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Evidence of warm and humid interstadials in central Europe during early MIS 3 revealed by a multi-proxy speleothem record

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ABSTRACT

Marine Isotope Stage 3 (MIS 3, 57–27 ka) was characterised by numerous rapid climate oscillations (i.e., Dansgaard-Oeschger (D/O-) events), which are reflected in various climate archives. So far, MIS 3 speleothem records from central Europe have mainly been restricted to caves located beneath temperate Alpine glaciers or close to the Atlantic Ocean. Thus, MIS 3 seemed to be too cold and dry to enable speleothem growth north of the Alps in central Europe.

Here we present a new speleothem record from Bunker Cave, Germany, which shows two distinct growth phases from 52.0 (+0.8, −0.5) to 50.9 (+0.6, −1.3) ka and 47.3 (+1.0, −0.6) to 42.8 (±0.9) ka, rejecting this hypothesis. These two growth phases potentially correspond to the two warmest and most humid phases in central Europe during MIS 3, which is confirmed by pollen data from the nearby Eifel. The hiatus separating the two phases is associated with Heinrich stadial 5 (HS 5), although the growth stop precedes the onset of HS 5. The first growth phase is characterised by a fast growth rate, and Mg concentrations and Sr isotope data suggest high infiltration and the presence of soil cover above the cave. The second growth phase was characterised by drier, but still favourable conditions for speleothem growth. During this phase, the $\delta^{13}C$ values show a significant decrease associated with D/O-event 12. The timing of this shift is in agreement with other MIS 3 speleothem data from Europe and Greenland ice core data.

1. Introduction

Marine Isotope Stage 3 (MIS 3, ca. 57-27 ka; Lisiecki and Raymo, 2005) was characterised by rapid climate oscillations (i.e., the Dansgaard-Oeschger (D/O) events). This high-frequency climate variability was first discovered in Greenland ice cores by Johnsen et al. (1992) and Dansgaard et al. (1993). Stable oxygen isotope ($\delta^{18}O$) records obtained from ice cores show the occurrence of high-magnitude climate cycles, where a rapid temperature increase (up to 10–16 °C on the summit of Greenland, Huber et al., 2006; Kindler et al., 2014) occurred within decades and was followed by a gradual cooling. For MIS 3, eleven D/O-events have been described in Greenland ice cores (D/O 5–15), based on the GICC05 timescale (Rasmussen et al., 2014). Furthermore, MIS 3 was characterised by Heinrich events 3 to 5, triggered by freshwater input in the North Atlantic, slowing down North-Atlantic deep-water formation (Böhm et al., 2015) and identified by ice-rafted debris (IRD) layers (Heinrich, 1988). The corresponding Heinrich stadials were cold

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phases with a typical duration of few thousand years, identified both in Greenland ice cores and in North Atlantic and Mediterranean sediment cores (e.g., Bond et al., 1993; Cacho et al., 1999; Sánchez Goñi et al., 2002). These marine records, however, often lack independent and precise dating control, rendering the identification of leads and lags during D/O-events partly ambiguous.

Speleothems have been used as archives of past climate and environmental variability in Europe (e.g., Fankhauser et al., 2016; Fohlmeister et al., 2012; Genty et al., 2003; Luetscher et al., 2015). The U-series disequilibrium method (Richards and Dorale, 2003; Scholz and Hoffmann, 2008) allows to obtain accurate and precise age-depth models. In addition, stable carbon and oxygen isotopes as well as trace elements can be measured at high temporal resolution in speleothems and have been widely used to investigate past climate change (Fairchild et al., 2006; Fairchild and Treble, 2009; Lachniet, 2009; McDermott, 2004). Furthermore, speleothem growth itself can be used as climate proxy, especially during glacial periods. Speleothem growth depends on several climatic and environmental factors, such as the availability of water (i.e., temperature > 0 °C) and a high pCO_2 in the soil above the cave (Mattey et al., 2016). Consequently, speleothem growth is mainly restricted to relatively warm and humid climate periods that are characterised by the availability of water, sufficient soil development and vegetation cover above the cave, such as during the Holocene (Mangini et al., 2007; McDermott et al., 1999) and previous interglacials (Baker et al., 1993; Gordon et al., 1989; Hennig et al., 1983). This results in drip water supersaturated with respect to calcite entering the cave and, eventually, the precipitation of speleothem calcite.

European speleothem records from MIS 3 are limited. Besides some records from southern and south-eastern Europe with only single ages indicating growth during MIS 3 (Constantin et al., 2007; Hodge et al., 2008), the majority of MIS 3 speleothem records have so far been reported from the Alpine region (Holzkämper et al., 2005; Luetscher et al., 2015; Moseley et al., 2014; Spötl and Mangini, 2002; Spötl et al., 2006). These speleothems grew in caves underneath temperate glaciers, which provided enough meltwater to enable speleothem growth (Spötl and Mangini, 2002), despite of cold climate conditions at the surface. Therefore, their growth cannot be used as a direct climate indicator, in particular for central Europe. Further speleothems from MIS 3 have been found in south-western (SW) and north-eastern (NE) France. In particular, MIS 3 stalagmites from Villars Cave (SW France) were subject of several studies and provided valuable information about climate variability during this period (Genty et al., 2003, 2005, 2010; Wainer et al., 2009). Another MIS 3 speleothem was found at Grotte des Puits de Pierra-la-Treiche (NE France, Pons-Branchu et al., 2010). The most north-western European MIS 3 speleothem record was published from Crag Cave (SW Ireland), where several broken stalagmites have been dated (Fankhauser et al., 2016). These authors showed that speleothem growth occurred episodically during MIS 3 interstadials, especially during mid to late MIS 3.

Here we present a new record of a stalagmite from Bunker Cave, central Germany, which grew during MIS 3. Currently, this is the northern-most MIS 3 speleothem record for central Europe, where centennial-scale climate records of this time interval are rare (McDermott, 2004; Voelker, 2002). The record shows two warm and humid phases during early MIS 3 separated by a hiatus corresponding to the Heinrich 5 cold event (HS 5).

2. Site and sample description

2.1. Bunker Cave

Bunker Cave has been described in detail by Riechelmann et al. (2011) and Fohlmeister et al. (2012) and is thus only briefly discussed here. The cave (51°22′03″N, 7°39′53″E) is located in western Germany (Sauerland, Fig. 1), the cave entrance at 184 m above sea level. The cave is developed in Middle to Upper Devonian low-Mg limestone, which contains dolomite veins, and the limestone overburden ranges from 15 to 30 m (Grebe, 1993). At present, the host rock is covered by up to 70 cm of brownish loamy soil, which developed from loess loam deposited during the last glacial (von Kamp and Ribbert, 2005). The thin soil horizon A (<10 cm) is humic, covering a brown/yellow soil horizon B. Soil horizon C is built up by this brown/yellow soil and the limestone host rock (Riechelmann et al., 2011). Today, the vegetation above the cave consists of C3-plants, mainly ash and beech trees as well as shrubs. The mean annual cave air and drip water temperature is 10.6 °C (2006–2009). Mean annual precipitation in the area is 919 mm (1988–2007, weather station Hagen-Fley), equally distributed over the year. The $\delta^{18}O$ values of precipitation range from −5‰ in summer to −13‰ in winter (Riechelmann et al., 2017). The $\delta^{18}O$ values of cave drip water (mean $\delta^{18}O = -7.9 \pm 0.3‰$, 1σ SD, n = 384, 2006–2013, Riechelmann et al., 2017) imply a well-mixed aquifer. Calcite precipitation in Bunker Cave was observed during the whole year by watch glass experiments at several drip sites (mean $\delta^{13}C = -8.6 \pm 0.6‰$, 1σ SD, n = 16; mean $\delta^{18}O = -6.1 \pm 0.2‰$, 1σ SD, n = 16, Riechelmann, 2010; Riechelmann et al., 2014). Therefore, Bunker Cave is highly suitable for reconstruction of long-term multi-annual climate trends in central Europe (Fohlmeister et al., 2012; Riechelmann et al., 2011, 2012b, 2017).

2.2. Stalagmite Bu2

Bu2 (Fig. 2) is a 32 cm-long stalagmite, sampled under an active drip site, which was investigated in the framework of a long-term cave monitoring program (corresponding to drip site TS 7, Riechelmann et al., 2011). The upper 76 mm of Bu2 grew during the Holocene and were already studied by Fohlmeister et al. (2012). Bu2 consists of clear white to beige calcite with only few detrital layers (Fig. 2). A single brown layer at 76 mm distance from top (DFT), separating the Holocene growth phase from the older part of Bu2, is clearly visible. The base of the stalagmite (Fig. 2) consists of brownish calcite and was not analysed.

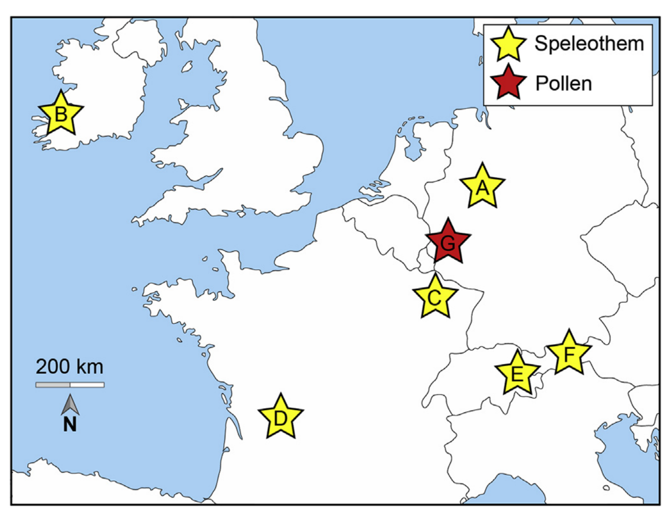

Fig. 1. Map showing north-western parts of Europe with the location of MIS 3 climate records from Bunker Cave [A, this study], Crag Cave [B, Fankhauser et al. (2016)], Grotte des Puits de Pierra-la-Treiche [C, Pons-Branchu et al. (2010)], Villars Cave [D, Genty et al. (2003)], Hölloch Cave [E, Moseley et al. (2014)], Kleegruben Cave [F, Spötl et al. (2006)] and the Eifel maar lakes [G, Sirocko et al. (2016)].