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Younger Dryas to Early Holocene paleoclimate in Cantabria (N Spain): Constraints from speleothem Mg, annual fluorescence banding and stable isotope records

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ABSTRACT

The Younger Dryas (YD) stadial represents the most abrupt climate change of the Earth's recent history. Thus, understanding its causes and different local responses is relevant for Quaternary paleoclimatology. We present a speleothem high-resolution proxy record of the Lateglacial to Early Holocene paleoclimate of the Cantabrian Cordillera (N Spain), a strategic location to evaluate the influence of North Atlantic events such as the YD on South-Western Europe. Fluorescence lamination, growth-rate, stable-isotope, and [Mg] records from stalagmite SIR-1 were dated using an age-depth model constrained by U-Th dates and annual-lamina counting. The YD is recorded as a prominent positive $\delta^{13}C$ excursion whose chronology (12.95 ± 0.14 to 11.62 ± 0.16 ka) and shape closely agree with the GS-1 stadial as defined in Greenland ice, supporting the event synchronicity in both areas. A colder and drier YD climate limited soil productivity and dripwater availability, leading to higher $\delta^{13}C$ and [Mg], reduced growth rate, and virtually absent fluorescence lamination. The early YD record (until ~12.5 ka) reflects increasing aridity, whereas the late YD (from ~12.2 ka on) shows the opposite trend. At the YD boundaries, temperature changes influenced the [Mg] record by modifying the Mg partition into calcite. However, this effect was superseded by major changes in dripwater Mg/Ca linked to rainfall variations. During the Early Holocene, the Arnero Sierra was forested and had a relatively warm and humid seasonal climate, indicated in SIR-1 by higher growth rates, lower δ13C and [Mg], and well-developed fluorescent lamination. Similar to other high-resolution stalagmitic records of the Cordillera, from ~8.5 to 8.0 ka SIR-1 reflects a temporary trend of increasing aridity.

1. Introduction

In the Northern Hemisphere, the Lateglacial warming was interrupted by a prominent and abrupt cooling event, known as the Younger Dryas (YD) in European terrestrial floral records (e.g. Rach et al., 2014), or Greenland Stadial 1 (GS1) in Greenland ice cores. Because the YD and GS1 boundaries are defined by different criteria, they are not necessarily coincident. However, both correspond to the same event, which, for convenience, will be referred here as the YD. According to the ice-core chronology of Rasmussen et al. (2006), the YD lasted ~1.2 ka, from 12.9 ± 0.14 to 11.7 ± 0.10 ka BP. The YD cooling was restricted to the Northern Hemisphere while the Southern Hemisphere actually experienced warming, pointing to a major disruption of the oceanic thermohaline circulation (Broecker, 1997; De Deckker et al., 2012). This disruption favored the expansion of winter sea-ice in the North Atlantic, cooling adjacent landmasses, and weakened the Asian monsoon (Denton et al., 2005). The YD oceanic re-organization is usually attributed to flooding of the Northern Atlantic by glacial meltwaters from the retreating Laurentide and/or Fennoscandian ice sheets (e.g. Muschitiello et al., 2015). Alternatively, the YD could be part of the sequence of events in transitions from glacial to interglacial climates (Broecker et al., 2010).

The YD represents the most abrupt climate change of the Earth's recent history (Steffensen et al., 2008). Therefore, understanding

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the causes and the different local responses to the YD is highly relevant not only for Quaternary paleoclimatology but also for present-day climate change. In mid-latitude continental regions, speleothems can provide valuable high-resolution proxy records of the YD (e.g. Belli et al., 2013), which have the additional advantage of their potentially precise U-Th chronologies.

The Cantabrian Cordillera of Northern Spain is located strategically to evaluate the influence of North Atlantic climatic events such as the YD on southwestern Europe (Baldini et al., 2015). Some Cantabrian-Cordillera caves developed conditions for speleothem growth during the Lateglacial, including the YD which is recorded in stalagmites from at least two caves near the Atlantic coast (El Pindal and La Garma: Moreno et al., 2010, and Baldini et al., 2015) (Fig. 1). In caves located at moderately higher altitudes in the Cordillera (Fig. 1), published speleothem records normally do not cover the Lateglacial but may include most of the Holocene, such as in Asiul (catchment area: ~300 m a.s.l.; Smith et al., 2016a,b) and Kaite caves (catchment area: ~900 m a.s.l.; Dominguez-Villar et al., 2009). In higher-altitude caves of the Cordillera, calcitic stalagmites apparently only record full interglacial conditions, e.g. in Courel-Sierra caves (catchment area: ~1300 m a.s.l.; Railsback et al., 2017) or Cobre Cave (catchment area: ~1800 m a.s.l.; Muñoz-García et al., 2007) (Fig. 1).

Here, we report a new Lateglacial to Early Holocene speleothem record from a mid-altitude cave in the Cantabrian Cordillera, with particular focus on the YD. We aim (1) to highlight the paleoclimate significance of combining high-resolution Mg concentration data with stable isotopic data, fluorescence imaging, and lamina counting; and (2) to determine the climatic response to the YD climate change in this area from the interpretation of these proxies. This interpretation is based on understanding the main controls on geochemical variability of modern dripwaters and speleothems, obtained in a previous study (Rossi and Lozano, 2016). Given the strategic location of the cave also in terms of altitude (catchment area: ~600 m a.s.l.), we emphasize the comparison to other coeval speleothem records in the region. Such comparison may help to discriminate regional climatic controls from possible local effects.

In stalagmites, variations in Mg concentration along the growth axis are frequently interpreted in terms of paleo-hydrology. During periods of decreasing effective rainfall the residence time of water in the vadose aquifer increases, as reduced water/air ratios in the porosity decrease the relative permeability to water. Due to the slower dissolution kinetics of dolomite relative to calcite, longer water-residence times enhance the release of Mg from dolomite dissolution, increasing Mg/Ca ratios in dripwater and speleothem calcite (Fairchild et al., 2000; Belli et al., 2017). Apart from enhanced water-rock interaction, the precipitation of $CaCO_3$ along vadose flow paths (Prior Calcite Precipitation: PCP) can also increase Mg/Ca ratios during drier climatic conditions (Fairchild et al., 2000; Cruz et al., 2007; Sinclair et al., 2012; Tremaine and Froelich, 2013). PCP preferentially removes Ca^{2+} from solution, increasing its Mg/Ca ratio. It can occur in the cave (e.g. in stalactites) or in other air-filled voids above the cave (Fairchild et al., 2000). Decreasing rainfall enhances PCP partly because such voids become more abundant, and partly because slower drip rates allow more $CaCO_3$ precipitation in stalactites or flowstones (Fairchild and Baker, 2012). Therefore dripwater Mg/Ca is usually controlled by effective rainfall because this influences both water-residence time and PCP (McDonald et al., 2007).

However, apart from drier climate, PCP-related increases in dripwater Mg/Ca can respond to higher supersaturations linked to enhanced ventilation (e.g. Wong et al., 2011), potentially complicating the paleo-hydrological interpretation of stalagmitic Mg records. In addition, these records may be influenced by changes in temperature, which determines the distribution of Mg into calcite (DMg), possible kinetic effects during rapid precipitation (Rimstidt et al., 1998), or variable Mg input in detrital particles (Belli et al., 2017) or marine aerosols (Baldini et al., 2015).

In some stalagmitic records, Mg and $\delta^{13}C$ are positively correlated (e.g. Johnson et al., 2006), a relationship potentially helpful to understand the controls on $\delta^{13}C$ variation in such cases. Stalagmitic $\delta^{13}C$ mainly depends on the balance of two carbon sources in dripwater: relatively light, soil-derived CO_2, and isotopically heavier carbonate from dissolved hostrock. Their relative proportions depend on the degree of open-versus closed-system dissolution (Fohlmeister et al., 2011; Fairchild and Baker, 2012). Therefore, higher stalagmitic $\delta^{13}C$ values can result from increasing the contribution of hostrock-derived carbon, linked to increased water-rock interaction during drier periods (Bajo et al., 2017). This effect should also increase dripwater Mg/Ca ratios, providing a plausible explanation for the $\delta^{13}C$-Mg covariation trends in stalagmites. Also, and similar to the case of Mg, both dripwater and stalagmitic $\delta^{13}C$

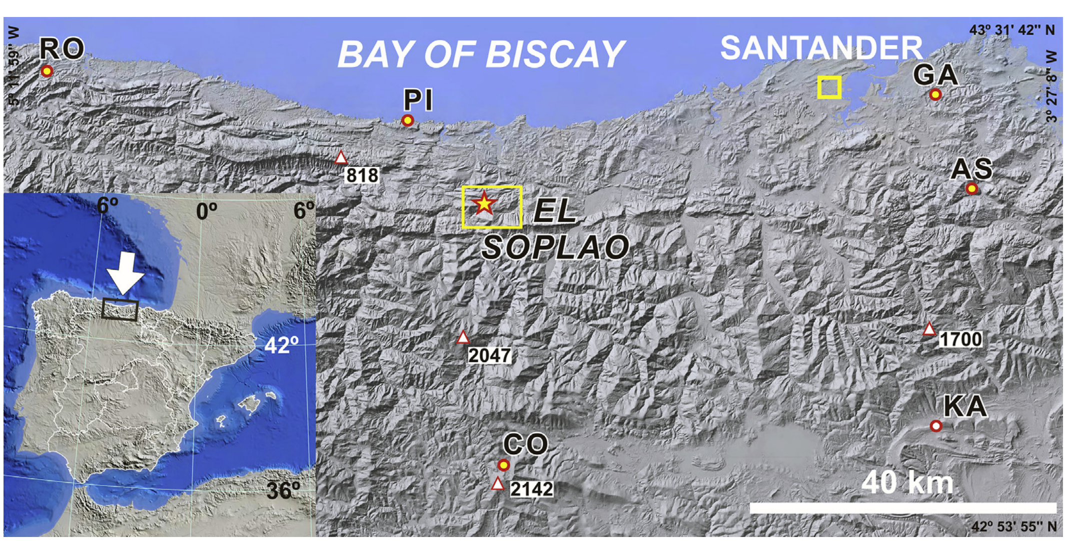

Fig. 1. Location of El Soplao cave in the Cantabrian Cordillera (N Spain), including elevations (m a.s.l) of representative peaks (triangles) and other caves mentioned in the text: Cobre (CO), Kaite (KA), Asiul (AS), La Garma (GA), El Pindal (PI) and Rosa (RO).