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

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Abstract

Stalagmite ky1, with a length of 75 mm and the upper part (from top to 42.769 mm depth) consisting of 678 laminae, was collected from Kaiyuan Cave in the coastal area~~s~~ of Shandong Peninsula, northern China, located ~~at~~ in a warm temperate zone in the East Asia monsoon area. Based on high precision dating with the U-^{230}Th technique and continuous ~~lamina~~ counting of laminae, ~~it can be confirmed that~~ the1st and 678th laminae ~~are~~ have been confirmed to be 1894±20 AD and 1217±20 AD from top to bottom, respectively. By the measurement of laminae thickness and δ^{18}O ratios, we ~~have got~~obtained the time series data of ~~laminae~~ thickness of laminae and δ^{18}O ratios from 1217±20 AD to 1894±20 AD, analyzed the climatic-environmental meaning~~s~~ of variations in the ~~laminae~~ thickness of laminae, ~~variations~~ which have a good correspondence~~ing relation~~ with the cumulative departure curve of the drought-waterlog index in the historical period. The results show~~s~~ that, in the ~678 years from 1217±20 AD to 1894±20 AD, both the ~~laminae~~ thickness of the laminae and the degree of fluctuation in the ~~laminae~~ thickness of the laminae ~~fluctuation degree~~ of stalagmite ky1 have obvious ~~staged~~ stages of variation ~~characteristic~~, and are completely synchronized with the contemporaneous intensity of the summer monsoons ~~intensity~~ and precipitation as time changed. ~~Among, t~~There is a negative correlation between the ~~laminae~~ thickness of the laminae and the summer monsoon intensity and precipitation. ~~On the other hand, t~~There is a positive correlation between the degree ~~–~~ of fluctuation in the ~~laminae~~ thickness of the laminae ~~fluctuation degree~~ and both the intensity of the summer monsoons ~~intensity~~ and the precipitation. Therefore, for the Kaiyuan Cave in the coastal area ~~both~~ of both the warm temperate zone and the East Asia monsoon area, the variations ~~of~~ in the ~~laminae~~ thickness of the laminae are not only relat~~iv~~ed to the change ~~of~~ in the climatic factors themselves~~,~~ but also relat~~iv~~ed to the degree of climatic stability ~~degree~~. ~~For to achieve this, i~~In the coastal area belonging to the warm temperate zone and the East Asia monsoon area, the climate change between the LIA (Little Ice Age) and the MWP (Medieval Warm Period)~~–~~, ~~besides~~ in

addition to less precipitation and low temperatures~~,~~ ~~that is to say,(~~ a type of dry and cold climate~~)~~,, also shows an obviously decreasing trend ~~of~~ in the degree of climatic stability ~~degree~~.

Keywords

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

1 Introduction

Calcareous speleothems, which have advantages ~~in~~ for precisely dating and high~~-~~ resolution sampling, are becoming one of the best geological record carriers ~~of~~ for 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 the 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~~ In addition to the most wi~~dely~~dely used carbon (C) and oxygen (O) stable isotopes and trace elements, laminae and the growth rate of stalagmites could also be used as proxies for the paleoclimate environment. However, different authors ha~~d~~ved very different climate and environment interpretations ~~about~~ relative to ~~laminae~~ thickness of laminae based on different stalagmites from different climatic regions. For instance, the stalagmite laminan~~n~~e were confirmed as annual laminae ~~at~~ in the earliest studies (Baker et al., 1993), the structure of the laminan~~n~~e reflected the intensity of the ancient rainfall (Baker et al., 1999), and there was a positive correlation between the growth rate of stalagmites and precipitation (Brook et al., 1999). However, there was a negative correlation between the growth rate of stalagmites and precipitation (Proctor et al., 2000; Proctor et al., 2002), there was a responsive relationship between the growth rate of the stalagmites and the winter temperature (Frisia et al., 2003), and the growth rate of the stalagmite~~s~~s was influenced by the vegetation density on the top of the cave (Baldini et al., 2005). There was a well-understood relationship between the speleothem growth rate and climate (Baldini, 2010; Mariethoz et al., 2012). The situation~~s~~ ~~are~~ is 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 the climate~~,~~ may also affect speleothem growth rates (Cai et al., 2011; Duan et al., 2012). The ~~research~~ investigation of stalagmite laminae in the middle reach of the Yangtze River indicates that the thickness of stalagmite ~~lamiane~~laminae may be regarded as ~~the~~ a substitute index ~~of~~ for the summer monsoon intensity ~~of~~ in East Asia (Liu et al., 2005).There was a good response relationship ~~with~~ between the variations in the thickness of the lamina~~n~~e ~~thickness variations~~ and the variations ~~of~~ in rainfall (Tan et al., 1997; Ban et al., 2005).There was a response relationship between the growth rate of the stalagmites and the temperature in summer; therefore, ~~so~~ the ~~laminae~~ thickness of the laminae may be regarded as a substitute index ~~of~~ for 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 mainly by the ~~rainfall~~ amount of rainfall and/or the summer/winter rainfall ratio, with ~~lighter~~ lower values corresponding to wetter conditions and/or more summer monsoon~~al~~ 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 a significant positive correlation (Tan et al., 2013).

The upper part of ky1(from the top to a depth of 42.769 mm ~~depth~~, 0-42.769 mm) consists of 678 continuous clearly transmitting annual laminae ~~clearly, because~~ because the transmitting laminae of the stalagmite ky1 are very similar to the annual laminae of Shihua Cave in Beijing~~,~~ and have ~~all the~~ all of the typical characteristics of the latter laminae, which consist of so-called ~~N~~northern type laminae (Zhou et al., 2010). There are clearly very thin opaque laminae between stalagmite laminae ~~clearly~~, but the calcite laminae were thick and transmitting between the stalagmite laminae (Tan et al., 1999; Tan et al., 2002). Because ~~of~~ stalagmite ky1, with a very

~~small~~ short length, has no trace of~~t~~ any weathering ~~trace~~, ~~so~~ the stalagmite may have stopped growing not long ago.~~,~~ ~~i~~Its deposition time may be the past several centuries or one millennium, which has recorded the climatic-environmental information of the Shandong Peninsula since the 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 the U-^{230}Th technique, we have observed and measured the ~~laminae~~ thickness of the laminae and dated ~~all the~~ all of the laminae in the upper part of stalagmite ky1, obtained and researched the time series data on~~f~~ ~~laminae~~ thickness of laminae~~,~~ and compared ~~it~~ these data with the time series data for both the ~~of~~ oxygen (O) stable isotope value and the drought-waterlog index, and we discuss~~ed~~ the climatic and environmental evolution of the coastal part of the warm temperate zone as well as the East Asia monsoon area since the LIA, especially in the transition periods of MWP/LIA and LIA/CWP.

2 Geological setting and sample description

Stalagmite ky1 was collected in 2008 AD 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~~Fig. 1, 2). The cave is located in the northwest hilly area of Lushan Mountain in Zibo ~~c~~City, Shandong ~~-~~P~~p~~rovince, with an elevation of 175 m above sea level (a.s.l.) (Fig. 2). As the largest peninsula in China, ~~it~~ the Shandong Peninsula ~~wa~~is located between the Bohai ~~s~~Sea and the Yellow ~~s~~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)~~,~~ a~~we~~re widely distributed with a thickness of 24-238 m, including ~~its~~ the lower section integrated with the Gezhuang ~~g~~Group and the upper section disconformity in contact~~ed~~ with the Carboniferous Benxi formation) (Shandong Provincial Bureau of Geology &

Minerals, 1991), which a~~we~~re the main components of the Lushan Mountain, Yishan Mountain~~,~~ and Mengshan Mountain with the highest elevation (1108 m,1031 m and 1150 ~~m respectively~~m, respectively). According to field investigation, the landforms ~~development~~ of the carbonate rocks in montanic caves are well developed, there are many cave~~s~~ outcroppings on the surface, secondary carbonate sedimentary bodies are developing well with typical morphological characteristics.

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

3 Analytical methods and data processing

3.1 Establishment of a ~~T~~time scale ~~establishment~~

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

Because the stalagmite ky1 had~~s~~ no hiatus, the upper part (0-42.769 mm) contains 678 clear and continuous lamina~~n~~e.~~,~~ ~~t~~These continuous and ongoing laminae have a clear and definite chronology themselves, pointing to ~~meanings~~interpretations ~~themselves~~. Therefore, based on high precision dating with the U-^{230}Th technique, we used the method of counting annual laminae ~~counting~~ to decide the sedimentation time of each of the laminae and the whole stalagmite ky1 layer~~-~~ by~~-~~ layer and established the time scale of the stalagmite. In the upper part (0-42.769 mm) of stalagmite ky1, we counted along the upward and downward directions according to some laminae ~~which~~ that had~~s~~ high precision dating results with the U-^{230}Th technique, ~~ensured~~ confirming ~~forming~~ times of formation of the 1^{st} and 678^{th} lamina~~n~~e first~~ly,~~ and then ensuring~~ed~~ the age of each of the lamina~~n~~e according to their ~~horizons~~positions.

3.2 Measurement of the thickness of the ~~L~~laminae ~~thickness measurement~~

~~First of all, t~~The stalagmite ky1 was first cut along the growth axis, and a slice was ~~picked~~ selected from the profile of the stalagmite and then polished. Second~~ly~~, under the LEIKA DMRX microscope (magnification of 200×, eyepiece of 10×, objective of 20×), we used transmission light to observe characteristics of the laminae ~~characteristic~~ along the growth axis layer~~-b~~ by~~-~~ layer. Third~~ly~~, we measured the thickness of 678 laminae along three different paths layer~~-~~by~~-~~layer, calculated the thickness of every one of the lamina~~n~~e ~~thickness~~ on average according to the three data points for ~~of the~~ each of the laminae. Fourth~~ly~~, we ~~had~~ dated every one of the laminae layer~~-~~by~~-~~layer and ~~get~~ determined the time series data ~~of~~ for the thickness of the ~~stalagmite~~ laminae of the stalagmite ~~thickness~~. ~~At last~~Finally, we contrasted the time series data and the $\delta^{18}O$ ratio data series, analyzed the paleoclimate environment characteristic of the different stages~~,~~ and discussed the climatic-environmental meaning~~s~~ of the variations ~~of~~ in the thickness of the laminae~~ thickness~~.

3.3 δ^{18}O isotope~~s~~ test

First~~ly~~, perpendicular to the growth axis and along the ~~horizons~~ position of 9.5 mm and 18.5 mm from the top, we collected ~~respectively~~ four~~4~~ samples equally spaced ~~in~~ at 20 mm from the growth center ~~equally spaced~~ that were used for the Hendy test. Second~~ly~~, along the ~~growing~~ direction of growth, 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 0.1296 mm on the average). ~~In~~ From the 330 samples~~ above~~, we chose 175 samples to measure their δ^{18}O ratios, basically following the principle of an interval test ~~in order~~ to avoid the mixed pollution between adjacent samples. Next, we confirmed the sedimentation time according to their ~~horizons~~ positions and formed the time series data ~~of~~ for δ^{18}O ratios. The δ^{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 the 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~~90ºC~~˚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 per mil (‰) 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 Results and discussion

4.1 The ~~laminae~~ thickness of the stalagmite laminae and the ~~dating~~ results of dating

In the upper part (0-42.769 mm) of stalagmite ky1, the dating result ~~of~~ for ages corrected in Table 1 show that the three samples in the ~~horizons~~ positions of ~~the~~ 6 mm, 15 mm and 25 mm are dated at 1761.9±20.3 AD, 1696.6±13.6 AD and 1556.4±13.6 AD, respectively (Table 1). Altogether~~mong~~, there are 221 laminae between the ~~horizons~~ positions of 6 mm and 25 mm, and their age intervals are 206 years according to the U-^{230}Th dating results.~~,~~ ~~t~~The difference ~~of~~ in age between the laminae determined by counting and by U-^{230}Th dating ~~results~~ is only 15 years. ~~But~~ However, there are 109 laminae between the ~~horizons~~ positions of 6 mm and 15 mm, and their age intervals are 65 years according to the result of the U-^{230}Th dating.~~,~~ ~~and t~~There are 112 laminae between the ~~horizons~~ positions of 15 mm and 25 mm, and their age intervals are 141 years according to the results of U-^{230}Th dating. ~~. On the other hand, i~~If we use the ~~horizon~~ position of 6 mm as a datum ~~to~~ for calculation~~e~~, the ages of the 1st and 678th laminae are 1894±20.3 and 1217±20.3 AD, respectively. If we use the ~~horizon~~ position of 25 mm as a datum ~~to~~ for calculation~~e~~, the ages of the 1st and 678th laminae are 1909±13.6 AD and 1232±13.6 AD, respectively.~~,~~ ~~t~~The age intervals are only 14 years different~~s~~. Finally, ~~in~~ considering ~~of~~ the error of the measurement of the thickness of the laminae ~~thickness measurement~~ accumulating downward layer-by-layer, we chose the ~~133th~~ 133rd of the laminae corresponding to the ~~horizon~~ position of 6 mm as ~~the~~ a datum to calculate the age of the other laminae in the upper part of stalagmite ky1. The results show that the deposition times of the 1st and 678th laminae are 1894±20.3 and 1217±20.3 AD (the dating error is ±20.3 years, similar~~ly~~ here~~in~~after for the AD ages in this paper), respectively, the age of the other laminae were calculated by analogy.~~,~~ ~~hereby~~ Thus, we ~~got~~ obtained the time series data ~~of~~ for the thickness of the laminae ~~thickness~~ of stalagmite ky1 (Fig. 5).

4.2 Characteristics of the ~~Laminae~~ shape of the laminae ~~characteristic~~

Stalagmite ky1 obviously developed continuous transmitting laminae ~~obviously~~ (Fig. 4). Under the microscope, first,~~ly,~~ the ~~laminae~~ thickness of the laminae ~~were~~ was rather changeable.~~,~~ ~~t~~The maximum thickness ~~reached~~ was more than 800 μm, and the minimum thickness ~~reached~~ was less than 15 μm (Fig. 6a). Because the variations in the thickness of the laminae ~~thickness variations~~ may correspond~~ing~~ to the climatic environmental changes when the lamina~~n~~e were growing, ~~it shows~~ the potential value of these transmitting lamina~~n~~e ~~in~~ for reconstructing the paleoclimate environment is illustrated (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). Second~~ly~~, most of the boundaries~~y~~ of the ~~lamiane~~laminae are straight, but some ~~lamiane~~laminae are obviously curved (Fig. 6b). ~~Hereby~~ ~~w~~When we analyzed the climatic-environmental meaning~~s~~ of the thickness of the stalagmite laminae ~~thickness~~, we acquired the laminae thickness values of ~~a~~ the same laminae in different paths and calculated their average values along multiple paths ~~in order~~ to ~~get~~determine the substituted index information ~~of~~ for climatic-environmental change that had statistical significance~~s~~. Third~~ly~~, colors in some of the boundaries of the transmitting ~~lamiane~~laminae were ~~deeper~~ obviously deeper (Fig. 6c).~~,~~ ~~t~~These laminae had a special structure similar to supera annual laminae. This special structure may indicate that climatic-environmental changes not only have seasonal changes~~,~~ but also have multi-interannual changes. Fourth~~ly~~, the light transmission of some transmitting ~~lamiane~~laminae is obviously different from the light transmission of adjacent ~~lamiane~~laminae:~~,~~ the color is deeper, and there are dark spots (Fig. 6a, d). Whether these dark laminae have some mineralogy and geochemistry characteristics different from other transmitting ~~lamiane~~laminae~~,~~ and what their climatic-environmental ~~meanings~~ significance ~~are~~may be, these dark laminae may need further and special research in the future.

4.3 Variations in the thickness of the ~~L~~laminae ~~thickness variations~~

The ~~variation~~ range of variation in the thickness of the 678 laminae ~~thickness~~ of stalagmite ky1 (upper part) were 13.03~872.8 μm. The ~~formed~~ age determined ~~of~~ for the maximum thickness (872.8 μm) of the laminae was 1551 AD~~,~~. ~~t~~The ~~formed~~ age determined for ~~of~~ the minimum thickness (13.03 μm) of the laminae was 1245 AD, and the average value ~~of~~ for all laminae ~~were~~ was 63.08 μm (Fig. 7a). In the 678 years from 1217 AD to 1894 AD, the ~~laminae~~ thickness of the laminae ~~of~~ from stalagmite ky1 have obvious stages~~d~~ of variation.~~s,~~ Stalagmite ky1 ~~it~~ had undergone the transition from low values to high values and again to low values, and both the ~~laminae~~ thickness of the laminae and the fluctuati~~o~~ng degree of variation~~s~~ ~~of~~ in the ~~laminae~~ thickness of the laminae had obvious stages~~d~~ of variation~~s~~ (Fig. 7a).From 1217 AD to 1471 AD~~, it~~ was the low value period of ~~laminae~~ thickness of the laminae with ~~the~~ an average value of 46.08 μm. ~~Among~~Then, the period from 1217 AD to 1372 AD was a relatively low fluctuation period~~ relatively,~~. ~~t~~The period from 1372 AD to 1471 AD was a period of relatively high fluctuation.~~ period relatively,~~ ~~t~~The two periods above presented the trend of rising first~~ly~~ and then falling~~ then~~. From 1471 AD to 1744 AD, it was a period of high value-high fluctuation ~~period of~~in the ~~laminae~~ thickness of the laminae, with the average value of 88.8307 μm. ~~Among, t~~This period could be divided into three secondary high value-high fluctuation periods, 1471 AD-1548 AD, 1548 AD-1637 AD and 1637 AD-1744 AD.~~,~~ ~~e~~Every period ~~has~~ shows the trend of increasing first~~ly~~ and then decreasing.~~ then,~~ ~~t~~The~~ir~~ average values ~~of~~ for the thickness of the laminae ~~thickness~~ were 82.2027 μm, 82.5491 μm and 98.8252 μm, successively. From 1744 AD to 1894 AD, ~~it~~ there was a period of relatively low values ~~period~~ of the ~~laminae~~ thickness of the laminae, with a group of peak values ~~appeared~~ appearing in ~~about~~ approximately 1776 AD ~~and~~ with ~~the~~ an average value of 45.1164 μm. ~~Among, t~~The period from 1217 AD to 1372 AD was a period of relatively low fluctuation.~~ period relatively,~~ ~~t~~The period from 1744 AD to 1831 AD was a period of relatively high fluctuation.~~ period relatively,~~ ~~t~~The two periods above present~~ed~~ the trend of rising first~~ly~~ and then falling.~~ then,~~ ~~t~~The period from 1831 AD to 1880 AD was a period of relatively high fluctuation, without ~~period relatively and not have~~ a trend of obviously rising or falling.~~ obviously,~~ ~~it~~ This period of rising was ~~a~~ short, ~~rising period~~ from 1880 AD to 1894 AD.

4.4 Variations in the $\delta^{18}O$ ratio ~~variations~~

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

4.5 Drought/waterlog index variations

In order tTo show the relationship between the variations of in the laminae thickness of the laminae, and the $\delta^{18}O$ ratios and the changes of in climate, we calculated –cumulative departure values of for the drought/water log index in the area of Kaiyuan Cave from 1470 AD to 1894 AD. The data source iwas the *Yearly*

~~c~~Charts of ~~d~~Dryness/~~w~~Wetness in China for the ~~l~~Last 500-year ~~p~~Period.~~,~~ ~~t~~The charts are compiled by the Chinese ~~a~~Academy of ~~m~~Meteorological ~~s~~Sciences of the China Meteorological Administration according to ~~lots~~ extensive ~~of~~ Chinese historical literature and published by the China Cartographic Publishing House (Chinese ~~a~~Academy of ~~m~~Meteorological ~~s~~Sciences of the China Meteorological Administration, 1981). In the charts, the degree of drought/waterlog– is represented by the drought/waterlog index ~~which~~ that has five values including 1, 2, 3, 4 and 5, with 1 representing the waterlog and 5 representing drought，and its distribution is represented through the index isolines. On the basis of *Yearly– ~~c~~Charts of ~~d~~Dryness/~~w~~Wetness in China for the ~~l~~Last 500-~~y~~Year ~~p~~Period*, we acquired the drought/waterlog ~~indexes~~ indices ~~in~~ for the area near Kaiyuan ~~c~~Cave according to its geographical coordinates, and we checked the drought/waterlog ~~indexes~~ indices again referring to the local chronicles. We dre~~a~~w a cumulative departure curve from 1470 to 1894 AD with a rising trend representing the changes ~~of~~ associated with becoming dryer and a declining trend representing the change ~~of~~ associated with becoming ~~waterlogging~~ waterlogged (Fig. 7b). Based on the cumulative departure curve, ~~it~~ there was a period of less precipitation ~~period~~ in this area from 1480 to 1744 AD.~~,~~ ~~t~~This period ~~is~~ starts~~ed~~ with the transition of MWP/LIA and ends~~ed~~ with the transition of LIA/CWP.~~,~~ ~~its~~ The primary fluctuations of this period ~~were~~ correspond~~ing~~ to the curve of the thickness of the laminae ~~thickness~~. (Fig. 7b). ~~So t~~The high value-high fluctuation period of the ~~laminae~~ thickness of stalagmite ky1 laminae above occurred under the background of drought and less precipitation. ~~On the other hand~~However, there is a correlation between the $\delta^{18}O$ ratios of stalagmite ky1 and the change ~~of~~ in the summer monsoon intensity and precipitation (Cheng et al., 2009). ~~This indicatinges that stronger~~ So, there is a correlation between the summer monsoon intensity/precipitation and the growth of stalagmites, weaker summer monsoon intensity and less precipitation may be of benefit to the growth of stalagmites ~~growing~~ in LIA.

4.6 Climatic-environmental meanings of variations in the thickness of the

laminae ~~thickness variations~~

~~Owing to~~Because of the difference ~~of~~ in homologous ~~laminae~~ thickness stages of the laminae and $\delta^{18}O$ ~~varios~~ ratios ~~stage ranged~~ ranging from 2 years to 14 years, in consideration of the error of the dating technique was ±20 years (the time series data ~~we got in~~from section 4.1) and the resolution of the $\delta^{18}O$ sample was 3.9 years, we could say the two synchronize with time~~-~~ variation~~ying~~, ~~mean that~~i.e., the low value period and the high value period of the $\delta^{18}O$ ratios ~~were~~ correspond~~ing~~ to the low value period and the high value period of the thickness of the stalagmite laminae. ~~thickness,~~ ~~t~~The low fluctuation period and the high fluctuation period ~~of~~ for the $\delta^{18}O$ ratios ~~were~~ correspond~~ing~~ to the low fluctuation period and high fluctuation period of thickness of stalagmite laminae ~~thickness~~ (Fig. 7~~a,c~~a, c). ~~On the other hand, t~~The analysis result ~~of~~ for the $\delta^{18}O$ ~~varios~~ variations showed that~~,~~ $\delta^{18}O$ ratios ~~of~~ for the four~~4~~ samples were −7.506‰, −7.753‰, −7.981‰ and −7.691‰ which for the samples that were collected at a 9.5 mm distance from the top of the stalagmite and the 5, 10, 15 and 20 mm distance from the ~~growing~~ axis of growth,~~–~~ respectively.~~,~~ The $\delta^{18}O$ ratios ~~of~~ for the four~~4~~ samples that were collected at ~~a~~an 18.5 mm distance from the top of the stalagmite were −6.571‰, −6.671‰, −6.540‰ and −6.542‰. ~~which were collected 18.5mm distance from the top of stalagmite and~~At 5, 10, 15 and 20 mm distances from the ~~growing~~ axis of growth, respectively, and the $\delta^{18}O$ ratios were similar ~~in~~ for the same laminae (Table 2)~~-~~. Hence, the Hendy Test carried out ~~about~~ for ~~Ky1~~ ky1 indicates that calcite in ~~K~~ky1 should be deposited under isotopic equilibrium conditions.~~,~~ ~~t~~The possibility of ~~its~~ the dynamic fractionation of the calcite in the sedimentary process is small; therefore,~~ so~~ the stalagmite $\delta^{18}O$ mainly ~~mainly~~ reflect~~sed~~ ~~mainly~~ the original external climate signal (Hendy, 1971). Therefore, the stalagmite $\delta^{18}O$ can be used to collect and reconstruct the information on~~f~~ 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 relationship between the variations in the ~~laminae~~ thickness of the laminae ~~variations~~ and the $\delta^{18}O$ ratios variations ~~of~~ in stalagmite ky1 shows a close~~ly~~ relationship between the variations in the ~~–~~deposition rate

~~variations~~ of the stalagmite and climate change (Fig. 7). Because Kaiyuan Cave is located ~~at~~ in a warm temperate zone influenced by the East Asia monsoon, its rainy season coincides with high temperatures.~~,~~ ~~t~~The precipitation, carried by the summer monsoon from the low latitude of the Pacific Ocean ~~of low latitude~~, concentrates in summer. However, when the winter monsoon from the interior Asian continent ~~with~~ at a high latitude ~~is~~ prevails~~ing~~, there is rare precipitation. In this research, we interpreted the climatic meanings of the stalagmite ky1 $\delta^{18}O$ ratios, based on the relationship between the cumulative departure of the drought/waterlog index and the curves of the $\delta^{18}O$ ratios.~~,~~ ~~t~~The characteristics of contemporary warm temperate weather, also referring 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 a stronger summer monsoon and higher $\delta^{18}O$ ratios representing a weaker summer monsoon, ~~that is to say,~~ the $\delta^{18}O$ ratios are anti-~~correlating~~ correlative with precipitation (Fig. 7). ~~Hereby, it~~There was a strong summer monsoon-more precipitation period from 1217 AD to1480 AD, a weak summer monsoon-less precipitation period from 1480 AD to 1746 AD~~,~~ and a strong summer monsoon-more precipitation period again from 1746 AD to 1894 AD ~~again~~. ~~On the other hand, t~~The degree of fluctuation ~~degree~~ of the summer monsoon intensity and precipitation is not the same or similar in different periods. As a whole, the degree of fluctuation ~~degree~~ was lower when the summer monsoon was stronger and the precipitation was ~~more~~greater.~~,~~ ~~t~~The degree of fluctuation ~~degree~~ was higher when the summer monsoon was weaker and the precipitation was less. ~~Among, t~~The period from 1217 AD to 1480 AD can be divided into one low fluctuation period and one high fluctuation period.~~,~~ ~~t~~The period from 1480 AD to 1746 AD can be divided into three high fluctuation periods.~~,~~ ~~t~~The period from 1746 AD to 1894 AD ~~was~~ included a high fluctuation period, a low fluctuation period and a weaker-less fluctuation period, successively.

According to the thickness of the laminae ~~thickness~~ and the $\delta^{18}O$ record of stalagmite ky1, the ~~laminae~~ thickness of the laminae and both summer monsoon intensity and precipitation have~~s~~ a negative correlation.~~,~~ ~~t~~The higher value period of ~~laminae~~ the thickness of the laminae ~~is~~ corresponds~~ing~~ to weaker summer monsoon-less precipitation, and the lower value ~~is~~ corresponds~~ing~~ to stronger summer monsoon-more precipitation. ~~On the other hand, t~~The thickness of the laminae ~~thickness~~ and the degree of fluctuation ~~degree~~ of the summer monsoon intensity-precipitation have a positive correlation.~~,~~ ~~t~~The period of the higher values ~~period of~~for the ~~laminae~~ thickness of the laminae ~~is~~ corresponds~~ing~~ to a high degree of fluctuation ~~degree~~ of the summer monsoon intensity-precipitation, and a lower value ~~is~~ corresponds~~ing~~ to a low degree of fluctuation ~~degree of~~in the summer monsoon-precipitation. Therefore, Kaiyuan Cave, in the coastal area both of a warm temperate zone and the East Asia monsoon area, demonstrates that the variations in the thickness of the laminae ~~thickness~~ are not only relative to the summer monsoon intensity-precipitation~~,~~ but also relative to their degree of fluctuation ~~degree. This is~~ because karstic water cycles~~d~~ faster and residence time ~~wa~~is shorter in the fracture of rock.~~,~~ ~~t~~The dissolution was insufficient and weak~~, so~~; therefore, the deposition rate and the thickness of the laminae ~~thickness of~~from the stalagmite were~~as~~ low in the period with more precipitation ~~period~~. ~~But~~ However, in the period of less precipitation ~~period~~, the karstic water cycled slower, and the residence time was longer in the fracture of the rock.~~,~~ ~~t~~The dissolution was sufficient and strong; therefore,~~ so~~ the deposition rate and the thickness of the laminae ~~thickness~~ of the stalagmite were high. However, karstic water would be reduced or dry up if the period of less precipitation lasted for a long time.~~,~~ ~~this~~ The period of less precipitation is also bad for water dissolution and growth of the stalagmite laminae ~~growing~~. ~~So u~~Under the background of weaker summer monsoons and less precipitation, the degree of fluctuation ~~degree~~ of the summer monsoon intensity-precipitation ~~goes~~ becomes higher, ~~this is~~ beneficial to increasing the average value of the thickness of the laminae ~~thickness~~ of the stalagmite, but the degree of~~ir~~ fluctuation ~~degree~~ also ~~goes~~ becomes higher. Because of the degree of fluctuation ~~degree~~ of the summer monsoon intensity-precipitation reflecting the degree of climatic ~~stabilized~~stabilization ~~degree~~, according to both the thickness of the laminae

~~thickness~~ and the δ^{18}O record of stalagmite ky1 from the Kaiyuan Cave, the climate change between MWP and LIA in the coastal area ~~both~~ of both a warm temperate zone and the East Asia monsoon area, ~~besides~~ in addition to less precipitation and a lower temperature, also shows that the degree of climatic stability obviously ~~degree~~ decreased ~~obviously~~.

5 Conclusions

The upper part of stalagmite ky1 (0-42.769 mm) clearly consists of 678 continuously transmitting annual laminae. ~~clearly,~~ ~~its~~ The ~~deposition~~ time of deposition ~~is~~ ranges from 1217±20 AD to 1894±20 AD; therefore, ~~so~~ the laminae contain~~s~~ the climatic-environmental change information ~~of~~ for the late MWP, the whole LIA and the early CWP. The analysis show~~s~~ that both the variations ~~of~~ in the thickness of the laminae ~~thickness~~ themselves and the fluctuating degree of variation~~s~~ ~~of~~ in the thickness of the laminae ~~thickness fluctuation degree~~ of stalagmite ky1 have obviously staged characteristics from 1217 AD to 1894 AD. ~~, it~~ Both the variations in the thickness of the laminae themselves and the fluctuating degree of variation in the thickness of the laminae of stalagmite ky1 had undergone the transition from low values to high values and again to low values, ~~which was~~ synchronized with the contemporaneous variations ~~of~~ in the δ^{18}O ratios and the degree of fluctuation ~~degree~~ of the δ^{18}O ratios. According to the comparison among the thicknesses of the laminae ~~thickness~~, the drought/waterlog index and the synchronous δ^{18}O ratios of stalagmite ky1, the thickness of the laminae ~~thickness~~ and the summer monsoon intensity-precipitation have a negative correlation. ~~,~~ ~~t~~The higher value periods of the thickness of the laminae ~~thickness are~~ correspond~~ing~~ to weaker summer monsoon-less precipitation, and low value periods ~~are~~ correspond~~ing~~ to stronger summer monsoon-more precipitation. ~~On the other hand,~~ ~~t~~The thickness of the laminae ~~thickness~~ and the degree of fluctuation ~~degree~~ of the summer monsoon intensity-precipitation have a positive correlation. ~~,~~ ~~t~~The higher value periods of thickness of the laminae ~~thickness are~~ correspond~~ing~~ to a high degree of fluctuation ~~degree~~ of summer monsoon intensity/precipitation, and the lower value periods are corresponding to a low degree of fluctuation degree ofin the summer monsoon-precipitation. Therefore, –Kaiyuan Cave, in the coastal area both of a warm temperate zone and the East Asia monsoon area, with the relationship between the variations ofin thickness of the laminae thickness and climate change, besides in addition to the effects of climate factor variations like such as temperature and precipitation on the thickness of the laminae thickness, also reflects closely the degree of fluctuation degree of the summer monsoon intensity and the degree of climatic stability degree in addition. As aOn the whole, it there was a period of stronger summer monsoons from 1217 AD to 1470 AD. Among, tThe climatic stability was high from 1217 AD to 1370 AD firstly, and was reduced from 1370 AD to 1470 AD. From 1470 AD to 1740 AD, it there was a period of weaker summer monsoon-lower degree of stability thatdegree period, could be divided into three secondary periods with a trend of stronger firstly and then weaker then or weaker firstly and then stronger then divided by 1550 AD and 1640 AD. Since 1640 AD, the summer monsoon has again entered a strong period again. Among, tThe degree of stability degree was high from 1740 AD to 1830 AD, and the degree of stability wadegree is reduced from 1830 AD to 1880 AD., tThe summer monsoon became weaker for a short time since 1880 AD.

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

Acknowledgements

The research waіs financially supported by the project of NNSFC (NO.41171158). The authors thank Professor Jiang Xiuyang (Fujian Normal

University) for his help in sample collection and high precision dating with the U-^{230}Th technique.

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

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 the corrected age.

^{c}[^{230}Th/^{238}U]$_{activity}$ = 1 - $e^{-\lambda 230 T}$ + ($\delta^{234}U_{measured}$/1000)[λ_{230}/(λ_{230} - λ_{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).

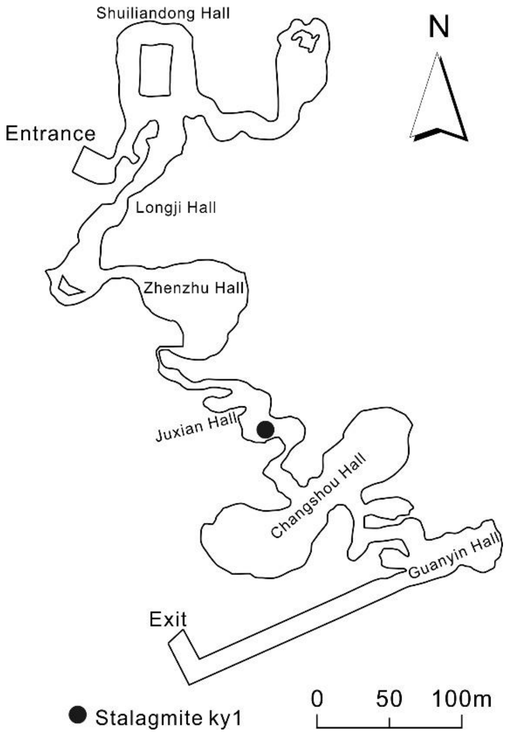
^{d}The degree of detrital ^{230}Th contamination is indicated by the [^{230}Th/^{232}Th] atomic ratio instead of the activity ratio.

^{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~~laminae of ky1 at depths of 9.5 mm 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 ~~n~~Number	**Distance from the ~~t~~Top~~/~~ mm**	**Distance from the ~~c~~Center of ~~g~~Growth~~/~~ mm**	**$\delta^{18}O$/‰**
KY1-9/10-5	9.5	5.0	-7.506
KY1-9/10-10		10.0	-7.753
KY1-9/10-15		15.0	-7.981
KY1-9/10-20		20.0	-7.691
KY1-18/19-5	18.5	5.0	-6.571
KY1-18/19-10		10.0	-6.671
KY1-18/19-15		15.0	-6.540
KY1-18/19-20		20.0	-6.542



~~Fig.1~~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 consists of six~~6~~ small malls.

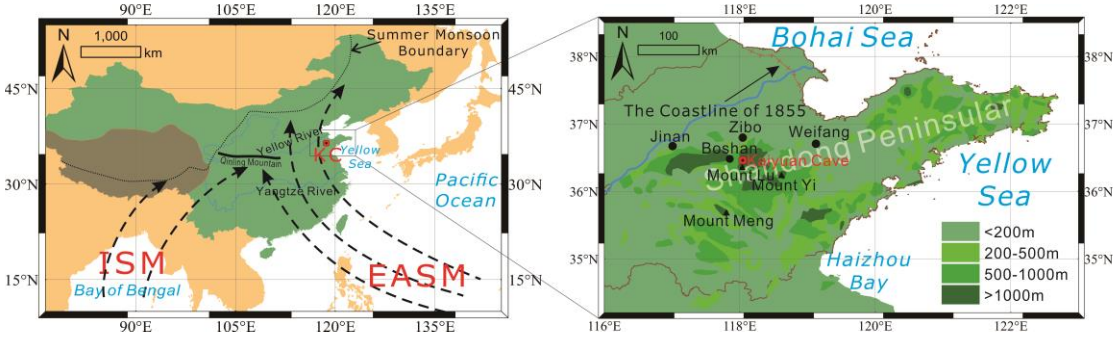


Fig. 2. Location of Kaiyuan Cave and Shandong pPeninsula in monsoonal China. KC: Kaiyuan Cave (36°24′32.20″N, 118°02′3.06″E). ISM: India Summer Monsoon; EASM: East Asia Summer Monsoon. The dashed black thin line indicates the northwestern boundary of the Asian summer monsoon. The dashed black lines with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

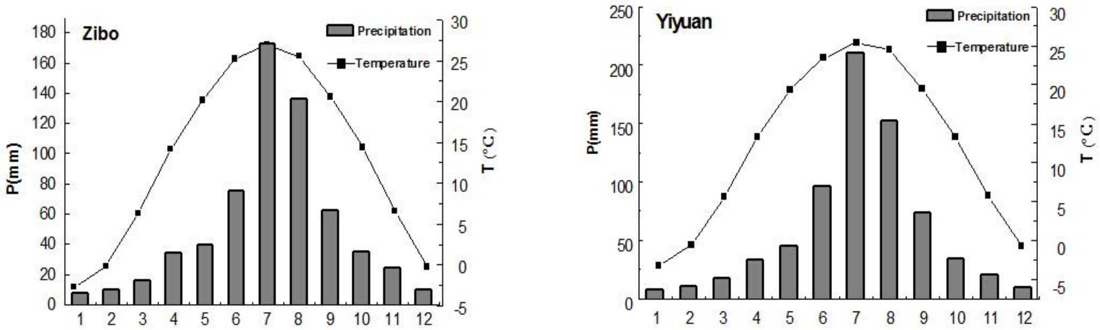


Fig. 3. Monthly mean temperature (T) and precipitation (P) ~~at~~of Zibo at Zibo Station (1952-1980) and Yiyuan (1958-2005) at the Yiyuan Station, two meteorological stations close to the study site (Fig. 1).

Fig. 4. Polished longitudinal cross-section of stalagmites ky1

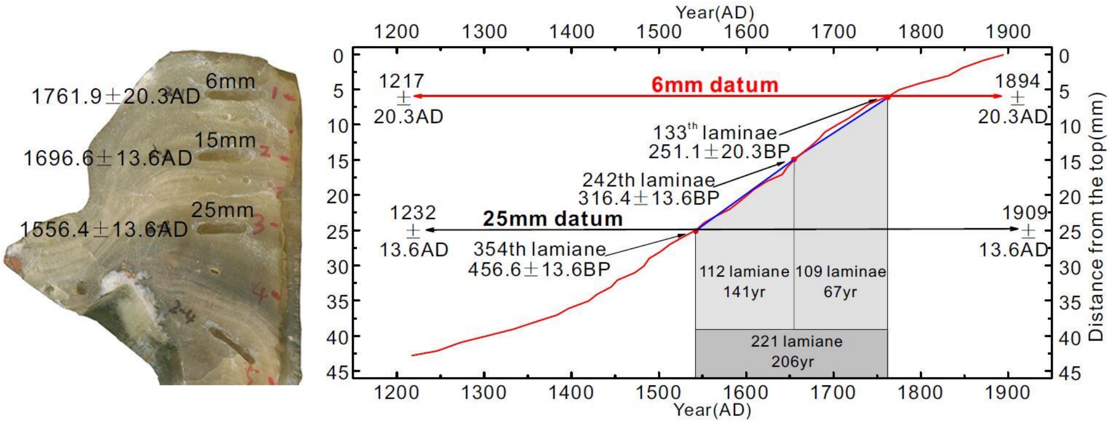


Fig. 5. The age model for stalagmite ky1 established by laminae counting of laminae and high precision dating results with the U-^{230}Th technique. It This figure is the photo of stalagmite ky1, and the age label was based on high precision dating results with the U-^{230}Th technique ion the left.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

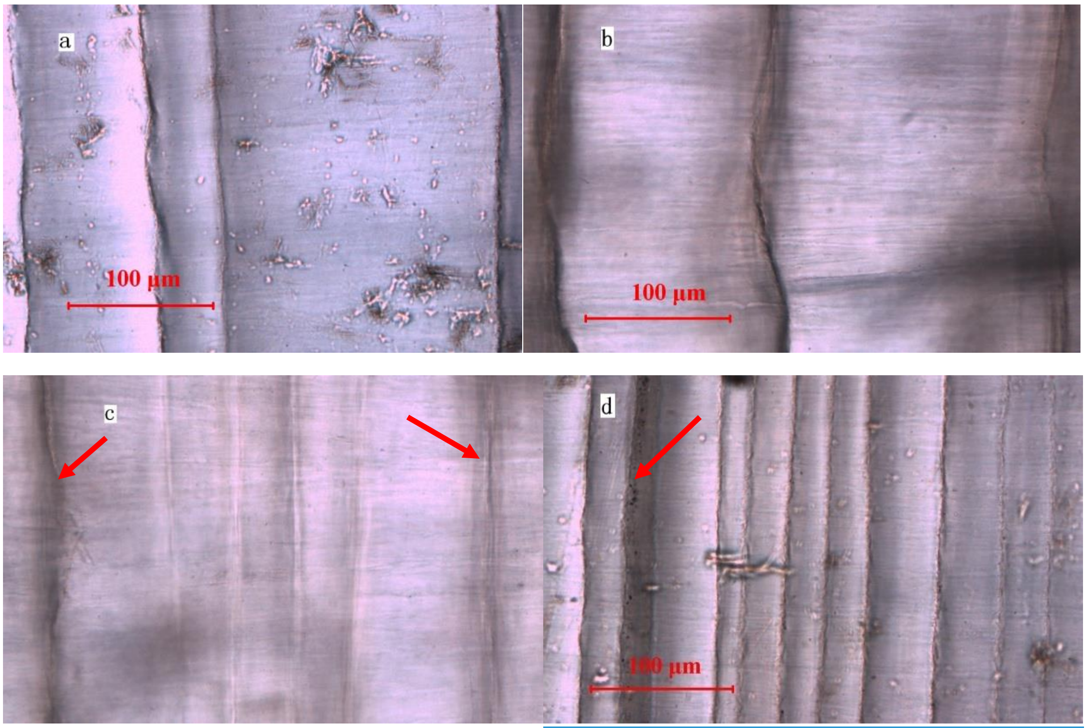


Fig. 6. The characteristics of the transmitting laminae in the upper part of stalagmite ky1~~,~~ show that the thickness of the laminae ~~thickness~~ has~~ve~~ obvious variations.~~,~~ ~~t~~The boundary was curved, and the color near the boundary was deeper ~~and~~ because of the dark transmitting laminae. The thickness of the ~~L~~laminae ~~thickness have~~shows obvious variations (a), the curve of the boundary of transmitting laminae (b), the color variations of the boundary of transmitting laminae, the arrows indicating~~e~~ the darker boundaries, the boundaries in the middle were obviously whiter ~~obviously~~ (c), dark transmitting laminae (d) (the arrows indicated in the figure).

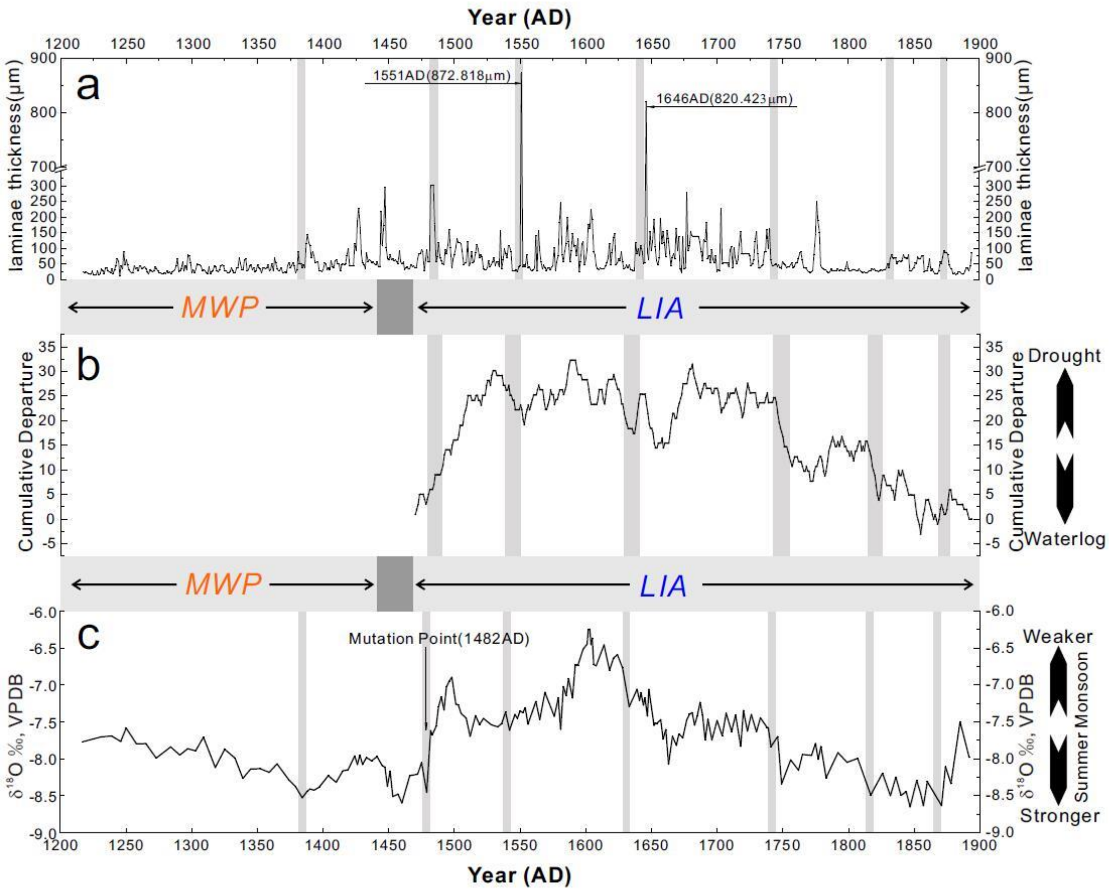


Fig. 7. The ~~formed~~ year of formation and the thickness data series of the 678 laminae in the upper part (0-42.769 mm) of stalagmite ky1 (a), the cumulative departure curve (b) and the $\delta^{18}O$ ratio data series ~~of~~ for 172 samples (c). The thickness of the laminae formed in 1551 AD and 1646 AD were up to 872.818 μm and 820.423 μm, respectively~~, they are~~, much higher than other laminae. The cumulative departure curve (b) is ~~drown~~ drawn by drought/waterlog ~~indexes~~ indices on the basis of the *Yearly ~~c~~Charts of ~~d~~Dryness/~~w~~Wetness in China for the ~~l~~Last 500-~~y~~Year ~~p~~Period* (Chinese ~~a~~Academy of ~~m~~Meteorological ~~s~~Sciences of the China Meteorological Administration~~,~~ 1981), the curve has a rising trend representing less precipitation and the climate becoming drier, and the curve has a declining trend representing more precipitation and the climate becoming~~es~~ ~~waterlogging~~waterlogged.