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Coeval dry events in the central and eastern Mediterranean basin at 5.2 and 5.6 ka recorded in Corchia (Italy) and Soreq caves (Israel) speleothems

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ABSTRACT

Soreq (Israel) and Corchia (central Italy) Caves are located 2500 km far apart along the Mediterranean winter-storm track and are ideally suited for investigating past variations of winter rainfall in the Mediterranean region. Analyses of speleothem $\delta^{18}O$ records from both caves for the period between ca. 7 to 4 ka BP show some striking similarities for the ca. 6 and 4 ka interval, but lack agreement between ca. 7 to 6 ka BP. Two prominent isotopic excursions, argued to reflect relatively drier conditions, are centred at ca. 5.6 and ca. 5.2 ka. The 5.2 ka event lasts less than a century, whereas the 5.6 ka event extends from ca. 5.7 to 5.4 ka. A period of progressive drying is also apparent from ca. 5 to 4 ka. Another prominent event, reflecting wetter conditions, is recorded in both records at ca. 5.8 ka and seems to last several decades. The 5.6 and 5.2 ka events occurred within a period of higher deposition of haematite-stained grains in cores of the sub-polar North Atlantic, and correlation with the wind strength proxy record from Hólmsá loess profile in Iceland suggests that rainfall reduction was related to a reduced vapour advection from Atlantic towards the Mediterranean connected to northward shift in the Westerlies. A comparison with Alpine records, including the Spannagel Cave isotope record, suggests that dry events recorded at Soreq and Corchia caves may correspond to wetter (lake high stands) and cooler (glacier expansion) conditions in the Alpine region, indicating complex regional climate re-organization.

1. Introduction

Winter precipitation is the main source for recharging aquifers in the Mediterranean region (Bolle, 2003). The principal origin of winter precipitation for much of the Mediterranean coast is regional-scale North Atlantic synoptic systems that generate cyclogenesis primarily in the Gulf of Genoa and to a lesser extent in the Aegean Sea (Trigo et al., 2002). The reduction, or significant failure, of meteoric precipitation for long periods of time represents a particular concern for modern societies and very likely imposed serious problems for ancient civilizations (e.g., Cullen et al., 2000; Drysdale et al., 2006; Kaniewski et al., 2012; Zanchetta et al., 2013). The identification of past periods of reduced meteoric precipitation in the Mediterranean is of particular relevance for the sensitivity and vulnerability of the region to future water shortages due to climate change (Giorgi, 2006; Giorgi and Lionello, 2008). For the investigation of the reduction in winter precipitation in the recent past (i.e. Holocene) it is necessary to utilise natural archives capable of capturing the climatic signal produced by precipitation during autumn and winter. Quantitative, pollen-based reconstructions of precipitation can be useful to analyse past seasonal rainfall regimes, and, in some cases, the resolution is suitable for resolving century-scale climatic events (Peyron et al., 2011; Magny et al., 2012a, 2012b). However, human impacts on the natural environment and vegetation since the Neolithic have likely reduced the reliability of these climatic reconstructions (e.g. Roberts et al., 2004, 2008, 2010). On the other hand, the use of oxygen isotopes from natural materials (e.g. carbonates) are less prone to the effects of human activity (e.g. Roberts et al., 2010), particularly from areas where widespread human impacts were sparse or absent. Such isotopic records could be better suited than other proxies to revealing changes in rainfall, especially in the Mediterranean area, where the amount of precipitation (sometimes called the

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"amount effect") impinges significantly on the isotopic composition of the rainfall when compared to the "temperature effect" (e.g. Bard et al., 2002; Bar-Matthews et al., 1996, 1999; Drysdale et al., 2004, 2009). In particular, speleothems (cave chemical deposits) have the advantage that they precipitate from waters that experience negligible ^{18}O-enrichment due to evaporative effects (e.g. Ayalon et al., 1998; Lachniet, 2009). On the contrary, water evaporation has an important effect on the $\delta^{18}O$ of many Mediterranean lakes (e.g. Baroni et al., 2006; Roberts et al., 2008; Leng et al., 2010). Evaporation is enhanced during the dry season, which in the Mediterranean region usually corresponds to the late-spring-to-summer season (e.g. Bolle, 2003), coinciding with the period of calcite precipitation in lakes. Therefore, oxygen isotope records obtained from lake carbonates are more informative on late spring–summer conditions rather than winter (Leng and Marshall, 2004). Similarly, lake-level reconstructions using, for instance, different types of lake concretions are mostly indicative of lake-level fluctuations during summer (e.g. Magny, 2006; Magny et al., 2007).

In this paper we compare high-resolution oxygen isotope data from Soreq Cave in Israel and Corchia Cave from central Italy (Fig. 1) for the period of 7 to 4 ka BP, which encompasses the middle to late Holocene transition (e.g. Wanner et al., 2008; Wirtz et al., 2010; Roberts et al., 2011; Magny et al., 2012a, 2012b), a period when the climate system was affected by the progressive reduction of Northern Hemisphere summer insolation, and which saw the commencement of slight increases in atmospheric CO_2 and CH_4 (e.g. Wanner et al., 2008).The investigated period overlaps the period of rapid climatic changes (RCC) identified by Mayewski et al. (2004) between ca. 6000 and 5000 cal yr BP. Chemical data from Greenland ice core GISP2 for this period shows increased concentrations of sodium (Na^+) and potassium (K^+) ions, interpreted as indicators of the strength of the Icelandic Low and Siberian High atmospheric pressure cells, respectively (Mayewski et al., 1997; Meeker and Mayewsky, 2002, Fig. 2) and an increase in ice-rafted debris entering the North Atlantic (Bond et al., 2001).

Both Soreq and Corchia caves are today influenced by the typical winter Mediterranean storm-density track configuration (Lionello et al., 2006, 2012; Reale and Lionello, 2013; Fig. 1) and their recharge occurs mostly during winter. It is therefore reasonable to expect that a substantial reduction of rainfall during winter should be recorded simultaneously in the oxygen isotope composition of the speleothem calcite at the two sites. Analyses performed by Reale and Lionello (2013) on winter storms for the coastal areas of the Mediterranean show that for locations at the eastern Mediterranean shore, most rain events are associated with cyclones generated inside the Mediterranean area, whereas in the western Mediterranean most events are of Atlantic origin. The fraction of events produced by Atlantic cyclones decreases eastward across the Mediterranean. The most pronounced rain events are associated with negative North Atlantic Oscillation index and negative Eastern Atlantic Western Russia patterns both in the western and eastern Mediterranean. However, these links appear stronger in the west than in the east (Reale and Lionello, 2013).

Similarity, between these two $\delta^{18}O$ records has already been described for millennia-scale trends (Zanchetta et al., 2007; Orland et al., 2009, 2012; Bar-Matthews and Ayalon, 2011; Giraudi et al., 2011; Regattieri et al., 2014) and here decadal to century-scale events are considered.

2. Site description and data

Both caves and their speleothem isotope records have been described in detail elsewhere (Asaf, 1975; Bar-Matthews et al., 1996, 2000, 2003; Danin, 1988; Drysdale et al., 2004; Piccini et al., 2008) and only general information is reported here.

2.1. Soreq Cave

The Soreq Cave is one of a series of karstic caves situated within the steeply westward-dipping flank of the Judean Hill anticline, and is located approximately 60 km inland and 400 m above sea level in Cenomanian dolomitic rocks. The cave is 80 m long, 60 m wide, and ca. 5.5 m in height. Its location in the steeply dipping terrain results in a variation of its depth below the surface from less than 10 m at its western end to 40–50 m at its eastern end. A ca. 30 cm-thick soil cover above the cave is relatively uniformly distributed and is composed of terra rossa and rendzina soils, which hosts a Mediterranean C3-type vegetation consisting of Maquis and forest. The climate in the area is typical of Eastern Mediterranean semi-arid conditions (annual average rainfall above the cave is 500 mm) with ca. 70% of the rainfall occurring during

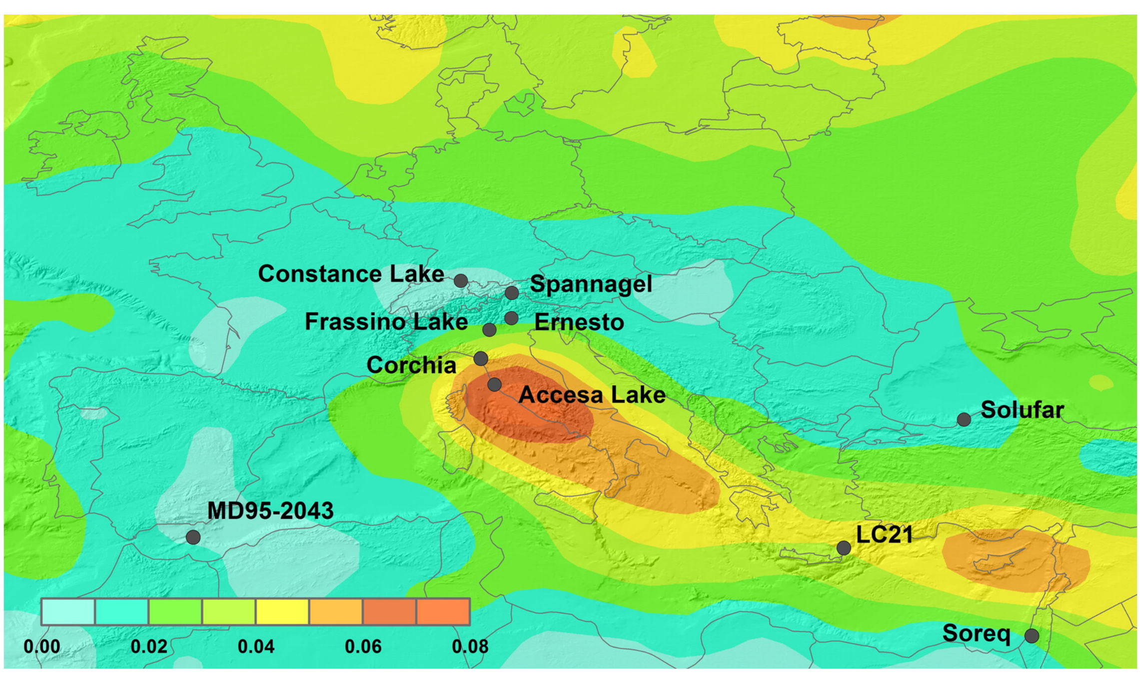

Fig. 1. Location map of the sites discussed in the text. The figure shows the density track of winter storms according to ERA-interim 1989–2009. Numerical values (number of cyclones/deg^2) represent the average spatial density of cyclone centers in the winter season. Only cyclones with a minimum of 1 day duration and 5 hPa depth with respect to the background are included (modified after Lionello et al., 2012).