Dear reviewer,

We would like thank you for having read and commented our manuscript and we would like to apologize for the delay in our answers. We are grateful for your questions and suggestions. It's very useful and enlightening. We will take consideration in the revised version. Here, we provide some quick replies to your questions.

Spelling and Grammar:

I have not edited this manuscript for spelling and grammar. I strongly encourage the authors to seek assistance from a very proficient or native English speaker. Also, please review the manuscript for organizational mistakes (e.g. Figures 2 and 3 are not cited in the text; incorrect citations).

Our response: Thank you for your suggestions. We would take consideration in the revised version and we will cite the Figures2 in chapter 3(Material and methods) and Figure 3 in chapter 4(Results).

Statistics:

The authors need to provide more information about the magnetostratigraphic ages. What is the temporal resolution of the records? What are the temporal uncertainties? Can the records accurately resolve all the cycles you discuss (e.g. precession)? Does variable deposition rate impact the signals?

Our response: The average temporal resolution of records is 3.8 kyr. The resolution of records for detecting the precession signal needs to be 4 kyr or less (Luo et al., 2017). 80 % of sampling intervals satisfied the requirement with the resolution. Thus, the records can theoretically document the eccentricity and obliquity cycle of entire period and document the precession cycle of 80 % period. The variable deposition rate does impact on the conservation of the signals especially for precession signal.

How did the authors decide that 4.8 Ma was the appropriate transition point? It seems arbitrary to me. I see no clear transition in Figure 3. Are the two periods (6.7-4.8 Ma and 4.8-3.6 Ma) statistically distinct?

Our response: Figure 3 may not show the distinct of two periods clearly enough due to variable deposition. Thus, we present figure of records versus stratigraphic depth (Fig 1s). Synthesized the values and variations of the carbonate content, elements content and magnetic susceptibility, a transition period is presented at 16.5-15 m (4.8-4.6 Ma). There is an obvious difference in the character of the fluctuations above and below the depth of 16.5-15 m. For example, above the 16.5 m, the carbonate content fluctuates at a lower level but with larger amplitude accompanied by the noted increase in nodule horizons underlaying leached zones in the field, and the magnetic susceptibility also fluctuates at greater amplitude. Meanwhile, a noticeable drop in deposition rate around 4.8 Ma occurred. Thus, we define the 4.8 Ma as the transition point.

The average value and coefficient of variation of the records during two periods (6.7-4.8 Ma and 4.8-3.6 Ma) have been given in Tables 1s. The coefficient of variation (CV) is defined as:

$$CV = 100 * \frac{\text{Standard deviation}}{\text{Mean}}$$

The higher the CV is, the more changeable the record is. It shows the average value and CV of the most records show the obvious difference between two periods and most of the records are more changeable during 4.8-3.6 Ma than 6.7-4.8 Ma.

I find the signal filtering in Figure 5 questionable. First, the authors filter the data at frequencies with insignificant power (e.g. the 100 kyr filtering of carbonate content). Further, the most significant signals exist at frequencies that are difficult to explain, which the authors dismiss, and many of the discussed signals are barely significant at 90% confidence. The wavelet plots highlight the limited signal strength. Even if the filtered signals are sound, the filtered signals changes do not well align with the benthic d^{18}O record.

Our response: The reason we filtered the carbonate at 100 kyr is that we observed that fluctuations of $CaCO_3$ and weathering indices agree well with eccentricity orbital variations at 4.8-3.9 Ma (Fig 2s-c). We perform the spectral analysis for carbonate content in two periods (6.7-4.8Ma and 4.8-3.6 Ma) respectively. It shows 100 kyr, 41 kyr and 21 kyr periodic signals of carbonate are significant in the period of 4.8-3.6 Ma (Fig 2s). However, most of the orbital periodic signals are insignificant in the period of 6.7-4.8 Ma.

As for non-orbital periodic signals, we have not found the driving force and the signals recorded by carbonate content are different from χ_{pedo}. It may indicate non-orbital periodic signals are fake and more significant non-orbital periodic signals of carbonate content are relate to the dissolution-reprecipitation process of carbonate. Thus, we do not filter the records at these frequencies. We consider removing wavelet plots.

Interpretation:

The potential drivers of the climate signals are often overstated. Connections are made with limited support. Many of the mechanisms discussed are still debated, particularly the Isthmus of Panama hypothesis and timing of Tibetan Plateau uplift. At the least, the authors need to do a better job citing recent literature and discussing the remaining uncertainties. Also, many of the citations are not primary sources for the associated statements.

Our response: We would pay special attention to these problems in the revised version.

Specific Comments:

Line 51: Earth's orbital went through many cycles over this period, so the "orbital configuration statement does not make much sense.

Our response: We would remove the statement "(ii) orbital configuration".

Lines 51-53: These statements, such as "comparable temperatures in the tropic region", require citations.

Our response: We would add the citations (Herbert et al., 2010, 2016).

Line 65: Please clarify the link between mean tropical Pacific east-west gradient and ENSO.

Our response: We would modify the statement of line 65 as "which may have given rise to permanent El Nino Southern Oscillation (Lawrence et al., 2006)."

Line 68: The timing of uplift of the Tibetan Plateau is heavily debated…

Our response: We consider removing the statement.

Line 70: Lunt et al. (2008) is not a direct source for the closure of the Isthmus of Panama. More recent works debate the timing of closure (e.g. Bacon et al., 2015; O'Dea et al., 2016).

Our response: We consider removing the statement.

Line 72: This statement is also not well supported. For example, Lunt et al. (2008), who are cited earlier, found closure of the Panama seaway to have little influence on NH glaciation. In general, the authors need to update their citations and discuss the Literature more thoroughly. These ideas are far from settled, yet they are presented as facts.

Our response: Thank you for your suggestions. We would modify the statement of lines 68-72 as "In addition, several major changes in global thermohaline and atmospheric circulation system occurred during the early Pliocene which are thought to be crucial preconditions for both the appearance of Northern Hemisphere ice sheets at ~2.6 Ma (Haug et al., 1998, 2005; Driscoll et al., 1998) and the development of the modern east-west hydrographic gradient in the equatorial Pacific (Lawrence et al., 2006; Chaisson et al., 2000)."

Line 80-82: Citation?

Our response: We would add the citations (An et al., 2001; Ding et al., 2001; Li et al., 2008, 2010; Clift et al., 2008; Nie et al., 2014; Ao et al., 2016).

Line 85: "Arctic volume" means "Arctic ice volume"?

Our response: Yes, we would correct it.

Lines 105-106: This statement does not make sense.

Our response: We would remove the statement.

Lines 136-140: Sources for these data?

Our response: We would modify the statement of lines 136-138 as "The mean annual temperature during 1986-2016 was ~7.0 ℃ and the annual precipitation was 260-550 mm. Most (80%) of the precipitation is in summer and autumn. (The data were obtained from the National Meteorological Information Center (http://data.cma.cn/) of the Chinese Meteorological Administration (MCA)"

Line 154: This requires more detail.

Our response: We would add the statement "The average temporal resolution of the records is 3.8 kyr. Some 80 % of the sequence has a sampling resolution of 4 kyr or less."

Line 175-182: How did you decide on these intervals? Did you test that they are statistically distinct?

Our response: We would add a brief statement "Profiles of the various proxies are illustrated in Fig 3 and there is an obvious difference in the character of the fluctuations above and below the depth of 16.5 m (~4.8 Ma). Above 16.5 m, the carbonate content fluctuates at a lower level but with greater amplitude, and the magnetic susceptibility also fluctuates at a greater amplitude. In addition, the CV of most of the records is greater above the boundary than below (Table 1). This suggests that the climate became more humid and variable after 4.8 Ma. Meanwhile, a noticeable drop in deposition rate around 4.8 Ma occurred (Li et al., 2017). Thus, the red clay sequence was divided into two intervals: *Interval* Ⅰ (6.7-4.8 Ma) and *Interval* Ⅱ (4.8-3.6 Ma). The characteristics of the individual proxy records are described in detail below" in front of "Carbonate content" in line 174. We will also add "We use the coefficient of variation (CV) to measure the variability of the records. The higher the CV, the more variable the record. The CV is defined as:

$$\mathrm{CV} = 100 * \frac{\text{Standard deviation}}{\text{Mean}}\text{,,}$$

at the end of chapter 3(line 172).

Line 224-226: How are you sure that it relates to monsoon strength? Could it be seasonal or evaporative changes?

Our response: We agree with you. However, on the condition moisture is carried by the monsoon and the monsoon is strong enough, $CaCO_3$ could indicate the monsoon strength (Fang et al., 1999; Sun et al., 2010).

Lines 235-237: Both statements are significant at 99% confidence?

Our response: The correlation between Sr and CaO* (silicate CaO) is significant at 99% confidence, while the correlation between Sr and $CaCO_3$ is not significant.

Lines 282-286: Are you sure these signals are real? If so, how might you explain the cycles not related to orbital variability?

Lines 294-295: Doesn't this "incomplete nature of the red climate time series" impact all of the frequency analyses? How can you distinguish real and fake signals?

Our response: The questions are really worth pondering. Firstly, our chronology is reliable. Secondly, all sampling intervals of XSZ red clay satisfies requirement to detect eccentricity and obliquity signals and 80 % of sampling intervals satisfies requirement to detect the precession signal. Thirdly, three orbital periodic signals were also detected in the other sites of the CLP from late Miocene to early Pliocene, which means changes of orbital parameters really had impact on climate of the CLP (Han et al., 2011; Li et al., 2008). Thus, 100 kyr, 41 kyr and 21 kyr periodic signals recorded by XSZ red clay are probably true.

Changes of Earth orbital parameters would dynamically lead to the variation of the climate. However, the change of Earth orbital parameters is just one of forcing factors and other factors (some internal process or feedback) could magnify or cover the orbital forcing, which means the climate changes probably show non-linear response to orbital forcing. In this specific case, it might be the expansion of the palaeo-ASM that enhanced the orbital periodic signals of XSZ red clay between 4.8 and 4.1 Ma. As for short cycles, the power of these cycles would be weakened by the low and uneven sedimentation accumulation rate (Luo et al., 2017). The incomplete nature of the red climate time series would also impact on the conservation of the signals especially for precession signal. Meanwhile, the age model has not been astronomically tuned. Thus, it's hard to completely match the filtered 41 kyr and 21 kyr components with the lagged obliquity and precession in phase and amplitude even these signals are real. Our results resemble to those of Han (2011) and Tian (2002) that three orbital periodic signals were significant while records and orbital variability were less matched from late Miocene to early Pliocene. On the other hands, at least to date, we have not found the driving force yielding these non-orbital periods. Thus, these non-orbital periodic signals are probably random or fake.

Line 302: I believe that a 23 kyr filter makes more sense for the climate response to

orbital change.

Our response: The 21kyr filtered component is filtered at 18-24kyr. The 23kyr filtered component was included.

Line 304: What record? Lisiecki and Raymo (2005)?

Our response: The data was the filtered components of the $\delta^{18}O$ record (Zachos et al., 2001) at the 21-kyr, 41-kyr, and 100-kyr bands.

Line 306: I do not observe this in the filtered record…Is this change significant? How much do these filter components contribute to the complete signal?

Our response: This shift may be not obvious in the 100-kyr filtered components but obvious in 41-kyr and 21-kyr filtered components especially in 41-kyr filtered components. We don't know how to measure the contribution. However, fig 2s shows 100 kyr, 41 kyr and 21 kyr periodic signals of carbonate content in the interval of 4.8-3.6 Ma are more significant than the interval of 6.7-4.8 Ma.

Line 309-310: Where is this shown? The 41 kyr signal in the benthic records do not well align with the data.

Our response: The shift may be not obvious in Fig 5 where we put all filtered curves together. Fig 4s shows 41 kyr signal in the benthic record and XSZ records enhanced between about 4.8 and 4.1 Ma. In my opinion, three curves have shown some similarities during the period of 4.8-3.6 Ma, with larger oscillation at the intervals of 4.7-4.4 Ma and 4.2-3.9 Ma, and damped oscillation at the interval of 3.9-3.6 Ma. On the other hands, the record has its own climatic significance and limitation, and even the 41 kyr filtered curves of $CaCO_3$ and χ_{pedo} show difference. Thus, the differences of the 41 kyr signal in benthic records and XSZ records are reasonable.

Lines 317-319: I see no clear changes in the records. You need statistical support.

Our response: Tables 2s has shown that from the period of 6.7-4.8 Ma to 4.8-3.6 Ma, average value of $CaCO_3$ decreased, weathering proxies and magnetic susceptibility increased. CV of the most proxies increased.

Line 361: ODP source?

Our response: Yes, ODP 1148.

Line 368: "…roughly parallel…" I do not see a correlation. Please quantify.

Our response: We interpolate the $d^{18}O$ with the age of Xiaoshuizi from 4.8 Ma to 6.7 Ma. Fig 4s-a shows that the extracted data (black line) match well with original $d^{18}O$ data (brown line). Fig 4s-b shows χ_{pedo} has a significant positive relationship with $d^{18}O$ at 80 % confidence during the period of 6.7- 4.8 Ma.

Line 384: This is possible but not necessarily the case.

Our response: We would modify "would have resulted" as "could result"

Lines 392-393: Cooler air can hold less vapor, but this statement is an extreme simplification.

Our response: We would modify the statement of lines 391-393 as "However, moisture sources for the westerly flow are distant from the CLP (Nie et al., 2014), and only a relatively small amount of moisture was carried to the CLP, resulting in a dry and stable climate in the XSZ region."

Lines 402-403: You record captures seasonal variability?

Our response: Research on migration process of carbonate indicated seasonally wet/dry climate is a key factor in driving carbonate dissolution and reprecipitation, and strong seasonally biased precipitation enhances the leaching process and produces thick leached horizons (Rossinsky and Swart, 1993; Zhao, 1995, 1998). We would add it in front of "The emergence of…"

Lines 469-471: Citation?

Our response: We would add the citations (Jackson and O'Dea, 2013; O'Dea et al., 2016).

Line 480: Why global moisture and not local moisture?

Our response: It referred to moisture at high northern latitudes. We would correct it.

Lines 484-487: This does not make sense.

Our response: We would remove the statement.

Lines 491-492: Are you talking about regional or global albedo?

Our response: It's reduced ice albedo at high northern latitudes. We would correct it.

Lines 492-495: Citation?

Our response: We would add the citations (Chang et al., 2011; Sun et al., 2015).

Lines 497-498: Could this discrepancy relate to differences between short term variability and the mean climate state?

Our response: Yes, it's one possibility.

Line 502: "We noticed"? You mean the authors of these other publications noticed?

Our response: We would modify it as "Several crucial changes linked with the summer monsoon occurred: There was a vast expansion of the western Pacific warm pool into subtropical regions in the early Pliocene (Brierley et al., 2009; Fedorov et al., 2013), and temperatures at the edge of the warm pool showed a warming trend of ~2℃ from the latest Miocene to the early Pliocene (Karas et al., 2011)"

Lines 502-506: How close are these events in time?

Our response: All of these events started at 5.2-4.8 Ma and developed at ~4.6 Ma.

Figures:

Figure 1a: The winds do not look correct. Also, 850 hPa winds do not exist over the Plateau

Our response: We would correct it and provide new figure (Fig 1).

Figure 2 and Figure 3 are not cited in the text.

Our response: We would cite the Figure 2 at the end of sentence "…clay is composed of brownish red and yellowish clay layers" in line 145 and Figure 3 in chapter 4(Results).

Figure 3: It is difficult to see how the axes align with the lines

Our response: We would use figure1s to replace the figure 3

Figure 5d: Do the black lines represent significance?

Our response: Yes, these lines are the 95% confidence limit line. We would provide new figure (Fig 5).

References

Han, W., Fang, X., Berger, A., & Yin, Q. (2011). An astronomically tuned 8.1 ma eolian record from the chinese loess plateau and its implication on the evolution of asian monsoon. Journal of Geophysical Research Atmospheres, 116(D24), -.

Li, F. J., Rousseau, D. D., Wu, N., Hao, Q., & Pei, Y. (2008). Late neogene evolution of the east asian monsoon revealed by terrestrial mollusk record in western chinese loess plateau: from winter to summer dominated sub-regime. Earth & Planetary Science Letters, 274(3–4), 439–447.

Luo, Z., Su, Q., Wang, Z., Heermance, R. V., Garzione, C., & Li, M., et al. (2017). Orbital forcing of plio-pleistocene climate variation in a qaidam basin lake based on paleomagnetic and evaporite mineralogic analysis. Palaeogeography Palaeoclimatology Palaeoecology.

Fang, X. M., Ono, Y., Fukusawa, H., Pan, B. T., Li, J. J., & Guan, D. H., et al. (1999). Asian summer monsoon instability during the past 60,000 years: magnetic susceptibility and pedogenic evidence from the western chinese loess plateau. Earth & Planetary Science Letters, 168(3–4), 219-232.

Rossinsky Jr., V., Swart, P.K., 1993. Influence of climate on the formation and isotopic composition of calcretes. In: Swart, P.K., Lohmann, K.C., McKenzie, J., Savin, S. (Eds.), Climate Change in Continental Isotopic Records, American GeophysicalUnion: Geophysical Monography, 78, pp. 67-75.

Sun, Y., An, Z., Clemens, S. C., Bloemendal, J., &Vandenberghe, J. (2010). Seven million years of wind and precipitation variability on the chinese loess plateau. Earth & Planetary Science Letters, 297(3–4), 525-535.

Zachos, J., Pagani, M., Sloan, L., Thomas, E., & Billups, K. (2001).Trends, rhythms, and aberrations in global climate 65 ma to present.Science, 292(5517), 686-93.

Zhao, J. B. (1995), A study of the $CaCO_3$ illuvial horizons of paleosols and permeated pattern far rain water, J Geogr Sci, 15(4), 344-350.

Zhao, J. B. (1998), Illuvial $CaCO_3$ layers of paleosol in loess and its environmental significance, Journal of Xi'an Engineering University, 20(3), 46-49.

Figures and tables

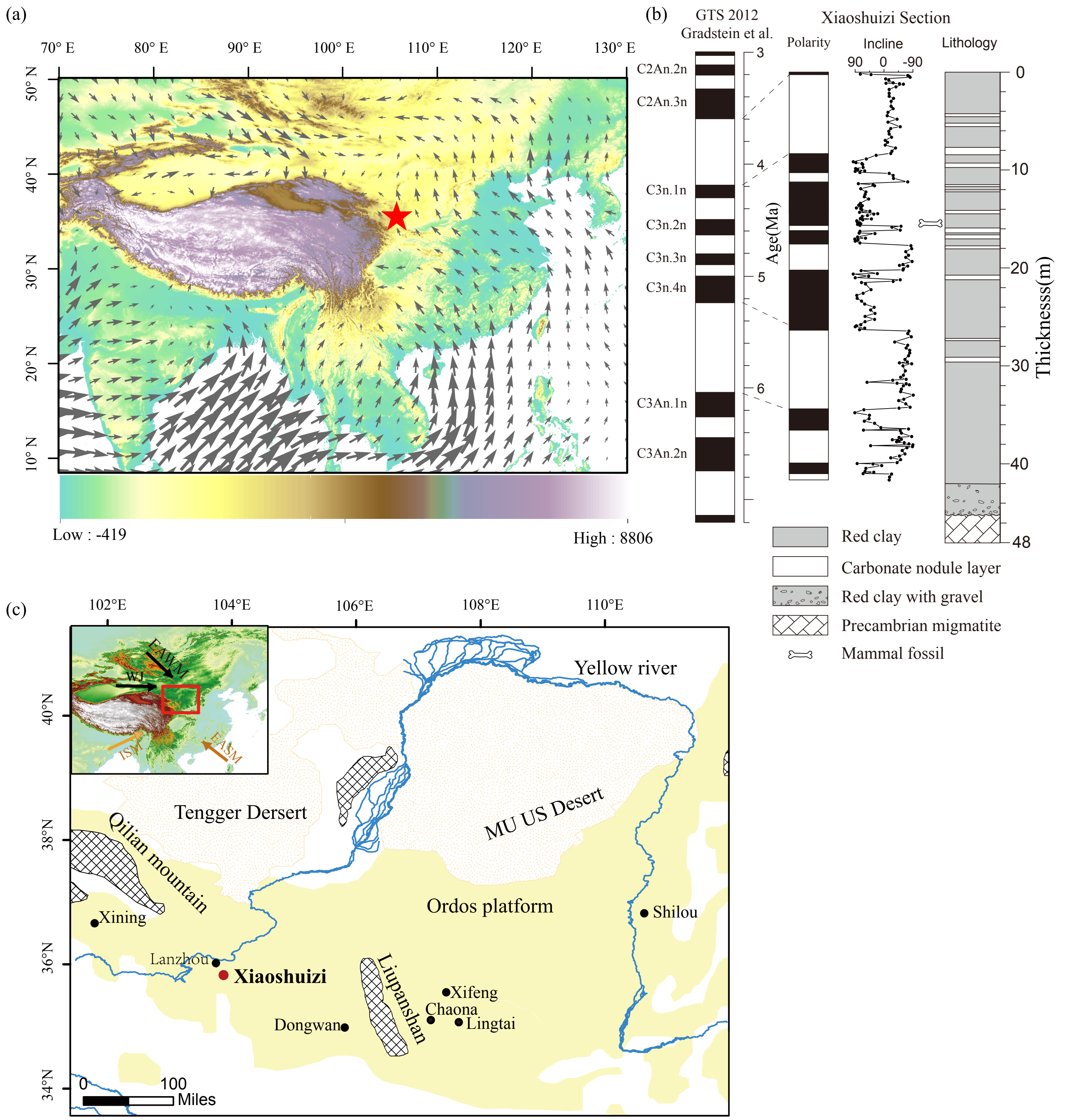


Fig. 1. The location of the study area and atmospheric circulation patterns. (a) 850 mb vector wind averaged from June to August for 1982-2012 based on NOAA Earth System Research Laboratory reanalysis data (Compo et al., 2013). (b) Lithology and magnetostratigraphy of the XSZ drill core. (c) The Chinese Loess Plateau with locations of the studied Xiaoshuizi site and other sections mentioned in the text.

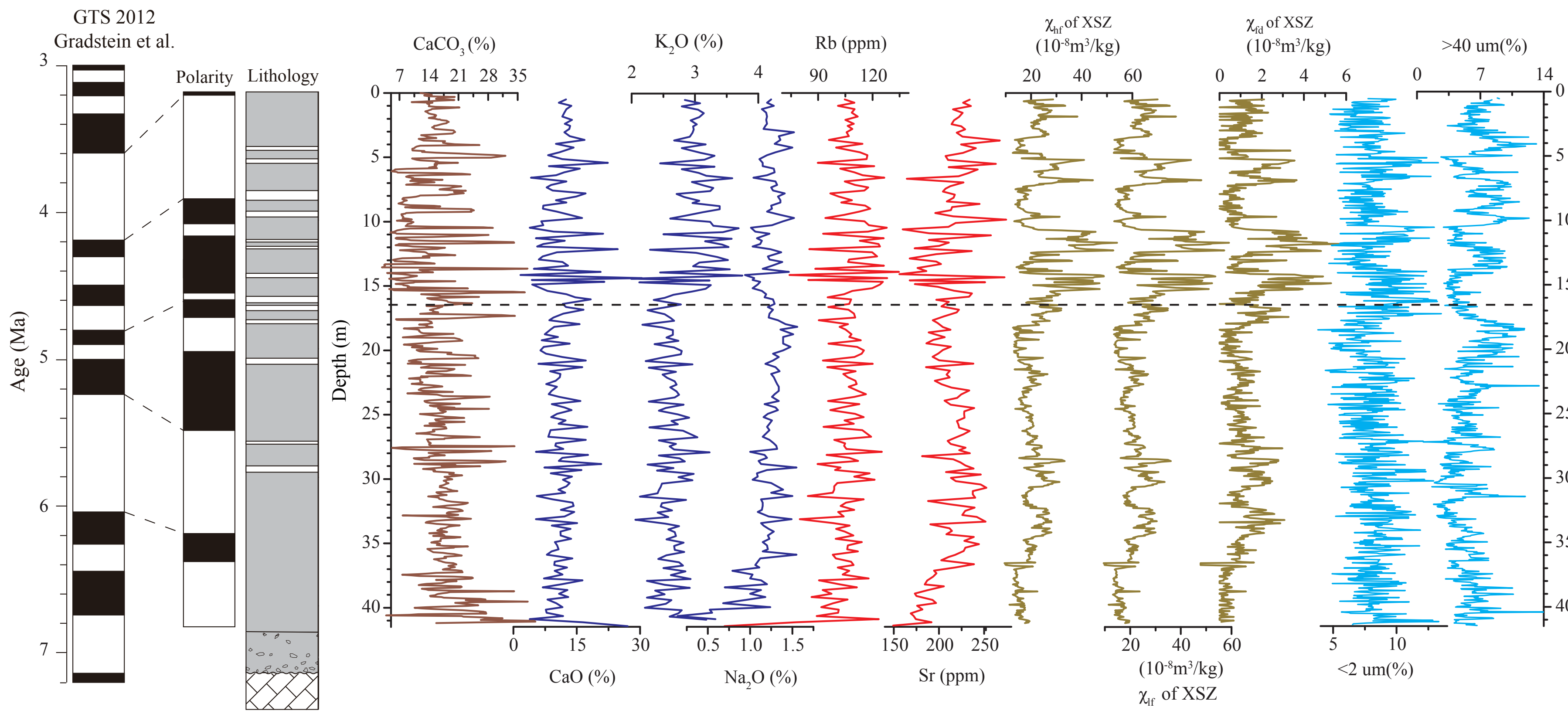


Fig. 1 s. Variations in carbonate content, major element concentration, minor element concentration, magnetic susceptibility and grain size from the XSZ red clay section, spanning 6.7-3.6 Ma

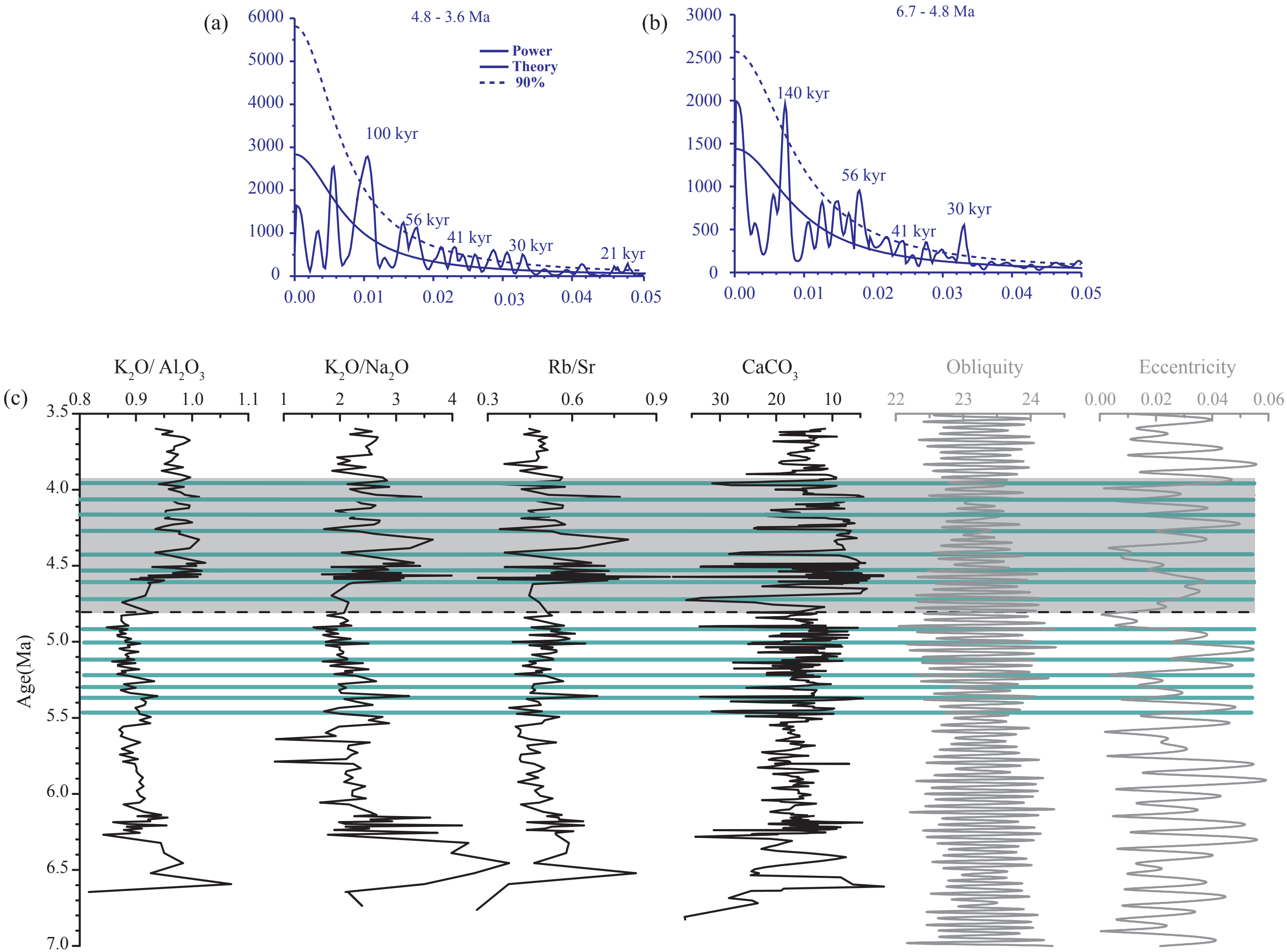


Fig. 2s. Spectrum analysis of carbonate content during the period of (a) 4.8-3.6 Ma (b) 6.7-4.8 Ma on original paleomagnetism chronology. (d) Carbonate and chemical weathering intensity fluctuations linked to eccentricity and obliquity orbital variations at 4.8–3.9 Ma.

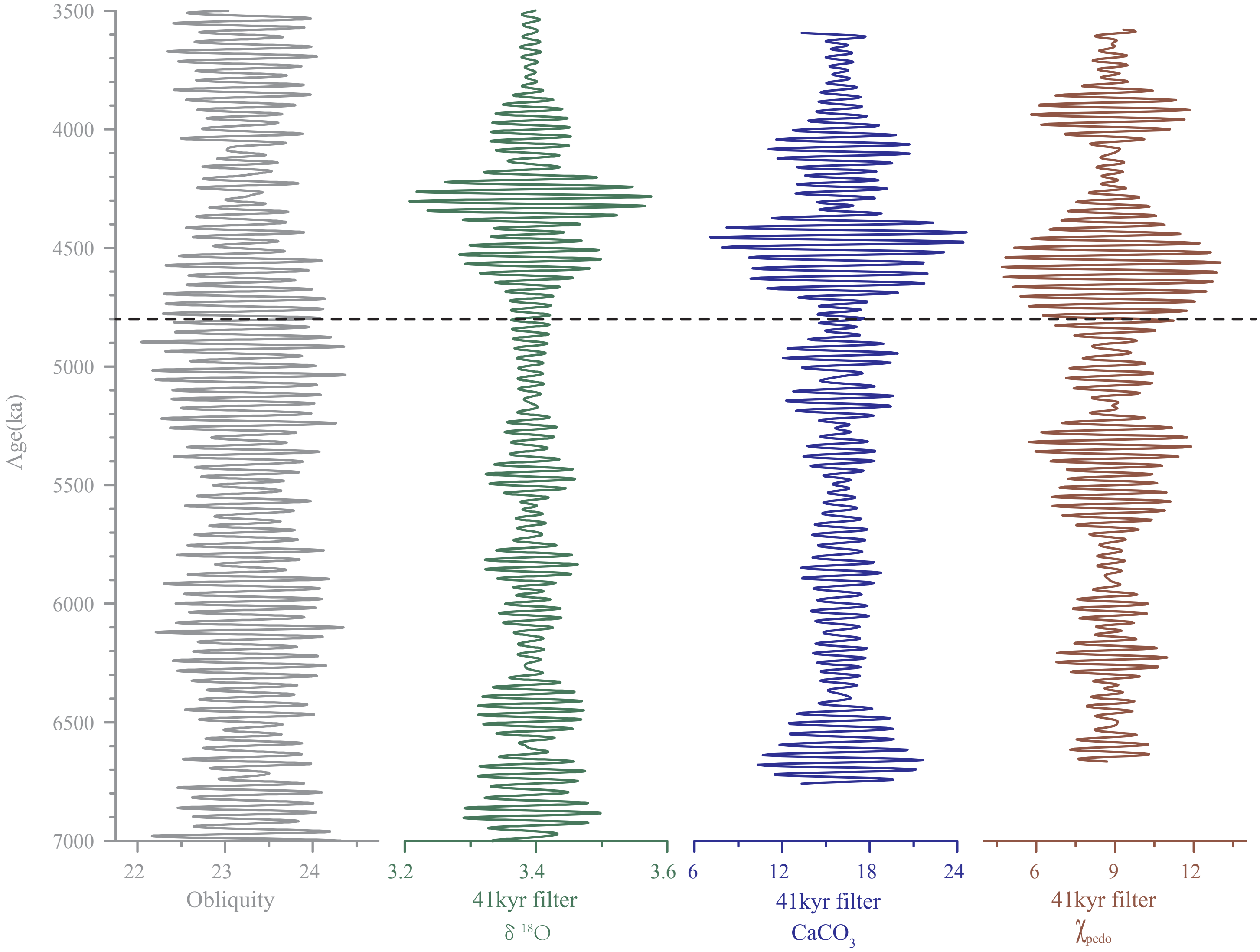
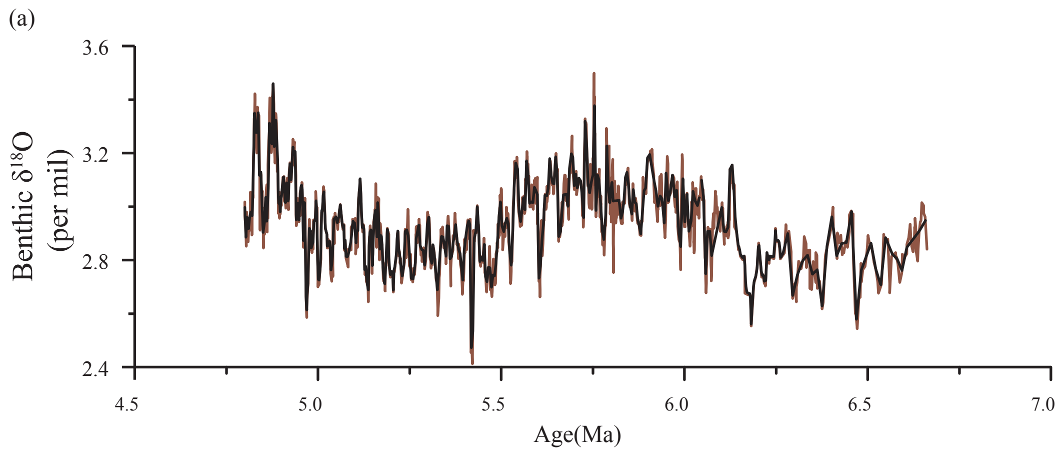


Fig. 3s. Comparison of obliquity (Laskar et al., 2004) with filtered components of the carbonate content, χ_{pedo} and $\delta^{18}O$ records (Zachos et al.,2001) at the 41-kyr bands.



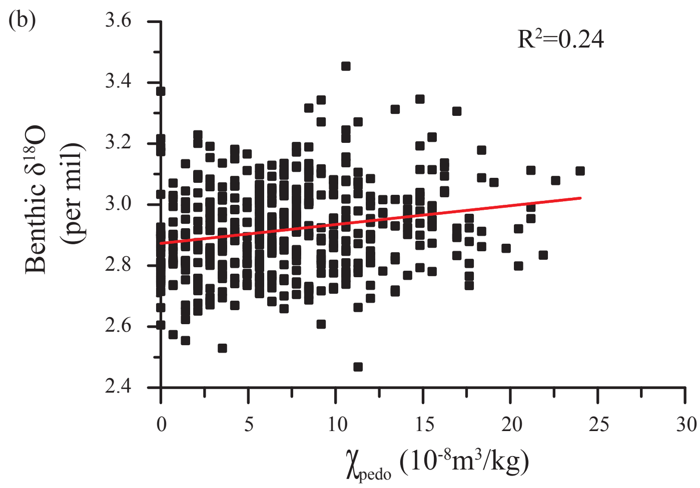


Fig. 4s. (a) The comparison of benthic $\delta^{18}O$ between extracted data (black line) and original $\delta^{18}O$ data (Zachos et al., 2001).

(b) Scatter plot of benthic $\delta^{18}O$ versus χ_{pedo} during 6.7-4.8 Ma

Table. 1s. The average value and coefficient of variation of the records during two periods of 6.7-4.8 Ma and 4.8-3.6 Ma.

		SiO_2(%)	Al_2O_3(%)	CaO(%)	Fe_2O_3(%)	K_2O(%)
4.8-3.6 Ma	Average	48.9	13.2	11.6	5.69	3
	CV	14.6	9.58	45.57	9.3	12.3
6.7-4.8 Ma	Average	49.5	12.2	11.2	5.2	2.6
	CV	11.6	9.09	32.18	9.6	10.3
		Na_2O(%)	MgO(%)	Sr(ppm)	Rb(ppm)	Ba(ppm)
4.8-3.6 Ma	Average	1.23	2.3	214.6	109.9	558
	CV	24.4	9	12.5	10.9	11.5
6.7-4.8 Ma	Average	1.2	3.1	211.7	103.9	494
	CV	10.2	61	10.04	10.8	13.2
		$CaCO_3$(%)	χ_{hf}	χlf	χfd	
4.8-3.6 Ma	Average	13.8	25.4	26.9	1.2	
	CV	45.6	38.3	36.2	78.2	
6.7-4.8 Ma	Average	17.4	19.4	20.3	1	
	CV	29.3	23.8	21.2	72.8	

Table. 2s. The average value and coefficient of variation of the proxies during two periods of 6.7-4.8 Ma and 4.8-3.6 Ma.

		$CaCO_3$	Rb/Sr	K_2O/Na_2O	χ_{lf}	χ_{pedo}	<2um/>43um
4.8 -3.6	Average	13.8	0.52	2.49	26.9	10.9	1.52
Ma	CV	45.59	23.1	19.4	36.17	78.24	55.7
6.7-4.8	Average	17.4	0.5	2.35	20.3	9.1	1.33
Ma	CV	29.31	14.6	21.3	21.93	72.79	47.55