Global and Planetary Change 72 (2010) 73–78

Contents lists available at ScienceDirect

Global and Planetary Change

journal homepage: www.elsevier.com/locate/gloplacha

Pliocene land snail record from western Chinese Loess Plateau and implications for impacts of the summer insolation gradient between middle and low latitudes on the East Asian summer monsoon

Fengjiang Li *, Naiqin Wu

Key Laboratory of Cenozoic Geology and Environment, Institute of Geology and Geophysics, Chinese Academy of Sciences, P. O. Box 9825, Beijing 100029, China

ARTICLE INFO

Article history:
Received 3 October 2009
Accepted 16 April 2010
Available online 28 April 2010

Keywords:
terrestrial mollusk
loess–palaeosol sequence
East Asian monsoon
insolation gradient
Pliocene

ABSTRACT

The East Asian monsoon probably existed as early as at the Palaeogene/Neogene boundary. However, its evolutionary process is still less well known owing mainly to the lack of long, continuous palaeoenvironmental records. The recently reported Miocene (22–6.2 Ma) and late Miocene–Pliocene (7.1–3.5 Ma) loess–palaeosol sequences from the western Chinese Loess Plateau (CLP) provide new insights into the evolution of the monsoon system. However, reports on the bioclimatic indicators from these deposits and the subsequent reconstruction of the palaeomonsoon are rare. Here we present a Pliocene terrestrial mollusk record from the western CLP and discuss the possible impact of isolation gradients on the East Asian summer monsoon. Our results show that most peak values of the dominant thermo-humidiphilous mollusk taxa, *Metodontia* and *Punctum*, a proxy of the East Asian summer monsoon, approximately correspond to maxima of mean summer insolation gradient between middle and low latitudes as well as some maximum values of the 35°N insolation, suggesting a possible causal link between the summer monsoon and the insolation parameters. The major frequencies from spectrum analysis of the sum of the two warmth- and moisture-loving taxa through the loess–palaeosol succession match those obtained from the mean summer insolation-gradient variations between middle and low latitudes over this geological period, providing further evidence for such a causal relationship. Mean summer insolation gradient between middle and low latitudes could influence atmospheric circulation (in the present condition the East Asian summer monsoon). Any elevated mean summer insolation gradients between middle and low latitudes would have intensified the East Asian summer monsoon and the flux of moisture and heat over the oceans to the interior region including the CLP, creating favorable conditions for the expansion of the mollusk fauna. As such, the mollusk record from the loess–palaeosol deposits in the western CLP provides evidence for insolation-gradient impacts on the development of the East Asian monsoon system in the Pliocene.

1. Introduction

Since the early 1980s, many lines of evidence have been obtained to suggest that the East Asian monsoon was probably established as early as at the Palaeogene/Neogene boundary, i.e., the Oligocene/Miocene boundary (Zhou, 1982; Wang, 1990; Liu and Guo, 1997; Sun and Wang, 2005). However, the evolutionary process and possible driving forces remain less well understood due largely to the lack of long, continuous palaeoenvironmental records. Miocene (22–6.2 Ma) and late Miocene–Pliocene (7.1–3.5 Ma) loess–palaeosol deposits were recently reported from the western Chinese Loess Plateau (CLP) (Guo et al., 2002; Hao and Guo, 2004). These Neogene deposits are of eolian origin and can stratigraphically be correlated across the region, providing further evidence supporting that the onset of the East Asian monsoon took place no later than the early Miocene (Guo et al., 2002; Hao and Guo, 2004; Liu et al., 2005, 2006; Li et al., 2006a,b; Qiao et al., 2006; Hao and Guo, 2007; Guo et al., 2008). The subsequent numerous studies on them have provided new insights into the evolution of the East Asian monsoon and possible forcing factors. Although studies on sedimentology, geomagnetism, and geochemistry of these sequences have contributed greatly to our understanding of the palaeomonsoon variability at a tectonic scale (Guo et al., 2002; Qiao et al., 2006; Hao et al., 2008a,b; Liang et al., 2009), the evolution of the palaeomonsoon and possible forcing factors at an orbital time scale remain poorly understood. Furthermore, palaeomonsoon reconstruction using bioclimatic indicators from these deposits has rarely been reported.

Fossil land snails are the most common and abundant fossil remains in the eolian deposits in the CLP. They are very sensitive to environmental changes and have long been used as 'indicator animals' in palaeo-climatic studies (Liu, 1985). Mollusk fossils have provided important clues for understanding of the origin of the Quaternary loess–palaeosol deposits and for the palaeoenvironmental

* Corresponding author. Tel.: +86 10 8299 8371; fax: +86 10 6201 0846.
E-mail address: fengjiangli@mail.iggcas.ac.cn (F. Li).

0921-8181/$ – see front matter © 2010 Elsevier B.V. All rights reserved.
doi:10.1016/j.gloplacha.2010.04.006

reconstructions (Braun, 1847; Richthofen, 1882; Liu, 1985; Wu et al., 1996; Rousseau and Wu, 1997, 1999; Wu et al., 2000, 2001, 2002, 2007). Recently, such fossil records have been used to obtain the key biological evidence for a wind-blown origin of the Miocene–Pliocene loess deposits on the western CLP (Li et al., 2006a,b). However, little study has been conducted on the development of the Neogene palaeomonsoon as reflected by the terrestrial mollusks.

In the present study, terrestrial mollusks preserved in the upper part of the Dongwan section on the western CLP were collected and examined for a better understanding of the East Asian summer monsoon at an orbital time scale and the possible driving factors in the Pliocene. Our study shows that a causal link probably exists between the summer monsoon system and the mean summer insolation gradient between middle and low latitudes and the 35°N insolation during the Pliocene.

2. Geological settings and methods

The Dongwan loess–palaeosol section used in this study is located at 105°47′E, 34°58′N in Qinan County on the western CLP (Fig. 1). This is a semi-arid region with a mean annual precipitation of 400 mm and a mean annual temperature of 10.4 °C with a July mean temperature of 22.7 °C (cf. Guo et al., 2002). In summer, the East Asian summer monsoon carries warm, moist air mass to the CLP, bringing heavy rainfalls across this region. Accordingly, more than half of the annual precipitation occurs in July to September. In winter, the winter monsoon winds from the Siberian High prevail over the CLP, resulting in a dry, cold climate.

The Dongwan loess section, which is 73.7 m thick, is exposed in a northeast-aligned, deep and narrow valley at an elevation of about 1880 m above sea level. This section contains 84 distinguishable loess–palaeosol couplets. Hao and Guo (2004) had established, based on 319 oriented samples collected at 20, 25 cm intervals, the chronology of the Dongwan section using palaeomagnetic reversals as age controls and then interpolation based on the susceptibility model developed by Kukla et al. (1990). With a reasonable assumption that the precipitation of natural magnetic dust from higher atmospheric levels occurs at a quasi-constant rate, this model weighted the thickness of each measured layer by its magnetic susceptibility, took into account of the accumulated values, and then calculated the apparent age of a given level by linear interpolation of the weighted values between palaeomagnetic reversals (Kukla et al., 1990). The time series based on this model correlates well with those of the deep sea oxygen isotope records. Although some assumptions used in this model are debated by some on the basis of rock magnetism, such a model has remained as an important method in obtaining an independent time scale for the loess–palaeosol succession and has been widely used in the research of the Quaternary loess and late Neogene Red Clay deposits (Kukla et al., 1990; Guo et al., 2000; Wu et al., 2001; Guo et al., 2001, 2002; Wei and Guo, 2003). This age model returned a geochronology for the Dongwan loess–palaeosol succession ranging from 7.1 to 3.5 Ma (Hao and Guo, 2004). The upper part of this succession used for this study spans from 5.1 to 3.5 Ma, and the calculated linear sedimentation rates for this part of section are 0.90 to 4.44 cm/ka (Hao and Guo, 2004). The sampling intervals of 10 to 40 cm thus correspond to a rough temporal resolution of 4.7 to 13 ka.

The upper 31.4 m of the section, corresponding to the time span of 5.1 to 3.5 Ma as already mentioned, was examined and sampled for the present study. A total of 152 samples each weighting about 30 kg were collected at an interval of 20 cm. Where prominent lithological changes exist, sampling took place between 10 and 40 cm at several locations. To reduce the cost on transportation of such a large amount of material, the samples were processed in the field. Because of the lithification or semi-lithification of the loess and soil layers, the regular washing and sieving for unconsolidated Quaternary deposits

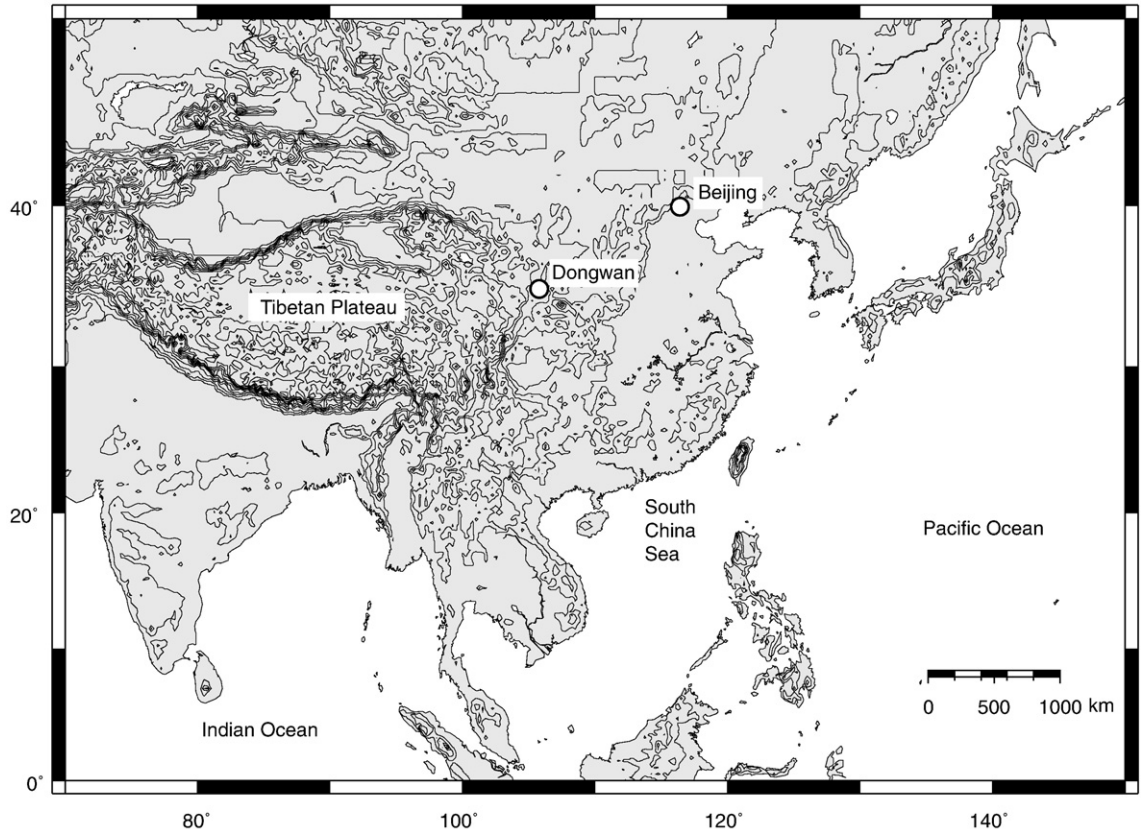

Fig. 1. Map showing location of the Dongwan loess sequence and the studied area.

is not possible. Instead, the samples were progressively broken into particles of about 0.5 mm size and the snails and any visible shell fragments picked up. This was a slow and painstaking procedure that involved in a large amount of work in the field, and only half to one sample was processed by one worker in one day. In the laboratory, the mollusk remains were repaired, identified and counted under a set of Leica binocular microscopes. The shell fragments were considered in the total count of individuals following the method developed by Puisségur (1976).

3. Results

Mollusk fossils are abundant through the Dongwan section, and they all are terrestrial taxa with excellent preservation conditions, containing both adults and juveniles (Li et al., 2006a). Of the 152 samples collected from the upper 31.4 m of the Dongwan section, 147 contain fossil mollusks, yielding a total of 9504 individuals with an average of over 64 shells per sample. Only 5 samples were found barren. The maximum count reaches 440/30 kg at 10.8 m depth. Of the 22 mollusk species identified (Fig. 2), 21 have been found in the Chinese Quaternary loess–palaeosol deposits, and most have their modern representatives. Thus, the mollusk species in the upper part of the Dongwan section can be grouped into cold-aridiphilous (species living in dry and relatively cold places) and thermo-humidiphilous (warmth and moisture-loving species) ecological groups, as previously defined in the Quaternary loess–palaeosol sequences (e.g., Liu, 1985; Wu et al., 1996; Rousseau and Wu, 1997, 1999; Rousseau et al., 2000; Wu et al., 2000, 2001, 2002, 2006, 2007). The thermo-humidiphilous group includes species belonging to genera of *Metodontia*, *Punctum*, *Kaliella*, *Macrochlamys*, and *Opeas* in which the former two taxa are predominate. These taxa are quite common through the section except at the depth of 0 to 8 m where only *Metodontia huaiensis* occurs (Fig. 2). This group of mollusk taxa generally indicates warm, humid conditions under a strong summer monsoon. The cold-aridiphilous group contains *Cathaica* sp., *Cathaica pulveratrix*, *Cathaica pulveraticula*, *Cathaica schensiensis*, *Cathaica placenta*, *Pupilla aeoli*, *Pupilla* sp., *Vallonia* sp., and *Pupopsis retrodens*. They were mainly found at depths ranging from 0 to17 m with a heterogeneous and discontinuous occurrence except *Cathaica* sp. (Fig. 2). It has long been suggested that the occurrence of these snails is closely related to a strong winter monsoon over the CLP (Wu et al., 1996; Rousseau and Wu, 1997, 1999; Rousseau et al., 2000; Wu et al., 2000, 2001, 2002, 2006, 2007).

Fig. 3 shows changes in the sum of *Metodontia* and *Punctum*, the two dominant thermo-humidiphilous taxa in the Dongwan section. They predominate in the early Pliocene from 5.1 to 4.0 Ma, suggesting the prevalence of warm, moist conditions under a strong summer monsoon during this geological episode. There are 36 to 39 high or low peaks in the abundance of the two taxa through the section from 5.1 to 3.5 Ma, indicating changes on orbital bands, among which 32 to 35 peak values can be correlated with the oscillations of the obliquity and mean summer insolation gradient between middle and low latitudes (35–0°N), high percentages approximately corresponding to maxima in both obliquity and insolation gradient between middle and low latitudes, suggesting a possible causal link between the summer monsoon and the insolation gradient. In addition, more than 20 peaks of these two mollusk genera match the maximum values of the 35°N insolation, indicating that local insolation may also have played a role in the expansion of the mollusk fauna (Fig. 3).

Spectrum analysis of the sum of *Metodontia* and *Punctum* shows that the variations lie within the orbital frequency, concentrated on obliquity and precession bands although another frequency at 29 ka is also noticeable (Fig. 4A), similar to the oscillations of the mean summer insolation gradient between middle and low latitudes that concentrated in obliquity (41 ka) and precession (23 and 19 ka) frequencies over this geological period (Fig. 4B), indicating again that, on the obliquity band, insolation gradient between middle and low latitude is an important factor contributing to the evolution of the East Asian summer monsoon during the early Pliocene, whereas local insolation or/and insolation gradient between middle and low latitude may both exert controls on the evolution of monsoon on the precession band. However, it is noteworthy that the sample thickness of 20 cm in the present study is not detailed enough to discuss the precession variations and higher density sampling is

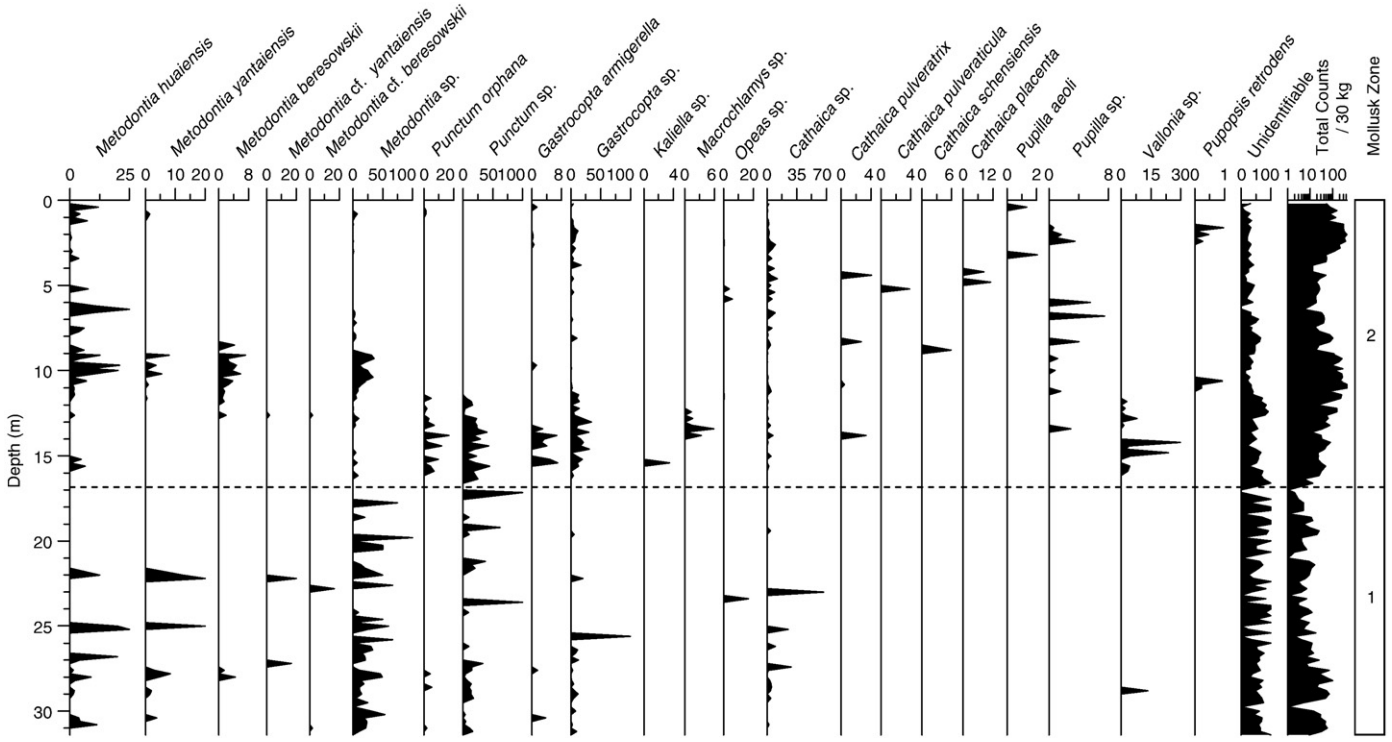

Fig. 2. Variations in percentages of the mollusk assemblages in the upper part of the Dongwan section.

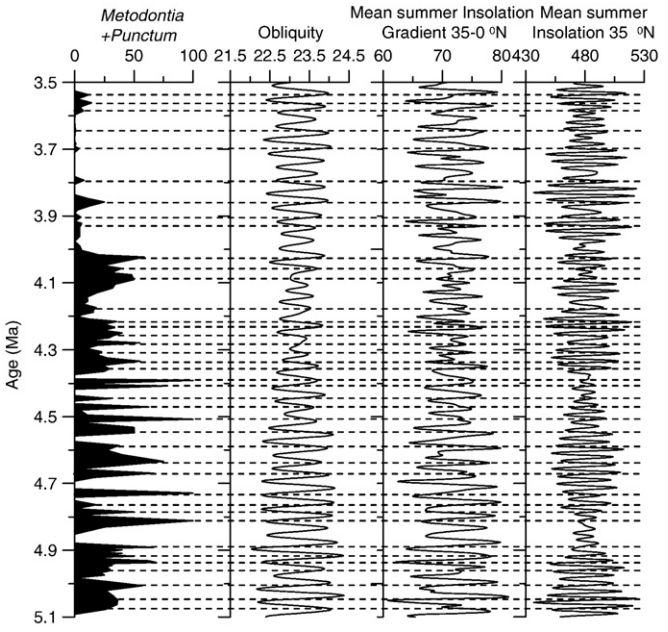

Fig. 3. Comparisons among thermo-humidiphilous mollusks (*Metodontia* and *Punctum*), obliquity, mean summer insolation gradient between 35°N and 0°, as well as mean summer insolation at 35°N. Obliquity and insolation data are from Laskar et al. (2004).

needed in the future in order to detect this frequency. In fact, it is possible that a record with increased temporal resolution would show that the spectral density at the precession band might exceed that at the obliquity band. However, the spectral analysis of the magnetic susceptibility record at 20 cm sampling interval from the Dongwan loess–palaeosol sequence indicates 57 ka and 34 ka frequencies, as well as a clear precession frequency but shows no peak at 41 ka frequency. As well, the 57 ka and 34 ka frequencies have higher spectral density than the precession band. In addition, alternations of loess–palaeosol layers, which have a good correlation with magnetic susceptibility (Hao and Guo, 2007; Hao et al., 2008b), show an average frequency of 42.6 ka for each loess–palaeosol couplet, roughly consistent with the oscillations at the obliquity frequency (Hao and Guo, 2004). Thus, it seems that the magnetic susceptibility and lithology of the Dongwan sequence have higher density at the obliquity band than at the precession band, supporting our interpretations on the basis of the terrestrial mollusk record.

4. Discussion

The CLP is located in a middle-latitude region where the East Asian winter and summer monsoons prevail, causing this region very sensitive to changes in both the high and low latitudes in the Northern Hemisphere. The winter monsoon carries cold, dry air from the high latitude, whereas summer monsoon brings warm, moist air over the low-latitude oceans into this region. Therefore, the thick eolian deposits in the CLP have great potentials of preserving the footprints of these two monsoons since the early Miocene (Liu, 1985; An et al., 2001; Guo et al., 2002; Hao and Guo, 2004). In the present study, the focus is placed on the development of the summer monsoon over the Pliocene warm period.

The mollusk record appears to suggest that the mean summer insolation gradient between middle and low latitudes has played an important role in shaping the East Asian summer monsoon at an orbital time scale. Obliquity is an important factor in controlling the latitudinal distribution of insolation (Berger, 1984). When this factor is large, the summer insolation increases at middle latitudes and decreases at low latitudes, strengthening the meridional mean summer insolation gradient. Meridional insolation gradients can exert controls on the atmospheric circulation (Berger, 1976; Young and Bradley, 1984; Johnson, 1991). Elevated such mean summer insolation gradients raises the air pressure gradient from low to middle latitudes and enhances the summer monsoon circulation, amplifying the moisture and heat transport over the low-latitude oceans to the middle-latitude CLP. In addition, local insolation is also an important factor impacting the East Asian summer monsoon as indicated by correlations between the two thermo-humidiphilous mollusk genera and the maximum values of the 35°N insolation. Therefore, both effects, increases of insolation gradient between middle and low latitudes and local insolation, remains as the likely driving forces behind the intensified summer monsoon and the expansion of thermo-humidiphilous mollusks during the Pliocene. A similar mechanism has also been proposed for the development of the late Quaternary East Asian summer monsoon on the basis of thermo-humidiphilous terrestrial mollusks in the loess–palaeosol deposits in the CLP (Chen and Wu, 2008; Rousseau et al., 2009). However, in the present paper we cannot give any evidence supporting that which factor, local insolation or insolation gradient, is more predominant on the precession bands at the present temporal resolution. Higher resolution studies are needed to focus on this issue.

The idea that insolation gradients can influence the climate at an orbital time scale has long been proposed. Early in the 1960s, Kutzbach et al. (1968) argued that changes in insolation gradient are

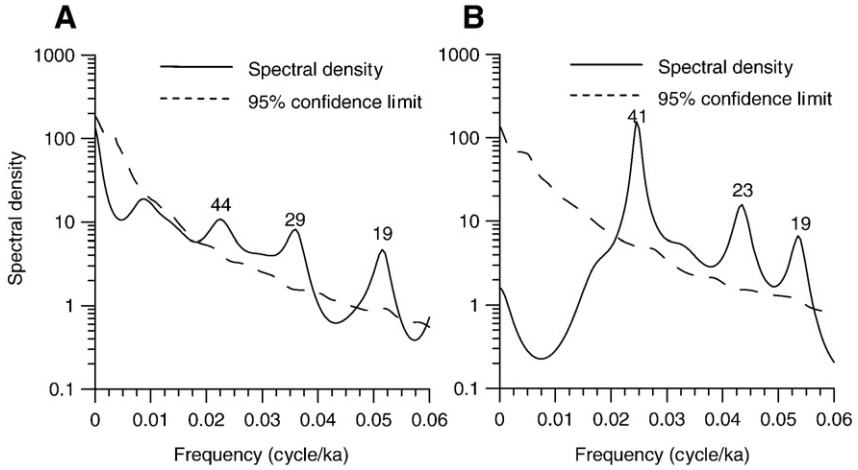

Fig. 4. Spectrum analysis of the dominant thermo-humidiphilous mollusks group (*Metodontia* and *Punctum*) (A) and mean summer insolation gradient between 35°N and 0° (B) from 5.1 to 3.5 Ma. Maximum entropy spectral analysis was performed using the PPPHALOS software (Guiot and Goeury, 1996).

great enough to impact climate. Later, Young and Bradley (1984) suggested that the hemispheric insolation gradients have played an important role in driving the global atmospheric circulation during the past 150 ka, and may have modulated the transport of moisture to high latitudes. Similarly, Johnson (1991) concluded that changes in insolation gradient can greatly amplify and alter the climatic effects of insolation variations. Recently, Raymo and Nisancioglu (2003) suggested that variations in the mean summer insolation gradient between high and low latitudes may exert a dominant control on the high-latitude climate between 3 and 0.8 Ma. However, little is known from the pre-Pleistocene geological archives. The Pliocene terrestrial mollusk record from the western CLP suggests a possible causal link between the East Asian summer monsoon and the insolation gradient between middle and low latitudes. An increased such meridional mean summer insolation gradient strengthened the atmospheric circulation including the East Asian summer monsoon (Trenberth and Caron, 2001) and amplified the moisture and heat transport to the middle-latitude regions including CLP, triggering the rapid expansion of the warmth- and moisture-loving mollusk taxa in the studied region during the Pliocene. Our study on the Pliocene mollusk fauna thus provides further evidence for insolation-gradient impacts on the development of the monsoon system at an orbital time scale. It should be pointed out that, although the growth and development of the Pliocene thermo-humidiphilous mollusks in the CLP was clearly related to the insolation gradient between middle and low latitudes and the local insolation, other possible influences cannot be excluded, such as the insolation gradient between high and low latitudes which may exert a dominant control on high-latitude atmospheric meridional transport of moisture and heat (Raymo and Nisancioglu, 2003), and thus may also have probable moisture input to the middle-latitude regions.

Apart from the insolation gradients and local insolation, another factor also probably played an active role in the development of the East Asian summer monsoon in the Pliocene. The closure of the Panama and Indonesian seaways changed the heat distribution in the Pacific and Atlantic, causing reorganization of the global climate patterns (e.g., Haug and Tiedemann, 1998; Cane and Molnar, 2001). For instance, this event altered the atmospheric moisture flux from a latitudinal to meridional transport, resulting in an increase in moisture at middle and high latitudes (Young and Bradley, 1984; Raymo and Nisancioglu, 2003). The closure of these seaways probably strengthened and enlarged the western Pacific warm pool, an important source of water vapor and latent heat for the higher latitudes (Maier-Reimer et al., 1990; Yan et al., 1992; Mikolajewicz et al., 1993; Mikolajewicz and Crowley, 1997; Haug and Tiedemann, 1998; Chaisson and Ravelo, 2000; Li et al., 2004). As such, an enlarged warm pool would have resulted in a strengthened summer monsoon and, subsequently, increased precipitations over the CLP, creating favorable conditions for the thermo-humidiphilous mollusk fauna.

It has been suggested that prior to 2.75 Ma, the East Asian summer and winter monsoon indicators, i.e., magnetic susceptibility and grain size, respectively, are in phase with one another whereas after 2.75 Ma, the summer and winter monsoon indicators are out of phase with one another (Clemens et al., 2008). In our study, the cross spectral analysis of the thermo-humidiphilous mollusk time series relative to cold-aridiphilous time series shows that they are not in phase with one another from 5.1 Ma to 3.5 Ma at the obliquity bands, differing from the findings by Clemens et al. (2008). There may be at least two reasons for this difference. First, the result from the cross spectral analysis may contain some deviations because the cold-aridiphilous snails are not continuous in distribution in the section during the Pliocene warm period due probably to a weak winter monsoon during this period. Therefore, the cold-aridiphilous terrestrial mollusks are not suitable for cross spectral analysis. Second, climatic conditions inferred from different climatic proxy indicators, such as grain size, magnetic susceptibility, and terrestrial mollusks, may differ because of their different sensitivity to climate change. For instance, the grain size, a proxy of winter monsoon, shows a dominant 100 ka cycle and a weak 41 ka frequency during the late Pleistocene, similar to the cycle as reflected by lithologic characters in the loess–palaeosol succession (Ding et al., 1995), whereas the cold-aridiphilous mollusk fossils, another winter monsoon proxy, shows a dominant 100 kyr and a strong 41 ka cycle in the past 350 ka (Wu et al., 2000, 2001).

5. Conclusions

The Pliocene terrestrial mollusk record from the western Chinese Loess Plateau (CLP) shows that thermo-humidiphilous taxa predominate during 5.1 to 3.5 Ma, indicating the prevalence of warm, moist conditions with intensified summer monsoons. The peak values of the sum of *Metodontia* and *Punctum*, the two typical thermo-humidiphilous mollusk taxa, correspond approximately to the maxima of the mean summer insolation gradient between middle and low latitudes and some maximum values of the 35°N insolation. Furthermore, the dominant orbital frequencies obtained from these two warmth- and moisture-loving taxa match those obtained from the meridional mean summer insolation-gradient variability, thus suggesting a possible causal link between the summer monsoon and the insolation gradient. The mean summer insolation gradient exerts controls on atmospheric circulations of the summer monsoon and, subsequently, the moisture and heat transport to the CLP located at middle-latitude regions, thus affecting the expansion or shrinkage of the thermo-humidiphilous mollusk fauna in this region. Spectrum analysis of the faunal record suggests that local insolation may be also important for the faunal abundance and the development of the summer monsoon during the Pliocene. As such, the mollusk record from the Pliocene loess–palaeosol deposits in the western CLP not only provides further evidence for insolation-gradient impacts on the evolution of the East Asian monsoon in the Pliocene, extending the validity of the insolation-gradient hypothesis on orbital time scales to the early Pliocene, but also may provide an impetus for model test of the relationship between the East Asian monsoon and insolation gradient.

Acknowledgements

This study is supported by the Chinese Academy of Sciences (KZCX2-YW-117), the National Natural Science Foundation of China (Projects 40730104, 40972119, and 40702030), the president excellent prize of Chinese Academy of Sciences, and China Postdoctoral Science Foundation (200801110 and 20070420066). Drs. Qingzhen Hao and Yunpeng Pei provided valuable field assistance and spectral analysis. The cross spectral analysis and calculation of the insolation were conducted by Drs. Guangshan Chen and Li Qin, respectively. Suggestions and comments by Drs. Steven Clemens and Slobodan Markovic greatly improved the quality of the manuscript. Special thanks go to Dr. George Gao from the Ontario Geological Survey for careful improvement of English. Useful discussion was also made with Dr. Denis-Didier Rousseau.

References

An, Z.S., Kutzbach, J.E., Prell, W.L., Porter, S.C., 2001. Evolution of Asian monsoons and phased uplift of the Himalayan–Tibetan plateau since Late Miocene times. Nature 411, 62–66.

Berger, A., 1976. Long term variations of daily and monthly insolation during the last Ice Age. Eos Transaction AGU 57, 254.

Berger, A., 1984. Accuracy and frequency stability of the Earth's orbital elements during the Quaternary. In: Berger, A.L., et al. (Ed.), Milankovitch and Climate, D. Reidel, Norwell, Mass, pp. 3–40.

Braun, A., 1847. Loess neues jahrbuch für min. Geogn. Geology und Peterfaktenkunde 1, 49–53.

Cane, M.A., Molnar, P., 2001. Closing of the Indonesian seaway as a precursor to east African aridification around 3–4 million years ago. Nature 411, 157–162.

Chaisson, W.P., Ravelo, A.C., 2000. Pliocene development of east–west hydrographic gradient in the equatorial Pacific. Paleoceanography 15, 497–505.
Chen, X.Y., Wu, N.Q., 2008. Relatively warm–humid climate recorded by mollusk species in the Chinese Loess Plateau during MIS 3 and its possible forcing mechanism. Quaternary Sciences 28, 154–161 (in Chinese with English abstract).
Clemens, S.C., Prell, W.L., Sun, Y., Liu, Z., Chen, G., 2008. Southern Hemisphere forcing of Pliocene $\delta^{18}O$ and the evolution of Indo-Asian monsoons. Paleoceanography 23. doi:10.1029/2008PA001638 PA4210.
Ding, Z.L., Liu, T.S., Rutter, N.W., Yu, Z.W., Guo, Z.T., Zhu, R.X., 1995. Ice-volume forcing of East Asian winter monsoon variations in the past 800,000 years. Quaternary Research 44, 149–159.
Guiot, J., Goeury, C., 1996. PPPBase, a software for statistical analysis of paleoecological and paleoclimatological data. Dendrochronologia 14, 295–300.
Guo, Z.T., Biscaye, P., Wei, L.Y., Chen, X.H., Peng, S.Z., Liu, T.S., 2000. Summer monsoon variations over the last 1.2 Ma from the weathering of loess–soil sequences in China. Geophysical Research Letters 27, 1751–1754.
Guo, Z.T., Peng, S.Z., Hao, Q.Z., Biscaye, P.E., Liu, T.S., 2001. Origin of the Miocene–Pliocene Red-Earth Formation at Xifeng in Northern China and implications for paleoenvironments. Palaeogeography, Palaeoclimatology, Palaeoecology 170, 11–26.
Guo, Z.T., Ruddiman, W.F., Hao, Q.Z., Wu, H.B., Qiao, Y.S., Zhu, R.X., Peng, S.Z., Wei, J.J., Yuan, B.Y., Liu, T.S., 2002. Onset of Asian desertification by 22 Myr ago inferred from loess deposits in China. Nature 416, 159–163.
Guo, Z.T., Sun, B., Zhang, Z.S., Peng, S.Z., Xiao, G.Q., Ge, J.Y., Hao, Q.Z., Qiao, Y.S., Liang, M.Y., Liu, J.F., Yin, Q.Z., Wei, J.J., 2008. A major reorganization of Asian climate by the early Miocene. Climate of the Past 4, 153–174.
Hao, Q.Z., Guo, Z.T., 2004. Magnetostratigraphy of a late Miocene–Pliocene loess–paleosol sequence in the western Loess Plateau in China. Geophysical Research Letters 31, L09209. doi:10.1029/2003GL019392.
Hao, Q.Z., Guo, Z.T., 2007. Magnetostratigraphy of an early–middle Miocene loess–soil sequence in the western Loess Plateau of China. Geophysical Research Letters 34, L18305. doi:10.1029/2003GL031162.
Hao, Q.Z., Oldfield, F., Bloemendal, J., Guo, Z.T., 2008a. Particle size separation and evidence for pedogenesis in samples from the Chinese Loess Plateau spanning the last 22 Ma. Geology 36, 727–730.
Hao, Q.Z., Oldfield, F., Bloemendal, J., Guo, Z.T., 2008b. The magnetic properties of loess and paleosol samples from the Chinese Loess Plateau spanning the last 22 million years. Palaeogeography, Palaeoclimatology, Palaeoecology 260, 389–404.
Haug, G.H., Tiedemann, R., 1998. Effect of the formation of the Isthmus of Panama on Atlantic Ocean thermohaline circulation. Nature 393, 673–676.
Johnson, R.G., 1991. Major Northern Hemisphere deglaciation caused by a moisture deficit 140 ka. Geology 19, 686–689.
Kukla, G., An, Z.S., Melice, J.L., Gavin, J., Xiao, J.L., 1990. Magnetic susceptibility record of Chinese loess. Transactions of the Royal Society of Edinburgh: Earth Sciences 81, 263–288.
Kutzbach, J.E., Bryson, R.A., Shen, W.C., 1968. An evaluation of the thermal Rossby number in the Pleistocene. Meteorological Monographs 8, 134–138.
Laskar, J., Robutel, P., Joutel, F., Gastineau, M., Correia, A.C.M., Levrard, B., 2004. A long-term numerical solution for the insolation quantities of the Earth. Astronomy and Astrophysics 428, 261–285.
Li, B.H., Wang, J.L., Huang, B.Q., Li, Q.Y., Jian, Z.M., Zhao, Q.H., Su, X., Wang, P.X., 2004. South China Sea surface water evolution over the last 12 Myr: a south–north comparison from Ocean Drilling Program Sites 1143 and 1146. Paleoceanography 19. doi:10.1029/2003PA000906 PA1009.
Li, F.J., Wu, N.Q., Pei, Y.P., Hao, Q.Z., Rousseau, D.D., 2006a. Wind-blown origin of Dongwan late Miocene–Pliocene dust sequence documented by land snail record in western Chinese Loess Plateau. Geology 34, 405–408.
Li, F.J., Wu, N.Q., Rousseau, D.D., 2006b. Preliminary study of mollusk fossils in the Qinan Miocene loess–soil sequence in western Chinese Loess Plateau. Science in China: Series D Earth Sciences 49, 724–730.
Liang, M.Y., Guo, Z.T., Kahmann, A.J., Oldfield, F., 2009. Geochemical characteristics of the Miocene eolian deposits in China: their provenance and climate implications. Geochemistry Geophysics Geosystems 10, Q04004. doi:10.1029/2008GC002331.
Liu, J.F., Guo, Z.T., Hao, Q.Z., Peng, S.Z., Qiao, Y.S., Sun, B., Ge, J.Y., 2005. Magetostratrigraphy of the Miziwan Miocene eolian deposits at Qin'an County (Gansu Province). Quaternary Sciences 25, 503–509 (in Chinese with English abstract).
Liu, J.F., Guo, Z.T., Qiao, Y.S., Hao, Q.Z., Yuan, B.Y., 2006. Eolian origin of the Miocene loess–soil sequence at Qin'an, China: evidence of quartz morphology and quartz grain-size. Chinese Science Bulletin 51, 117–120.
Liu, T.S., 1985. Loess and the Environment. China Ocean Press, Beijing. 251 pp.
Liu, T.S., Guo, Z.T., 1997. Geological environment in China and global change. In: An, Z. (Ed.), Selected Works of Liu Tungsheng. Science Press, Beijing, pp. 192–202.
Maier-Reimer, E., Mikolajewicz, U., Crowley, T., 1990. Ocean general circulation model sensitivity experiment with an open central American isthmus. Paleoceanography 5, 349–366.
Mikolajewicz, U., Crowley, T.J., 1997. Response of a coupled ocean/energy balance model to restricted flow through the central American isthmus. Paleoceanography 12, 429–441.
Mikolajewicz, U., Maier-Reimer, E., Crowley, T.J., Kim, K.Y., 1993. Effect of Drake and Panamanian gateways on the circulation of an ocean model. Paleoceanography 8, 409–426.
Puisségur, J.J., 1976. Mollusques continentaux quaternaires de Bourgogne. Significations stratigraphiques et climatiques. Rapports avec d'autres faunes boréales de France: Université de Dijon Mémoires Géologiques, 3, 241 pp.
Qiao, Y.S., Guo, Z.T., Hao, Q.Z., Yin, Q.Z., Yuan, B.Y., Liu, T.S., 2006. Grain-size features of a Miocene loess–soil sequence at Qinan: implications on its origin. Science in China: Series D Earth Sciences 49, 731–738.
Raymo, M.E., Nisancioglu, K., 2003. The 41 kyr world: Milankovitch's other unsolved mystery. Paleoceanography 18, 1011. doi:10.1029/2002PA000791.
Richthofen, F.V., 1882. On the mode of origin of the loess. Geological Magazine 9, 293–305.
Rousseau, D.D., Wu, N.Q., 1997. A new molluscan record of the monsoon variability over the past 130 000 yr in the Luochuan loess sequence, China. Geology 25, 275–278.
Rousseau, D.D., Wu, N.Q., 1999. Mollusk record of monsoon variability during the L_2–S_2 cycle in the Luochuan loess sequence, China. Quaternary Research 52, 286–292.
Rousseau, D.D., Wu, N.Q., Guo, Z.T., 2000. The terrestrial mollusks as new indices of the Asian paleomonsoons in the Chinese loess plateau. Global and Planetary Change 26, 199–206.
Rousseau, D.D., Wu, N.Q., Pei, Y.P., Li, F.J., 2009. Three exceptionally strong East Asian summer monsoon events during glacial times in the past 470 kyr. Climate of the Past 5, 157–169.
Sun, X.J., Wang, P.X., 2005. How old is the Asian monsoon system? —palaeobotanical records from China. Palaeogeography, Palaeoclimatology, Palaeoecology 222, 181–222.
Trenberth, K.E., Caron, J., 2001. Estimates of meridional atmosphere and ocean heat transports. Journal of Climate 14, 3433–3443.
Wang, P.X., 1990. Neogene stratigraphy and paleoenvironments of China. Palaeogeography, Palaeoclimatology, Palaeoecology 77, 315–334.
Wei, J.J., Guo, Z.T., 2003. Changes in the content of eolian iron during the past 900 ka and the implications. Chinese Science Bulletin 48, 1882–1886.
Wu, N.Q., Rousseau, D.D., Liu, T.S., 1996. Land mollusk records from the Luochuan loess sequence and their paleoenvironmental significance. Science in China: Series D Earth Sciences 39, 494–502.
Wu, N.Q., Rousseau, D.D., Liu, X.P., 2000. Response of mollusk assemblages from the Luochuan loess section to orbital forcing since the last 250 ka. Chinese Science Bulletin 45, 1617–1622.
Wu, N.Q., Rousseau, D.D., Liu, T.S., Lu, H.Y., Gu, Z.Y., Guo, Z.T., Jiang, W.Y., 2001. Orbital forcing of terrestrial mollusks and climatic changes from the Loess Plateau of China during the past 350 ka. Journal of Geophysical Research 106, 20045–20054.
Wu, N.Q., Liu, T.S., Liu, X.P., Gu, Z.Y., 2002. Mollusk record of millennial climate variability in the Loess Plateau during the Last Glacial Maximum. Boreas 31, 20–27.
Wu, N.Q., Pei, Y.P., Lu, H.Y., Guo, Z.T., Li, F.J., Liu, T.S., 2006. Marked ecological shifts during 6.2–2.4 Ma revealed by a terrestrial molluscan record from the Chinese Red Clay Formation and implication for palaeoclimatic evolution. Palaeogeography, Palaeoclimatology, Palaeoecology 233, 287–299.
Wu, N.Q., Chen, X.Y., Rousseau, D.D., Li, F.J., Pei, Y.P., Wu, B., 2007. Climatic conditions recorded by terrestrial mollusc assemblages in the Chinese Loess Plateau during marine Oxygen Isotope Stages 12–10. Quaternary Science Reviews 26, 1884–1896.
Yan, X.H., Ho, C.R., Zheng, Q., Klemas, V., 1992. Temperature and size variabilities of the west Pacific warm pool. Science 258, 1643–1645.
Young, M.A., Bradley, R.S., 1984. Insolation gradients and the paleoclimatic record. In: Berger, A.L., et al. (Ed.), Milankovitch and Climate. D. Reidel, Norwell, Mass, pp. 707–713.
Zhou, T.R., 1982. Palaeogeography. Beijing Normal University Press, Beijing. 342 pp. (in Chinese).