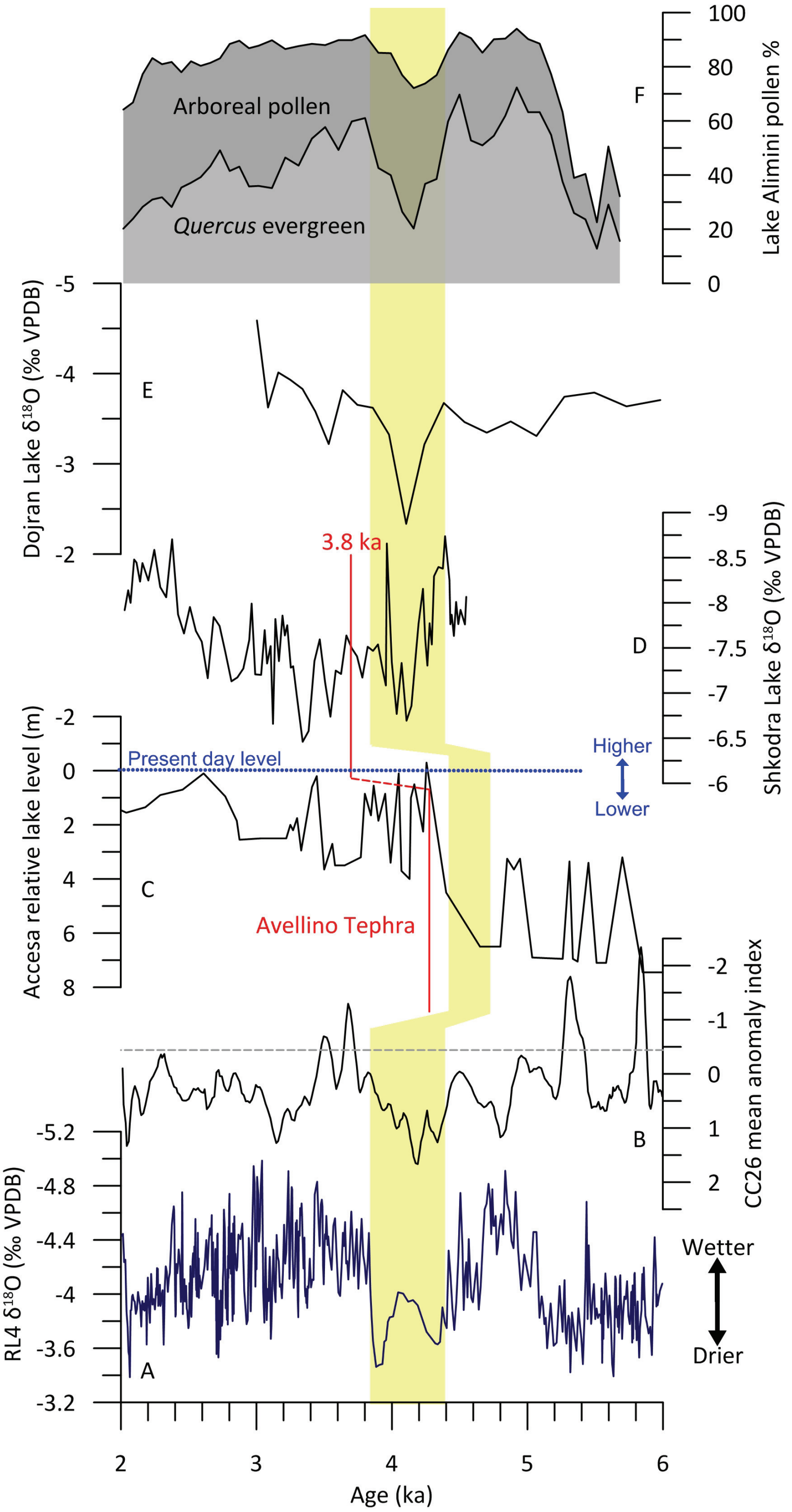

Fig. 5 - A) $\delta^{18}O$ records from RL4 flowstone; B) Mean anomaly index for CC26 stalagmite from Corchia Cave (Regattieri et al., 2014a); C) Lake level from Accesa (Magny et al., 2007). Note the position of Avellino tephra, reported with its correct age, and the chronology of the record. D) Shkodra $\delta^{18}O$ record (Zanchetta et al., 2012b); E) Pollen from Alimini Piccolo lake (Di Rita & Magri, 2009). For site location refers to Fig. 1.

cisi, 2001; Magri & Parra, 2002; Di Rita & Magri, 2009; Sadori et al., 2011), even if the chronology of this event in these pollen records is not always well constrained (Di Rita & Magri, 2009; Zanchetta et al., 2012a). As an example, poorly dated pollen successions from alluvial deposits facing the Apuan Alps indicate an opening of vegetation occurring roughly at this age as well as changes in fluvial activity (Bini et al., 2015; Sarti et al., 2015). A well-dated pollen record for this period is represented by Lake Alimini Piccolo (Di Rita & Magri, 2009), in southern Italy (Fig. 1) where a clear opening of the forest accompanied by a strong decrease in *Quercus*-dominated evergreen vegetation is recorded between 4.3 and 3.8 ka (Fig. 5). Interestingly, neither reliable anthropogenic pollen markers nor increasing trends in the charcoal curve are found at this time in the Alimini record, suggesting no relationships of this deforestation phase with human activity (Di Rita e Magri, 2009).

The δ^{18}O record from Lake Shkodra (Albania/Montenegro, Zanchetta et al., 2012b, Fig. 1) indicates a short and rapid drier phase at ca. 4.1 cal ka BP, preceded by a pronounced wetter period (Fig. 5). At Shkodra, this drying event is bracket by two tephra layers: Avellino from Somma-Vesuvius and Agnano Pomici Principali from Campi Flegrei (Zanchetta et al., 2012b). This tight tephrostratigraphic constraint has allowed us to define the beginning of this important climatic deterioration over the Apennine as coincident with the start of re-growth of the Calderone glacier (Abruzzo, central Italy) (Giraudi et al., 2011; Zanchetta et al., 2012a). In addition, Zanchetta et al. (2000) found a drastic change in the isotopic composition of pedogenic carbonate in the Campania region again between Agnano Mt. Spina and Avellino tephras, and interpreted this change as a temperature lowering of ca. 2°C. However, the pedogenic carbonate record is, by definition, rather discontinuous and from this record no precise consideration can be made on the duration of this period of climatic deterioration.

A short, prominent δ^{18}O positive peak at this time is found also in the record from Lake Dojran (Francke et al., 2015), confirming that this event is also traceable in the Balkans region (Fig. 5).

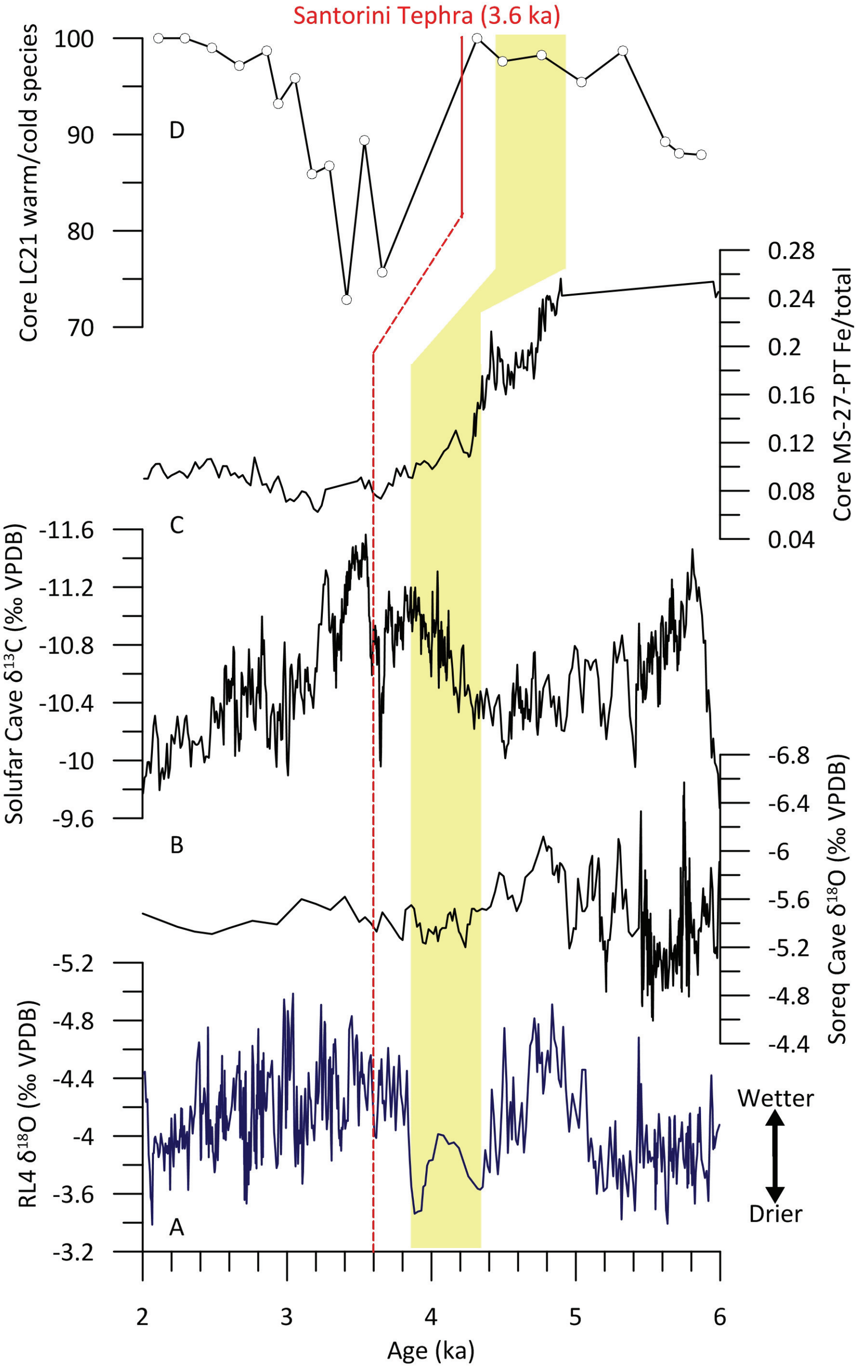

Fig. 6 - Correlation for δ^{18}O record of RL4 record (A) with Soreq δ^{18}O record (data from Bar-Matthews & Ayalon 2011) (B); δ^{18}O record Sofular Cave (Göktürk et al., 2011) (D); Fe content from marine core MD5-27 (Revel et al., 2010) (E); Percentage of marine warm foraminifera species in core LC21 (Rohling et al., 2002). The position of Thera tephra (now dated at ca. 3.6 cal ka BP) is also reported.

From the eastern Mediterranean, it is interesting the correlation with Soreq Cave (Fig. 6, Bar-Matthews et al., 1996, 1999; Bar-Matthews & Ayalon 2011). Here the δ^{18}O record, which is interpreted similarly to Alpuan Alps (i.e., affected by strong hydrological imprint), shows a long-term trend with an inferred progressive drying since ca. 4.7 ka, with poorly expressed phases of higher δ^{18}O centered at 4.2, 4 and 3.8 ka. However, in contrast with Renella, the isotopic values at Soreq never returned at the previous values. In the NE of Mediterranean climate boundaries, Sofular cave isotopic records (Fig. 1, Göktürk et al., 2011) show a quite different situation (Fig. 6). Here the δ^{13}C record, which is considered the best hydrological indicator (Göktürk et al., 2011), shows a progressive decreasing since ca. 4.5 culminating at ca. 3.8 ka. According to the interpretation of Göktürk et al., (2011) this would indicate a progressive increase of cave recharge (i.e. increasing of precipitation) and/or temperature. Towards northern Italy, δ^{18}O record from Grotta Savi (Figs. 1, 7) does not show particular changes at that time (Frisia et al., 2005), similar to the δ^{18}O record from Grotta di Ernesto (Scholz et al., 2012). At Savi, a dependance of δ^{18}O on temperature is suggested (Frisia et al., 2005), therefore no significant temperature changes at that time seem to be recorded. Similarly no significant changes are observed at Grotta di Ernesto (Scholz et al., 2012), although the dependence of the δ^{18}O with temperature/amount of rainfall is less clear.

At Spannagel Cave, the δ^{18}O record (also called COMNISPA II, Fig. 1, Fohlmeister et al., 2013) shows a long-term trend of increasing values, culminating between ca. 3.9 and 4.2 ka. The δ^{18}O variations during the Holocene are seen as principally due to the response in temperature (Mangini et al., 2006; Vollweiler et al., 2006, Fohlmeister et al., 2013), even if this link is probably complex. Therefore, it seems to indicate a decrease in temperature over the NE Alps for the period considered. At Lago di Ledro (Fig. 1), lake-level oscillations reconstructed by Magny et al. (2012) indicate a prominent high stand between 3.8 and 4.5 ka, interrupted by a short and poorly pronounced low lake level at 4.0 ka. At Lake Frassino, the relatively low resolution of the δ^{18}O records does not allow to infer particular trends at that time (Baroni et al., 2006).

Overall, the presented archives show a regionally complex climate pattern. Some archives indicate increasing humidity and probably colder conditions for northern Italy and the Alps, even if invariant conditions appear to be recorded in other archives in the southern Alps. Over the Alps, glaciers seem to advance in a period roughly centred at ca. 4 ka (see figure 4 of Wanner et al., 2008 and references therein), whereas central-southern Italy and the southern Balkans show a marked drier phase. Although very few records are considered here, Turkey and, in general, eastern Mediterranean climatic patterns at that time are more complex. Finné et al. (2011) report a compilation of many records from this part of the Mediterranean, concluding that although aridity was widespread around 4200 yrs BP in the eastern Mediterranean region, there is not enough evidence to support the notion of a single climate event with rapidly drying conditions in the region. Part of this complexity can arise from discrepancy in age models. Indeed, in some cases it is indisputably demonstrated that differences in age models between archives are too large to ensure the precise correlation of events (Zanchetta et al., 2011; 2012ab). This also impacts our estimation on the duration of the event in different records. On the other hand, our understanding of proxy records in some case is incomplete. For instance, there could be an excessive use of pollen data for some regions, like the records used by Finné et al. (2011) for inferring past precipitation and temperature regime. This because the human impacts on the natural environment and vegetation since the Neolithic likely reduced the reliability of these climatic reconstructions (e.g. Roberts et al., 2004, 2008, 2010).

Connection between lower and high latitudes

According to the re-analyses and review of globally distributed proxy records, Wanner et al. (2011) failed to clearly identify a prominent event between ca. 3.8 and 4.2 ka. Similarly, a compilation and re-analyses of several different proxy data sets from the Scandinavia region (Seppä et al., 2009) revealed no significant changes for the period considered, whereas a prominent cooling and wetter conditions appear to have occurred between 3800 and 3000 yr cal BP. Detailed studies from peat-based records in Great Britain and Ireland suggest no regionally coherent, prolonged phase of wetter and/or colder climatic conditions associated with a 4.2 ka event in Great Britain and Ireland (Roland et al., 2014). According to Roland et al. (2014), and consistent with the finding of Seppä et al. (2009), the lack of a coherent 4.2 ka event in Great Britain and Ireland implies that the dominant forcing mechanisms of the period of change may not lie in the North Atlantic, or at least that any atmospheric-oceanic circulation changes in the region may not have been severe enough to register change in the peatland archives. Indeed, only a modest increase of Ice Rafted Debris in the Subpolar North Atlantic occurs at the time (Bond et al., 1997).

Comparison of the Renella and Corchia records with the Hólmsá loess profile in Iceland (Jackson et al., 2005), where grain size is regarded as a proxy for the strength of westerly flow, indicates that at ca. 4 ka westerly wind strength was generally low in the higher latitudes of Europe (Fig. 8). This suggests that the portion of vapor originating in the North Atlantic and responsible in part for cyclogenesis in the western Mediterranean, particularly over Genoa Gulf and Apuan Alps (Reale and Lionello, 2013), was not particularly reduced (Fletcher et al., 2013; Zanchetta et al., 2014), at least during winter. Considering the negative relation between meteoric precipitation over Apennine and North Atlantic pressure patterns (López-Moreno et al., 2011), this would indicate that a convincing explanation for a decrease in the recharge in the Apuan Alps is not related to changes in winter conditions. On the other hand, when westerlies in northern Europe are weak (weaker zonal flow), this allows the penetration of Arctic air into the middle latitudes and may favor colder conditions in the Alps, allowing glaciers to advance. This cooling can also reduce the sea temperatures for a longer period of time, reducing the amount of evaporation in the following seasons.

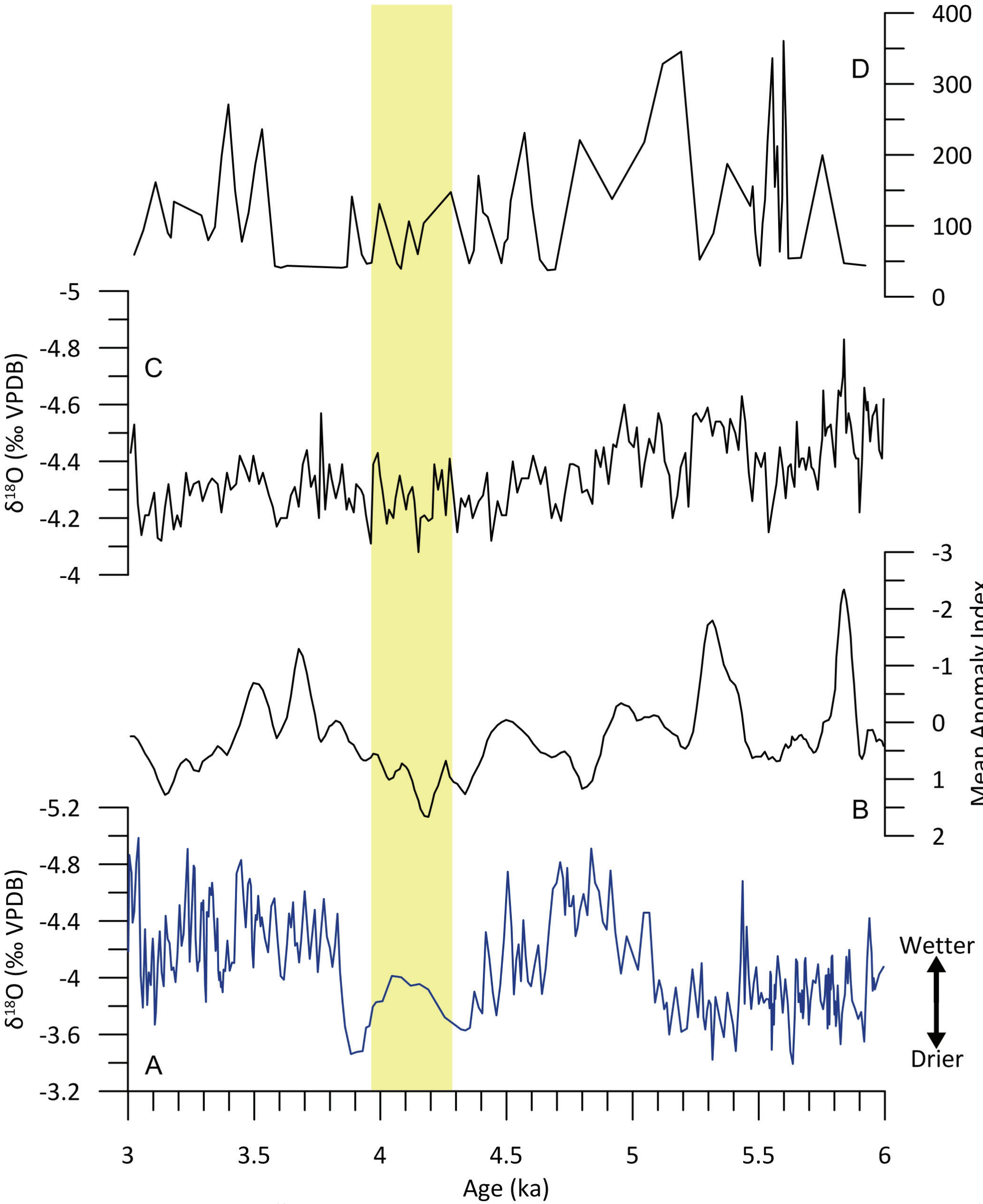

Fig. 8 - Comparison among Renella RL4 $\delta^{18}O$ record (A, this paper), CC26 mean anomaly index (Regattieri et al., 2014a, B), $\delta^{18}O$ record of CC26 (Corchia cave, Zanchetta et al., 2007, C), and Hòlmsà grain-size records (Jackson et al., 2005, D).

Previously, Di Rita & Magri (2009) and Zanchetta et al. (2011) have suggested that this event may have been characterized by long summer drought due to a progressive persistence of the Azores High over the western Mediterranean instead of significant changes during winter. This can be indirectly supported by pollen evidence (Di Rita & Magri, 2009), which suggests changes in the prevailing winds based on the presence of *Cedrus* pollen grains in the Latium pollen succession, indicative of a likely source from North Africa (Magri & Parra, 2002).

Longer summers (basically at the expense of spring and autumn seasons) compared to winter, can affect the isotopic budget of our caves, and can additionally help in explaining our isotopic records. It is well known that, at middle latitudes, summer precipitations have higher isotopic composition (Fricke & O'Neil 1999), and in these conditions (i.e. enhanced summer heating related to cloud-free weather) it is likely that the Western Mediterranean can supply a more evaporation-affected component to the precipitation, producing precipitation with higher isotopic composition (Celle-Jeanton et al., 2001).

So, along with a decrease in total precipitation, during summer these resulted ^{18}O enriched. In this frame, we return to the question of why the isotopic composition of CC26 from Corchia lacks a significant expression of reduced precipitation, which on the contrary is so evident in the RL4 record and in the Corchia multi-proxy index. Renella is a small cave where drips show a seasonal variability not evident in the drips of Corchia, which has a very deep, well-mixed plumbing system (Piccini et al., 2008; Baneschi et al., 2011; Fig. 4). On the other hand, trace elements at Corchia are more affected by re-routing effects, changes in residence time and mixing than by the same factors that affect the isotopic composition of drips (Regattieri et al., 2014a). Therefore, if for some reason calcite precipitation in Renella is skewed towards summer conditions, this will immediately affects the isotopic signal, whereas in Corchia this would be dampened by mixing of the plumbing system dominated by winter recharge. It is also possible that higher altitude cave site was less susceptible to reduced rainfall and only records a modest reduction, compared to Renella. However, the strong orographic effect offered by Apuan Alps should prevent this (Piccini et al., 2008).

Indirect evidence that an event at ca. 3.8-4.2 ka in the Mediterranean is more pronounced in proxy records susceptible to changes in summer rather than changes in winter precipitation is provided by the paleoclimatic record of core LC21 in the Aegean Sea (Fig. 1, Rohling *et al.*, 2002), although the resolution is quite low compared to the interval of interest. In the LC21 record there is no evidence of the 4.2 ka event in the percentage of warm-water foraminifera species, which are interpreted as indicators of winter temperatures affected by the incursion of cold air masses from Siberia (Fig. 6). The proxy record of Fig. 6 is believed to be indicative of the winter temperature (Rohling et al., 2002). Note that the position of the Thera tephra in the LC21 record, now radiocarbon dated at ca. 3.6 cal ka BP (Friedrich *et al.*, 2006; Manning *et al.*, 2006) rules out the possibility of confusion between the 4.2 ka event and the prominent event at ca. 3.4-3.6 ka BP (Zanchetta et al., 2011). This is consistent with the notion that the 4.2 ka event is not particularly prominent in proxies indicating winter temperature.

At lower latitudes the presence of dust spikes in the Arabian sea and in Kilimanjaro ice cores is strongly suggestive of aridification due to changes in the position of the Intertropical Convergence Zone -ITCZ- (Cullen et al., 2000; Thompson et al., 2002). Marshall et al. (2011) reported recently a substantial long-term drying for Lake Tana, the source of the Blue Nile, culminating in a low stand at ca. 4.2 ka, interpreted as driven by a progressive southward shift of the ITCZ during summer. According to the Ti concentrations, used as a proxy for the clastic input within the lake and thus as an indirect measure of summer monsoon intensity, detrital influx started to decrease well before at ca. 4.8-4.9 ka. A major dry spell is also documented at 4.2-4.0 ka BP in the northern monsoon domain of Africa as reported in lake level and stable isotopes data from many lakes (Gasse, 2000).

Also, the high-resolution Fe record from MS27PT marine core recovered in hemipelagic sediments deposited on the Nile margin (Revel et al., 2010) is considered a proxy for the East African monsoon regime intensity over Ethiopia. This record (Fig. 6) shows a consistent drop at ca. 4.3 ka, which never recovered afterwards, which indicates a reduction in the monsoon intensity and Blue Nile recharge at that time.

So, generally at ca. 4.3-4.5 ka in Africa a progressive southward shift of the ITCZ seems to occur, reaching a maximum of drying at ca. 4.2-4.0 ka BP. This event seems progressively recorded in the Mediterranean and in particular in central Mediterranean. The role of the ITCZ and African monsoon systems onto the summer conditions over the Mediterranean is well known from instrumental data and modelling (e.g. Gaetani et al., 2011) and it is supposed for millennial-scale events (e.g. Tzedakis, 2007; Sanchez-Goni et al., 2008; Regattieri et al., 2015). However, to find a precise mechanisms linking weakening and southward shift of African summer monsoon, evidence of increasing summer drought and/or southern circulation over central Mediterranean without significant changes in the North Europe is not an easy task. The 4.2 ka event was most likely caused by a complex set of interactions within the global ocean-atmosphere circulation system.

Booth et al. (2005), starting from current meteorological observation, has noted that widespread midlatitude and subtropical drought, associated with increased moisture at some high latitudes (however, not verified for the 4.2 event), has been linked in the instrumental record to an unusually steep sea-surface temperature gradient between the tropical eastern and western Pacific Ocean (La Niña) and increased warmth in other equatorial oceans. Similar SST patterns may have occurred at 4.2 ka, possibly associated with external forcing or amplification of these spatial modes by variations in solar irradiance or volcanism. In particular, Booth et al. (2005) suggested a link with Multidecadal Atlantic Oscillation (a mode of variability occurring in the North Atlantic Ocean that has its principal expression in the sea surface temperature field). However, boundary conditions at that time were probably different, with the oceanic polar front in the North Atlantic displaced southwards as suggested by IRD distribution (Bond et al., 1997). Magny et al. (2013) have suggested that the major palaeohydrological oscillation around 4500-4000 cal BP may be a non-linear response to the gradual decrease in insolation, with additional key seasonal and interhemispheric changes. We can conclude that, despite the geographical articulation of the event at 4.2 ka become much clear, the mechanisms behind this event remain elusive.

6. CONCLUDING REMARKS

Abrupt changes are part of natural climate variability and their investigation is fundamental for understanding the underlying driving factors, their potential impact and the projection of future climatic changes. The so-called “4.2 event” is of particular interest for its possible impact on past ancient civilizations. Revision on new data from Renella and Corchia caves and other data from the central Mediterranean indicate that in central to southern

Italy this event is characterized by drier conditions, whereas in northern Italy the event seems less expressed or, for example over the Alps, could be characterized by cooler, wetter conditions. Several lines of evidence suggest that this event would be characterized by a longer summer drought with possibly little impact on precipitation during winter, even if this aspect needs to be explored in more detail in the future, looking at different proxies. This event is particularly prominent in the African Northern Monsoon domain, which has been robustly linked to southward shift of the ITCZ, whereas the presence is uncertain on northern European latitudes. The composition of this climatic puzzle is still open and the mechanism behind this event still remains elusive.

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