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Large variations of oxygen isotopes in precipitation over south-central Tibet during Marine Isotope Stage 5

***By Yanjun Cai et al.*, 2009**

Supplementary Figures

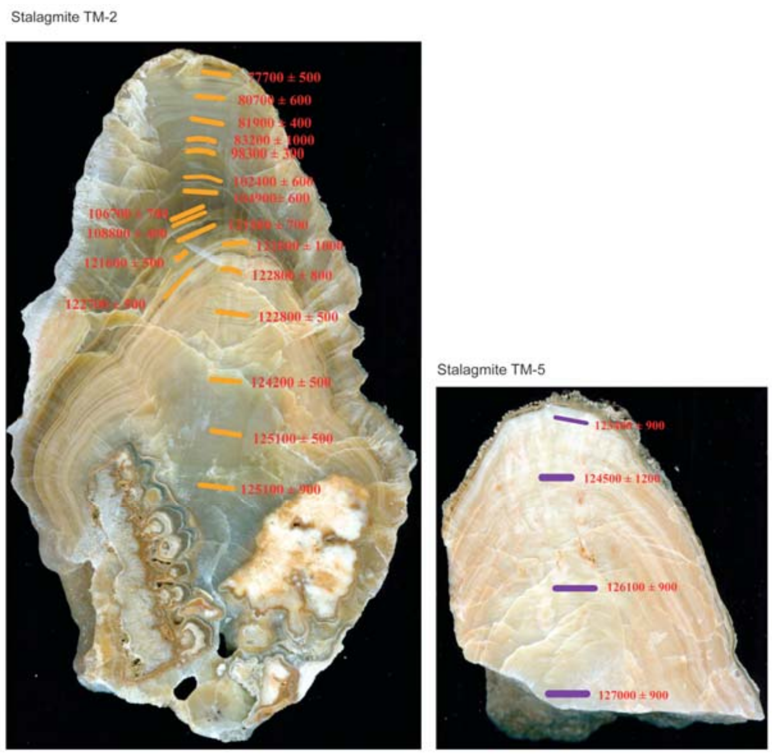

Figure DR1. **Images of stalagmites TM-2 (left) and TM-5 (right) that were used to establish the Tianmen δ^{18}O record.** ^{230}Th dating positions and results are indicated by color bars and numbers beside the bar.

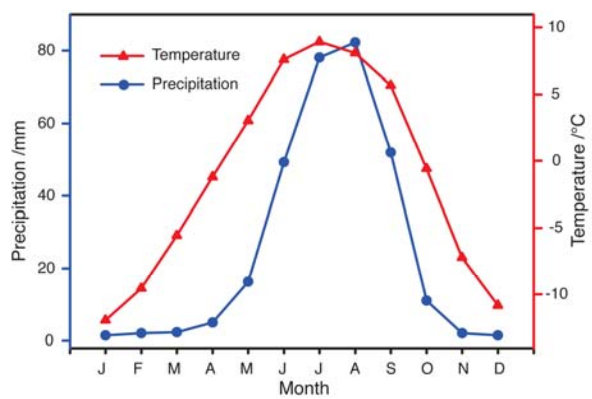

Figure DR2. **Monthly mean precipitation (blue) and temperature (red) records over 44 years (1957-2000) at the Bange meteorological observatory (31°23'N, 90°01'E, elevation 4800 m)**. The summer monsoon precipitation (from June to September) contributes 86% of annual precipitation.

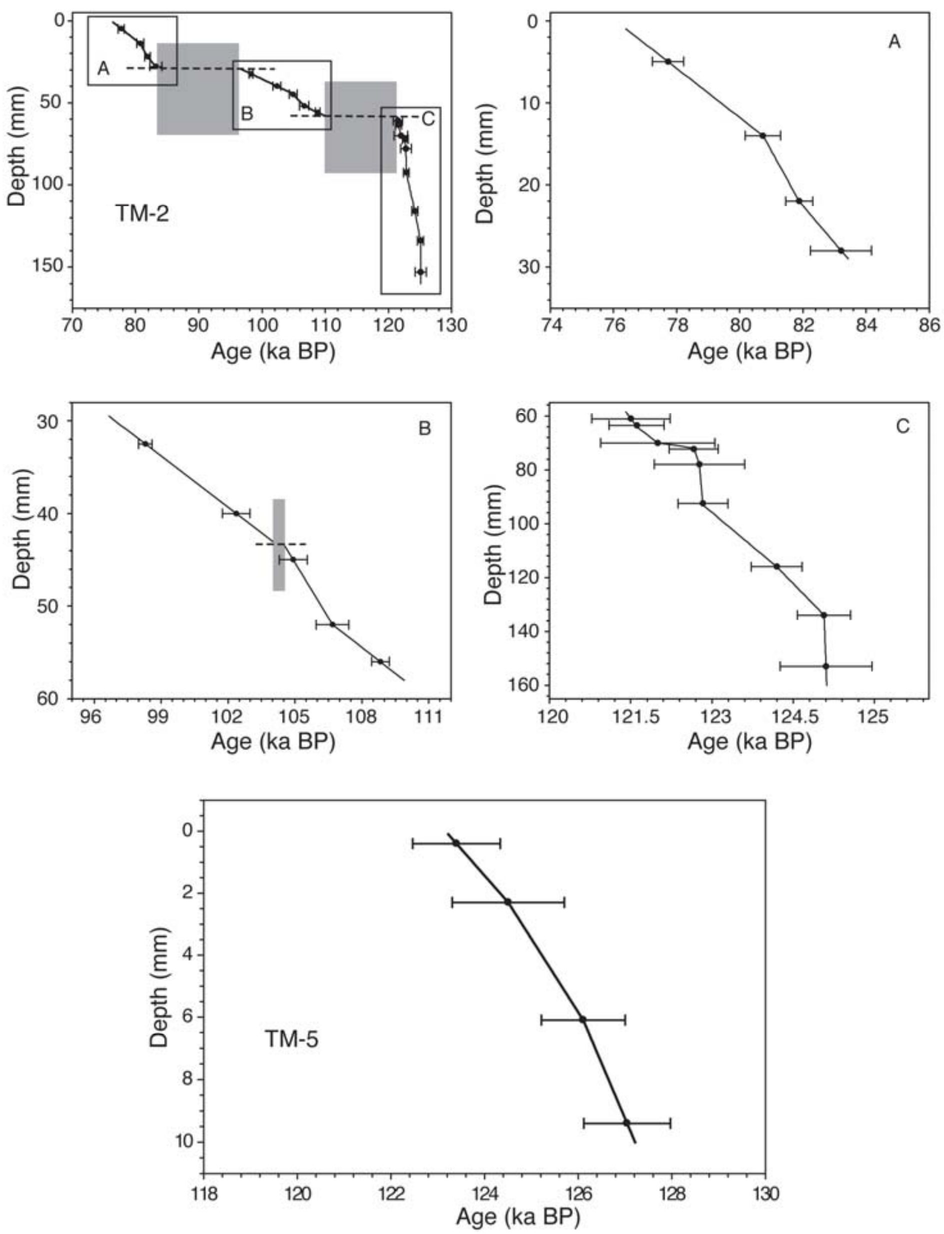

Figure DR3. **Plots of age versus depth for two stalagmites TM-2 and TM-5.** (A), (B) and (C) are the enlarged insets in the plot of TM-2. The chronologies were established by linear interpolations between ^{230}Th dates. Error bars indicate 2σ ^{230}Th dating errors. Note the three main growth phases (which correspond to times of high summer insolation) separated by two large hiatuses in TM-2 (grey bar, which correspond to times of low summer insolation). In inset B, also shown is a short hiatus in the middle growth phase which correlates to the stadial period between Greenland and Chinese Interstadials 23 and 24.

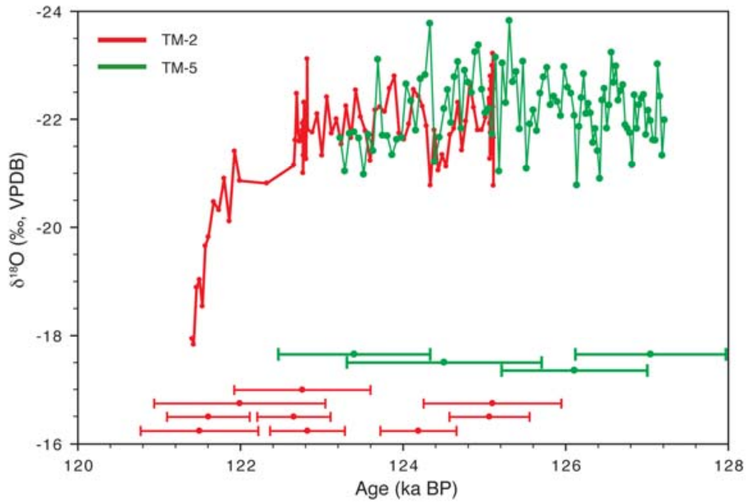

Figure DR4. **Comparison between the δ^{18}O time series of TM-2 and TM-5 during the contemporaneously growing period between 123.2 and 125.2 ka BP.** The ^{230}Th dates with errors are also depicted at the bottom. The similarity between two speleothem records within the quoted errors show a robust replication (Cheng et al., 2006; Hendy and Wilson, 1968; Wang et al., 2008), indicating that these speleothems were most likely formed under an equilibrium precipitation condition.

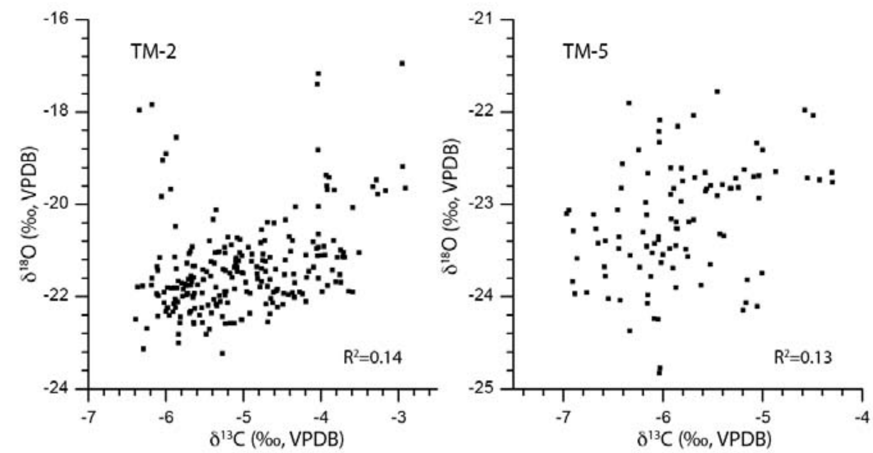

Figure DR5. The plot of δ^{13}C versus δ^{18}O of stalagmite TM-2 and TM-5. The low correlations (R^2=0.14, 0.13) between δ^{13}C and δ^{18}O indicate that carbon and oxygen are not highly correlated. It suggests that the speleothem most likely grew under isotopic equilibrium conditions (Hendy, 1968).

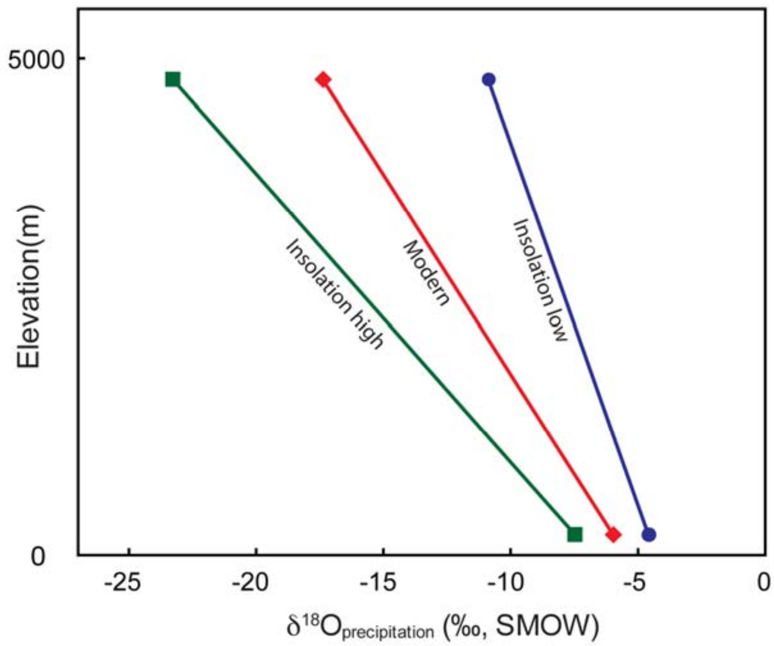

Figure DR6. Conceptual plot of elevation vs $\delta^{18}O_{precipitation}$ at different insolation times. The calculated $\delta^{18}O_{precipitation}$ (O'Neil et al., 1969) show a increased lapse rate during the period of high insolation and vice versa, assuming the orbital-scale Indian monsoon variation are similar to the monsoon changes in East Asia. Table DR1 presents the known (black) and calculated (blue) mean values with the presumed conditions (red) at low and high elevation during the different times in the figure.

Methods

The stalagmite samples were cut into halves along the growth axis with diamond saw and the surface polished. Sub-samples for ^{230}Th dating were drilled along growth axes at Institute of Earth Environment, Chinese Academy of Sciences. The chemical procedures were similar to those described in Edwards et al. (1987) and accomplished in the clean lab of Minnesota Isotope Laboratory. The measurements were run on an inductively coupled plasma mass spectrometer (Thermo-Finnigan ELEMENT) using procedures described in Cheng et al. (2000) and Shen et al. (2002). A total of 22 ^{230}Th dates were obtained with typical errors in age (2σ) of less than 1%. Linear interpolations between ^{230}Th dates were used to establish chronologies for stalagmites TM-2 and TM-5.

Sub-samples for stable isotope analysis were drilled directly from the polished section of the stalagmites. Approximately 100 μg of powder samples were drilled along growth axes of stalagmites and analyzed with an on-line, automated carbonate preparation system (Kiel III), linked to a Finnigan MAT-252 gas source mass spectrometer at the Isotope Laboratory at Institute of Earth Environment, Chinese Academy of Sciences. NBS19 and Laboratory standard TTB1 were run every 10 to 12 samples and arbitrary selected duplicates were run every 10 to 20 samples. Results show that the precision of $\delta^{18}O$ analysis is better than 0.12‰ (2σ). The sub-sampling interval is, 1mm for stalagmite TM-5 and TM-2 (59 to 174mm away from the top), and 0.5mm for TM-2 (0 to-59mm away from the top) along the growth axis.

Supplementary Tables

Table DR1. The known (black) and calculated (blue) mean values with the presumed conditions (red) at low and high elevation during the different times in the figure.

	Low Elevation (New Delhi, India, ~200m above sea level.)			High Elevation (Bange County, China, ~4800m above sea level)		
	$\delta^{18}O_{calcite}$ / ‰, VPDB	$\delta^{18}O_{precipitation}$ / ‰, VSMOW	Temperature / Celsius	$\delta^{18}O_{calcite}$ / ‰, VPDB	$\delta^{18}O_{precipitation}$ / ‰, VSMOW	Temperature / Celsius
High Insolation	-10.8	-7.5	28	-22.0	-23.3	9
Modern	-8.8	-6.0	25	-14.3	-17.4	1
Low Insolation	-6.8	-4.6	22	-6.6*	-10.9**	-4

*This is a hypothetical value as we would not expect actual calcite deposition at -4 degrees.

**This value is calculated from the -6.6 per mil value estimated for the calcite, using the standard water/calcite fractionation equation extrapolated to negative temperatures.

Table DR2. ^{230}Th dating results. The error is 2σ**.**

Sample ID	Distan /mm	^{238}U ppb	^{232}Th ppt	δ^{234}U measured[a]	[^{230}Th/^{238}U] activity[c]	[^{230}Th/^{232}Th] atomic $\times 10^{-6}$ [d]	Age uncorrected	Age corrected [c,e]	δ^{234}U$_{initial}$ corrected[b]	^{230}Th Age (yr B.P.)[f]
TM2-5	5	355.3 ± 0.8	2886 ± 8	402.1 ± 2.4	0.7380 ± 0.0030	1497 ± 7	78,000 ± 500	77,800 ± 500	501.0± 3.1	77,700 ± 500
TM2-14	14	390.2 ± 0.5	5870 ± 60	408.2 ± 1.6	0.7619 ± 0.0033	840 ± 10	81,100 ± 500	80,800 ± 600	512.8± 2.1	80,700 ± 600
TM2-22	22	351.8 ± 0.7	1189 ± 7	420.2 ± 2.7	0.7743 ± 0.0024	3780 ± 20	82,000 ± 400	81,900 ± 400	529.7± 3.4	81,900 ± 400
TM2-28	28	487.2 ± 0.6	2500 ± 30	415.6 ± 1.7	0.7811 ± 0.0062	2510 ± 40	83,000 ± 1000	83,300 ± 1000	525.7± 2.6	83,200 ± 1000
TM2-34	34	399.1 ± 0.4	1290 ± 20	391.0 ± 1.4	0.8568 ± 0.0014	4360 ± 50	98,400 ± 300	98,300 ± 300	516.1± 1.9	98,300 ± 300
TM2-40	40	333.4 ± 0.8	130 ± 6	392.4 ± 2.9	0.8794 ± 0.0027	37300 ± 1700	102,400 ± 600	102,400 ± 600	524.2± 3.9	102,400 ± 600
TM2-45	45	513.2 ± 1.2	193 ± 8	403.7 ± 2.8	0.9011 ± 0.0028	39600 ± 1600	105,000 ± 600	105,000 ± 600	543.1± 3.8	104,900 ± 600
TM2-52	52	651.3 ± 1.8	341 ± 6	411.9 ± 3.0	0.9165 ± 0.0033	28900 ± 500	106,700 ± 700	106,700 ± 700	557.0± 4.2	106,700 ± 700
TM2-54	54	625.5 ± 0.7	1720 ± 20	415.1 ± 1.5	0.9310 ± 0.0018	5580 ± 60	108,900 ± 400	108,900 ± 400	564.4± 2.1	108,800 ± 400
TM2-61	61	617.0 ± 1.3	457 ± 7	370.9 ± 2.3	0.9595 ± 0.0028	21400 ± 300	121,600 ± 700	121,600 ± 700	522.9± 3.4	121,500 ± 700
TM2-64	64	784.6 ± 1.0	670 ± 10	369.4 ± 1.5	0.9595 ± 0.0020	18600 ± 400	121,700 ± 500	121,700 ± 500	520.7± 2.2	121,600 ± 500
TM2-70	70	680.5 ± 0.9	3530 ± 40	361.0 ± 1.6	0.9551 ± 0.0046	3040 ± 40	122,000 ± 1100	122,000 ± 1000	509.4± 2.8	122,000 ± 1000
TM2-72	72	560.4 ± 0.6	1080 ± 10	361.1 ± 1.4	0.9579 ± 0.0017	8200 ± 100	122,800 ± 500	122,700 ± 500	510.5± 2.1	122,700 ± 500
TM2-78	78	248.1 ± 0.5	723 ± 8	362.0 ± 2.9	0.9585 ± 0.0030	5430 ± 60	122,900 ± 800	122,800 ± 800	512.2± 4.2	122,800 ± 800
TM2-93	93	302.2 ± 0.3	870 ± 10	352.2 ± 1.6	0.9518 ± 0.0016	5440 ± 80	122,900 ± 500	122,900 ± 500	498.1± 2.3	122,800 ± 500
TM2-116	116	354.8 ± 0.4	1280 ± 20	361.4 ± 1.4	0.9651 ± 0.0017	4410 ± 50	124,300 ± 500	124,300 ± 500	513.2± 2.1	124,200 ± 500
TM2-134	134	345.4 ± 0.4	160 ± 10	361.8 ± 1.6	0.9690 ± 0.0017	34000 ± 2000	125,100 ± 500	125,100 ± 500	514.9± 2.4	125,100 ± 500
TM2-153	153	376.3 ± 0.7	766 ± 3	358.2 ± 2.0	0.9670 ± 0.0034	7830 ± 40	125,200 ± 900	125,200 ± 900	510.2± 3.0	125,100 ± 900
TM5-4	4	164.3 ± 0.3	2312 ± 9	323.9 ± 2.6	0.9325 ± 0.0034	1094 ± 6	123,800 ± 900	123,500 ± 900	459.1± 3.9	123,400 ± 900
TM5-23	23	176.0 ± 0.4	2393 ± 8	336.2 ± 3.3	0.9469 ± 0.0044	1150 ± 6	124,800 ± 1200	124,600 ± 1200	478.1± 5.0	124,500 ± 1200
TM5-61	61	269.5 ± 0.5	1214 ± 7	335.9 ± 3.1	0.9527 ± 0.0029	3490 ± 20	126,300 ± 900	126,200 ± 900	479.7± 4.6	126,100 ± 900
TM5-94	94	445.4 ± 1.0	1691 ± 5	331.0 ± 2.1	0.9539 ± 0.0035	4140 ± 20	127,200 ± 900	127,100 ± 900	474.1± 3.3	127,000 ± 900

The chemical procedures were similar to those described in ref. S5 and accomplished in the clean lab of Minnesota Isotope Laboratory. The measurements were run on an inductively coupled plasma mass spectrometer (Thermo-Finnigan ELEMENT) using procedures described in ref. S6 and ref. S7. Analytical errors are 2σ of the mean. [a]$\delta^{234}U = ([^{234}U/^{238}U]_{activity} - 1) \times 1000$. [b]$\delta^{234}U_{initial}$ corrected was calculated based on ^{230}Th age (T), i.e., $\delta^{234}U_{initial} = \delta^{234}U_{measured} \times e^{\lambda 234 * T}$, 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 (Kaufman and Broecker, 1965). Decay constants are 9.1788×10^{-6} yr^{-1} for ^{230}Th, 2.8263×10^{-6} yr^{-1} for ^{234}U (Cheng et al., 2000), 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 were calculated using an average crustal ^{230}Th/^{232}Th atomic ratio of 4.4 x $10^{-6} \pm 2.2 \times 10^{-6}$. 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]B.P. stands for "Before Present" where the "Present" is defined as the year 1950 A.D.

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