Quaternary Science Reviews 160 (2017) 1–12

Contents lists available at ScienceDirect

Quaternary Science Reviews

journal homepage: www.elsevier.com/locate/quascirev

Stalagmite-inferred centennial variability of the Asian summer monsoon in southwest China between 58 and 79 ka BP

Tao-Tao Zhang [a, b, c], Ting-Yong Li [a, b, c, *], Hai Cheng [d], R. Lawrence Edwards [e], Chuan-Chou Shen [f], Christoph Spötl [g], Hong-Chun Li [f], Li-Yin Han [a], Jun-Yun Li [a], Chun-Xia Huang [a], Xin Zhao [a]

[a] *Chongqing Key Laboratory of Karst Environment, School of Geographical Sciences, Southwest University, Chongqing, 400715, China*
[b] *State Key Laboratory of Loess and Quaternary Geology, Institute of Earth Environment, Chinese Academy of Sciences, Xi'an, 710075, China*
[c] *Field Scientific Observation & Research Base of Karst Eco-environments at Nanchuan in Chongqing, Ministry of Land and Resources of China, Chongqing, 408435, China*
[d] *Institute of Global Environmental Change, Xi'an Jiaotong University, Xi'an, 710049, China*
[e] *Department of Earth Sciences, University of Minnesota, Minneapolis, MN, 55455, USA*
[f] *Department of Geosciences, National Taiwan University, Taipei, 10617, Taiwan, ROC*
[g] *Institut für Geologie, Universität Innsbruck, 6020 Innsbruck, Austria*

ARTICLE INFO

Article history:
Received 15 July 2016
Received in revised form
27 January 2017
Accepted 1 February 2017

Keywords:
Stalagmite $\delta^{18}O$
Asian summer monsoon
Greenland interstadials
Heinrich event 6
Southern Hemisphere

ABSTRACT

We use a new spliced stalagmite oxygen isotope record from Yangkou Cave and, Chongqing, southwest China, to reconstruct the centennial-millennial-scale changes in Asian Summer Monsoon (ASM) intensity between 58.0 and 79.3 thousand years before present (ka BP, before AD 1950). This multidecadally resolved record shows four strong ASM periods, corresponding to Greenland Interstadials (GIS) 17–20, and three weak ASM episodes, starting at 61.5 ± 0.2 ka BP and ending at 59.4 ± 0.2 ka BP that may correlate with Heinrich Event 6. The close agreement of climate events between China and Greenland supports the notion that the ASM is dominantly governed by high-latitude forcings in the Northern Hemisphere. The short-lived interstadial GIS 18, however, lasted for over 3 kyr in the records derived from ASM region, reflecting a gradual decline of ASM intensity, which coincides with a millennial-scale warming trend in Antarctica. This suggests an additional forcing of the ASM by the Southern Hemisphere, which also affected GIS 8–12, H4 and H5, as shown by previous speleothem studies from the ASM region.

1. Introduction

The Asian Summer Monsoon (ASM) is an integral part of the global climatic system and plays a central role in rapid climate changes involving both the Northern Hemisphere (NH) and the Southern Hemisphere (SH) (Cai et al., 2006; Barker and Knorr, 2007; Rohling et al., 2009; An et al., 2000, 2011, 2015). In recent years, the evolution of the ASM on centennial-millennial time scales since the last glacial period (LGP) has been studied using various paleoclimatic records, including stalagmites. These studies show that variability of the ASM is tightly correlated to climate changes in the northern high latitudes (e.g., Wang et al., 2001, 2005, 2008; Burns et al., 2003; Yuan et al., 2004; Shakun et al., 2007; Cosford et al., 2008; Liu et al., 2013; Duan et al., 2014, 2015; Cai et al., 2015). Other studies indicate that the ASM was also influenced by SH temperature changes during Heinrich events (H) 4 and 5 and Greenland Interstadials (GIS) 5–12 via the transequatorial flow and the migration of the position of the Intertropical Convergence Zone (ITCZ) (Cai et al., 2006; Rohling et al., 2009; Zhou et al., 2014; Han et al., 2015). High-resolution stalagmite records mainly cover Marine Isotope Stages (MIS) 1–3, while little detailed information is available on the evolution of the ASM during MIS 4. With decreasing summer insolation in the Northern Hemisphere (Berger and Loutre, 1991), increasing ice volume and sea-level lowering (Waelbroeck et al., 2002), the MIS 4 interval was an extended cold period considered to be comparable to the last glacial maximum (LGM) (North Greenland Ice Core Project members, 2004). Therefore, a detailed study of the ASM changes during MIS 4 will improve our understanding of the progress and

---

[*] Corresponding author. School of Geographical Sciences, Southwest University, No. 2 Tiansheng Road, Beibei district, Chongqing, 400715, China.
E-mail address: cdlty@swu.edu.cn (T.-Y. Li).

http://dx.doi.org/10.1016/j.quascirev.2017.02.003
0277-3791/

mechanisms of ASM evolution during the LGP and its role within the Earth climate system.

Furthermore, although GIS and H events were first identified in Greenland ice cores (Johnsen et al., 1992; Dansgaard et al., 1993) and North Atlantic sediments (Heinrich, 1988; Bond et al., 1993), their footprint has since been found throughout both hemispheres (e.g., Wang et al., 2001, 2006; Burns et al., 2003; Carolin et al., 2013; Deplazes et al., 2013; Zhou et al., 2014; Stríkis et al., 2015). Precise chronologies of GIS and H events are essential to understand their mechanisms and influences on the climate system. For marine sediments, the timing of H6 is beyond the limit of the ^{14}C dating method. And for ice cores, even the most accurate ice-core age model – the annual layer-counted GICC05 timescale – is associated with uncertainties exceeding 2.6 ka at ages >60 ka (based on 2σ maximum counting errors - Svensson et al., 2008). This lack of accurate and precise chronologies can be compensated by speleothems taking advantage of recent improvements in high-precision ^{230}Th dating (Shen et al., 2012; Cheng et al., 2013). For example, Xia et al. (2007) and Boch et al. (2011) constrained the timing of GIS using stalagmite records from Sanbao Cave, China, and the European Alps, respectively. They reported slightly younger ages for GIS 19–20 than those recorded in NGRIP. However, neither the Sanbao nor the Alps speleothems recorded the equivalents of GIS 18 and H6. Similarly, these climate events are also not registered in the seminal Hulu Cave record (Wang et al., 2001). In order to address the question whether these rapid climate events had less impact on certain regions such as China higher-resolution and precisely dated speleothem records from other caves are crucial. This is the key motivation of this study and we report here a new stalagmite record from Yangkou Cave in China, which covers the entire MIS 4 interval. High U concentrations resulted in age uncertainties of less than 0.5% (Li et al., 2014a; Han et al., 2016) allowing to accurately reconstruct the evolution of ASM during MIS 4 and to assess potential forcing mechanisms.

2. Cave site and stalagmite sample

Stalagmite JFYK7 was collected in Yangkou Cave (29°02′N, 107°11′E, 2140 m a.s.l.) (Fig. 1), which is located in Jinfo Mountain, Chongqing City, southwest China. The study site is situated at the northern border region between the Sichuan Basin and the Yun-Gui Plateau. The cave is 2245 m in length and developed in Permian limestones. The climate in this region is mainly controlled by the Asian monsoon. The mean annual temperature and precipitation are about 8.5 °C and 1400 mm, respectively. About 83% of the rain falls in the rainy season between April and October (Zhang et al., 1998).

Stalagmite JFYK7 is approximately 125 mm and 40 mm wide at the bottom and top, respectively. It is composed of dark brown calcite and its the internal structure reveals a clear submillimeter-scale layering (Fig. 2 in Han et al., 2016). The length of the growth axis, which changed its orientation during the growth history, is 555 mm. With the exception of a clear hiatus between 452.5 and 453 mm distance from top the stalagmite shows no macroscopic evidence of further growth interruptions.

In this study, we present data from the section between 367 mm and 555 mm distance from the top, which covers MIS 4.

3. Methods

3.1. U-Th dating

Sixteen sub-samples were ^{230}Th-dated. Approximately 80 mg of calcite powder was drilled along individual growth layers using a 1-mm carbide dental drill. Procedures for chemical separation and purification of U and Th are described in Shen et al. (2003, 2012). Dating was performed at the University of Minnesota, USA, and the Xi'an Jiaotong University, China. A Thermo Fisher Neptune multi-collector inductively coupled plasma mass spectrometer (MC-ICP-MS) with a secondary electron multiplier was used for the determination of the U-Th isotopic contents and compositions (Shen et al., 2012; Cheng et al., 2013). The decay constants of ^{230}Th, ^{234}U, and ^{238}U are $9.1705 \times 10^{-6}\ yr^{-1}$, $2.82,206 \times 10^{-6}\ yr^{-1}$ (Cheng et al., 2013), and $1.55,125 \times 10^{-10}\ yr^{-1}$ (Jaffey et al., 1971), respectively. The age correction for the initial ^{230}Th was performed using the average crustal $^{230}Th/^{232}Th$ ratio of $4.4 \pm 2.2 \times 10^{-6}$ (Taylor and McLennan, 1995).

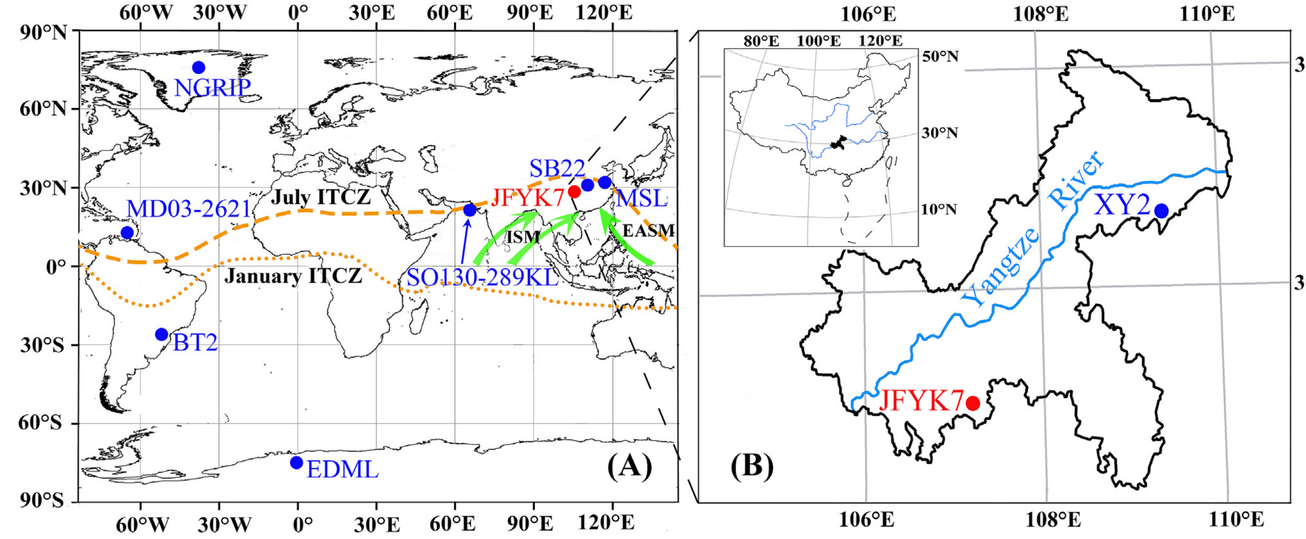

Fig. 1. (A) Location of Yangkou cave (stalagmite JFYK7, red dot) and other paleoclimatic records (blue dots): MSL (Hulu Cave; Wang et al., 2001), SB22 (Sanbao Cave; Wang et al., 2008), SO130-289KL (northeastern Arabian Sea), MD03-2621 (Cariaco Basin, Deplazes et al., 2013), BT2 (Botuverá Cave, Cruz et al., 2005), NGRIP (North Greenland Ice Core Project members, 2004), and EDML (EPICA Community Members., 2006). Green arrows depict the present-day surface wind directions of the ISM and EASM. (B) Chongqing City and the locations of Yangkou cave (stalagmite JFYK7, red dot) and Xinya Cave (stalagmite XY2, blue dot). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)