Timing and structure of the 8.2 kyr B.P. event inferred from $\delta^{18}O$ records of stalagmites from China, Oman, and Brazil

Hai Cheng[1,7]*, Dominik Fleitmann[2,3]*, R. Lawrence Edwards[1], Xianfeng Wang[1], Francisco W. Cruz[4], Augusto S. Auler[5], Augusto Mangini[6], Yongjin Wang[7], Xinggong Kong[7], Stephen J. Burns[8], and Albert Matter[2]
[1]Department of Geology and Geophysics, University of Minnesota, Minneapolis, Minnesota 55455, USA
[2]Institute of Geological Sciences, University of Bern, Bern, Switzerland
[3]Oeschger Centre for Climate Change Research, University of Bern, Bern, Switzerland
[4]Instituto de Geociências, Universidade de São Paulo, Rua do Lago, Brazil
[5]Instituto do Carste, Rua Kepler 385/04, Belo Horizonte, Brazil
[6]Heidelberg Academy of Sciences, c/o Institute of Environmental Physics, University of Heidelberg, Heidelberg, Germany
[7]College of Geography Science, Nanjing Normal University, Nanjing, China
[8]Department of Geosciences, University of Massachusetts, Amherst, Massachusetts 01003, USA

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 monsoonal 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; Rohling and Pälike, 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 ^{230}Th 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 separate 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[1]). New stalagmite chronologies between ca. 7.7 and 8.5 kyr B.P. are based on ^{230}Th 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 $\delta^{18}O$ (‰) relative to the Vienna Peedee belemnite standard.

*E-mails: cheng021@umn.edu; fleitmann@geo.unibe.ch.

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 $\delta^{18}O$ excursions, due to lower resolution in sampling for ^{230}Th 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 $\delta^{18}O$ 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 16 ^{230}Th dates, is in excellent agreement with annual band counting (Figs. DR2 and DR3). Average temporal resolution of the H14 $\delta^{18}O$ 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 $\delta^{18}O$ 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

[1]GSA Data Repository item 2009254, analytical methods, Figures DR1–DR6, and Tables DR1 and DR2, is available online at www.geosociety.org/pubs/ft2009.htm, or on request from editing@geosociety.org or Documents Secretary, GSA, P.O. Box 9140, Boulder, CO 80301, USA.

Indian Monsoon (IM) (e.g., Fleitmann et al., 2003), and the SASM (Cruz et al., 2006; Wang et al., 2007a, 2007b). All stalagmite $\delta^{18}O$ records from China and Oman provide clear evidence of a weak AM event ca. 8.2 kyr B.P. and, in contrast, $\delta^{18}O$ 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 $\delta^{18}O$ 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 $\delta^{18}O$ 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, Cariaco Basin, and Dongge, the amplitude of $\delta^{18}O$ 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 $\delta^{18}O$ 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 gray-scale record from Cariaco Basin (a proxy of changes in the zonal wind speed; Hughen et al., 1996) also matches within dating errors the AM

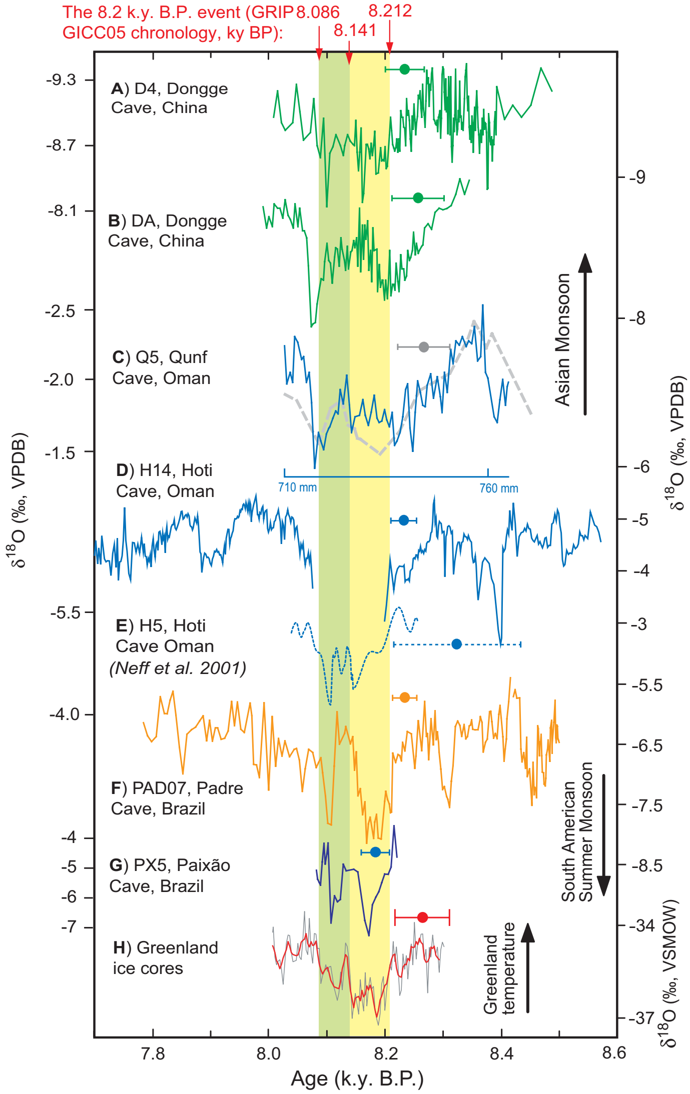

Figure 1. $\delta^{18}O$ time series over 8.2 kyr B.P. event from stalagmites. A: D4, Dongge Cave, China. B: DA, Dongge Cave, China. C: Q5, Qunf Cave, Oman. D: H14, Hoti Cave, Oman. E: H5, Hoti Cave, Oman. F: PAD07, Padre Cave, Brazil. G: PX5, Paixão Cave, Brazil. H: Stacked composite $\delta^{18}O$ 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 $\delta^{18}O$ 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 antiphased 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 $\delta^{18}O$ 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 plunges over Greenland. VSMOW—Vienna standard mean ocean water; VPDB—Vienna Peedee belemnite.

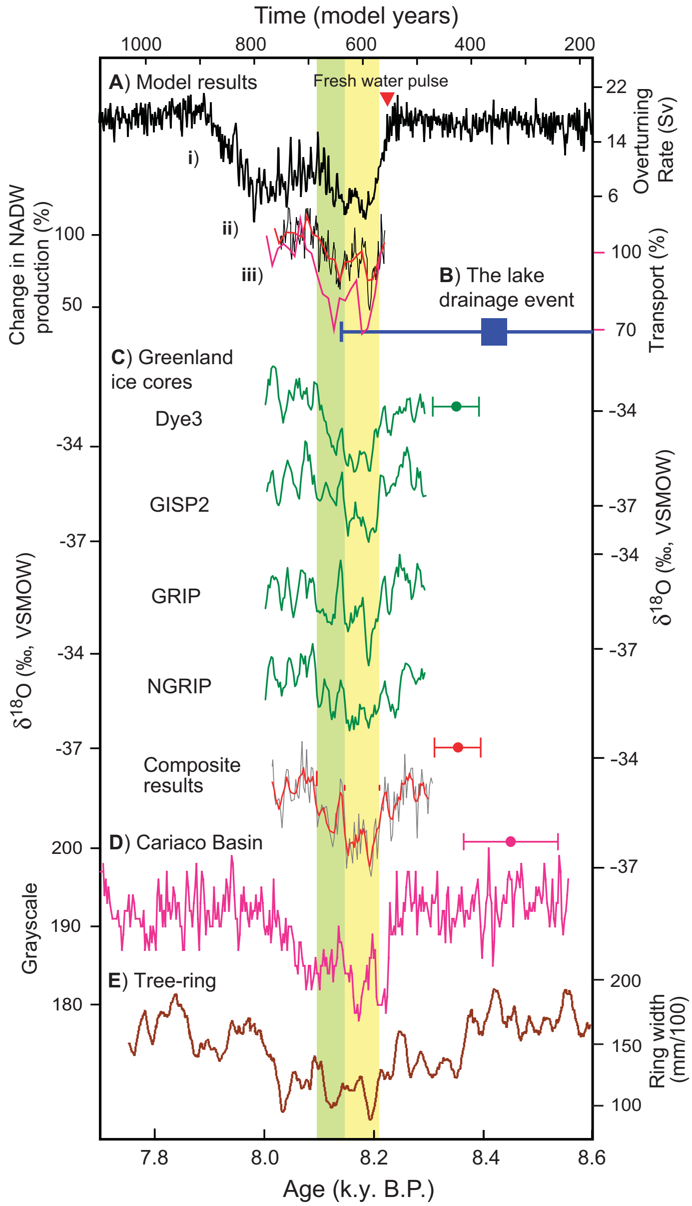

Figure 2. Well-dated climate anomalies of 8.2 kyr B.P. event in comparison to model simulations and time of glacial lake drain event. A: Time series (model years): i—simulated change of overturning rates in Nordic Seas (Wiersma and Renssen, 2006); ii—North Atlantic Deep Water (NADW) production (LeGrande 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: $\delta^{18}O$ 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 SASM) records (Fig. 1) and changes of ocean overturning rates as predicted by simulation results. VSMOW—Vienna standard mean ocean water.

and SASM records (Fig. 2). Recent marine records from North Atlantic deep-sea sediment cores are also marked by two cooling events ca. 8.4 kyr B.P. (Ellison et al., 2006; Kleiven et al., 2008), although the marine 8.2 kyr B.P. event is ~200 years older, possibly related to uncertainties in ^{14}C reservoir age corrections. Therefore, the 8.2 kyr B.P. event revealed in the stalagmite records is consistent in timing and structure with other well-dated records. The synchroneity among records from Asia, eastern Brazil, Greenland, the Cariaco Basin, and Germany suggests a global extent of the event and a strong and rapid teleconnection among tropical, monsoonal, and high-latitude climate systems, involving both oceanic and atmospheric transmission (Alley et al., 1997).

Mechanism

Changes in solar activity could be one of the primary forcing causes of the 8.2 kyr B.P. event of the IM and AM (Neff et al., 2001; Wang et al., 2005). However, changes in solar activity alone might not be enough to have caused the 8.2 kyr B.P. event, as (1) the monsoon-solar correlation coefficient for the Holocene is not exceedingly high, (2) the variation in solar irradiance necessary to cause the observed changes in $\delta^{14}C$ is relatively small (Solanki and Fligge, 1999), (3) the correlation between monsoonal and solar changes at the time of the event appears to be dubious at the new high-precision dating level (Fig. DR5), and (4) the antiphased relationship for the AM and the SASM cannot be explained in a simple fashion by solar forcing. Instead, the antiphased relationship for the 8.2 kyr B.P. event is consistent with the mechanism of freshwater discharge and its resulting weakening of Atlantic Meridional Overturning Circulation (AMOC) (Alley et al., 1997; Barber et al., 1999; Alley and Ágústsdóttir, 2005; Kleiven et al., 2008; Lajeunesse and St-Onge, 2008). High-resolution data from the Cariaco Basin (Hughen et al., 1996), Germany (Spurk et al., 2002), and Greenland (Vinther et al., 2006; Thomas et al., 2007) are consistent with this idea. As demonstrated in earlier studies, the timing (ca. 8.42 ± 0.30 kyr B.P.; Barber et al., 1999; Kleiven et al., 2008; Lajeunesse and St-Onge, 2008) of the draining of glacial lakes Agassiz and Ojibway through the Hudson Bay into the North Atlantic is within error of the timing of the onset, making this event a plausible candidate for subsequent onset of the most distinct climatic event in the Holocene. Furthermore, the double-plunging structure of the event in AM records and peaked structure of the event in SASM records mimic the modeled change in overturning rate of the North Atlantic as simulated by a single meltwater pulse or two meltwater pulses (LeGrande et al., 2006; Wiersma and Renssen, 2006; LeGrande and Schmidt, 2008; Lajeunesse and St-Onge, 2008) (Fig. 2). Our antiphased relationship is also consistent with the pattern predicted by recent simulation studies following a North Atlantic freshening, which show a weakened AM and enhanced eastern Brazil precipitation during the modeled 8.2 kyr B.P. event (Fig. DR6) (Zhang and Delworth, 2005; LeGrande et al., 2006; Wiersma and Renssen, 2006; LeGrande and Schmidt, 2008). Thus, our data support the idea that the event is tied to AMOC changes, which affect North Atlantic climate, and in turn affect the monsoon and the mean latitudinal position of the Intertropical Convergence Zone (Wang et al., 2007a, 2007b), resulting in the observed low-latitude precipitation patterns. It is noticeable that Brazilian records of the event have larger amplitude shifts (~2.5‰ shift in $\delta^{18}O$) than AM records (≤1‰) and track Greenland records more closely in terms of structure (Fig. 1). This is plausibly the result of a tight link between the Atlantic sector of the Intertropical Convergence Zone (Wang et al., 2007a, 2007b) and North Atlantic climate (Fig. DR6) (Zhang and Delworth, 2005).

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