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Climate variability in the western Mediterranean between 121 and 67 ka derived from a Mallorcan speleothem record

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ABSTRACT

The western Mediterranean region is exceptionally vulnerable to predicted climate changes of increasing temperature and aridity. Characterizing past climate oscillations since the last interglacial (LIG) is critical to understand climate patterns during the present warm period. Here we present an accurately dated speleothem record (CAM-1) of paleoclimate between 121 and 67 ka from the island of Mallorca. The growth history combined with the isotopic record and mineral changes, provides evidence of dramatic climatic shifts in the western Mediterranean. Isotopic equilibrium deposition was assessed by Hendy tests and by comparing the $\delta^{18}O$ in modern drip water with newly precipitated calcite. We argue that variability of $\delta^{18}O$ in CAM-1 is mainly related to changes in source of precipitation, whereas high $\delta^{13}C$ values reflect a dry climate. Calcite rather than aragonite growth is related to cooler, drier climate. The MIS 5e/5d transition, C24, C23, and C21 cold events concomitantly recorded in CAM-1, ODP 984, and NGRIP highlights the teleconnection between high and mid-latitudes in the Northern Hemisphere. Our record reveals a prolonged aridity during MIS 5c and a sudden climate shift from drier to wetter conditions beginning with MIS 5b. A growth hiatus at 67 to 53 ka probably marks the driest period, after which slow calcite growth indicates markedly drier climate during the last glacial and Holocene than during MIS 5. Many of the significant changes in growth rates and stable isotopic composition are synchronous with events that are likely driven by regional climate and large circulation patterns linked to the North Atlantic.

1. Introduction

The geographic position of the Mediterranean Basin makes this region particularly vulnerable to climate change, where predicted global warming and changes in precipitation regime (Adloff et al., 2015) are likely to generate major societal and economic impacts (Giannakopoulos et al., 2009; IPCC, 2013). In order to assess future regional hydrologic vulnerability, a thorough understanding of Mediterranean climate forcing, internal variability, and responses triggered by past climate fluctuations is required. The last interglacial period (LIG) is of a great interest for both paleoclimatologists and climate modelers as it is considered to be an interval when temperatures were higher than today, thus a possible analogue for future warmer climates (Tzedakis, 2003; Sprovieri et al., 2006; Bardají et al., 2009; Nehme et al., 2015; Vansteenberge et al., 2016). Records of climate variability in the Mediterranean Basin since the last interglacial period (LIG) are numerous and come from a variety of terrestrial and marine archives, such as sea sediments, pollen, speleothems, etc. (Sánchez Goñi et al., 2002; Moreno et al., 2005; Drysdale et al., 2007; Hodge et al., 2008a, b; Abrantes et al., 2012 and references therein; Rohling et al., 2013; Nehme et al., 2015). These studies show evidence of significant site-specific hydro-climate changes indicating that the Mediterranean region is sensitive to both mid-latitude and subtropical circulation patterns (Rohling et al., 2009; Lionello, 2012). Specifically, the eastern Mediterranean regions strongly respond to changes in the intensity of the African and Indian Ocean monsoons, whereas the western Mediterranean parts respond to the North Atlantic Oscillation (NAO) and Western Mediterranean Oscillation (WeMO; Martín-Vide and López-

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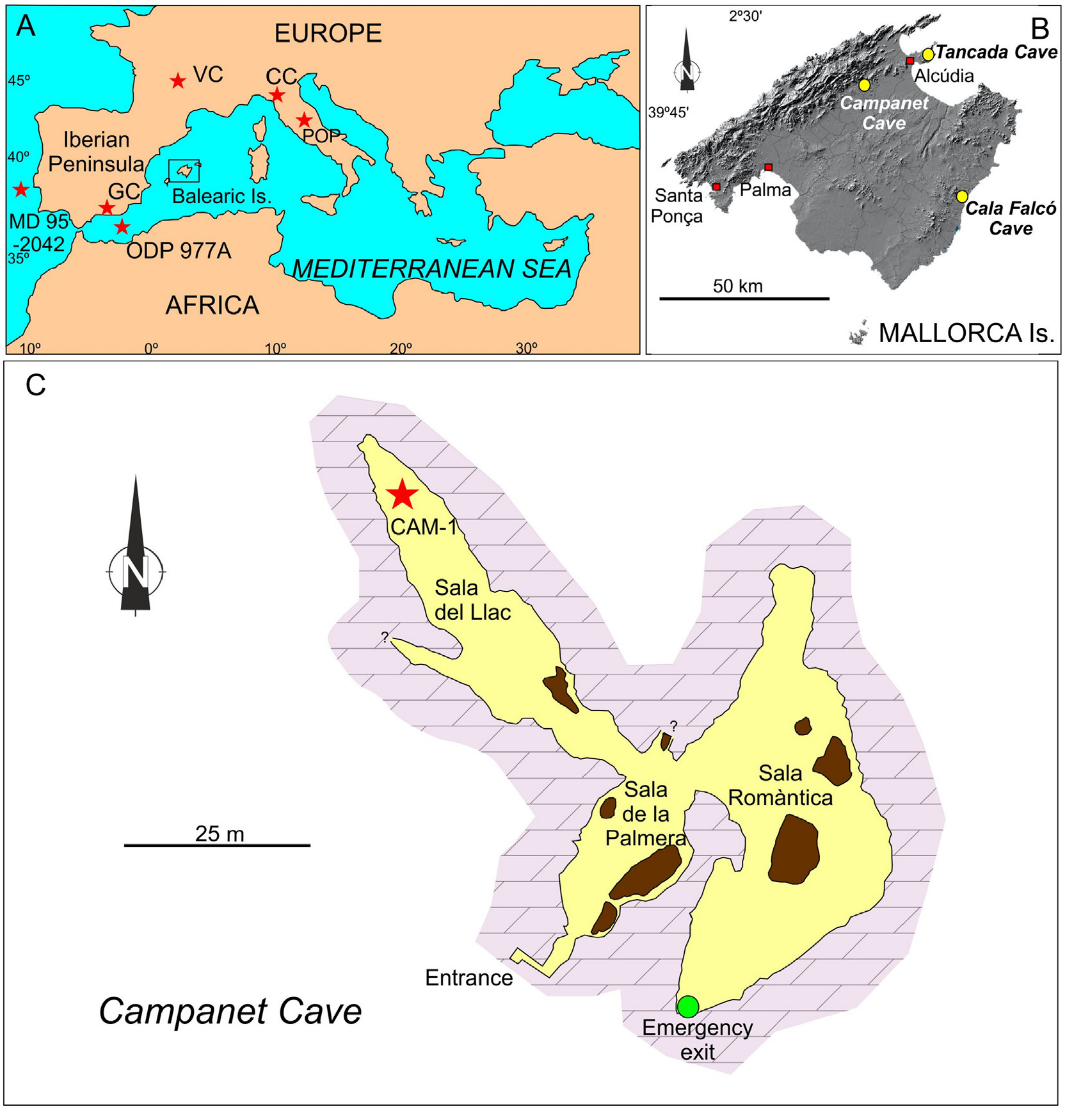

Fig. 1. A. Map showing Mallorca (rectangle) in the western Mediterranean along with other paleoclimate sites discussed in the text (MD95-2042: marine core; GC: Gitana Cave; ODP-977A marine core; VC: Villars Cave; CC: Corchia Cave; POP: lacustrine sequence); B. Location of Campanet, Cala Falcó, and Tancada caves within Mallorca; C. Campanet Cave map with the sampling site of CAM-1 stalagmite (red star). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

Bustins, 2006), which are widely considered the most important sources of climate variability for the western regions. These contrasting settings may explain some inconsistencies between paleoclimate reconstructions using different archives. However, regional climate variability remains difficult to understand since discrepancies exist even between records situated in close proximity. This lack of understanding represents a major source of uncertainty for estimating future regional hydrologic vulnerability, thus the need for new accurate, high-resolution records, especially for the western Mediterranean region.

For the past two decades, speleothems have been widely recognized as ideal climate archives due to their long term preservation of climate signals, the ability to provide precise and reliable U-series chronology, and the variety of climatic proxies that can be measured (Dorale et al., 2002; Fairchild and Baker, 2012; Lachniet, 2009; Frisia, 2015; Wong and Breecker, 2015). To fill in the existing gap of paleo-records and to better understand the forcing mechanisms behind the climatic pattern observed during the LIG in the western Mediterranean, we present here a detailed isotopic record ($\delta^{13}C$ and $\delta^{18}O$) of a precisely dated stalagmite (CAM-1) from Campanet Cave, Mallorca (Fig. 1A). By using a multi-proxy approach (the growth history combined with the isotopic record, and mineral changes), we report a continuous insular record from the western Mediterranean for the period between 121 and 67 ka.

The main goal of this paper is to identify the physical processes that triggered the observed variation in CAM-1 growth rates, mineral changes, and $\delta^{18}O$ and $\delta^{13}C$ values. Considering the unique location of Mallorca within the Western Mediterranean, this study further advances our understanding of the factors responsible for climate variability and helps identifying the major past climatic events in this region.

Our study evaluates the following hypotheses:

First, CAM-1 is precipitated in isotopic equilibrium with the seepage water, and thus, the $\delta^{18}O$ values of the stalagmite reflect the $\delta^{18}O$ values of precipitation from the surface. Under present-day high relative humidity and poor ventilation at the sampling site (Dumitru et al., 2015), evaporation is negligible, suggesting the likelihood of isotopic equilibrium during speleothem deposition. To further test this hypothesis we compare the $\delta^{18}O$ values of newly precipitated aragonite in a soda straw with predicted values calculated from the $\delta^{18}O$ values of drip water and a fractionation factor for the cave temperature. Additionally, we examined the isotopic equilibrium by performing four Hendy tests (Hendy, 1971).