

Abstract

The prominent “8.2 ka event” was well documented in the Greenland ice cores. It remains unclear, however, about its duration, structure and forcing mechanism at low- to mid-latitude regions. Here we use the physical and geochemical data of stalagmites from the Nuanhe Cave in Liaoning province, northeastern China to reconstruct a detailed history of East Asian monsoons throughout the event. Two contemporaneous stalagmites were annually counted for at least 770 yr anchored by five ^{230}Th dates to establish an inter-calibrated high-resolution timescale. Two oxygen isotope profiles replicate each other at annual-decadal timescales although their counted growth rates are not consistent, indicating that the $\delta^{18}\text{O}$ variability has a climatic origin, largely associated with changes in the rainfall $\delta^{18}\text{O}$ from the West Pacific during summer season. A signal from the “8.2 ka event” was faint in our $\delta^{18}\text{O}$ records, not as significant as Indian monsoon dominated stalagmite $\delta^{18}\text{O}$ records from Qunf in Oman and Dongge in Southern China. However, our $\delta^{13}\text{C}$ and Ba/Ca profiles, as indicators of local environmental changes, provide a strong support for a deteriorated climate episode centred at 8.2 ka BP, likely controlled by winter monsoon circulations via the westerly winds associated with North Atlantic climates. Therefore, we concluded that the winter- and summer-Asian monsoons responded independently to the high northern latitude climates.

1 Introduction

Holocene climate changes are unstable, during which a degradative anomaly centred at 8.2 ka BP (termed as “8.2 ka event”) was firstly observed in the Greenland ice cores and then presented in various archives extending geographically to low latitudes (e.g. O’Brien, 1995; Alley et al., 1997; Thomas et al., 2007; Wang et al., 2005; Thompson et al., 2002; Lachniet et al., 2004; Cheng et al., 2009). In spite of being intensively concerned, however, the timing, duration and structure of the 8.2 ka event has

CPD

8, 1591–1614, 2012

Stable isotope and trace element investigation

J. Y. Wu et al.

Title Page

Abstract

Introduction

Conclusions

References

Tables

Figures

◀

▶

◀

▶

Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion



not been well-constrained in low- and mid-latitudes due to a deficit of highly resolved and precisely dated records. Morrill et al. (2003) reviewed 36 published studies relevant to the Asian monsoon (AM) and concluded that no strong evidence was found for an abrupt change in the AM at ~8.2 ka BP. Overall, a signal of the event has little evidence of being presented in the eastern part, but not much stronger than other Holocene anomalies in the western part of Asia (Alley and Ágústsdóttir, 2005). Rohling and Pälike (2005) claimed that the “8.2 ka event” expressed as an anomaly superimposed on a 400 ~ 600-yr cold/aridity background in many of the low- to mid-latitude records and difficult to reconcile with changes in the Greenland temperature. Using a composite of four Greenland ice core records, Thomas et al. (2007) found a small increase in Ca^{2+} and Cl^- during the 8.2 ka event, about 5 % amplitude of that observed in the Younger Dryas. As the two proxies represent changes in low- and mid-latitude atmospheric circulation and its moisture source, it was then suggested that the larger-scale atmospheric response was very subdued, and certainly not proportional to the local climate signal in the North Atlantic.

Therefore, it is important to explore multi-proxies of archives at the same location to investigate the different behaviour of climates in response to the 8.2 ka event, particularly winter- and summer-dominated proxies associated with a seasonal significance that must be taken into account (Rohling and Pälike, 2005). For example, the greyscale from the Cariaco basin shows a short-lived enhancement of wintertime trade winds during 8.25 ~ 8.10 ka BP (Hughen et al., 1996), while the Ti percentage indicates a period of aridity between 8.40 and 7.75 ka BP induced by southward migration of the Intertropical Convergence Zone (ITCZ) in summer (Haug et al., 2001). In the same manner, we use different proxies of stalagmites to investigate seasonal variations of climates in northeastern China, typically dominated by East Asian monsoons. In addition, annually-laminated sequences in stalagmites can be used as a valid means of ascertaining accuracy in the timescale (Proctor et al., 2002; Tan et al., 2003; Paulsen et al., 2003; Baker et al., 2007) as the tree-ring chronology, one of the key aspects to

Stable isotope and trace element investigation

J. Y. Wu et al.

Title Page

Abstract

Introduction

Conclusions

References

Tables

Figures



Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion



determine the duration, structure of the 8.2 ka event. Here we try to use two contemporaneous annually-laminated stalagmites to develop an annually-resolved timescale.

2 Materials and methods

The Nuanhe Cave (41°20' N, 124°55' E) is located at Hengren county in Liaoning Province (Fig. 1), typically influenced by East Asian monsoons (EAM). The climates here are characterised by cold/dry atmospheric circulation during winter and warm/humid air masses during summer. The seasonal temperature ranges between -13° (January) and 22° (July). Relative humidity in the cave is 100 % and the cave temperature keeps constant throughout a year and approximates a mean annual value (6°). The mean annual precipitation at the site is between 800 mm and 900 mm, 60 % of which falls between June and September.

Two columnar-shaped stalagmites (NH6 and NH33) were collected in the deep site of the cave. Sample NH33 is 56 mm in length and 35 to 60 mm in diameter. Sample NH6 is 165 mm in length and 45 to 150 mm in diameter. When halved and polished, both samples show well-developed micro-meter-scale laminations on polished surface, composed of typical coalescent columnar-fabric calcite crystals. Under a microscope, the thin section exhibits densely-distributed laminations, no evidence of any hiatus was found. The lamina sequences are unclear for the top part in the two samples (0 ~ 9.5 mm for Sample NH33, 0 ~ 43 mm for Sample NH6), thus, we focus on the intervals with a continuously-developed laminations, i.e. 9.5 ~ 56 mm for Sample NH33, and 43 ~ 88 mm for NH6, respectively.

Five sub-samples were collected along the growth axis of the two stalagmites with 0.9-mm-diameter carbide dental burrs for ²³⁰Th dating. The measurements were performed by inductively coupled plasma mass spectrometry (ICP-MS) on a Finnigan-MAT Element at the Department of Geology and Geophysics, University of Minnesota, USA. The procedures are similar to those described in Shen et al. (2002), with results listed in Table 1. All dates are in stratigraphic order with typical analytical errors (2 σ).

Stable isotope and trace element investigation

J. Y. Wu et al.

Title Page

Abstract

Introduction

Conclusions

References

Tables

Figures

◀

▶

◀

▶

Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion



Stable isotope and trace element investigation

J. Y. Wu et al.

Title Page

Abstract

Introduction

Conclusions

References

Tables

Figures

◀

▶

◀

▶

Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion



A total of 608 sub-samples (350 for NH33 and 258 for NH6) were collected by knife shaving along the growth axis for stable isotopic analysis. Measurement was performed with a Finnigan-MAT 253 mass spectrometer fitted with a Kiel Carbonate Device at the College of Geography Science, Nanjing Normal University. Spatial resolution varies from 0.06 to 0.2 mm, corresponding to a temporal resolution of 1 to 15 yr. Values of $\delta^{18}\text{O}$ and $\delta^{13}\text{C}$ were reported relative to Vienna Pee Dee Belemnite (VPDB) and with standardization determined relative to NBS19 ($\delta^{18}\text{O} = -2.2\text{‰}$, $\delta^{13}\text{C} = 1.95\text{‰}$). The precision of $\delta^{18}\text{O}$ values is 0.06‰ at the 1- σ level.

Band counting was performed under an Olympus optical microscope following the procedures described in Tan et al. (2003). Counts along the growth axes yielded a total of 883 bands for NH33 and 778 bands for NH6, respectively. The thickness of each band ranges from 10 to 370 μm , with the most between 30 and 70 μm . Counting uncertainty is likely larger during intervals of low growth rate. However, the annual bands in both samples show a distinct feature of lamina throughout the studied interval, so that errors of counted bands are assumed to be small, ± 10 bands for NH33 and ± 22 bands for NH6, based on statistical error along three different tracks.

Trace element analyses were produced by the Avaatech XRF Core Scanner (X-ray fluorescence spectrometry), which is equipped with a variable optical system that enables any resolution between 10 and 0.1 mm. This work was performed at the Surficial Geochemical Laboratory, Nanjing University. Here, 308 data for element Ba were measured, with an average resolution of ~ 2 yr. The values of Ba/Ca ratio vary between 2.8×10^{-3} and 10.4×10^{-3} with a mean of 5.5×10^{-3} .

3 Results

3.1 Annually-resolved chronology

^{230}Th dates are shown in Table 1, covering a period of 8.6 \sim 7.7 ka BP for NH33 and 8.6 \sim 7.3 ka BP for NH6 (relative to 1950 AD). Higher ^{232}Th concentrations

($398 \sim 625 \times 10^{-3}$, see Table 1) lead to a large error of ^{230}Th dates, particularly for Sample NH6. The band-counting growth rate can be checked against the ^{230}Th -based (Fig. 3). Our timescale for the $\delta^{18}\text{O}$ was reconstructed by adjusting the floating annually-counting growth rate to the dated one. The annuality of bands can be supported by the ^{230}Th -based growth rates and the consistence in annual growth rate between the two samples, except for an interval of the oldest 200 yr.

The two band-counting growth rate profiles replicate each other over a period younger than 8.42 ka BP (Fig. 3), narrowing the uncertainty of ^{230}Th dates for Sample NH6 within ± 50 yr. Despite the two samples showing a large difference in growth rate prior to 8.42 ka BP, their duplicate $\delta^{18}\text{O}$ profiles (shown below) ensure that their uncertainty of ^{230}Th age is trivial, within ± 60 yr.

3.2 Stable isotope and ALT variability

NH33 $\delta^{18}\text{O}$ profile at ~ 2.5 -yr resolution varies from -7.9‰ to -10.3‰ with an average of -9.0‰ . NH6 $\delta^{18}\text{O}$ profile at ~ 3 -yr resolution shifts between -8.1‰ and -10.0‰ , with an overall mean of -9.2‰ . No long-term trend is observed in the two profiles. A striking similarity between them is evident over $8.38 \sim 8.04$ ka BP in terms of their decadal cycles and absolute values. Despite that NH6 $\delta^{18}\text{O}$ values are slightly enriched ($\sim 0.2\text{‰}$) with respect to those of NH33 during an interval of $8.63 \sim 8.38$ ka BP, a similar pattern between them is observed. A replication becomes worse during $8.04 \sim 7.83$ ka BP. The $\delta^{18}\text{O}$ profiles (Fig. 4) are characterised by high frequency (~ 20 -yr periodicity dominated) and high amplitude (as large as $\sim 2\text{‰}$ between cycles) oscillations. The overall $\delta^{18}\text{O}$ pattern can be roughly divided into three phases at 8.35 and 8.05 ka BP, respectively, based on their mean values of $\delta^{18}\text{O}$.

The use of stalagmite $\delta^{18}\text{O}$ as a palaeoclimate proxy, however, requires evaluation of the veracity of the records. For example, if the CO_2 degassing during stalagmite growth is sufficiently rapid, Rayleigh fractionation causes systematic changes in calcite $\delta^{18}\text{O}$ that have no direct relationship to the cave dripwater isotopic composition, nor

Stable isotope and trace element investigation

J. Y. Wu et al.

[Title Page](#)[Abstract](#)[Introduction](#)[Conclusions](#)[References](#)[Tables](#)[Figures](#)[⏪](#)[⏩](#)[◀](#)[▶](#)[Back](#)[Close](#)[Full Screen / Esc](#)[Printer-friendly Version](#)[Interactive Discussion](#)

Stable isotope and trace element investigation

J. Y. Wu et al.

Title Page

Abstract

Introduction

Conclusions

References

Tables

Figures

◀

▶

◀

▶

Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion



to climate (Hendy, 1971). Here we provided a rigorous test for isotopic equilibrium due to the replication of contemporaneous stalagmite $\delta^{18}\text{O}$ records from the same cave (Dorale and Liu, 2009). If shifts in our $\delta^{18}\text{O}$ largely reflect changes in $\delta^{18}\text{O}$ values of meteoric precipitation interpreted for Hulu and Sanbao $\delta^{18}\text{O}$ records (Cheng et al., 2006, 2009; Wang et al., 2001, 2008), the variations we observed here likely relate to the proportion of summer monsoon (low $\delta^{18}\text{O}$) rainfall in the annual total (Cheng et al., 2009), sometimes referred to as “monsoon intensity”.

$\delta^{13}\text{C}$ values range from -9.9‰ to -11.9‰ , with an average of -10.7‰ for NH33, and from -9.7‰ to -12.1‰ , with an average of -10.8‰ for NH6. The two $\delta^{13}\text{C}$ records replicate each other prior to 8.2 ka BP, particularly a similar increasing trend in $\delta^{13}\text{C}$ between 8.42 ~ 8.20 ka BP. After that time, the two records have some discrepancies with a deviation of 0.57‰. Despite the difference, the two $\delta^{13}\text{C}$ profiles show a consistent trend that is likely related to soil biogenic CO_2 production (plant root respiration and microbial activity of the soil and the epikarst zone). Since the amplitude of $\delta^{13}\text{C}$ is small ($<2\text{‰}$) and occurs on the century timescale, their changes, in turn, are linked to climatic factors such as temperature and humidity (Genty et al., 2003). It is, therefore, inferred that a climatic deterioration began at 8.42 ka BP and developed extremely at ~8.20 ka BP that would subdue the microbial activity and vegetation cover in the soil overlying the cave.

Annual layer thickness (ALT) values for the two samples range from 10 to 370 μm , centred on 20 ~ 70 μm . Variation of ALT is relatively small, ranging from 20 to 210 μm for Sample NH33 and it is large ranging from 10 to 370 μm for Sample NH6. However, both records show a similar decreasing trend from 8.6 to 7.6 ka BP, with a large deviation prior to 8.4 ka BP. This suggests that the cave environment changed significantly since that time, consistent with the inference from the $\delta^{13}\text{C}$ data.

4 Discussions

4.1 ALT and its environmental significance

The fabric feature of annual layer in our cave, bears a resemblance to those from several other caves in China dominantly controlled by seasonal variations in temperature and rainfall (Tan et al., 2003; Wu et al., 2006), which can be summarized as below. (i) A clear division between bands exhibits a dark stripe under transmission light and luminescence light under UV excitation, indicating a higher content of organic matter and dust input between bands; (ii) the bands were mainly composed of one phase, i.e. columnar-fabric crystals of calcite minerals perpendicular to the growing substrate; (iii) variation of ALT is relatively small, ALT usually less than 1 mm, focusing on 30 ~ 200 μm . The formation of these kind of layers is closely related to the monsoon climate, i.e. distinctly seasonal contrast of precipitation and temperature (Tan et al., 2006; Baker et al., 2008). At our cave site, 60 % of annual precipitation falls between June to September and the permafrost period lasts about 4 months (December to February) that causes drip cessation. Thus, impurities including dust and organic matter at ceased-growing boundary are beneficial in creating new crystallization cores of calcite, leading to an apparent division between bands.

If the growth axis is stable as we observed here, it can be implied that the drip waters remains a steady hydrological state during the entire growth period. As a result, changes in the growth rate likely depend on external environmental influences. Two factors should be considered. One is carbonic acid concentration in cave dripwater, which has a strong influence on speleothem growth rate, and is linked to carbon dioxide concentration in the soils above (Dulinski and Rozanski, 1990). This kind of variance often causes a remarkable change in ALT (Fairchild et al., 2006). In Sample NH6, differences of ALT in adjacent layers reach as much as 20 times and have a remarkable boundary at ~8.4 ka BP. The corresponding $\delta^{13}\text{C}$ profiles suggest that high soil CO_2 concentration may dissolve in dripwater prior to ~8.42 ka BP, exerting a strong influence on stalagmite growth rate. Another factor is variation of seepage amount from year

Stable isotope and trace element investigation

J. Y. Wu et al.

Title Page

Abstract

Introduction

Conclusions

References

Tables

Figures



Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion



Stable isotope and trace element investigation

J. Y. Wu et al.

Title Page

Abstract

Introduction

Conclusions

References

Tables

Figures

◀

▶

◀

▶

Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion



to year, broadly responding to local precipitation, which provides the total amount of annual precipitates for stalagmite growth. If controlled only by this factor, the ALT is basically characterised by gradual changes between layers and with small amplitude. Thus, the ALT can indicate the variations of the precipitation if other condition remains unchanged (Baker et al., 1993, 1998; Genty and Quinif, 1996). For the samples from Nuanhe Cave, an infiltration control of ALT probably occurred after 8.42 ka BP.

In summary, the ALT profiles in the Nuanhe Cave suggest that the two factors of $p\text{CO}_2$ and yearly seeping-water amount may play an important role in changing ALT signal alternatively or at the same time. During the infiltration-dominated period of 8.4 ~ 7.9 ka BP, the two ALT profiles also show remarkable differences somewhere (Fig. 4), implicating that the two factors existed at the same time or more factors were involved. Thus, our ALT records should be calibrated if used as a valid climate indicator.

Growth rate can provide a good test if kinetic fractionation of oxygen isotope exists between water and rock (Mickler et al., 2004). For Sample NH33, there is no statistically significant correlation between ALT and oxygen isotope ($r = 0.02$, $n = 883$), suggesting little kinetic effect on $\delta^{18}\text{O}$. For Sample NH6, the ALT has a statistical correlation with oxygen isotope ($r = -0.3$, $n = 778$), suggesting a small kinetic effect on $\delta^{18}\text{O}$, particularly at the $p\text{CO}_2$ -dominated period of the oldest 200 yr during which a negative shift of 0.5‰ compared with that of NH33.

4.2 Monsoonal 8.2 ka event

Speleothem $\delta^{18}\text{O}$ records from Qunf (Fleitmann et al., 2003) and Dongge Cave (Wang et al., 2005) indicate an Asian Monsoon (AM) failure roughly between 8.6 and 8.1 ka BP. In addition, a well-dated census of African summer-monsoon-fed lakes (Gasse et al., 2000) illustrates a well-defined reduction in monsoon intensity or penetration between approximately 8.5 and 7.8 ka BP. These anomalies are attributed to “8.2 ka event” itself, but distinctly different from the typical of 8.2 ka event recorded in Greenland ice cores. The 8.2 ka event at Greenland was estimated about the magnitude of cooling to $6 \pm 2^\circ$ (Alley et al., 1997) and with a total duration of 160.5 yr and centred peak of

69 yr (Thomas et al., 2007). At present there has been no strong evidence for the monsoonal 8.2 ka event equivalent to that at Greenland, including the latterly re-dated cave records in Indian and East Asian regions (Cheng et al., 2009). In addition, the monsoon anomalies do not show abrupt changes at the onset and termination, appearing to be superimposed on a longer-term monsoon reduction (Rohling and Pälike, 2005).

Despite our $\delta^{18}\text{O}$ records show a significant difference from the previously published cave data from the Asian continent (Fleitmann et al., 2003; Wang et al., 2005; Cheng et al., 2009), a similar feature among the records can be summarized as below (Fig. 5). Firstly, a reduction monsoon period lasted two or three centuries in the cave $\delta^{18}\text{O}$ records at ~ 8.2 ka BP and that duration is well estimated to be 300 yr in our new records; secondly, a trend of monsoon weakening is not so significant as recorded at Greenland, particularly muted in the Nuanhe $\delta^{18}\text{O}$ records (with a mean value of 0.3‰ in amplitude). Thirdly, the re-dated records show an abrupt change at 8.21 ± 0.02 ka BP (Cheng et al., 2009), the corresponding change in the new records displays a 60-yr transition (Fig. 5). An interpretation for the significant difference between the new and Dongge/Qunf records is likely that the cave sites are situated in the East Asian and Indian monsoon, or subtropical and tropical monsoon-dominated regions, respectively.

In order to tie our $\delta^{18}\text{O}$ records to the 8.2 ka event at Greenland, we selected the NH33 $\delta^{13}\text{C}$ record for comparison because the record at a ~ 2.5 -yr higher resolution shows a climatically deteriorated trend from 8.42 to 8.20 ka BP (Fig. 6). This deteriorated trend is similar to those in the re-dated Dongge/Qunf records (Fig. 5), but ~ 80 yr longer. The duration of 8.2 ka event in GISP2 (Stuiver and Grootes, 2000) was estimated ~ 170 yr and the cold period lasts ~ 70 yr. The central event is asymmetrical in shape with considerable decadal variability in the record, as shown by the presence of a relatively warm spike at around 8.2 ka BP. The stalagmite $\delta^{13}\text{C}$ time series exhibit climate degradation during the corresponding interval (8.29 \sim 8.10 ka BP), agreeing well with that at Greenland.

Stable isotope and trace element investigation

J. Y. Wu et al.

[Title Page](#)[Abstract](#)[Introduction](#)[Conclusions](#)[References](#)[Tables](#)[Figures](#)[⏪](#)[⏩](#)[◀](#)[▶](#)[Back](#)[Close](#)[Full Screen / Esc](#)[Printer-friendly Version](#)[Interactive Discussion](#)

Stable isotope and trace element investigation

J. Y. Wu et al.

Title Page

Abstract

Introduction

Conclusions

References

Tables

Figures



Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion



We validate the deteriorated signal in NH33 $\delta^{13}\text{C}$ record by the elemental ratio of Ba/Ca at ~ 2 -yr resolution over the same growth interval, as this ratio, in particular, provides a valid means for understanding past climate variations (e.g. Desmarchelier et al., 2006; Johnson et al., 2006; Treble et al., 2003). Ba/Ca ratios are expected to be higher during drier periods due to calcite precipitation in soils and water-soil contact times (Ayalon et al., 1999). However, Barium is considered as a rather immobile element in soils, due to a high cation exchange selectivity for Ba^{2+} (McBride and Homenuth, 1994). An increased Ba^{2+} concentration could reflect increased leaching of soil cations by more concentrated carbonic acid (Hellstrom and McCulloch, 2000). As inferred by the $\delta^{13}\text{C}$ records, our Ba/Ca profile likely reflects changes in productivity of soil plant and biomass and $p\text{CO}_2$ in soil. In fact, our Ba/Ca record bears a remarkable resemblance to the 8.2 ka event recorded in the GISP2 ice core in terms of its timing, duration and structure (Fig. 6).

The discrepancies of the analogous event between regional climate proxy of $\delta^{18}\text{O}$ and local environmental proxies ($\delta^{13}\text{C}$ and Ba/Ca) suggest different seasonal responses at the cave site to the high-latitude forcing, with a weak anomaly in a summer-dominated $\delta^{18}\text{O}$ proxy and a strong response in proxies of $\delta^{13}\text{C}$ and Ba/Ca. As widely noticed, freshwater discharge and its resulting weakening of Atlantic Meridional Overturning Circulation (AMOC) (Alley et al., 1997; Barber et al., 1999) play an important role in changing strength of Asian winter monsoons via the westerly jets (Porter and An, 1995), leading to accordance with northern high-latitude climates. Our $\delta^{13}\text{C}$ and Ba/Ca records reflect a deteriorated climate initiated at 8.42 ka BP, agreeing well with the timing of the draining of glacial lakes Agassiz and Ojibway through the Hudson Bay into the North Atlantic (8.42 ± 0.30 ka BP; Barber et al., 1999; Kleiven et al., 2008; Lajeunesse and St-Onge, 2008). The culminated episode centred at ~ 8.20 ka BP is very consistent with the timing, duration and structure of the 8.2 ka event in the GISP2 record. As an inference, our $\delta^{13}\text{C}$ and Ba/Ca probably represent an environmental effect of climate deterioration associated with enhanced intensities of the winter monsoon. This supports a strong coupling of East Asian Winter Monsoon (EAWM) and North Atlantic

a threefold difference in ALT over the contemporaneous intervals. Variations of the $\delta^{13}\text{C}$ and Ba/Ca reflect a deteriorated climate initiated at 8.42 ka BP and centred at ~ 8.20 ka BP, a copy of the typical event at Greenland, suggesting a strong coupling of EAWM and North Atlantic climates. In contrast, the 8.2 ka event is weakly expressed in the summer monsoon-dominated $\delta^{18}\text{O}$ record, indicating that reorganisation of low-latitude atmospheric circulations and hydrological cycles may subdue the signal of the 8.2 ka event around the North Atlantic.

Acknowledgements. This work was supported by grants of National Nature Science Foundation of China (No. 40972111, No. 2007105GZ10033) and the Basic Research Programme of Jiangsu Province (No. BK2008025).

References

- Alley, R. B. and Ágústsson, A. M.: The 8k event: cause and consequences of a major Holocene abrupt climate change, *Quaternary Sci. Rev.*, 24, 1123–1149, 2005.
- Alley, R. B., Mayewski, P. A., Sowers, T., Stuiver, M., Taylor, K. C., and Clark, P. U.: Holocene climate instability: A prominent, widespread event 8200 yr ago, *Geology*, 25, 483–486, 1997.
- Ayalon, A., Bar-Matthews, M., and Kaufman, A.: Petrography, strontium, barium and uranium concentrations, and strontium and uranium isotope ratios in speleothems as palaeoclimatic proxies: Soreq Cave, Israel, *Holocene*, 9, 715–722, 1999.
- Baker, A., Smart, P. L., and Ford, D. C.: Northwest European paleoclimate as indicated by growth frequency variations of secondary calcite deposits, *Palaeogeogr. Palaeoclimatol.*, 100, 291–301, 1993.
- Baker, A., Genty, D., Dreybrodt, W., Barnes, W. L., Mockler, N. J., and Grapes, J.: Testing theoretically predicted stalagmite growth rate with recent annually laminated samples: Implications for past stalagmite deposition, *Geochim. Cosmochim. Acta*, 62, 393–404, 1998.
- Baker, A., Asrat, A., Fairchild, I. J., Leng, M. J., Wynn, P. M., Bryant, C., Genty, D., and Umer, M.: Analysis of the climate signal contained within $\delta^{18}\text{O}$ and growth rate parameters in two Ethiopian stalagmites, *Geochim. Cosmochim. Acta*, 71, 2975–2988, 2007.
- Baker, A., Fuller, L., Genty, D., Fairchild, I. J., Jex, C., and Smith, C. L.: Annually laminated stalagmites: a review, *Int. J. Speleol.*, 37, 193–206, 2008.

Stable isotope and trace element investigation

J. Y. Wu et al.

Title Page

Abstract

Introduction

Conclusions

References

Tables

Figures



Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion



Stable isotope and trace element investigation

J. Y. Wu et al.

Title Page

Abstract

Introduction

Conclusions

References

Tables

Figures



Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion



- Barber, D. C., Dyke, A., Hillaire-Marcel, C., Jennings, A. E., Andrews, J. T., Kerwin, M. W., Bilodeau, G., McNeely, R., Southon, J., Morehead, M. D., and Gagnon, J. M.: Forcing of the cold event of 8,200 years ago by catastrophic drainage of Laurentide Lakes, *Nature*, 400, 344–348, 1999.
- 5 Bond, G., Kromer, B., Beer, J., Muscheler, R., Evans, M. N., Showers, W., Hoffmann, S., Lotti-Bond, R., Hajdas, I., and Bonani, G.: Persistent solar influence on North Atlantic climate during the Holocene, *Science*, 294, 2130–2136, 2001.
- Cheng, H., Edwards, R. L., Wang, Y. J., Kong, X. G., Ming, Y. F., Gallup, C. D., Kelly, M. J., Wang, X. F., and Liu, W. G.: A penultimate glacial monsoon record from Hulu Cave and two-phase glacial terminations, *Geology*, 34, 217–220, 2006.
- 10 Cheng, H., Fleitmann, D., Edwards, R. L., Wang, X. F., Cruz, F. W., Auler, A. S., Mangini, A., Wang, Y. J., Kong, X. G., Burns, S. J., and Matter, A.: Timing and structure of the 8.2 kyr BP event inferred from $\delta^{18}\text{O}$ records of stalagmites from China, Oman, and Brazil, *Geology*, 37, 1007–1010, 2009.
- 15 Desmarchelier, J. A., Hellstrom, J. C., and McCulloch, M. T.: Rapid trace element analysis of speleothems by ELA-ICP-MS, *Chem. Geol.*, 31, 102–117, 2006.
- Dorale, J. A. and Liu, Z. H.: Limitations of Hendy test criteria in judging the paleoclimatic suitability of speleothems and the need for replication, *J. Cave Karst Stud.*, 71, 73–80, 2009.
- Dulinski, M. and Rozanski, K.: Formation of $^{13}\text{C}/^{12}\text{C}$ isotope ratios in speleothems: a semi-dynamic model, *Radiocarbon*, 32, 7–16, 1990.
- 20 Fairchild, I. J., Smith, C. L., Baker, A., Fuller, L., Spötl, C., Matthey, D., McDermott, F., and E. I. M. F.: Modification and preservation of environmental signals in speleothems, *Earth-Sci. Rev.*, 75, 105–153, 2006.
- Fleitmann, D., Burns, S. J., Mudelsee, M., Neff, U., Kramers, J., Mangini, A., and Matter, A.: Holocene Forcing of the Indian Monsoon recorded in a stalagmite from Southern Oman, *Science*, 300, 1737–1739, 2003.
- 25 Gasse, F.: Hydrological changes in the African tropics since the last glacial maximum, *Quaternary Sci. Rev.*, 19, 189–211, 2000.
- Genty, D. and Quinif, Y.: Annually laminated sequences in the internal structure of some Belgian stalagmites-Importance for paleoclimatology, *J. Sediment Res.*, 66, 275–288, 1996.
- 30 Genty, D., Blamart, D., Ouahdi, R., Gilmour, M., Baker, A., Jouzel, J., and Van-Exter, S.: Precise dating of Dansgaard-Oeschger climatic oscillations in western Europe from stalagmite data, *Nature*, 421, 833–837, 2003.

Stable isotope and trace element investigation

J. Y. Wu et al.

Title Page

Abstract

Introduction

Conclusions

References

Tables

Figures

◀

▶

◀

▶

Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion



Haug, G. H., Hughen, K. A., Peterson, L. C., Sigman, D. M., Peterson, L. C., and Rohl, U.: Southward migration of the Intertropical Convergence Zone through the Holocene, *Science*, 293, 1304–1308, 2001.

Hellstrom, J. C. and McCulloch, M. T.: Multi-proxy constraints on the climatic significance of trace element records from a New Zealand speleothem, *Earth Planet. Sc. Lett.*, 179, 287–297, 2000.

Hendy, C. H.: The isotopic geochemistry of speleothems – I. The calculation of the effects of different modes of formation on the isotopic composition of speleothems and their applicability as palaeoclimatic indicators, *Geochim. Cosmochim. Acta*, 35, 801–824, 1971.

Hughen, K. A., Overpeck, J. T., Peterson, L. C., and Trumbore, S.: Rapid climate changes in the tropical Atlantic region during the last deglaciation, *Nature*, 380, 51–54, 1996.

Johnson, K. R., Hu, C., Belshaw, N. S., and Henderson, G. M.: Seasonal trace-element and stable isotope variations in a Chinese speleothem: the potential for highresolution paleomonsoon reconstruction, *Earth Planet. Sc. Lett.*, 244, 394–407, 2006.

Kleiven, H. F., Kissel, C., Laj, C., Ninnemann, U. C., Richter, T. O., and Cortijo, E.: Reduced North Atlantic Deep Water coeval with the glacial Lake Agassiz freshwater outburst, *Science*, 319, 60–64, 2008.

Lachniet, M. S., Asmerom, Y., Burns, S. J., Patterson, W. P., Polyak, V. J., and Seltzer, G. O.: Tropical response to the 8200 yr B.P. cold event? Speleothem isotopes indicate a weakened early Holocene monsoon in Costa Rica, *Geology*, 32, 957–960, 2004.

Lajeunesse, P. and St-Onge, G.: The subglacial origin of the Lake Agassiz-Ojibway final outburst flood, *Nat. Geosci.*, 1, 184–188, 2008.

McBride, M. B. and Homenauth, O. P.: Adsorption of aniline on layer silicate clays and an organic soil, *Soil Sci. Soc. Am. J.*, 58, 347–354, 1994.

Mickler, P. J., Banner, J. L., Stern, L., Asmerom, Y., Edwards, R. L., and Ito, E.: Stable isotope variations in modern tropical speleothems: Evaluating equilibrium vs. kinetic isotope effects: *Geochim. Cosmochim. Acta*, 68, 4381–4393, 2004.

Morrill, C., Overpeck, J. T., and Cole, J. E.: A synthesis of abrupt changes in the Asian summer monsoon since the last deglaciation, *Holocene*, 13, 456–476, 2003.

Muscheler, R., Beer, J., and Vonmoos, M.: Causes and timing of the 8200 yr BP event inferred from the comparison of the GRIP ^{10}Be and the tree ring $\Delta^{14}\text{C}$ record, *Quaternary Sci. Rev.*, 23, 2105–2115, 2004.

Stable isotope and trace element investigation

J. Y. Wu et al.

[Title Page](#)[Abstract](#)[Introduction](#)[Conclusions](#)[References](#)[Tables](#)[Figures](#)[Back](#)[Close](#)[Full Screen / Esc](#)[Printer-friendly Version](#)[Interactive Discussion](#)

- Neff, U., Burns, S. J., Mangini, A., Mudelsee, M., Fleitmann, D., and Matter, A.: Strong coherence between solar variability and the monsoon in Oman between 9 and 6 kyr ago, *Nature*, 411, 290–293, 2001.
- 5 O'Brien, S. R., Mayewski, P. A., Meeker, L. D., Meese, D. A., Twickler, M. S., and Whitlow, S. I.: Complexity of Holocene climate as reconstructed from a Greenland ice core, *Science*, 270, 1962–1964, 1995.
- Paulsen, D. E., Li, H. C., and Ku, T. L.: Climate variability in central China over the last 1270 years revealed by high-resolution stalagmite records, *Quaternary Sci. Rev.*, 22, 691–701, 2003.
- 10 Poter, S. C. and An, Z. S.: Correlation between climate events in the North Atlantic and China during the last glaciation, *Nature*, 375, 305–308, 1995.
- Proctor, C. J., Baker, A., and Barnes, W. L.: A three thousand year record of North Atlantic climate, *Clim. Dynam.*, 19, 449–454, 2002.
- Rohling, E. J. and Pälike, H.: Centennial-scale climate cooling with a sudden cold event around 8,200 years ago, *Nature*, 434, 975–979, 2005.
- 15 Shen, C. C., Edwards, R. L., Cheng, H., Dorale, J. A., Thomas, R. B., Moran, S. B., Weinstein, S., and Edmonds, H. N.: Uranium and thorium isotopic and concentration measurements by magnetic sector inductively coupled plasma mass spectrometry, *Chem. Geol.*, 185, 165–178, 2002.
- 20 Stuiver, M. and Grootes, P. M.: GISP2 Oxygen Isotope Ratios, *Quaternary Res.*, 53, 277–284, 2000.
- Tan, M., Liu, D. S., Hou, J., Qin, X. G., Zhang, H., and Li, T. Y.: Cyclic rapid warming on centennial-scale revealed by a 2650-year stalagmite record of warm season temperature, *Geophys. Res. Lett.*, 30, 1617–1621, 2003.
- 25 Tan, M., Baker, A., Genty, D., Smith, C., Esper, J., and Cai, B.: Applications of stalagmite laminae to paleoclimate reconstructions: comparison with dendrochronology/climatology, *Quaternary Sci. Rev.*, 25, 2103–2117, 2006.
- Thomas, E. R., Wolff, E. W., Mulvaney, R., and Steffensen, J. P.: The 8.2 ka event from Greenland ice cores, *Quaternary Sci. Rev.*, 26, 70–81, 2007.
- 30 Thompson, L. G., Mosley-Thompson, E., Davis, M. E., Henderson, K. A., Brecher, H. H., Zagorodnov, V. S., Mashiotta, T. A., Lin, P. N., Mikhalenko, V. N., Hardy, D. R., and Beer, J.: Kilimanjaro ice core records: evidence of Holocene climate change in Tropical Africa, *Science*, 298, 589–593, 2002.

Stable isotope and trace element investigation

J. Y. Wu et al.

Title Page

Abstract

Introduction

Conclusions

References

Tables

Figures

◀

▶

◀

▶

Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion



Treble, P., Shelley, J. M. G., and Chappell, J.: Comparison of high resolution sub-annual records of trace elements in a modern (1911–1992) speleothem with instrumental climate data from southwest Australia, *Earth Planet. Sc. Lett.*, 216, 141–153, 2003.

5 Wang, Y. J., Cheng, H., Edwards, R. L., An, Z. S., Wu, J. Y., Shen, C. C., and Dorale, J. A.: A high-resolution absolute-dated late Pleistocene monsoon record from Hulu Cave, China, *Science*, 294, 2345–2348, 2001.

Wang, Y. J., Cheng, H., Edwards, R. L., He, Y. Q., Kong, X. G., An, Z. S., Wu, J. Y., Kelly, M. J., Dykoski, K. A., and Li, X. D.: The Holocene Asian Monsoon: links to solar changes and North Atlantic climate, *Science*, 308, 854–857, 2005.

10 Wang, Y. J., Cheng, H., Edwards, R. L., Kong, X. G., Shao, X. H., Chen, S. T., Wu, J. Y., Jiang, X. Y., Wang, X. F., and An, Z. S.: Millennial- and orbital-scale changes in the East Asian monsoon over the past 224,000 years, *Nature*, 451, 1090–1093, 2008.

15 Wu, J. Y., Shao, X. H., Kong, X. G., and Wang, Y. J.: Imprint of solar activity on Nanjing stalagmite annual layer thickness sequence during the Last Glacial Maximum, *Chinese Sci. Bull.*, 51, 441–447, 2006.

Stable isotope and trace element investigation

J. Y. Wu et al.

Table 1. ^{230}Th dating results from stalagmite NH from Nuanhe Cave, China.

| Sample number | Depth (mm) | $^{238}\text{U}/\times 10^{-9}$ | $^{232}\text{Th}/\times 10^{-12}$ | $\delta^{234}\text{U}$ (measured) | $^{230}\text{Th}/^{238}\text{U}$ (activity) | ^{230}Th Age (a BP) (uncorrected) | ^{230}Th Age (a BP) (corrected) | $\delta^{234}\text{U}_0$ (corrected) |
|---------------|------------|---------------------------------|-----------------------------------|-----------------------------------|---|--|--|--------------------------------------|
| NH33-2 | 9 | 102.8 ± 0.1 | 398 ± 8 | 1031 ± 3 | 0.1421 ± 0.0006 | 7862 ± 36 | 7748 ± 53 | 1054 ± 3 |
| NH33-l | 29 | 163.4 ± 0.3 | 625 ± 13 | 1034 ± 3 | 0.1511 ± 0.0005 | 8360 ± 30 | 8245 ± 48 | 1056 ± 3 |
| NH33-3 | 54 | 122.7 ± 0.1 | 482 ± 10 | 1005 ± 3 | 0.1556 ± 0.0007 | 8754 ± 45 | 8638 ± 60 | 1030 ± 3 |
| NH6-43 | 43 | 114.5 ± 0.3 | 399 ± 3 | 1054.8 ± 6.0 | 0.14611 ± 0.00181 | 7995 ± 105 | 7946 ± 105 | 1078.7 ± 6.1 |
| NH6-87 | 87 | 123.7 ± 0.3 | 612 ± 4 | 1034.0 ± 4.8 | 0.15665 ± 0.00170 | 8683 ± 100 | 8614 ± 106 | 1059.4 ± 4.9 |

Errors are 2σ analytical errors. Decay constant values are $\lambda_{230} = 9.1599 \times 10^{-6} \text{ yr}^{-1}$, $\lambda_{234} = 2.8263 \times 10^{-6} \text{ yr}^{-1}$, $\lambda_{238} = 1.55125 \times 10^{-10} \text{ yr}^{-1}$, $^{234}\text{U} = ((^{234}\text{U}/^{238}\text{U})_{\text{activity}} - 1) \times 1000$, $^{234}\text{U}_{\text{initial}} = ^{234}\text{U}_{\text{measured}} \times e^{234 \times T}$, corrected ^{230}Th ages assume an initial $^{230}\text{Th}/^{232}\text{Th}$ atomic ratio of $(4.4 \pm 2.2) \times 10^{-6}$.

Corrected ^{230}Th ages are indicated in bold and presented in years before 1950 AD.

Title Page

Abstract

Introduction

Conclusions

References

Tables

Figures

◀

▶

◀

▶

Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion



Stable isotope and trace element investigation

J. Y. Wu et al.

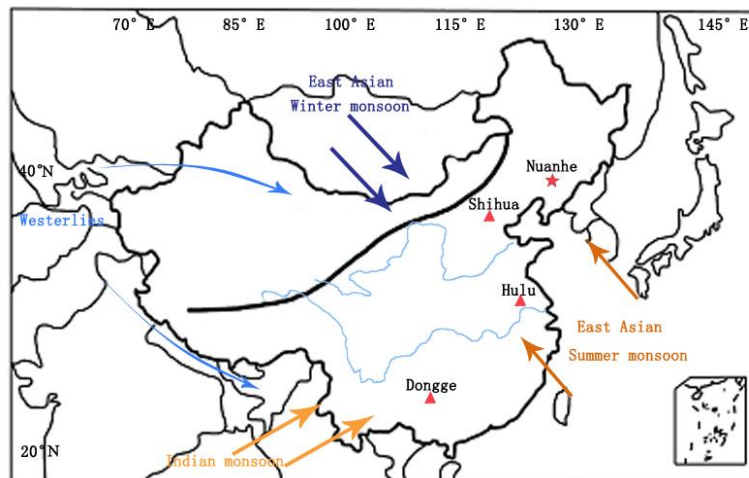


Fig. 1. Location of Nuanhe Cave. The orange arrows show different sub-systems of Asian summer monsoon, blue arrows indicate East Asian winter monsoon and westerly winds, respectively. The bold line illustrates the northern limit of summer monsoon. The red star and triangles indicate the location of Nuanhe Cave and other cave sites mentioned in this study.

Title Page

Abstract

Introduction

Conclusions

References

Tables

Figures

◀

▶

◀

▶

Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion



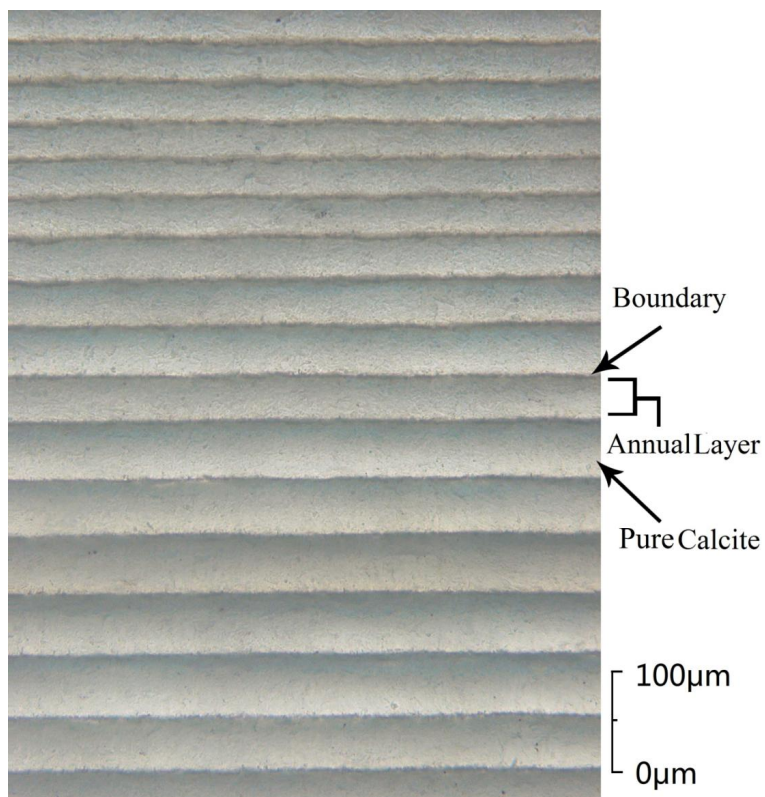


Fig. 2. Micrograph (using a 10 × objective lens) showing examples of typical well-formed annual bands preserved in a small columnar stalagmite NH33.

Stable isotope and trace element investigation

J. Y. Wu et al.

Title Page

Abstract

Introduction

Conclusions

References

Tables

Figures

◀

▶

◀

▶

Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion



Stable isotope and trace element investigation

J. Y. Wu et al.

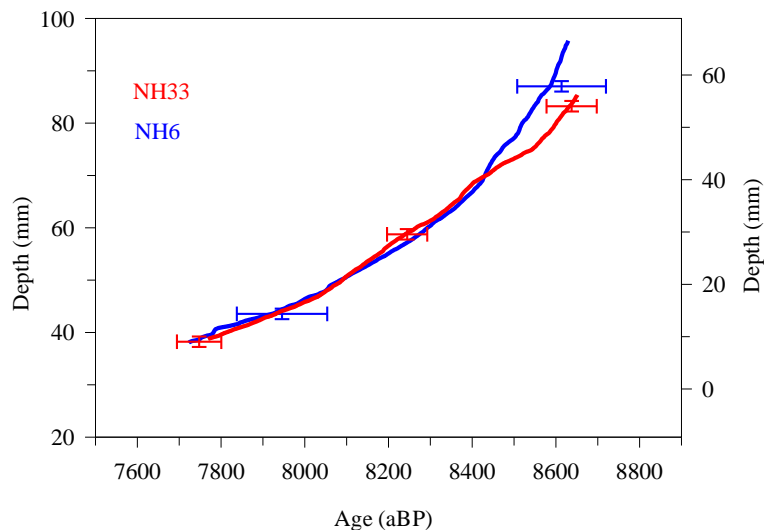


Fig. 3. Independent assessment of stalagmites NH lamina chronology anchored by five ^{230}Th dates. Uncertainties of dating (± 48 to ± 106 yr) and sampling position (± 0.5 to ± 1 mm) are represented by horizontal and vertical bar, respectively.

Full Screen / Esc

Printer-friendly Version

Interactive Discussion



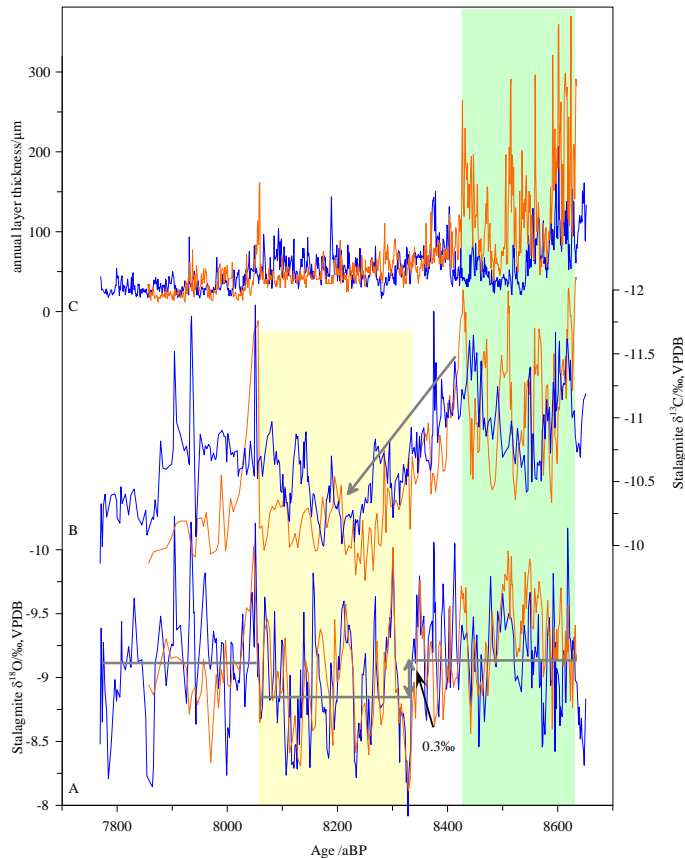


Fig. 4. Comparison of multi-proxy records between two stalagmites (NH33-blue curves and NH6-orange curves). **(A)** $\delta^{18}\text{O}$ records, the gray lines designate average values of $\delta^{18}\text{O}$ in 3 phases; **(B)** $\delta^{13}\text{C}$ records, the gray arrow illustrates the same trend between two $\delta^{13}\text{C}$ records; **(C)** annual layer thickness records.

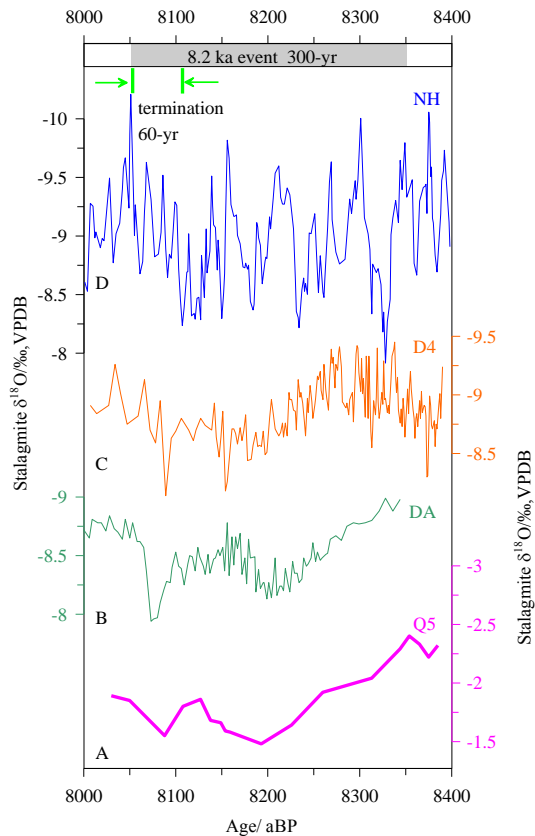


Fig. 5. $\delta^{18}\text{O}$ time series over 8.2 ka event from stalagmites. **(A)** Q5, Qunf Cave, Oman; **(B)** DA, Dongge Cave, China; **(C)** D4, Dongge Cave, China; **(D)** NH33, Nuanhe Cave, China. Q5, DA and D4 records were re-dated by Cheng et al. (2009). Gray bar indicates the broadly consistent duration of the 8.2 ka event from all monsoon records. The end of the 8.2 ka event in NH33 $\delta^{18}\text{O}$ lasts about 60 yr.

Stable isotope and trace element investigation

J. Y. Wu et al.

Title Page

Abstract

Introduction

Conclusions

References

Tables

Figures



Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion



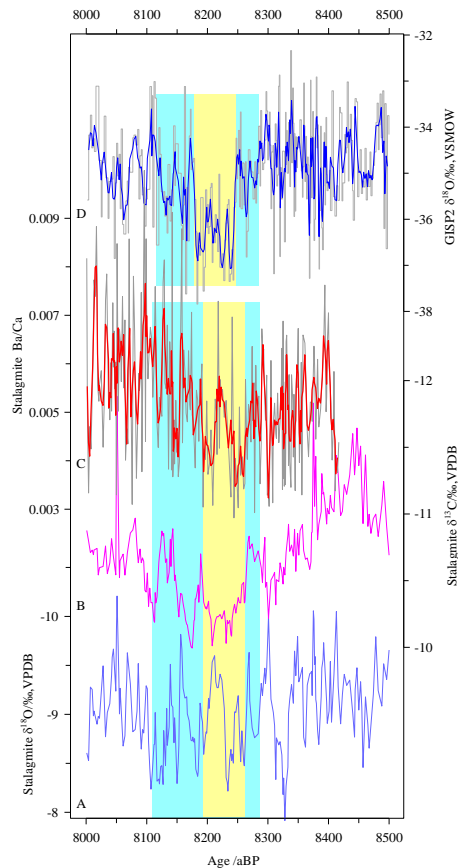


Fig. 6. Detailed comparison of multi-proxy records from stalagmite NH33 – $\delta^{18}\text{O}$ (A); $\delta^{13}\text{C}$ (B); Ba/Ca (C); and GISP2 $\delta^{18}\text{O}$ record (D) (Stuiver and Grootes, 2000). The blue and yellow blocks indicate the 8.2 ka event and its central vale, respectively. All records are plotted on their respective time scales, in years before 1950 AD.

Stable isotope and trace element investigation

J. Y. Wu et al.

Title Page

Abstract

Introduction

Conclusions

References

Tables

Figures



Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion

