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Changes in climate and vegetation of central Guizhou in southwest China since the last glacial reflected by stalagmite records from Yelang Cave

Min Zhao [a,b], Hong-Chun Li [b,*], Zai-Hua Liu [a], Horng-Sheng Mii [c], Hai-Long Sun [a], Chuan-Chou Shen [b,d], Su-Chen Kang [b]

[a] *State Key Laboratory of Environmental Geochemistry, Institute of Geochemistry, Chinese Academy of Sciences, 46 Guanshui Road, Guiyang 550002, China*
[b] *Department of Geosciences, National Taiwan University, Taipei 10617, Taiwan, ROC*
[c] *Department of Earth Sciences, National Taiwan Normal University, Taipei 11677, Taiwan, ROC*
[d] *High-Precision Mass Spectrometry and Environment Change Laboratory (HISPEC), Department of Geosciences, National Taiwan University, Taipei 10617, Taiwan, ROC*

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ABSTRACT

Two stalagmites (6-cm and 18-cm long) from Yelang Cave (26°2′28″N, 105°44′11″E) in central Guizhou of China have been dated by ICP-MS ^{230}Th/U, ^{210}Pb and AMS ^{14}C dating methods. Low U but high Th contents in the young stalagmites were difficult to apply ^{230}Th/U dating. Instead, AMS ^{14}C dating solved the chronological problem of these stalagmites. Both stalagmites had fast growth rates during Holocene Optimum and the last 600 years, but absent growth between 4 and 8 ka. The δ^{18}O record of Stalagmite 20120824-13 agrees well with the Dongge δ^{18}O records on centennial or longer scales, showing dry climates during the Last Glacial Maximum (LGM) and Younger Dryas and wet climates during Holocene Optimum following the solar insolation trend. The summer monsoon strength decreased from 4.12 ka to 1.5 ka, but increased during the Medieval Warm Period to produce wet climates and abundant vegetation in the study area. The δ^{18}O record during the last 600 years exhibits strongly decadal variations. Twelve light δ^{18}O excursions on decadal scales during the last 600 years can be identified, agreeing with the local Dry–Wet index record. The Pacific Decadal Oscillation (PDO) strongly affects decadal variability of the moisture budget in the study area, with cold PDO (La Niña condition) in favor of stronger EASM and wet climates. The δ^{13}C record indicates that natural vegetation in the study area was strongly destroyed by human activity after the reign of Emperor Yong Zheng (AD 1722-1735) of Qing Dynasty. Since then, the karst-desertification in central Guizhou has been strongly developed due to rapidly increased population and land-use.

1. Introduction

The East Asian summer monsoon (EASM) affects strongly climatic conditions of East Asia where nearly one-third of the world's population lives in. As a major climatic system, the EASM is not only related to solar insolation and temperature in high latitudes of North Hemisphere (Wang et al., 2001; Wan et al., 2011a), but also interacted/teleconnected with El Niño/Southern Oscillation (ENSO), Intertropical Convergent Zone (ITCZ), North Pacific Subtropical High (NPSH) and Pacific Warm Pool (PWP) (Wang et al., 2006; Wan et al., 2011b; Yin et al., 2014). Studies on variability of the EASM strength and its forcing factors have been contributed by many precisely dated speleothem records (e.g., Ku and Li, 1998; Li et al., 1998, 2011a,b; Wang et al., 2001, 2005, 2008; Paulsen et al., 2003; Yuan et al., 2004; Hu et al., 2008; Wan et al., 2011a,b; Yin et al., 2014). This is because carbonate cave deposits in the monsoonal regions are assumed to record the intensity of monsoon precipitation as the δ^{18}O of the carbonate tracks the isotopic signature of precipitation, with a lighter speleothem δ^{18}O swing indicating stronger summer monsoon and increased rainfall (Li et al., 1998, 2011a,b; Wang et al., 2001, 2005; Yin et al., 2014). On one hand, many speleothem δ^{18}O records over the eastern China show similarities on orbital scales following the 23-kyr precessional cycles of solar insolation which seems to be a major influencing factor on temperature contrast between land and ocean surface hence the EASM strength (Wang et al., 2001, 2008; Yuan et al., 2004; Wan et al., 2011a; Zhang et al.,

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[*] Corresponding author at: P.O. Box 13-318, No. 1, Sec. 4, Roosevelt Road, Taipei 106, Taiwan, ROC.
E-mail address: hcli1960@ntu.edu.tw (H.-C. Li).

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2013). On the other hand, speleothem $\delta^{18}O$ records on interannual-to-centennial scales during the late Holocene show significant discrepancies (e.g., Wan et al., 2011b; Chu et al., 2012; Yin et al., 2014). In general, "amount effect" and changes in $\delta^{18}O$ of moisture source and depositional temperature can all become major factors to influence speleothem $\delta^{18}O$. Hence, influence of solar irradiance variation on the EASM strength and the monsoonal rainfall over monsoonal regions is complicated. For instance, a strengthening of the EASM could result in increased summer rainfall in north and south China, but decreased rainfall in low-middle Yangtze River catchment basins (Zhang et al., 2010). The "amount effect" on speleothem $\delta^{18}O$ may not be the same in different cave sites over eastern China under the same monsoonal regimes. Besides solar activity, ocean–atmospheric circulation on annual-to-centennial scales becomes another important factor to affect the EASM strength (Wang et al., 2006; Yin et al., 2014 and references therein). Apparently, factors to influence the monsoonal rain and speleothem $\delta^{18}O$ on short time scales are much more complicated than these on orbital scales.

Zhang et al. (2010), Wan et al. (2011b) and Chu et al. (2012) have demonstrated spatial variations of the monsoonal rain in different regions of eastern China with modern meteorological observations, historic records and speleothem $\delta^{18}O$ records. On annual to decadal scales, it is clear that a strong summer monsoon can cause wet condition in a region but dry condition in another region in the eastern China, and no simple correlations between EASM intensity and precipitation or temperature. For these reasons, no single speleothem $\delta^{18}O$ record can represent variation of monsoonal precipitation of the entire eastern China (Yin et al., 2014). Therefore, in order to understand paleomonsoon activity and monsoonal climate, more speleothem $\delta^{18}O$ records especially high-resolution, well-dated records of the late Holocene distributed over the monsoonal regions are needed.

Although stalagmite $\delta^{18}O$ records in eastern China have been used as a proxy of summer monsoonal variability, interpretation of the $\delta^{18}O$ in terms of wetness is still under debating as the "amount effect" may not be the major influencing factor. For instance, changes in atmospheric circulation which lead to moisture source change could affect $\delta^{18}O$ of precipitation (Pausata et al., 2011). Since 1950, the EASM strength had a decreasing trend, but the summer rainfall in central China increased. The summer/spring rainfall ratio changed from <1 to >1 after 1950 in Lianhua Cave area, which dominated the stalagmite $\delta^{18}O$ variation on such a time scale (Yin et al., 2014). For this reason, other proxies for climatic conditions in speleothem records are needed. Up-to-date, stalagmite $\delta^{13}C$ is the most common candidate.

As the main source of dissolve inorganic carbon (DIC) in dripping water which is the parent solution for stalagmite formation comes from soil CO_2 and bedrock carbonate dissolution, stalagmite $\delta^{13}C$ registers mainly changes in $\delta^{13}C$ of soil CO_2, portion of CO_2 from bedrock dissolution, and carbon isotopic fractionations caused by degassing, precipitation and dissolution in a cave system. Fairchild et al. (2006) and Li et al. (2012) reviewed factors that influence $\delta^{13}C$ of stalagmite including (1) variation of vegetation (both abundance and C3/C4 plant ratio) or bio-mass above the cave, (2) seasonal change of CO_2-$\delta^{13}C$ in soil, (3) fracture of epikarst zone and difference of latticework in vadose zone (open/close system), (4) residence time of seepage water, (5) dissolution of bedrock, (6) prior precipitation of calcite in vadose zone, and (7) CO_2 degassing of drip water. For the above factors, factors (1) and (2) are related to the biological activity in the overlying soil above a cave and strongly controlled by vegetation change and climatic conditions. On decadal or longer time scales, more abundant vegetation coverage and/or higher C3/C4 ratio under wet climatic conditions produce lighter $\delta^{13}C$ in stalagmites, and vice versa (Ku and Li, 1998; Paulsen et al., 2003). Factors (3)–(6) are related to hydro-chemical process in the vadose zone and affected by climatic conditions except factor (3). In general, drier condition leads to increase in the residence time of seepage water, the contribution of dissolved bedrock carbonate and prior precipitation of calcite in vadose zone, which in turn result in heavier $\delta^{13}C$ in stalagmites (Fairchild et al., 2006). Therefore, factors (1) to (6) can be considered having similar effects: i.e., a light $\delta^{13}C$ shift in stalagmite under wet climatic conditions, and a heavy $\delta^{13}C$ swing under dry conditions on decadal or longer time scales. Factor (7) is influenced by dripping rate and pCO_2 of cave air. The later one is related to ventilation, temperature and relative humidity of the cave. Stronger CO_2 degassing of drip water under slower dripping rate/stronger ventilation/warmer temperature/low relative humidity will cause heavier $\delta^{13}C$ of calcite deposit in stalagmites (Oster et al., 2010, 2012). Unlike stalagmite $\delta^{18}O$, stalagmite $\delta^{13}C$ is strongly dripping site dependent due to heterogeneity of the DIC-$\delta^{13}C$ in drip water inside a cave (Baker et al., 1997). For some monitoring studies, scientists even found that DIC-$\delta^{13}C$ or $\delta^{13}C$ of speleothem could not remain consistent for the studying periods at the same site of a cave (e.g., Linge et al., 2001). This is the reason why stalagmite $\delta^{13}C$ record is not used as commonly as stalagmite $\delta^{18}O$ record for paleoclimate reconstruction. However, previous studies have published stalagmite $\delta^{13}C$ records and demonstrated that a stalagmite $\delta^{13}C$ record may be used for reconstruction of paleoclimate and paleoenvironment when changes in vegetation and climatic conditions became major factors to control the $\delta^{13}C$ value (e.g., Dorale et al., 1992; Bar-Matthews et al., 1996; Ku and Li, 1998; Genty et al., 2003, 2006, 2010; Paulsen et al., 2003; Zhu et al., 2006; Cosford et al., 2009; Fleitmann et al., 2009; Zhang et al., 2004, 2009; Kuo et al., 2011; Li et al., 2011a,b; Oster et al., 2012; Kotlia et al., 2012; Denniston et al., 2013). These previous studies might indicate that the factors (3)–(7) had relatively weak influence on the $\delta^{13}C$ records on decadal and longer time scales. Recently, more and more cave monitoring studies have shown that speleothem $\delta^{13}C$ records may be used for paleoclimatic and paleoenvironmental reconstructions (Li et al., 2011a,b, 2012; Oster et al., 2010, 2012).

Guizhou Province containing more than 5000 caves is located in the center of the well-known karst regions of South China, and nearly 3/4 of its exposed land is composed of carbonate rocks. However, except stalagmite $\delta^{18}O$ records from Dongge Cave (Yuan et al., 2004; Dykoski et al., 2005; Wang et al., 2005), Yamen Cave (Yang et al., 2010) and Jinshi Cave (Wan et al., 2011a) which are all located in the southeast corner of Guizhou, few speleothem records exist in this abundant cave region. Part of the reason is due to poor quality of $^{230}Th/U$ dating on the stalagmites from central Guizhou because of very low uranium content especially for young stalagmites (Kuo et al., 2011). Recently, we have found that Accelerate Mass Spectrometry (AMS) ^{14}C dating on low U but high Th (detritus) contents is feasible. In this paper, we will present the $\delta^{18}O$ and $\delta^{13}C$ records of two stalagmites from Yelang Cave that is located in central Guizhou. These AMS ^{14}C well-dated stalagmites provide not only the monsoonal climate change but also vegetation variation under climate changes and human impacts in the studying area since last glaciation.

2. Cave site and local climate condition

Yelang Cave (26°2′28.00″N, 105°44′10.93″E) is located in Huangguoshu Township of Anshun City in the central Guizhou where is on the eastern edge of the Yunnan–Guizhou Plateau (Fig. 1). The cave is currently 3 km long with about 1.5 km of groundwater river path. With a hilly topography of karst landscape at an elevation of 1285 m, the region has an annual mean temperature of 15.4 °C and precipitation of 1300 mm based on the