

Preliminary study of mollusk fossils in the Qinan Miocene loess-soil sequence in western Chinese Loess Plateau

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Abstract The first near continuous mollusk fossil record from the Qinan Miocene loess-soil sequence is presented. Results show that mollusk species are abundant in the QA-I section between 22 and 6.2 Ma, and both loess layers and soil layers yield mollusk fossil individuals. All mollusk species are terrestrial and well preserved in the section. Most species are identical to those identified in the Quaternary loess-soil sequence of the Loess Plateau. The thermo-humidiphilous group generally is distributed in soil layers, whereas cold-aridiphilous group can be observed in loess layers. From the Miocene to Quaternary, the occurrence and divergence of new species of *Metodontia* and *Cathaica* correspond to the crucial periods of regional and global environmental changes, indicating that mollusk species are sensitive to environmental variations. Preliminary study on the QA-I mollusk record indicates that the Qinan Miocene loess-soil sequence may have a similar sedimentary environment to the Quaternary loess-soil sequence of the Loess Plateau.

Keywords: mollusk fossils, Miocene loess, Loess Plateau, mollusk evolution, sedimentary environment.

The Qinan Miocene loess-soil sequence (~22–6.2 Ma)^[1] discovered from the Gansu Group^[2] several years ago extends the well-known Quaternary loess-soil sequence and the late Tertiary Red Clay sequence of the Loess Plateau to early Miocene epoch. Most recently, the Dongwan late Miocene–Pliocene loess-soil sequence (~7.1–3.5 Ma)^[3] further extends the upper limit of the reported Qinan Miocene loess-soil sequence into the Pliocene. These extensions have great potentials for the study of loess-based paleoclimatology. Moreover, these studies indicate that the spatial and temporal changes of sedimentary facies of the so-called Gansu Group^[2] are complicated and

involved in a new understanding of tectonic and environmental evolution in this area and even in western China^[4]. Therefore, detailed investigations and multidisciplinary studies of the long-term QA-I sequence at Qinan are needed. Among these, biological approaches are particularly valuable.

Fossil land snails are the most common and abundant fossil remains found in loess sequences. They are very sensitive to environmental changes and so have long been regarded as “indicator animal” for the study of loess paleoenvironment^[5]. Mollusk fossils have played an important role in the early studies of wind-blown origin of the Quaternary loess-soil se-

quences^[5-8]. For example, in 1847, Braun found that most mollusk fossils preserved in European loess were terrestrial species, and moreover, were mostly the cold-adapted taxa^[6]. His findings provided an indispensable biological evidence for subsequent studies of the origin and sedimentary environment of loess strata. In the 1880s, Richthofen noted that loess in China contained fully preserved terrestrial mollusk shells that were well dispersed in loess strata^[7,8], which strongly supported his wind-blown hypothesis for loess. In this study, we analyzed mollusk fossils preserved in the newly found Miocene loess-soil sequence at Qinan^[1] with the objectives to investigate (1) the sedimentary environment of the QA-I sequence, and (2) the evolution of land snail taxa from the Miocene to Quaternary and their possible relationship with regional and global environmental changes.

1 Materials and methods

The studied QA-I sequence (35°2'N, 105°27'E) is the first Miocene loess-soil section found in the Loess Plateau. It is located 27 km northwest of Qinan County. This region is characterized by valleys flanked by elongated hills with a top elevation of ~1880 m above sea level. The current climate at Qinan is semiarid with a mean annual precipitation varying between 400 and 507 mm and a mean annual temperature of ~10.4 °C^[1]. Vegetation in this region is a semiarid temperate steppe^[9]. The QA-I section deposits on metamorphic bedrock of Proterozoic era and is overlain by the Quaternary loess. This sequence is 253.1 m thick and contains 231 visually definable loess-soil couplets^[1]. Magnetostratigraphic measurements and micromammalian fossils indicate an age of this sequence between 22 and 6.2 Ma^[1], almost covering the whole Miocene epoch.

In this study, 35 loess and soil layers were investigated along the depth described by Guo *et al.*^[1]. Since all loess and soil layers had solidified, thus preventing any washing and sieving in the field as performed in the Quaternary loess-paleosol studies, we broke earth blocks progressively into small pieces of ~0.5 mm in diameter, at the same time collecting all available individual shells. In laboratory, all collected shells were identified under a binocular microscope.

2 Preliminary result of mollusk fossils in the QA-I section

Fig. 1 shows all mollusk species and their distribution in the QA-I section. Preliminary result shows that mollusk fossils have a near continuous distribution in the section. All the investigated 35 loess and soil layers yield mollusk fossil individuals. Generally, mollusk fossil individuals in loess layers are more than those in soil layers except in the upper part of the section where soil layers yield more fossil individuals. In this study, fifteen mollusk fossil species have been identified including two unidentifiable taxa. These identified species can be mainly grouped into thermo-humidiphilous taxa (warmth and moisture loving species) and cold-aridiphilous ones (species living in dry and relatively cold places) according to their ecological requirements of the same species in Quaternary loess-paleosol sequences^[5,10-14]. The thermo-humidiphilous group includes *Metodontia* cf. *huaiensis* (Fig. 2a,b,c), *Metodontia* cf. *yantaiensis* (Fig. 2d,e,f), *Metodontia* sp., *Gastrocopta* sp. (Fig. 2g), *Punctum orphana* (Fig. 2h,i,j), *Punctum* sp. The cold-aridiphilous group contains *Cathaica pulveratrix* (Fig. 2k,l,m), *Cathaica* sp. (Fig. 2n,o,p), *Vallonia* cf. *pulchella* (Fig. 2t,u), *Vallonia* sp. The warm- and humid-adapted species generally distribute in soil layers at the depth of 5 m, 6.6 m, 18 m and 148.6 m, whereas the cold- and arid-adapted species can be found in loess layers such as *Cathaica* at the depth of 58 m, 149 m, and 240.3 m, and *Vallonia* at 126.5 m and 236 m depth. Among all mollusk fossil genera, *Metodontia* and *Cathaica* are two relatively continuously distributed genera in the section. *Punctum* and *Vallonia*, two typical land snail genera in the Quaternary loess-soil sequences, are also identified from the QA-I section.

3 Discussions

3.1 Mollusk fossil evidence for the origin of the QA-I section

Since the Qinan Miocene loess-soil sequence was discovered a few years ago, presently there are only several lines of sedimentological and geochemical and pedogenic evidence^[1] supporting its eolian origin. Thus, it is still highly necessary to address this issue

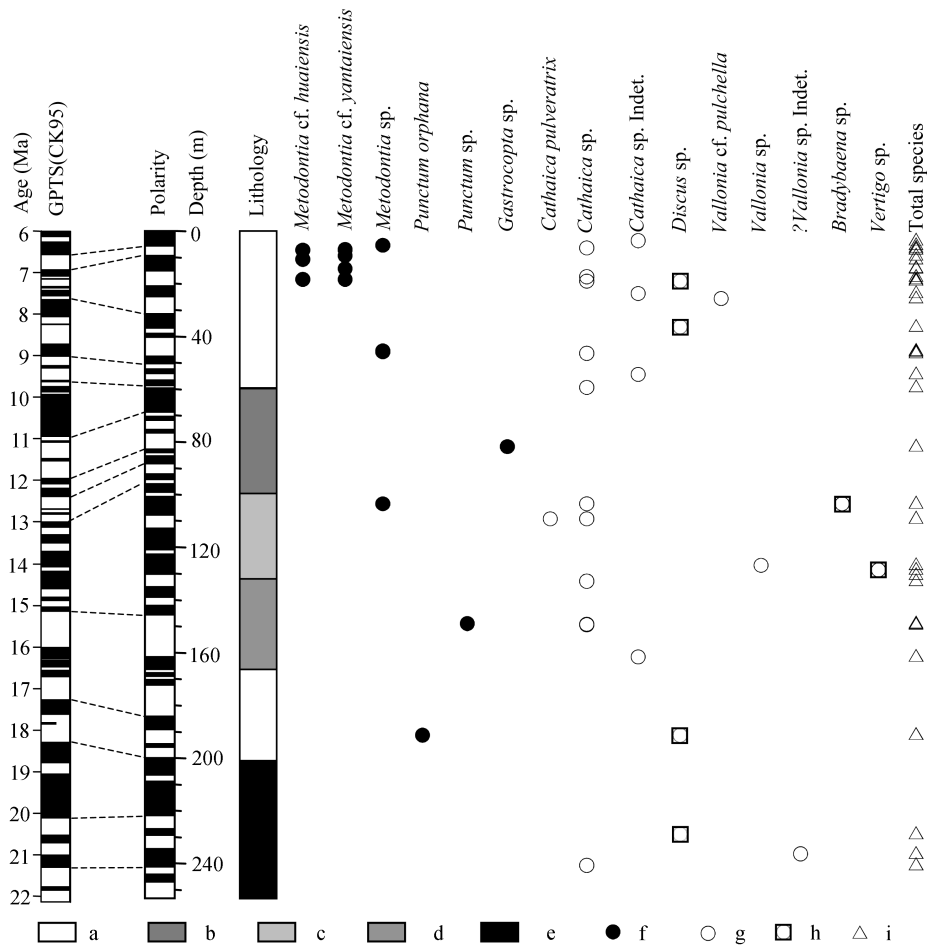


Fig. 1. Paleogeomagnetic age (from Guo *et al.*^[1]), lithology, and distribution of mollusk fossils in the QA-I Miocene loess-soil section. a, Generally weakly developed soil layers interbedded with loess layers and both have similar thickness; b, thinner loess layers interbedded with relatively strongly developed thicker soil layers; c, thicker loess layers interbedded with weakly developed thinner soil layers; d, thicker loess layers interbedded with thinner soil layers whose developments are stronger than those of the upper part; e, thinner loess layers interbedded with relatively strongly developed thicker soil layers; f, thermo-humidiphilous mollusk fossils; g, cold-aridiphilous mollusk fossils; h, mollusk fossils whose ecological groups are presently unclear; i, total mollusk species.

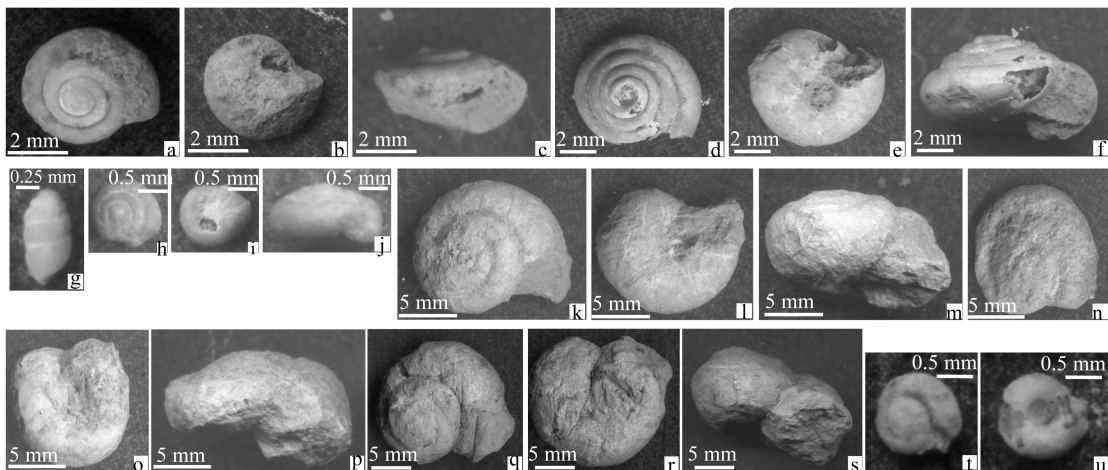


Fig. 2. Mollusk fossils in the QA-I Miocene loess-soil section. a-c, *Metodontia cf. huaiensis*; d-f, *Metodontia cf. yantaiensis*; g, *Gastrocopta sp.*; h-j, *Punctum orphana*; k-m, *Cathaica pulveratrix*; n-p, *Cathaica sp.*; q-s, *Bradybaena sp.*; t, u, *Vallonia cf. pulchella*.

through further efforts, among which biological evidence is indispensable. Here we provide a near continuous mollusk fossil record to discuss the origin of this sequence.

Preliminary investigation of the preservation condition of mollusk fossils in the QA-I section indicates that most individuals have complete shells and dispersedly distributed in the loess and soil layers. No imprints of suffered current transportation and selection were found in fossil populations (Fig. 3). The preservation condition of mollusk fossils reveals a terrestrial *in situ* ecological population in the QA-I Miocene loess-soil section.

The composition of mollusk fossils at the QA-I sequence has the following features: (1) All mollusk assemblages found in the section are composed of terrestrial taxa. No aquatic and amphibious taxa have been found in the whole sequence. The identified 13 species can be attributed to 5 families and 8 genera of Pulmonata subclass, most being the common species of extant land snails in loess region. These indicate that the mollusk composition in the studied section is a typical terrestrial population of eolian sequence. (2) Most mollusk species in the QA-I section have analogues in the Quaternary loess-soil sequences of the Loess Plateau^[5,10–14]. (3) These identified species can be divided into two major ecological groups, which are the same as those in the Quaternary loess-soil sequences^[11–14]. (4) The preservation of mollusk fossils in the QA-I section shows the original population. Additionally, the mollusk fossil distribution in the strata is dispersed, and most individuals preserved in an original living habit, with the characteristic of mixed

adults and juveniles, showing a similar pattern to the Quaternary eolian deposits in the Loess Plateau^[5,7,8]. Thus, we can conclude that the Qinan Miocene loess-soil sequence has a similar sedimentary environment to the Quaternary loess-soil sequences of the Loess Plateau. The composition and conservation of mollusk fossils support the view of wind-blown origin of the studied sequence, as indicated by sedimentological and geochemical and pedogenic studies^[1].

3.2 Preliminary study of mollusk species evolution from the Miocene to Quaternary

It has long been known that the life evolution is closely related to environmental changes. From the Miocene to Quaternary, terrestrial mollusk taxa in the Loess Plateau show a series of successions, which might result from the environmental changes happened during this period. Two examples are given below to address the changing trends. First, the species of *Metodontia*, a principal element of the Oriental Region (Mollusk fauna), developed in three periods with the characteristic of changing size and aperture shape. As shown in Fig. 4, the earliest occurrence of *Metodontia* sp. was at about 13 Ma, a warm and wet period in the middle Miocene; During ~8–7 Ma, *M. cf. huaiensis* and *M. cf. yantaiensis* appeared. The time interval of ~5.4–4.4 Ma was a period of *Metodontia* developed abundantly and rapidly in which *M. huaiensis*, *M. yantaiensis*, *M. cf. beresowskii* and *M. beresowskii* appeared successively. The evolution of shell morphology of *Metodontia* taxa is from relatively small individual, bow-like aperture of *M. cf. huaiensis* to relatively big individual, half-moon aperture of *M.*

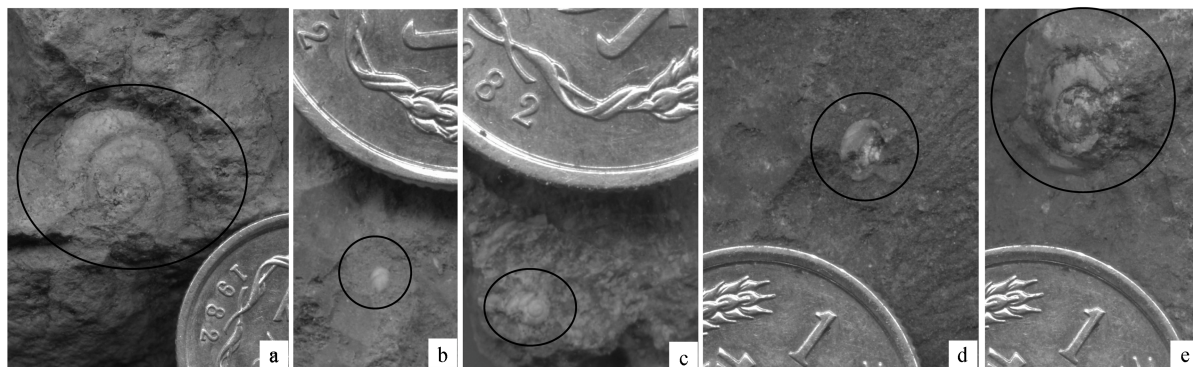


Fig. 3. Preservation condition of mollusk fossils in the QA-I Miocene loess-soil section. Ellipses and circles indicate mollusk fossils. a, 108.8 m; b, 128.2 m; c, 228.5 m; d, 236 m; e, 240.3 m.

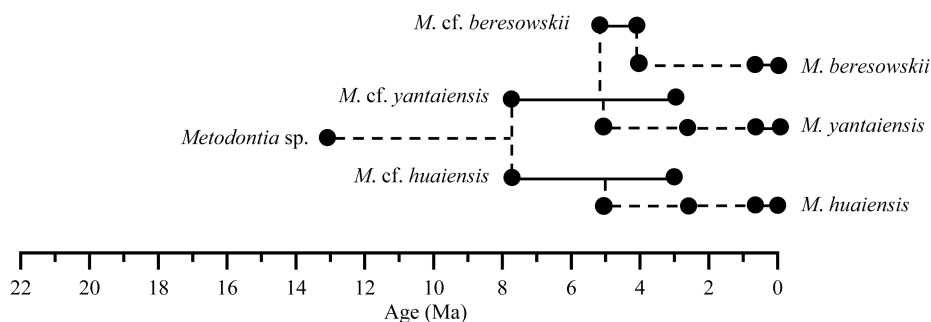


Fig. 4. Evolutionary trend of *Metodontia*. Dots indicate the fossils found; solid lines indicate the exact evolutionary trend and dashed lines speculated.

yantaiensis, *M. cf. beresowskii* and *M. beresowskii*. Second, *Cathaica*, an aboriginal and important genus in Chinese loess region, began to appear at ~21 Ma and then had a near continuous distribution in stratigraphy from ~16 Ma (Fig. 1). Based on our presently available fossil materials, *C. pulveratrix* appeared at around 13 Ma. From ~8–6 Ma, four to five species of *Cathaica* occurred^[15]. From about 2.6 Ma, the onset of the Quaternary, more than 10 species of this genus developed^[5]. The ratio of width and height of the shells of *Cathaica sp.* shows that the morphology of shells has an evolutionary trend from relatively tall and narrow to flat and wide (Fig. 5). It can be seen that the occurrences of new species of these two mollusk genera are closely related to the major environmental changes happening during the Miocene to Quaternary. For example, the time interval of 8–7 Ma was an important evolutionary period of *M. cf. huaiensis*, *M. cf. yantaiensis* and *Cathaica*, corresponding to the onset or intensification of the Indian monsoon^[16] and intensification of the East Asian monsoon^[17,18]. During ~5.4–4.4 Ma, four species of *Metodontia* occurred in response to the Pliocene warm period. At the beginning of the Quaternary, the *Cathaica* developed more species, reflecting the advent of the Quaternary glaciation. The evolutionary stages in mollusk species are consistent with the regional and global major environmental changes during this period. This may be a response of land ecological system, including mollusk species, to global cooling since the middle Miocene^[19,20] and strengthening East Asian monsoon circulations from the late Miocene^[17,18].

The Miocene loess-soil sequence at the QA-I sec-

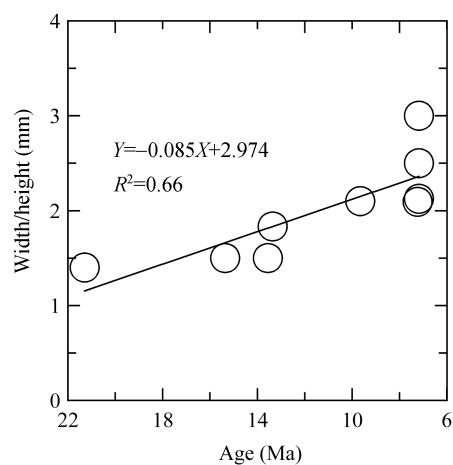


Fig. 5. Evolution of shell morphology of *Cathaica sp.* in the Miocene epoch.

tion spans ~16 Ma and contains 231 loess-soil couplets, indicating periodic or cyclic characteristics of long-term climate changes^[1]. At the QA-I section, the cold-aridophilous *Cathaica*, a representative of the East Asian winter monsoon variation according to the studies of the Quaternary loess-soil sequences^[5,11–14], is distributed mainly in loess layers, while the thermo-humidophilous *Metodontia*, a typical species reflecting the East Asian summer monsoon change^[5,11–14], is often observed in soil layers, similar to their distribution in the Quaternary loess-soil sequences in the Loess Plateau, as mentioned above. Thus, the distribution of these two species in the section reveals that the Miocene climate fluctuation might be similar to that of Quaternary. Recent study indicated that the East Asian summer monsoon appeared in ~22 Ma^[21]. The Oligocene/Miocene transition was a period of changing environmental patterns from

planetary wind system dominating type to monsoon system dominating type in China^[22–24]. The onset of eolian sequence at Qinan is coincident with the change in environmental patterns. Additionally, recent new study shows that the Northern Hemisphere glaciation had existed before 34 Ma^[25], and moreover, the middle Miocene climate transition from a 41 ka to 100 ka world happened at the time interval of 14.7–12.7 Ma, showing a similarity to the “Middle Pleistocene revolution”^[26]. These studies imply that the Qinan Miocene loess-soil sequence may contain a similar monsoon climate context to the Quaternary loess-soil sequences. However, the terminal Eocene glaciation should not be larger than the Quaternary one according to the gradual global cooling trend^[19,20]. Thus, the Miocene monsoon environment in the Loess Plateau should be different from that of the Quaternary glacial-interglacial cycles. It can be speculated that the seasonal difference might be weaker in Miocene than in Quaternary. The Qinan Miocene loess-soil sequence presently is the longest terrestrial eolian record with the characteristic of visually definable soil and loess layers. Mollusk fossil is one of the best indicators for the paleoenvironmental reconstruction of this sequence. In the subsequent study, more work on mollusk fossils would make a greater contribution to the long-term paleoenvironmental study of this section.

4 Conclusions

Our preliminary study of mollusk fossils from the Qinan Miocene loess-soil sequence provides the first near continuous mollusk fossil record spanning about 16 Ma. The results show that between 22 and 6.2 Ma, mollusk species are abundant in the QA-I section and both loess layers and soil layers yield mollusk fossil individuals. All species are exclusively terrestrial and well preserved in the section. Most species are identical to those identified in the Quaternary loess-soil sequence of the Loess Plateau. The thermo-humidiphilous group generally distributes in soil layers, whereas cold-aridiphilous group can be observed in loess layers. Preliminary results indicate that the Qinan Miocene loess-soil sequence has a similar sedimentary environment to the Quaternary loess-soil sequence of the Loess Plateau. The evolutionary trend of mollusk spe-

cies is distinct from the Miocene to Quaternary. The occurrences of new species of *Metodontia* and *Catharica* are closely related to the regional and global major environmental changes during this period, indicating that mollusk species are a sensitive proxy for the study of environmental conditions in the Miocene epoch. However, it should be pointed out that this study is a preliminary work on the Miocene mollusk record, especially regarding the evolution of mollusk species. More detailed studies are needed in the future.

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