The climate reconstruction in Shandong Peninsula, North China during the last millennia based on stalagmite laminae together with its comparison to $\delta^{18}O$

Qing Wang[1*], Houyun Zhou[2*], Ke Cheng[1], Hong Chi[1], Chuan-chou Shen[3], Changshan Wang[1], Qianqian Ma[1]

[1] {Coastal Research Institute of Ludong University, Yantai 264025, China}

[2] {School of Geography, South China Normal University, Guangzhou 510631, China}

[3] {High-precision Mass Spectrometry and Environment Change Laboratory (HISPEC), Department of Geosciences, National Taiwan University, Taipei 10617, Taiwan, ROC}

Correspondence to: Qing Wang (schingwang@126.com), Houyun Zhou (hyzhou@gig.ac.com)

Abstract

Stalagmite ky1, with a length of 75mm and the upper part(from top to 42.769mm depth) consisting of 678 laminae, was collected from Kaiyuan Cave in coastal areas of Shandong Peninsula, northern China, located at warm temperate zone in East Asia monsoon area. Based on high precision dating with U-^{230}Th technique and continuous lamina counting, it can be confirmed that the1st and 678th laminae are 1894±20AD and 1217±20AD from top to bottom respectively. By the measurement of laminae thickness and δ^{18}O ratios, we have got the time series data of laminae thickness and δ^{18}O ratios from 1217±20AD to 1894±20AD, analyzed the climatic-environmental meanings of laminae thickness variations which have good corresponding relation with cumulative departure curve of drought-waterlog index in historical period. The result shows that, in the ~678 years from 1217±20AD to 1894±20AD, both the laminae thickness and the laminae thickness fluctuation degree of stalagmite ky1 have obvious staged characteristic, and completely synchronized with the contemporaneous summer monsoon intensity and precipitation as time changed. Among, there is negative correlation between the laminae thickness and summer monsoon intensity and precipitation. On the other hand, there is positive correlation between the laminae thickness fluctuation degree and both the summer monsoon intensity and the precipitation. Therefore, for the Kaiyuan Cave in the coastal area both of warm temperate zone and East Asia monsoon area, the variations of laminae thickness are not only relative to change of climatic factors themselves, but also relative to climatic stability degree. For to achieve this, in the coastal area belong to warm temperate zone and East Asia monsoon area, the climate change between LIA(Little Ice Age) and MWP(Medieval Warm Period) , besides less precipitation and low temperature, that is to say, a type of dry and cold climate, also shows an obviously decreasing trend of the climatic stability degree.

Keywords

Little Ice Age, laminae thickness, climatic stability degree, Kaiyuan Cave in Shandong Peninsula of CHINA, the coastal area of warm temperate zone, East Asia

monsoon area

1 Introduction

Calcareous speleothems, which have advantages in precisely dating and high-resolution sampling, are becoming one of the best geological record carriers of major climate changes (Burns et al., 2003; Cheng et al., 2009; Dykoski et al., 2005; Genty et al., 2003; Fairchild et al.,2006; Wang et al., 2001; Wang et al., 2008; Qin et al., 1999; Yuan et al., 2004) and high resolution reconstruction of paleoclimate and environment (Committee on Surface Temperature Reconstructions for the Last 2,000 Years and National Research Council, 2006; Fleitmann et al., 2003; Hou et al., 2003; McDermott et al., 2001; Paulsen et al., 2003; Tan et al., 2003; Tan, 2007; Wang et al., 2005; Zhang et al., 2008). Besides the most widely-used carbon(C) and oxygen(O) stable isotopes and trace elements, laminae and growth rate of stalagmite could also be used as proxies for paleoclimate environment. However, different authors had very different climate and environment interpretation about laminae thickness based on different stalagmite from different climatic region. For instance, the stalagmite lamiane were confirmed as annual laminae at the earliest(Baker et al., 1993), the structure of lamiane reflected the intensity of ancient rainfall (Baker et al., 1999), there was positive correlation between the growth rate of stalagmite and precipitation(Brook et al., 1999).However, there was negative correlation between the growth rate of stalagmite and precipitation(Proctor et al., 2000; Proctor et al., 2002), there was response relation between the growth rate of stalagmite and winter temperature (Frisia et al., 2003),and the growth rate of stalagmite was influenced by vegetation density on the top of cave(Baldini et al., 2005). There was a well-understood relationship between speleothem growth rate and climate(Baldini, 2010; Mariethoz et al.,2012).The situations are more complex in humid and semi-humid regions because other factors, such as drip rate, atmospheric P_{CO2} in the cave and the seasonality of climate, may also affect speleothem growth rates(Cai et al., 2011;Duan et al., 2012). The research of stalagmite laminae in the middle reach of the Yangtze River indicates that the thickness of stalagmite lamiane may be regarded as the substitute index of the summer monsoon intensity of East Asia(Liu et al., 2005).There was good response relation with between the lamiane thickness variations and the variations of rainfall (Tan et al. 1997;Ban et al., 2005).There was response relation between the growth rate of stalagmite and the temperature in summer, so the laminae thickness may be regarded as a substitute index of East Asia monsoon intensity (Tan et al., 2004).The $\delta^{18}O$ record of ZJD-21 indicates that $\delta^{18}O$ in the stalagmite was mainly influenced by rainfall amount and/or summer/winter rainfall ratio, with lighter values corresponding to wetter conditions and/or more summer monsoonal rains(Kuo et al., 2011).The Wanxiang Cave WX42B record indicates that the stalagmite $\delta^{18}O$ has recorded local/regional moisture change(Li et al., 2011).The growth rate and the observed temperature had significant positive correlation(Tan et al., 2013).

The upper part of ky1(from top to 42.769mm depth, 0-42.769mm) consist of 678 continuous transmitting annual laminae clearly, because the transmitting laminae of stalagmite ky1 are very similar to the annual laminae of Shihua Cave in Beijing, and have all the typical characteristics of the latter laminae, which consist of so-called Northern type laminae (Zhou et al., 2010). There are very thin opaque laminae between stalagmite laminae clearly, but the calcite laminae were thick and transmitting between stalagmite laminae (Tan et al., 1999; Tan et al., 2002). Because of stalagmite ky1, with a very small length, has not any weathering trace, so the stalagmite may have stopped growing not long ago, its deposition time may be the past several centuries or one millennium which has recorded the climatic-environmental information of the Shandong Peninsula since late MWP(Medieval Warm Period), including the late MWP, the whole LIA(Little Ice Age), and the early CWP(Current Warm Period) (Lamp, 1965; Lamp, 1972; Matthews, 2005; Ogilvie and Jónsson, 2001). In this research, on the basis of high precision dating with U-^{230}Th technique, we have observed and measured the laminae thickness and dated all the laminae in the upper part of stalagmite ky1, obtained and researched the time series data of laminae thickness, and compared it with the time series data both of oxygen (O) stable isotope value and the drought-waterlog index, and discussed the climatic and environmental evolution of the coastal part of the warm temperate zone as well as the East Asia monsoon area since LIA, especially the transition periods of MWP/LIA and LIA/CWP.

2 Geological setting and sample description

Stalagmite ky1 was collected in 2008AD from Kaiyuan Cave (36°24′32.20″N, 118°02′3.06″E) in western Shandong Peninsula, the coastal area of northern China (Fig.1, 2). The cave is located in the northwest hilly area of Lushan Mountain in Zibo city, Shandong province, with elevation of 175m above sea level (a.s.l.) (Fig.2). As the largest peninsula in China, it was located between the Bohai sea and the Yellow sea, and in its western region the *Cambrian Middle* Zhangxia formation (mainly the oolitic shale, shale in clip to thin-layer limestone, oolitic limestone, algal clot limestone) and the *Ordovician* of Badou formation and Gezhuang formation (mainly for the gray-dark gray thick layer of mud wafer-thin limestone dolomitic limestone and marl), were widely distributed with thickness of 24-238m including its lower section integrated with the Gezhuang group and upper section disconformity contacted with the Carboniferous Benxi formation) (Shandong Provincial Bureau of Geology＆Mineral, 1991), which were main component of the Lushan Mountain, Yishan Mountain, Mengshan Mountain with the highest elevation 1108m,1031m and 1150m respectively. According to field investigation, the landform development of carbonate rocks montanic caves are well, there are many caves outcropping on the surface, secondary carbonate sedimentary bodies are developing well with typical morphological characteristics.

Kaiyuan cave developed in the dolomite of the Ordovicia Zhifangzhuang formation with the total strata thickness about 110m. The total length of the cave is 1280m, the overall distribution is northwest-southeast strike along with twists and turns, space width inside the cave is generally 2 to 8m and can be up to 30m. At the top of the cave, the surface of the bedrock is covered by soil with general thickness of 50-80cm and the biggest thickness more than 1.0m, the soil type are calcareous rocky soil and drab soil (The soil and fertilizer workstation of Shandong Province, 1994). The area of Kaiyuan cave is currently influenced by both summer and winter monsoons with annual precipitation of ~620 mm and annual mean temperature of ~13℃, and Summer monsoon prevails during July and August, contributing to half of the annual precipitation (Fig. 3).

3 Analytical methods and data processing

3.1 Time scale establishment

The stalagmite ky1 is conical in shape and consists of very pure calcite.(Fig.4) The polished surface of stalagmite and laminae observation by microscope show that stalagmite ky1 has no hiatus during growing process, the upper part (0-42.769mm) is made up of 678 lamiane overlain by continuous deposits, all lamiane were typical transmitting annual lamiane. It has ^{232}Th concentrations ranging from 704.6±5.1ppt to 1245.2±5.0ppt (Table 1), which was conducted at the High-precision Mass Spectrometry and Environment Change Laboratory (HISPEC) of the National Taiwan University using high precision dating with U-^{230}Th technique (Shen et al., 2002).

Because the stalagmite ky1 has no hiatus, the upper part (0-42.769mm) contains 678 clear and continuous lamiane, these continuous and ongoing laminae have clear and definite chronology pointing meanings themselves. Therefore, based on high precision dating with U-^{230}Th technique, we used the method of annual laminae counting to decide the sedimentation time of each laminae and the whole stalagmite ky1 layer-by-layer and established the time scale of stalagmite. In the upper part (0-42.769 mm) of stalagmite ky1, we counted along upward and downward direction according to some laminae which has high precision dating result with U-^{230}Th technique, ensured forming times of 1st and 678th lamiane firstly, and then ensured age of each lamiane according to their horizons.

3.2 Laminae thickness measurement

First of all, the stalagmite ky1 was cut along the growth axis, and a slice was picked from the profile of stalagmite and then polished. Secondly, under the LEIKA DMRX microscope (magnification of 200×, eyepiece of 10×, objective of 20×), we used transmission light to observe laminae characteristic along the growth axis layer-by-layer. Thirdly, we measured the thickness of 678 laminae along three different path layer-by-layer, calculated every lamiane thickness on average according to the three data of the each laminae. Fourthly, we had dated every laminae layer-by-layer and get the time series data of stalagmite laminae thickness. At last, we contrasted the time series data and the $\delta^{18}O$ ratio data series, analyzed the paleoclimate environment characteristic of different stage, and discussed the climatic-environmental meanings of the variations of laminae thickness.

3.3 $\delta^{18}O$ isotopes test

Firstly, perpendicular to growth axis and along the horizons of 9.5 mm and 18.5 mm from top, we collected respectively 4 samples in 20mm from growth center equally spaced that were used for Hendy test. Secondly, along growing direction, we collected a 4 mm depth×5 mm width×75 mm length stone strip along growing axis, and scraped 330 samples using medical scalpel from top to bottom with a sampling density of 7-8 samples/mm(separation distance of 0.1296mm on average). In the 330 samples above, we chose 175 samples to measure their $\delta^{18}O$ ratios, basically following the principle of interval test in order to avoid the mixed pollution between adjacent samples. Next, we confirmed the sedimentation time according to their horizons and formed the time series data of $\delta^{18}O$ ratios. $\delta^{18}O$ ratios were measured using an automated individual-carbonate reaction (Kiel) device coupled with a Thermo-Fisher MAT 253 mass spectrometer at the State Key Laboratory of Palaeobiology and Stratigraphy of Nanjing Institute of Geology and Palaeontology, Chinese Academy of Sciences. Each powdered sample (~0.08 to 0.1 mg of carbonate) was reacted with 103% H_3PO_4 at 90°C to liberate sufficient CO_2 for isotopic analysis. The standard used is NBS19 and one standard was analyzed with every ten samples. One sample out of ten was duplicated to check the replication. All isotope ratios are reported in permil (‰) deviations relative to the Vienna Peedee Belemnite (VPDB) standard in the conventional manner. The standard deviation (1σ) for replicate measurements on NBS-19 is <±0.10‰.

4 Result and discussion

4.1 The laminae thickness of stalagmite and dating results

In the upper part (0-42.769mm) of stalagmite ky1, the dating result of age corrected in Table 1 show that the three samples in the horizons of the 6mm, 15mm and 25mm are 1761.9±20.3AD, 1696.6±13.6AD and 1556.4±13.6AD resectively (Table 1). Among, there are 221 laminae between the horizons of 6mm and 25mm, their age interval are 206 years according to the U-^{230}Th dating results, the difference of age between laminae counting and U-^{230}Th dating results is only 15 years. But there are 109 lamiane between the horizons of 6mm and 15mm, their age interval are 65 years according to the result of U-^{230}Th dating, and there are 112 laminae between the horizons of 15mm and 25mm, their age interval are 141 years according to the result of U-^{230}Th dating. On the other hand, if we use the horizon of 6mm as datum to calculate, the age of 1st and 678th laminae are 1894±20.3 and 1217±20.3AD respectively. If we use the horizon of 25mm as datum to calculate, the age of 1st and 678th laminae are 1909±13.6AD and 1232±13.6AD respectively, the age interval are only 14 years differs. Finally, in consider of the error of laminae thickness measurement accumulating downward layer-by-layer, we chose the 133th laminae corresponding to the horizon of 6mm as the datum to calculate the age of other lamiane in the upper part of stalagmite ky1. The results show that the deposition time of 1st and 678th laminae are 1894±20.3 and 1217±20.3AD(the dating error is ±20.3 years, similarly hereinafter for AD age in this paper) respectively, the age of other lamiane were calculated by analogy, hereby we got the time series data of lamiane thickness of stalagmite ky1(Fig.5).

4.2 Laminae shape characteristic

Stalagmite ky1 developed continuous transmitting laminae obviously (Fig.4). Under the microscope, firstly, the laminae thickness were rather changeable, the maximum thickness reached more than 800μm, and the minimum thickness reached less than 15μm (Fig.6a). Because laminae thickness variations may corresponding to the climatic environmental change when lamiane were growing, it shows the potential value of these transmitting lamiane in reconstructing the paleoclimate environment (Genty et al., 1996; Baker et al., 1999; Tan et al., 2004; Ban et al., 2005; Liu et al., 2005; Zhang et al., 2008; Muangsong et al., 2014; Liu et al., 2015). Secondly, most boundary of lamiane are straight, but some lamiane are obvious curved (Fig.6b). Hereby when we analyzed the climatic-environmental meanings of stalagmite laminae thickness, we acquired the laminae thickness values of a same laminae in different paths and calculated their average values along multiple paths in order to get substituted index information of climatic-environmental change that had statistical significances. Thirdly, color in some boundaries of transmitting lamiane were deeper obviously (Fig.6c), these laminae had special structure similar to supera annual laminae. This may indicate that climatic-environmental changes not only have seasonal change, but also have multi-interannual change. Fourthly, the light transmission of some transmitting lamiane is obviously different from adjacent lamiane, the color is deeper and there are dark spots (Fig.6a, d). Whether these dark laminae have some mineralogy and geochemistry characteristic different from other transmitting lamiane, and what their climatic-environmental meanings are, these may need further and special research in the future.

4.3 Laminae thickness variations

The variation range of the 678 laminae thickness of stalagmite ky1 (upper part) were 13.03~872.8μm.The formed age of maximum thickness (872.8μm) laminae was 1551AD, the formed age of the minimum thickness (13.03μm) of laminae was 1245AD, the average value of all laminae were 63.08μm (Fig.7a). In the 678 years from 1217AD to 1894AD, the laminae thickness of stalagmite ky1 have obvious staged variations, it had undergone the transition from low value to high value and again to low value, and both the laminae thickness and the fluctuation degree variations of laminae thickness had obvious staged variations (Fig.7a).From 1217AD to 1471AD, it was the low value period of laminae thickness with the average value of 46.08μm. Among, the period from 1217AD to 1372AD was low fluctuation period relatively, the period from 1372AD to 1471AD was high fluctuation period relatively, the two periods above presented the trend of rising firstly and falling then. From 1471AD to 1744AD, it was a high value-high fluctuation period of laminae thickness with the average value of 88.8307μm. Among, this period could be divided into three secondary high value-high fluctuation periods, 1471AD-1548AD, 1548AD-1637AD and 1637AD-1744AD, every period has the trend of increasing firstly and decreasing then, their average value of laminae thickness were 82.2027μm, 82.5491μm and 98.8252μm successively. From 1744AD to 1894AD, it was a relative low value period of laminae thickness with a group of peak values appeared in about 1776AD and the average value of 45.1164μm. Among, the period from 1217AD to 1372AD was a low fluctuation period relatively, the period from 1744AD to 1831AD was a high fluctuation period relatively, the two periods above presented the trend of rising firstly and falling then, the period from 1831AD to 1880AD was high fluctuation period relatively and not have a trend of rising or falling obviously, it was a short rising period from 1880AD to 1894AD.

4.4 $\delta^{18}O$ ratio variations

The variation range of $\delta^{18}O$ ratios of the 172 samples above was −6.247‰-−8.599‰, the maximum value(−6.247‰) appeared in 1603AD, the minimum value (−8.599‰) appeared in 1460AD, the value of all samples was −7.674‰ on average (Fig.7c). In the 678 years from 1217AD to 1894AD, $\delta^{18}O$ ratios had obvious staged variations, it had undergone the transition from low value to high value and again to low value, and both the $\delta^{18}O$ ratios and the fluctuation degree of $\delta^{18}O$ ratios had obvious staged variations (Fig.7c). From 1217AD to 1480AD, it was a low value period of $\delta^{18}O$ ratios with an average value of −8.104‰. Among, the period from 1217AD to 1384AD was low fluctuation period relatively, this period has a trend of decreasing slowly in total, the period from 1384AD to 1480AD was high fluctuation period relatively, and this period presented the trend of rising firstly and falling then. From 1480AD to 1746AD, it was the high value-high fluctuation period with the average value of $-7.301‰$. Among, this period could be divided into three secondary high value-high fluctuation periods: 1480AD-1542AD, 1542AD-1633AD and 1633AD-1746AD, every secondary period has the trend of increasing firstly and decreasing then or decreasing firstly and increasing then, their inflection points appeared in the age of 1498AD, 1603AD and 1663AD respectively, their average value of $\delta^{18}O$ ratios were $-7.393‰$, $-6.953‰$ and $-7.513‰$ successively. From 1764AD to 1894AD, it was a low value period with an average value of $-8.199‰$. Among, the period from 1746AD to 1831AD was a high fluctuation period relatively, this period presented a trend of rising firstly and falling then, the period from 1831AD to 1880AD was a low fluctuation period relatively and did not have a trend of rising or falling obviously, it was a short rising period from 1880AD to 1894AD.

4.5 Drought/waterlog index variations

In order to show the relation between the variations of laminae thickness and $\delta^{18}O$ ratios and the changes of climate, we calculated cumulative departure values of the drought/waterlog index in the area of Kaiyuan Cave from 1470AD to 1894AD. The data source is the *Yearly charts of dryness/wetness in China for the last 500-year period*, the charts are compiled by Chinese academy of meteorological sciences of China Meteorological Administration according to lots of Chinese historical literature and published by China Cartographic Publishing House (Chinese academy of meteorological sciences of China Meteorological Administration, 1981). In the charts, the degree of drought/waterlog is represented by the drought/waterlog index which has five values including 1, 2, 3, 4 and 5 with 1 representing waterlog and 5 representing drought，and its distribution is represented through the index isolines. On the basis of *Yearly charts of dryness/wetness in China for the last 500-year period*, we acquired the drought/waterlog indexes in the area near Kaiyuan cave according to its geographical coordinate, and we checked the drought/waterlog indexes again refer to local chronicles. We draw a cumulative departure curve from 1470 to 1894AD with rising trend representing change of becoming dryer and declining trend representing change of becoming waterlogging (Fig.7b). Based on the cumulative departure curve, it was a less precipitation period in this area from 1480 to 1744AD, this period is started with the transition of MWP/LIA and ended with the transition of LIA/CWP, its primary fluctuations were corresponding to the curve of laminae thickness. (Fig.7b). So the high value-high fluctuation period of laminae thickness of stalagmite ky1 above occurred under the background of drought and less precipitation. On the other hand, there is a correlation between the $\delta^{18}O$ ratios of stalagmite ky1 and the change of summer monsoon intensity and precipitation. This indicates that stronger summer monsoon intensity and less precipitation may be of benefit to stalagmite growing in LIA.

4.6 Climatic-environmental meanings of laminae thickness variations

Owing to the difference of homologous laminae thickness stage and $\delta^{18}O$ varios stage ranged 2 years to 14 years, in consideration of the error of dating technique was $\pm$20 years(the time series data we got in section 4.1) and the resolution of $\delta^{18}O$ sample was 3.9 years, we could say the two synchronize with time-varying, mean that the low value period and high value period of $\delta^{18}O$ ratios were corresponding to the low value period and high value period of the stalagmite laminae thickness, the low fluctuation period and high fluctuation period of $\delta^{18}O$ ratios were corresponding to the low fluctuation period and high fluctuation period of stalagmite laminae thickness (Fig.7a,c). On the other hand, the analysis result of $\delta^{18}O$ varios showed that, $\delta^{18}O$ ratios of the 4 samples were −7.506‰, −7.753‰, −7.981‰ and −7.691‰ which were collected 9.5mm distance from the top of stalagmite and 5,10,15 and 20mm distance from the growing axis respectively, $\delta^{18}O$ ratios of the 4 samples were −6.571‰, −6.671‰, −6.540‰ and −6.542‰ which were collected 18.5mm distance from the top of stalagmite and 5,10,15 and 20mm distance from the growing axis respectively, the $\delta^{18}O$ ratios were similar in the same laminae (Table 2) . Hence, the Hendy Test carried out about Ky1 indicate that calcite in Ky1 should be deposited under isotopic equilibrium conditions, the possibility of its dynamic fractionation in the sedimentary process is small, so the stalagmite $\delta^{18}O$ mainly reflected the original external climate signal(Hendy, 1971). Therefore, the stalagmite $\delta^{18}O$ can use to collect and reconstruct the information of climate change (Tan et al., 2009; Kuo et al., 2011; Li et al., 2011; Tan et al., 2013; Liu et al., 2015).

The obvious synchronization relation between the laminae thickness variations and $\delta^{18}O$ ratios variations of stalagmite ky1 shows closely relationship between the deposition rate variations of stalagmite and climate change (Fig.7). Because Kaiyuan Cave is located at warm temperate zone influenced by East Asia monsoon, its rainy season coincides with high temperature, the precipitation, carried by summer monsoon from Pacific Ocean of low latitude, concentrates in summer. However, when the winter monsoon from the interior Asian continent with high latitude is prevailing, there is rare precipitation. In this research, we interpreted the climatic meanings of the stalagmite ky1 $\delta^{18}O$ ratios, based on the relation between the cumulative departure of drought/waterlog and curves of $\delta^{18}O$ ratios, the characteristics of contemporary warm temperate weather, also refer to the assumption of the Asia monsoon intensity by Cheng et al. (2009) and the precipitation as is assumed by Zhang et al. (2008) about the climatic meanings of stalagmite $\delta^{18}O$ records, with lower $\delta^{18}O$ ratios representing stronger summer monsoon and higher $\delta^{18}O$ ratios representing weaker summer monsoon, that is to say, the $\delta^{18}O$ ratios are anti-correlating with precipitation (Fig.7). Hereby, it was strong summer monsoon-more precipitation period from 1217AD to1480AD, weak summer monsoon-less precipitation period from 1480AD to 1746AD, and strong summer monsoon-more precipitation period from 1746AD to 1894AD again. On the other hand, the fluctuation degree of summer monsoon intensity and precipitation is not the same or similar in different periods. As a whole, the fluctuation degree was lower when the summer monsoon was stronger and the precipitation was more, the fluctuation degree was higher when the summer monsoon was weaker and the precipitation was less. Among, the period from 1217AD to 1480AD can be divided into one low fluctuation period and one high fluctuation period, the period from

1480AD to 1746AD can be divided into three high fluctuation period, the period from 1746AD to 1894AD was included a high fluctuation period, a low fluctuation period and a weaker-less period successively.

According to the laminae thickness and $\delta^{18}O$ record of stalagmite ky1, the laminae thickness and both summer monsoon intensity and precipitation has negative correlation, the higher value period of laminae thickness is corresponding to weaker summer monsoon-less precipitation, and lower value is corresponding to stronger summer monsoon-more precipitation. On the other hand, the laminae thickness and the fluctuation degree of summer monsoon intensity-precipitation have positive correlation, the higher value period of laminae thickness is corresponding to high fluctuation degree of summer monsoon intensity-precipitation, and lower value is corresponding to low fluctuation degree of summer monsoon-precipitation. Therefore, Kaiyuan Cave, in the coastal area both of warm temperate zone and East Asia monsoon area, the variations of laminae thickness are not only relative to summer monsoon intensity-precipitation, but also relative to their fluctuation degree. This is because karstic water cycled faster and residence time was shorter in the fracture of rock, the dissolution was insufficient and weak, so the deposition rate and laminae thickness of stalagmite was low in the more precipitation period. But in the less precipitation period, karstic water cycled slower and the residence time was longer in the fracture of rock, the dissolution was sufficient and strong, so the deposition rate and laminae thickness of stalagmite were high. However, karstic water would reduce or dry up if the period of less precipitation lasted for a long time, this is also bad for water dissolution and stalagmite laminae growing. So under the background of weaker summer monsoon and less precipitation, the fluctuation degree of summer monsoon intensity-precipitation goes higher, this is beneficial to increasing the average value of the laminae thickness of stalagmite, but their fluctuation degree also goes higher. Because of the fluctuation degree of summer monsoon intensity-precipitation reflecting the climatic stabilized degree, according to both the laminae thickness and $\delta^{18}O$ record of stalagmite ky1 from the Kaiyuan Cave, the climate change between

MWP and LIA in the coastal area both of warm temperate zone and East Asia monsoon area, besides less precipitation and lower temperature, also shows the climatic stability degree decreased obviously.

5 Conclusions

The upper part of stalagmite ky1 (0-42.769mm) consists of 678 continuous transmitting annual laminae clearly, its deposition time is from 1217±20AD to 1894±20AD, so the laminae contains the climatic-environmental change information of the late MWP, the whole LIA and the early CWP. The analysis showss that both the variations of laminae thickness themselves and the variations of laminae thickness fluctuation degree of stalagmite ky1 have obvious staged characteristic from 1217AD to 1894AD, it had undergone the transition from low value to high value and again to low value, which was synchronized with the contemporaneous variations of $\delta^{18}O$ ratios and the fluctuation degree of $\delta^{18}O$ ratios. According to the comparison among the laminae thickness, the drought/waterlog index and the synchronous $\delta^{18}O$ ratios of stalagmite ky1, the laminae thickness and summer monsoon intensity-precipitation have negative correlation, the higher value periods of laminae thickness are corresponding to weaker summer monsoon-less precipitation, and low value periods are corresponding to stronger summer monsoon-more precipitation. On the other hand, the laminae thickness and the fluctuation degree of summer monsoon intensity-precipitation have positive correlation, the higher value periods of laminae thickness are corresponding to high fluctuation degree of summer monsoon intensity/precipitation, and lower value periods are corresponding to low fluctuation degree of summer monsoon-precipitation. Therefore, Kaiyuan Cave, in the coastal area both of warm temperate zone and East Asia monsoon area, the relation between the variations of laminae thickness and climate change, besides the effects of climate factor variation like temperature and precipitation on laminae thickness, reflects closely the fluctuation degree of summer monsoon intensity and climatic stability degree in addition. As a whole, it was a period of stronger summer monsoon from

1217AD to 1470AD. Among, the climatic stability was high from 1217AD to 1370AD firstly, and reduced from 1370AD to 1470AD. From 1470AD to 1740AD, it was a weaker summer monsoon-lower stability degree period, could be divided into three secondary periods with a trend of stronger firstly and weaker then or weaker firstly and stronger then divided by 1550AD and 1640AD. Since 1640AD, summer monsoon entered a strong period again. Among, the stability degree was high from 1740AD to 1830AD, the stability degree is reduced from 1830AD to 1880AD, the summer monsoon became weaker for a short time since 1880AD.

The conclusions of this research can enrich the acquaintance about the climatic-environmental meaning of the laminae thickness of stalagmite, and contribute to comprehend the specific manifestation of the MWP and LIA in the coastal area both of warm temperate zone and East Asia monsoon area of northern China, especially the transition time of MWP/LIA and the lasting time of LIA and the climatic characteristic of LIA, and that may also deepen the research of climate change in Asian summer monsoon area based on the secondary carbonate record in the karst cave.

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Table 1. U-series isotopic results and ages for stalagmite ky1 from Kaiyuan Cave，Shandong peninsula，Northern china.

Sample ID	1	2	3
Dist. from top (mm)	6.0	15.0	25.0
^{238}U ppb^{a}	347.47± 0.63	434.45± 0.92	334.58± 0.61
^{232}Th ppt	1245.2± 5.0	959.9± 4.9	704.6± 5.1
δ^{234}Umeasured	1457.9± 5.5	1341.2± 5.1	1320.3± 4.6
[^{230}Th/^{238}U] activity^{c}	0.00652± 0.00014	0.00732± 0.00011	0.01021± 0.00013
[^{230}Th/^{232}Th] ppm^{d}	30.0± 0.68	54.63± 0.89	79.9± 1.2
Age uncorrected BP^{f}	289.6± 6.5	341.4± 5.4	480.6± 6.3
Age corrected^{c,e} BP^{f}	251.1± 20.3	316.4± 13.6	456.6± 13.6
Age corrected^{c,e} AD	1761.9± 20.3	1696.6± 13.6	1556.4± 13.6
$\delta^{234}U_{initial}$ corrected^{b}	1458.9± 5.5	1342.4± 5.1	1322.1± 4.6

Chemistry was performed on July. 8, 2013 with the analysis method of Shen et al.（2003), and instrumental analysis on MC-ICP-MS (Shen et al., 2012).Analytical errors are 2σ of the mean.

^{a}[^{238}U] = [^{235}U] x 137.818 (±0.65‰) (Hiess et al., 2012); δ^{234}U = ([^{234}U/^{238}U]$_{activity}$ - 1) x 1000.

$^{b}\delta^{234}U_{initial}$ corrected was calculated based on ^{230}Th age (T), i.e., $\delta^{234}U_{initial} = \delta^{234}U_{measured} X\ e^{\lambda 234 * T}$, and T is corrected age.

^{c}[^{230}Th/^{238}U]$_{activity}$ = $1 - e^{-\lambda 230 T} + (\delta^{234}U_{measured}/1000)[\lambda_{230}/(\lambda_{230} - \lambda_{234})](1 - e^{-(\lambda 230 - \lambda 234)\ T})$, where T is the age. Decay constants are 9.1705 x 10^{-6} yr^{-1} for ^{230}Th, 2.8221 x 10^{-6} yr^{-1} for ^{234}U (Cheng et al., 2013, EPSL), and 1.55125 x 10^{-10} yr^{-1} for ^{238}U (Jaffey et al., 1971).

^{d}The degree of detrital ^{230}Th contamination is indicated by the [^{230}Th/^{232}Th] atomic ratio instead of the activity ratio.

^{e}Age corrections for samples were calculated using an estimated atomic ^{230}Th/^{232}Th ratio of 4 ± 2 ppm. Those are the values for a material at secular equilibrium, with the crustal ^{232}Th/^{238}U value of 3.8. The errors are arbitrarily assumed to be 50%.

^{f}BP(Before Present)”, “present” in this table refers to 2013 AD.

Table. 2 The results of the Hendy tests conducted along two growth lamiane of ky1 at depths of 9.5mm and 18.5 mm individually, which indicate that calcite in ky1 was deposited under isotopic equilibrium conditions according to the Hendy Test rules（Hendy,1971）.

Sample number	Distance from the top/mm	Distance from the center of growth/mm	δ^{18}O/‰
KY1-9/10-5		5.0	-7.506
KY1-9/10-10	9.5	10.0	-7.753
KY1-9/10-15		15.0	-7.981
KY1-9/10-20		20.0	-7.691
KY1-18/19-5		5.0	-6.571
KY1-18/19-10	18.5	10.0	-6.671
KY1-18/19-15		15.0	-6.540
KY1-18/19-20		20.0	-6.542

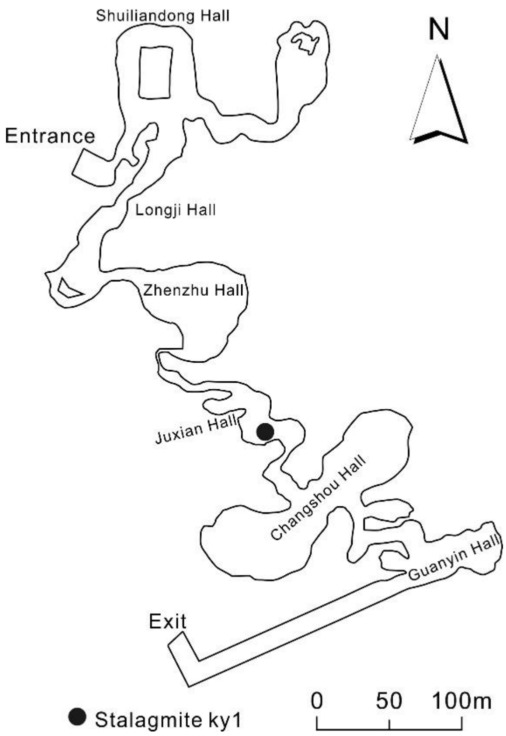

Fig.1 The map of Kaiyuan Cave. The black point is the location where we collected the sample in the Cave. The cave has an entrance and an exit, and consist of 6 small malls.

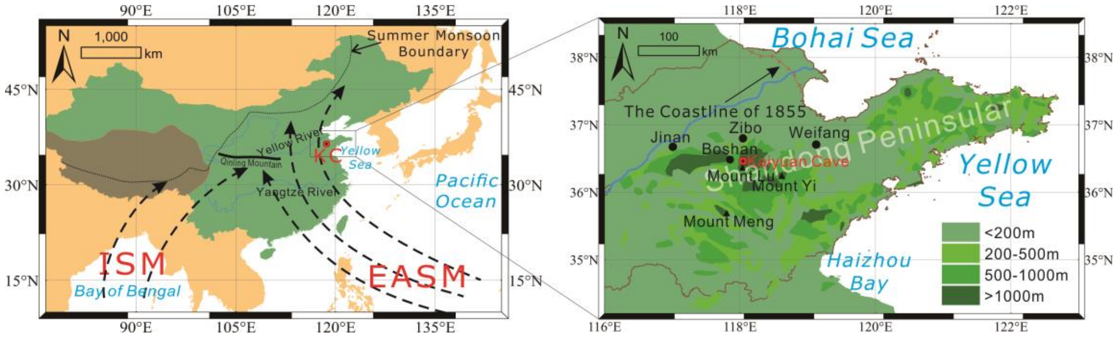

Fig.2 Location of Kaiyuan Cave and Shandong peninsula in monsoonal China. KC: Kaiyuan Cave (36°24′32.20″N, 118°02′3.06″E). ISM: India Summer Monsoon; EASM: East Asia Summer Monsoon. The dashed black thin line indicates the northwestern boundary of the Asian summer monsoon. The dashed black lines with arrow indicate the routes of the summer monsoon. The dashed black lines with arrows in the left indicate the routes of the summer monsoon. The brown area is the Qinghai-Tibet Plateau. The green area is China and the yellow area is other area.

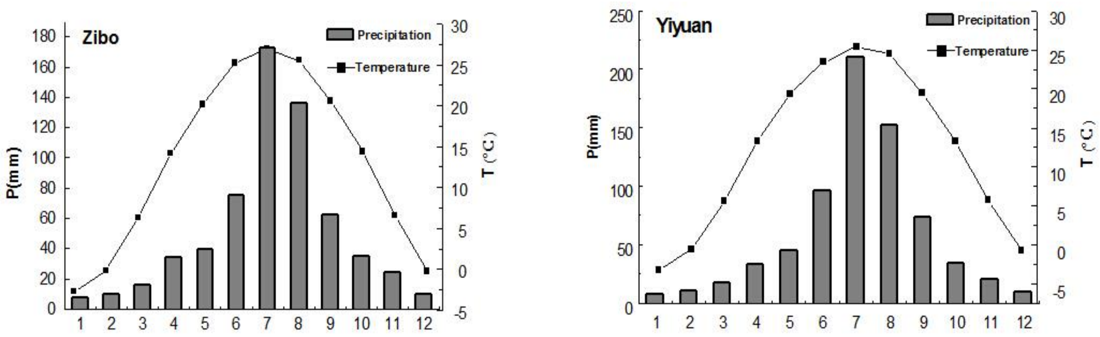

Fig. 3 Monthly mean temperature (T) and precipitation (P) at Zibo (1952-1980) and Yiyuan (1958-2005) at Yiyuan Station, two meteorological stations close to the study site (Fig. 1).

Fig.4 Polished longitudinal cross-section of stalagmites ky1

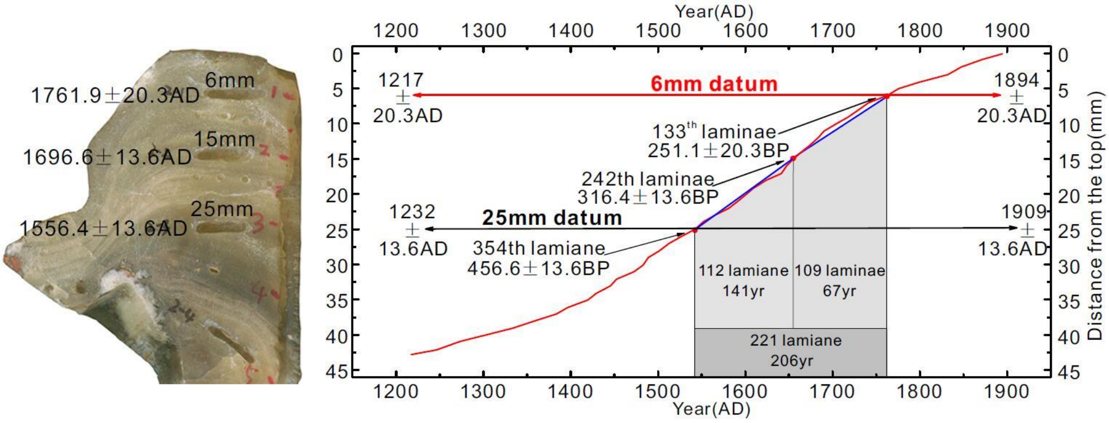

Fig.5 The age model for stalagmite ky1 established by laminae counting and high precision dating results with U-^{230}Th technique. It is the photo of stalagmite ky1, and the age label was based on high precision dating results with U-^{230}Th technique in the left. The blue line is the high precision dating results with U-^{230}Th technique and their connect lines. The red line is the age scale established by this article, the age of other laminas were determined by annually laminae counting upward and downward based on the 133th laminae corresponding to the horizon of 6mm, the age of which is 1762±20.3AD that is decided by high precision dating results with U-^{230}Th technique.

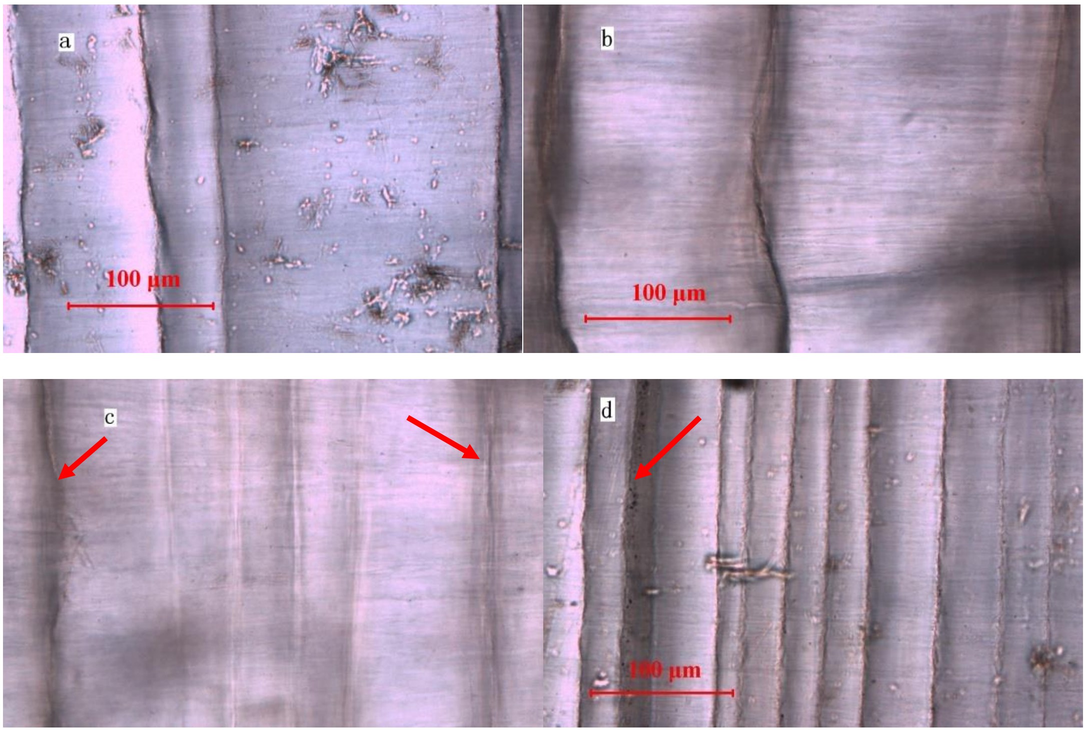

Fig.6 The characteristic of the transmitting laminae in the upper part of stalagmite ky1, show that laminae thickness have obvious variations, the boundary was curved, the color near the boundary was deeper and the dark transmitting laminae. Laminae thickness have obvious variations (a), the curve of the boundary of transmitting laminae (b), the color variations of the boundary of transmitting laminae, the arrows indicate the darker boundaries, the boundaries in the middle were whiter obviously (c), dark transmitting lamina(d) (the arrows indicated in the figure).

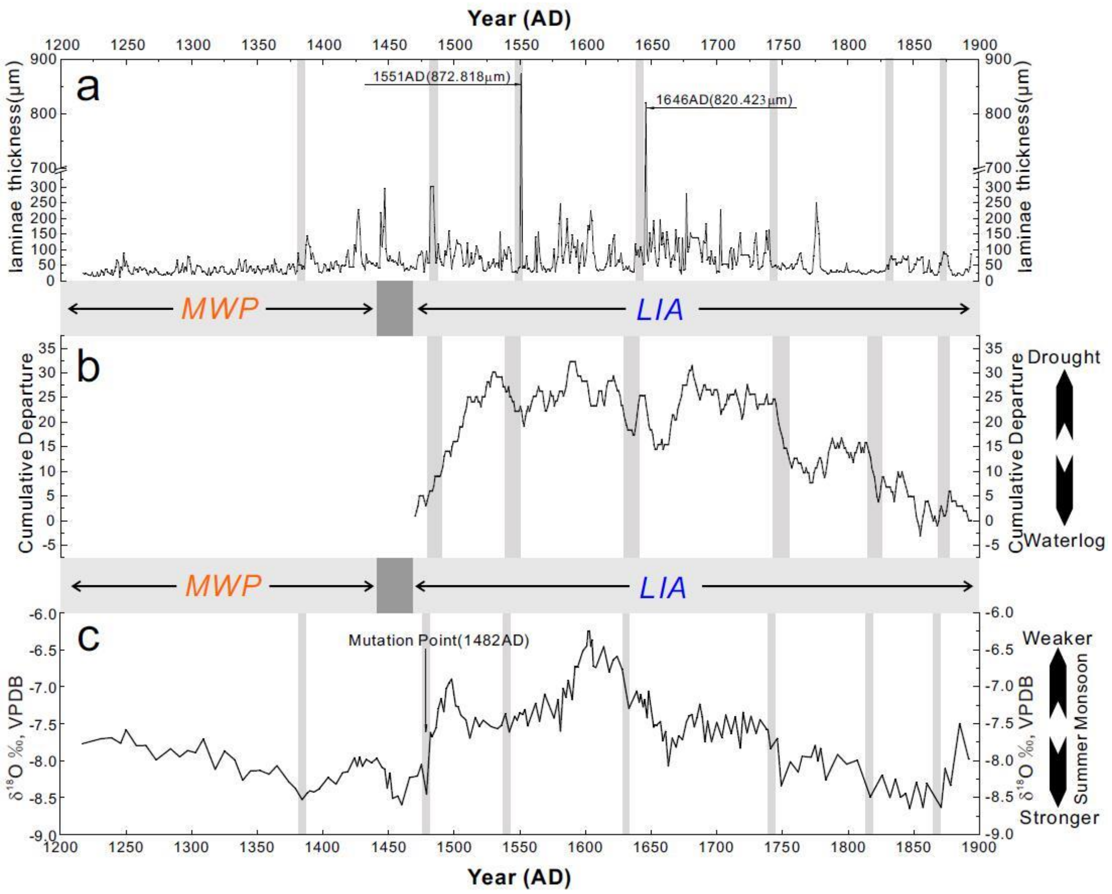

Fig.7 The formed year and thickness data series of the 678 laminae in upper part (0-42.769mm) of stalagmite ky1(a), the cumulative departure curve(b) and the $\delta^{18}O$ ratio data series of 172 samples(c). The thickness of the laminae formed in 1551AD and 1646AD were up to 872.818μm and 820.423μm respectively, they are much higher than other laminae. The cumulative departure curve (b) is drown by drought/waterlog indexes on the basis of *Yearly charts of dryness/wetness in China for the last 500-year period* (Chinese academy of meteorological sciences of China Meteorological Administration, 1981), the curve has a rising trend representing less precipitation and climate becoming drier, the curve has a declining trend representing more precipitation and climate becomes waterlogging.