Timing and structure of the 8.2 kyr B.P. event inferred from δ¹⁸O records of stalagmites from China, Oman, and Brazil

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ABSTRACT

Oxygen isotope records of stalagmites from China and Oman reveal a weak summer monsoon event, with a double-plunging structure, that started 8.21 ± 0.02 kyr B.P. An identical but antiphased pattern is also evident in two stalagmite records from eastern Brazil, indicating that the South American Summer Monsoon was intensified during the 8.2 kyr B.P. event. These records demonstrate that the event was of global extent and synchronous within dating errors of <50 years. In comparison with recent model simulations, it is plausible that the 8.2 kyr B.P. event can be tied in changes of the Atlantic Meridional Overturning Circulation triggered by a glacial lake draining event. This, in turn, affected North Atlantic climate and latitudinal position of the Intertropical Convergence Zone, resulting in the observed low-latitude monsoon precipitation patterns.

INTRODUCTION

A prominent abrupt climate event ca. 8.2 kyr B.P. (the 8.2 kyr B.P. event) is evident in Greenland ice cores and other climate proxy records from across the Northern Hemisphere (Alley et al., 1997). However, due to a distinct lack of highly resolved and precisely dated records, the timing, structure, and geographical extent of the event are not well documented (Alley and Ágústsdóttir, 2005; Rohlbing and Pålke, 2005). A key question is whether climatic anomalies ca. 8.2 kyr B.P. are indeed representative of one synchronous event with similar structure, different events, or of one time-transgressive event in different geographical regions (Alley and Ágústsdóttir, 2005). Precisely dated stalagmite records from Asia and Brazil can help to answer this question. In order to accurately characterize the 8.2 kyr B.P. event in Asian Monsoon (AM) and South American Summer Monsoon (SASM) records, we present new and revised sets of precisely dated stalagmite records from China, Oman, and Brazil. Improved ²³⁰Th dating techniques with very small age errors of 15–45 years (2σ) for ca. 8.2 kyr B.P. allow us to: (1) correlate AM records from widely separated locations; (2) test the relationship between the AM and SASM and their correlations to Greenland ice core records on decadal time scales; (3) provide a benchmark for global correlation and age calibration of the event; (4) characterize the common structure of the 8.2 kyr B.P. event; and (5) probe the mechanism underlying the event in comparison with model simulations.

SAMPLES AND METHODS

We dated six stalagmites from Dongge Cave, southern China (D4 and DA, 25°17′N, 108°5′E), Qunf Cave, Oman (Q5, 17°10′N, 54°18′E), Hoti Cave, Oman (H14, 23°05′N, 57°21′E), Padre Cave (PAD07, 13°13′S, 44°3′W), eastern Brazil, and Paixão Cave (PX5, 12°39′S, 41°3′W), eastern Brazil (GSA Data Repository Figs. DR1 and DR2, Table DR1). New stalagmite chronologies between ca. 7.7 and 8.5 kyr B.P. are based on ²³⁰Th dates obtained using multicollector inductively coupled plasma–mass spectrometry (for methods and analytical procedures, see the Data Repository). Typical age uncertainties (2σ) vary between 15 and 45 years at most key points of stalagmite records of the 8.2 kyr B.P. event. Oxygen isotope ratios are reported as δ¹⁸O (%) relative to the Vienna PeeDee belemnite standard.

RESULTS AND DISCUSSION

Stalagmite Records

Environmental settings for the cave sites in China and Oman were described in previous studies (Dykoski et al., 2005; Wang et al., 2005; Fleitmann et al., 2007). Previously published chronologies of stalagmites D4, DA, and Q5 were revised, as we had difficulties in our previous work in precisely correlating possibilities for the 8.2 kyr B.P. event as recorded by δ¹⁸O excursions, due to lower resolution in sampling for ²³⁰Th dates and uncertainties of ~100 years. Uncertainties for the new chronologies for samples D4, DA, and Q5 are as much as three times better (Fig. DR2; Table DR1), so it is feasible to correlate and characterize the 8.2 kyr B.P. event in those records. Stalagmites H14 from Hoti Cave, Oman, and PAD07 and PX5 from Padre and Paixão Caves, Brazil, are presented here for the first time.

Stalagmite PAD07 is ~42 cm long with a nearly constant growth rate of ~0.25 mm/a around ca. 8.2 kyr B.P.; stalagmite PX5 is ~24 cm long with an annual growth rate of ~0.11 mm. The δ¹⁸O profiles of stalagmites have resolutions of ~3.5 years and ~5 years, respectively (Table DR2). Sample H14 is ~36 cm long with a hiatus around the 8.2 kyr B.P. event, and its chronology, based on 26 Th dates, is in excellent agreement with annual band counting (Figs. DR2 and DR3). Average temporal resolution of the H14 δ¹⁸O profile is ~2 years. Stalagmites Q5, D4, and DA have average resolutions of ~5 years, ~3.5 years, and ~3.5 years, respectively (Fleitmann et al., 2003; Dykoski et al., 2005; Wang et al., 2005).

Timing and Structure of the 8.2 kyr B.P. event

Previous studies have shown that changes in stalagmite δ¹⁸O relate to fluctuations in overall monsoon intensity with anticorrelations to the East Asian Monsoon (e.g., Wang et al., 2005; Cheng et al., 2006), the
Indian Monsoon (IM) (e.g., Fleitmann et al., 2003), and the SASM (Cruz et al., 2006; Wang et al., 2007a, 2007b). All stalagmite δ¹⁸O records from China and Oman provide clear evidence of a weak AM event ca. 8.2 kyr B.P. and, in contrast, δ¹⁸O records from eastern Brazil reveal a strong SASM event ca. 8.2 kyr B.P. (Fig. 1). Based on our age models, the major shift at the onset of each event (as determined by δ¹⁸O values and, for H14 from Oman, by annual band thickness as well) occurred ca. 8.21 ± 0.02 kyr B.P. and took place within merely a few years (Fig. 1). This abrupt monsoonal change is in excellent agreement with Greenland ice cores, which place the 8.2 kyr B.P. event at 8.21 ± 0.05 kyr B.P. on the GICC05 time scale (Vinther et al., 2006). This close match reveals that the abrupt Greenland temperature changes (~5–8 °C for the 8.2 kyr B.P. event [Alley and Ágústsdóttir, 2005; Vinther et al., 2006]) correlate to the abrupt weakening of the AM and strengthening of the SASM.

The 8.2 kyr B.P. event in our stalagmite δ¹⁸O records shows common features: (1) a trend of AM weakening and SASM strengthening is evident between 8.30 and 8.21 kyr B.P.; (2) the abrupt change occurred ca. 8.21 ± 0.02 kyr B.P.; (3) the first AM plunge (or SASM peak) lasted ~70 years; (4) a rebound lasted for ~60 years; (5) a second AM plunge and SASM peak lasted ~20 years; and (6) an abrupt termination of the event occurred 8.08 ± 0.03 kyr B.P. (Fig. 1). Briefly, the 8.2 kyr B.P. event in AM and SASM records is similar and characterized by an asymmetric AM double-plunging (or SASM double peaked) structure between 8.21 and ca. 8.06 kyr B.P., with the first plunge (or peak) about three times longer in duration than the second (Fig. 1).

**Antiphase Relation between the AM and the SASM**

The AM is antiphased with the SASM for major events during the last glacial period, including the Younger Dryas (YD), Dansgaard-Oeschger, and Heinrich events (Cruz et al., 2006; Wang et al., 2007a, 2007b). Analogous to the Greenland ice core, Cariaoco Basin, and Dongge, the amplitude of δ¹⁸O changes of the 8.2 kyr B.P. event in the Padre record is half the amplitude of the YD event as a strong SASM event (Fig. DR4). The 8.2 kyr B.P. event of both Padre and Paixão records is also characterized by a double-peaked structure that is antiphased to the double-plunging AM records, the first peak lasting longer than the second (Fig. 1), suggesting that the antiphase relationship between the AM and the SASM can still hold at centennial to decadal scales.

**Correlations**

The timing and structure of the 8.2 kyr B.P. event recorded in both AM and SASM records are consistent with Greenland ice cores (Figs. 1 and 2). Using a volcanic horizon ca. 8.186 ± 0.046 kyr B.P. as a tie point, a common chronology (GICC05) of the 8.2 kyr B.P. event was obtained for Greenland ice cores Dye3, GISP2, GRIP, and NGRIP (Vinther et al., 2006). The duration of the main drop in δ¹⁸O of the Greenland ice cores is ~70 years (yellow bars in Figs. 1 and 2), equivalent to the length of main weak AM intervals (~80 years) and almost exactly equal to the strong SASM interval (~70 years). Similar to AM and SASM records, there is a second shorter cold event ca. 8.1 kyr B.P. following the main cold event in the Greenland ice cores (Fig. 2) (Thomas et al., 2007), that is also synchronous within dating errors with the weak AM and strong SASM events (Fig. 1). Thus it is plausible that the Greenland temperature might also have a double-plunging structure (Vinther et al., 2006) similar to those revealed in AM and SASM records. Another high-resolution record with an annually precise chronology is the German oak tree-ring record, which is a proxy of temperature and precipitation (Spurk et al., 2002). The 8.2 kyr B.P. event in this record also shows very similar timing and structure, with an abrupt onset of the event at 8.207 kyr B.P. and a second plunge ca. 8.125 kyr B.P. (Fig. 2). The grayscale record from Cariaoco Basin (a proxy of changes in the zonal wind speed; Hughen et al., 1996) also matches within dating errors the AM

![Figure 1. δ¹⁸O time series over 8.2 kyr B.P. event from stalagmites. A: D4, Dongge Cave, China. B: DA, Dongge Cave, China. C: Q5, Qunf Cave, Oman. D: H14, Hoti Cave, Oman. E: H5, Hoti Cave, Oman. F: PAD07, Padre Cave, Brazil. G: PX5, Paixão Cave, Brazil. H: Stacked composite δ¹⁸O data of Greenland ice cores (Dye3, GRIP, GISP2, and NGRIP; resolution of ~2.5 years in gray and four-point average in red; Thomas et al., 2007). The δ¹⁸O scales are reversed for Asian Monsoon (AM) records (Dongge, Qunf, and Hoti Caves, increasing down) as compared with South American Summer Monsoon (SASM) records from Padre and Paixão Caves. Three arrows depict anti-phased changes between AM and SASM and changes in Greenland temperature. Color-coded error bars indicate typical dating errors (2σ) for each record around 8.2 kyr B.P. event. Dashed gray curve of Q5 record was redated and plotted with previous δ¹⁸O record on distance scale (blue curve; Fleitmann et al., 2003), which generally matches the redated chronology due to nearly linear growth around 8.2 kyr B.P. event (Fig. DR2C). Yellow bar indicates central 8.2 kyr B.P. event in Greenland, and green bar indicates second event following central event (Thomas et al., 2007). AM records of 8.2 kyr B.P. event are broadly similar with each other and antiphased to SASM variations. Structure of double-plunging AM or double-peaked SASM is consistent with double temperature plumes over Greenland. VSMOW—Vienna standard mean ocean water; VPDB—Vienna Peedee belemnite.](./image)
Figure 2. Well-dated climate anomalies of 8.2 kyr B.P. event in comparison to model simulations and time of glacial lake drain event. 

A: Time series (model years): i—simulated change of overturning rates in Nordic Seas (Wiersma and Renssen, 2006); ii—North Atlantic Deep Water (NADW) production (LeGrande et al., 2006); iii—decadal NADW formation anomaly (pink) (LeGrande and Schmidt, 2008). 
B: Timing of Lakes Agassiz and Ojibway outburst ca. 8.42 ± 0.30 kyr B.P. (Barber et al., 1999; Kleiven et al., 2008; Lajeunesse and St-Onge, 2008). C: δ18O records of Greenland ice cores Dye3, GISP2, GRIP, and NGRIP and their stacked composite data on GICC05 chronology (Vinther et al., 2006; Thomas et al., 2007). D: Grayscale record from Cariaco Basin (Venezuela) (Hughen et al., 1996). E: German oak tree-ring record (Spurk et al., 2002). Error bars are color coded. Yellow and green bars as in Figure 1. Timing of 8.2 kyr B.P. event is synchronous within dating errors with Asian Monsoon (AM) and South American Summer Monsoon (SASM) changes, and structure of event is broadly similar to double-plunging AM (or double-peaked ASM) records (Fig. 1) and changes of ocean overturning rates as predicted by simulation results. VSMOW—Vienna standard mean ocean water.
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