Wind-blown origin of Dongwan late Miocene–Pliocene dust sequence documented by land snail record in western Chinese Loess Plateau

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ABSTRACT

Recently, the first late Miocene–Pliocene eolian deposits from the western Chinese Loess Plateau have been reported. These deposits would complement the eolian record between Quaternary loess-paleosol sequences and Miocene loess sequences, if their wind-blown origin could be documented. However, although several lines of evidence indicate the eolian origin of this sequence, it is still necessary to address this issue through further efforts. Among these, biological approaches are of particular value. Here we analyze the composition and preservation conditions of mollusk assemblages in the Dongwan section. Our results show that all mollusk fossil individuals are preserved in perfect condition without indicating any reworking. All identifiable mollusk species are terrestrial, and are mostly identical to those identified in the Quaternary loess-paleosol sequences of the Chinese Loess Plateau. Generally, the cold-aridiphilous species are dominant in the loess layers, while thermo-humidiphilous species are mostly encountered in the paleosols. The close similarity of the mollusk record in both the Dongwan late Miocene–Pliocene deposits and the Quaternary loess sequence in the Chinese Loess Plateau supports the supposition that the Dongwan section is a typical loess-paleosol sequence, and is, without any doubt, of wind-blown origin.

Keywords: terrestrial mollusk fossils, loess, Chinese Loess Plateau, late Miocene, Pliocene.

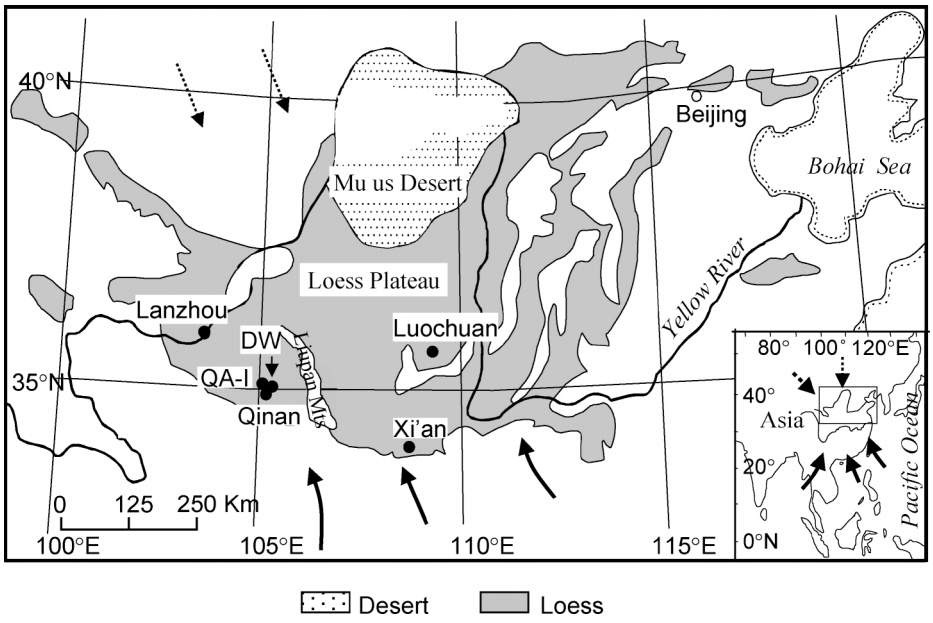

Figure 1. Map of Loess Plateau in central China and location of Dongwan studied section. Solid arrows—southeastward East Asian summer monsoon; dashed arrows—northwestward East Asian winter monsoon (modified after Wu et al., 2002). DW—Dongwan.

INTRODUCTION

In the western Loess Plateau of China, a set of yellow-red silt and clay sediments is distributed extensively as part of the Gansu Group, previously attributed to the late Tertiary (Neogene) (Liu, 1985). It has long been regarded as a mixture of eolian and fluvial and alluvial deposits (Bureau of Geology and Mineral Resources of Gansu Province, 1989; Editorial Committee of Stratigraphy of Gansu Province, 1980; Li, 1984). Neither its origin nor sedimentary environment was studied in detail before Guo et al. (2002) recognized an eolian deposition from the Gansu Group based on field observations and sedimentological and geochemical studies. Their study demonstrated that the so-called Gansu Group contained well-preserved eolian deposits of Miocene age, between 22 and 6.2 Ma (Guo et al., 2002). Hao and Guo (2004) most recently described a new sequence, the Dongwan sequence, of late Miocene–Pliocene age (7.1–3.5 Ma) in the same area. The Dongwan sequence would complement the eolian record between Quaternary loess-paleosol sequences and Miocene loess sequences, if its wind-blown origin could be documented. However, presently there are only a few lines of sedimentological and geochemical evidence indicating the eolian origin of this sequence (Hao and Guo, 2004). More evidence, especially the characterization of the original sedimentary environment, is necessary to clarify the initial conditions. Fossil land snails are the most abundant fossil remains found in loess sequences and have played an important role in the studies of wind-blown origin of the Quaternary loess-soil sequences (e.g., Liu, 1985). The present study focuses on the composition and preservation of mollusk fossils yielded by the Dongwan sequence in order to address the environmental conditions that existed at the time of its deposition.

MATERIALS AND METHODS

The studied section, Dongwan sequence (34°58′N, 105°47′E) (Hao and Guo, 2004) is located in Qinan County (Fig. 1). The current climate at Qinan is semi-arid, with a mean annual precipitation varying between 400 and 507 mm and a mean annual temperature of

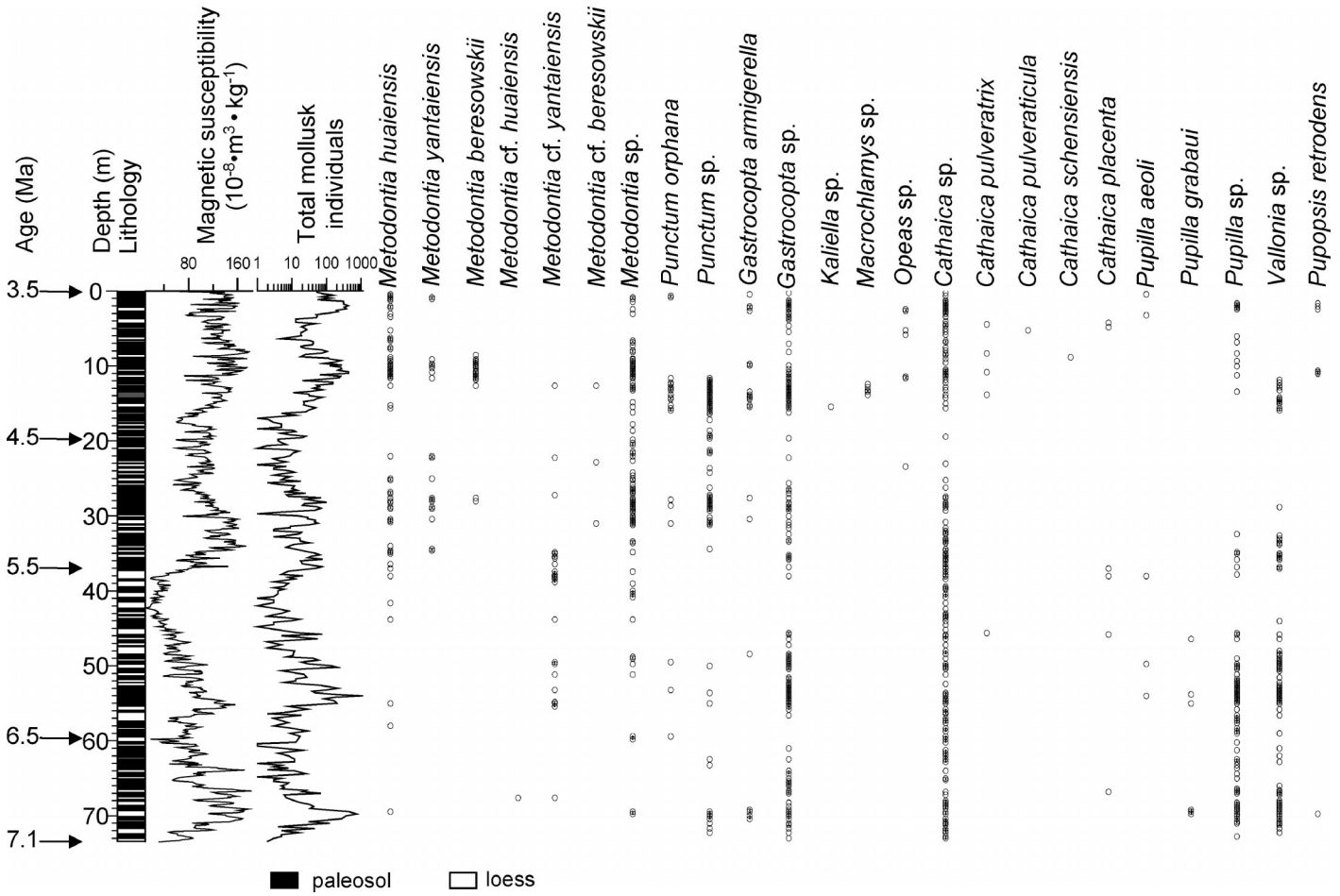

Figure 2. Late Miocene–Pliocene sequence in Dongwan, showing age, lithology, magnetic susceptibility (after Hao and Guo, 2004), total mollusk individuals, and distribution of identified mollusks (this study).

~10.4 °C (Guo et al., 2002). July average temperature, the warmest month, is ~22.7 °C. In summer, the East Asian summer monsoon carries warm, moist air masses to the Loess Plateau, causing heavy rainfall in this area. Accordingly, most of the annual rainfall (>50%) in the area occurs from July to September. In winter, the winter monsoon winds from the Siberian High prevail in the Loess Plateau, resulting in a dry and cold climate. Vegetation in this region corresponds to a semi-arid temperate steppe (Hou, 1983).

The Dongwan section is located ~30 km northeast of the town of Qinan, ~30 km east of previously reported Miocene eolian sequences (QA-I and QA-II) (Guo et al., 2002) (Fig. 1). It is exposed on the slope of a narrow valley with high, elongated hilly flanks that extend northeastward at an elevation of ~1880 m above sea level. This section is ~73.7 m thick, and is composed of 84 distinguishable loess-soil couplets, where each couplet has a thickness of <1.5 m on average. Only two horizons, at 52.0–54.0 m and 62.6–63.3 m depth, respectively, contain thin horizontal stratifications corresponding probably to two water-reworked levels (Hao and Guo, 2004).

In this study, 310 mollusk fossil assemblages were collected with a sampling interval of 20 cm, except in some parts where the sampling intervals varied between 10 and 50 cm according to the lithological changes. Each sample weighed ~30 kg. Since all loess and soil layers had solidified, thus preventing any relatively easy washing and sieving in the field, as performed in Quaternary loess-paleosol studies, we broke all samples progressively into small pieces of ~0.5 mm in diameter, at the same time collecting all available individual shells and visible broken pieces. All the identifiable mollusk remains were considered in the total count of individuals following the method developed by Puisségur (1976).

The chronology of the Dongwan section has been previously established based on magnetostratigraphic measurements and micromammalian fossils (Hao and Guo, 2004), resulting in an age ranging from 7.1 to 3.5 Ma, which places it as an approximately contemporaneous deposit with the Red Clay sequences from the eastern Loess Plateau.

MOLLUSK RECORD IN THE LATE MIOCENE–PLIOCENE DONGWAN SEQUENCE

Mollusk fossils are abundant in the Dongwan sequence, with a strong concentration at ~2, 10, 30, 50, and 70 m depth. Among all the 310 samples, 298 yielded 16,439 mollusk fossil individuals, averaging over 55 shells per sample. Only 12 samples did not yield mollusk fossils. Samples yielding more than 10 individuals compose over 70% of the total. The maximum count reached 1121/30 kg at 54 m depth (Fig. 2). All mollusk fossil remains exhibited an excellent preservation, were well dispersed in the section, and furthermore showed both adults and juveniles. The variation in total mollusk individuals parallels the fluctuations of the magnetic susceptibility (MS) values (Fig. 2), indicating that post-pedogenic processes, such as carbonate dissolution, did not affect the mollusk assemblages preserved, whereas mollusk individuals in the Quaternary strongly developed paleosol layers are often few because of carbonate dissolution (Rousseau and Wu, 1997; Wu et al., 1996, 2000).

A total of 24 mollusk species were identified in the Dongwan section. Figure 2 shows the distribution of all identified species in the section over the investigated period of 7.1–3.5 Ma. Those include thermo-humidiphilous (warmth and moisture loving taxa) species, such as *Gastrocopta armigerella* (Fig. 3A), *Gastrocopta* sp., *Punctum orphana* (Figs. 3C, 3D, and 3E), *Punctum* sp., *Metodontia beresowskii* (Fig. 3H), *M. huaiensis* (Fig. 3I), *M. yantaiensis*, *Metodontia* cf. *huaiensis*, *Metodontia* cf. *yantaiensis*, *Metodontia* cf. *bere-*

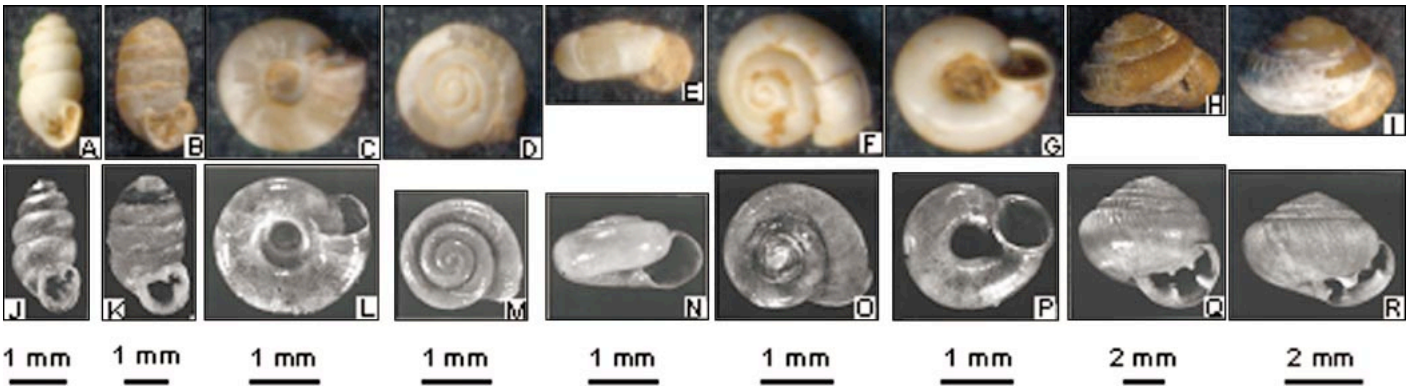

Figure 3. Typical mollusk species identified in late Miocene–Pliocene Dongwan sequence, and comparison with those from Quaternary loess-soil sequences. Labels A to I are mollusk species from Dongwan sequence. Labels J to R are mollusk species from Luochuan Quaternary loess-soil sequence (Wu et al., 1996). A, J—*Gastrocopta armigerella*; B, K—*Pupilla aeoli*; C, L—*Punctum orphana*. D, M—*Punctum orphana*; E, N—*Punctum orphana*; F, O—*Vallonia* cf. *pulchella*; G, P—*Vallonia* cf. *pulchella*; H, Q—*Metodontia beresowskii*; I, R—*Metodontia huaiensis*.

sowskii, *Metodontia* sp., *Kaliella* sp., *Macrochlamys* sp., and *Opeas* sp., and cold-aridiphilous (taxa living in dry and relatively cold places) species like *Cathaica* sp., *Cathaica pulveratrix*, *C. pulveraticula*, *C. schensiensis*, *C. placenta*, *Pupilla aeoli* (Fig. 3B), *Pupilla grabaui*, *Pupilla* sp., *Vallonia* cf. *pulchella* (Figs. 3F and 3G), *Vallonia* sp., and *Pupopsis retrodens*. Most of these taxa have been identified in previous mollusk studies of Chinese Quaternary loess-paleosol sequences (e.g., Liu, 1985; Rousseau and Wu, 1997, 1999; Rousseau et al., 2000; Wu et al., 1996, 2000, 2001, 2002). As shown in Figure 2, the most continuously distributed mollusk taxon is *Cathaica* sp., a typical representative of cold-aridiphilous species in northwestern China (Wu et al., 1996; Rousseau and Wu, 1997). *Gastrocopta* sp., *Pupilla* sp., and *Vallonia* sp. are other well-represented taxa; the former is a species living in cool-humid habitats, whereas the latter two are cold-aridiphilous taxa common in Quaternary glacial-loess deposits. The thermo-humidiphilous species of *Metodontia*, *Punctum*, *Macrochlamys*, and *Opeas*, however, mostly concentrate on the upper part of the section, at the time interval of ca. 5.3–3.5 Ma. Generally, the cold-aridiphilous species are dominant in the loess layers (Fig. 4A), while thermo-humidiphilous species are mostly encountered in the paleosols (Fig. 4B), much like the glacial and interglacial assemblages from the Quaternary loess-paleosol sequence in the Chinese Loess Plateau (Rousseau and Wu, 1997, 1999; Rousseau et al., 2000; Wu et al., 1996, 2000, 2001).

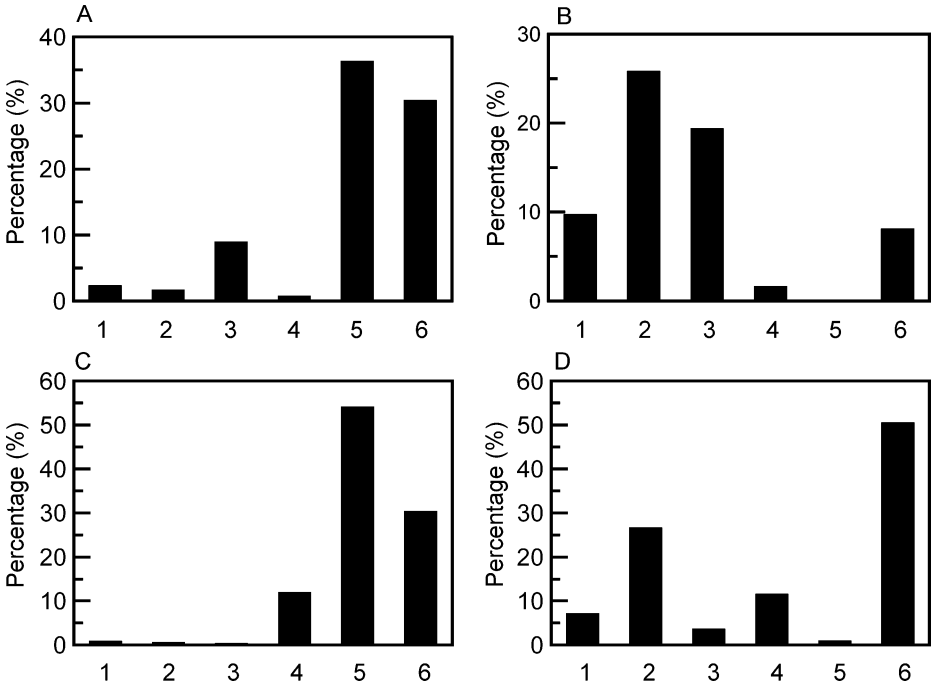

Figure 4. Comparison of main species and frequencies in late Miocene–Pliocene and Quaternary loess and paleosol mollusk assemblages. A: Dongwan loess (ca. 6.8–7.1 Ma). B: Dongwan soil (ca. 4–4.2 Ma). C: Luochuan loess (ca. 250–280 ka). D: Luochuan soil (ca. 280–350 ka). 1—*Metodontia*; 2—*Punctum*; 3—*Gastrocopta*; 4—*Cathaica*; 5—*Pupilla*; 6—*Vallonia*.

WIND-BLOWN ORIGIN OF DONGWAN DUST SEQUENCE DOCUMENTED BY LAND SNAIL RECORD

According to our field visual observations and laboratory analysis, the composition and preservation of mollusk fossils in the Dongwan sequence have the following four characteristics:

1. All identified 24 mollusk taxa from the Dongwan section are exclusively terrestrial species, attributable to 7 families and 10 genera of subclass Pulmonata. Typical land snails in loess regions, such as *Vallonia*, *Pupilla*, *Cathaica*, *Metodontia*, *Punctum*, and *Gastrocopta*, dominate the entire mollusk population. No freshwater and paludal taxa were identified in the sequence.

2. The terrestrial mollusk assemblages in the Dongwan section show almost the same composition as those in the Quaternary loess-paleosol sequences (Rousseau and Wu, 1997, 1999; Rousseau et al., 2000; Wu et al., 1996, 2000, 2001, 2002) (Fig. 3). Among the 24 species, 22 species have been found in the Quaternary loess-soil sequences, excepting *Pupilla grabaui* and *Pupopsis retrodens*. Moreover, the mollusk fossils in the loess and soil layers of the Dongwan section can be grouped within the same cold-aridiphilous and thermo-humidiphilous ecological groups as the samples in the Quaternary glacial-interglacial cycles, both representing distinctly different climatic conditions (e.g., Liu, 1985; Wu et al., 1996; Rousseau and Wu, 1997). *Vallonia*, *Pupilla*, and *Cathaica* are the most abundant species in the loess units, whereas *Metodontia*, *Punctum*, and *Gastrocopta* are most commonly encountered in soil layers (Fig. 4). The comparison of the occurrence and content of the main mollusk genera between loess and paleosol layers in the Dongwan section and those in the Quaternary loess-paleosol sequences in the Loess Plateau shows the same compositions and similar changes in percentage, indicating similar living conditions (Fig. 4).

3. Almost all mollusk fossil remains exhibit a good preservation of the shells (Fig. 3). Most of the taxa seem to indicate that original living conditions have been preserved as supported by complete carbonate shells and, even more, the occurrence of both mature and young individuals. Furthermore, careful examination of the whole section did not indicate any evidence of transportation or selection, reflecting again the preservation of initial terrestrial conditions. Finally, no freshwater species were identified, even in the two horizons presenting stratifications. Indeed these two horizons still yielded undisturbed assemblages. Moreover, an interesting observation is that the highest counts were found in soil layers rather than in loess layers, showing a synchronous variation with MS values (Fig. 2). This seems to indicate that the mollusk assemblages appear to be undisturbed by postburial modifications, such as pedogenic processes and carbonate dissolution, which are often documented in the Quaternary soil layers. We believe that the significant similarity between the total mollusk individuals and the MS of the sequence reflects that a drier climatic condition, possibly similar to the present climatic pattern, existed in the western Loess Plateau since the late Miocene relative to the eastern Loess Plateau. This might have caused weaker soil development leading to much less mollusk shell dissolution. A similar situation can be observed in the late Quaternary loess deposits in Lanzhou (Keen, 1995). Under the condition of drier climate and weak weathering, increased soil moisture (or precipitation) and plant cover may have stimulated land snail biomass and also enhanced the MS values (Lu et al., 2000). In addition, a 20-cm-thick paleosol layer accumulates longer-term sediments than the same thickness of loess layer, such as the one we analyzed using the same sampling interval. This might be another reason for the result that more land snail biomass and higher MS values are found in paleosol layers than in loess.

4. Most fossil species in the Dongwan section have modern analogues in the Loess Plateau. *Cathaica pulveratrix*, *C. pulveraticula*, *C. schensiensis*, *Pupilla aeoli*, and *Vallonia* sp. are the most common species that prefer living in relatively cold and dry environments and are presently distributed in the northwest of China. They have been regarded as an indication of strengthened winter monsoon. Conversely, *Metodontia huaiensis*, *M. yantaiensis*, *M. beresowskii*, *Gastrocopta armigerella*, and *Punctum orphana* are species that prefer living in a warmer and more humid environment and are mostly distributed in the southeast part of the Loess Plateau, where the warm and moist summer monsoon carries enough precipitation. The occurrence of these species in the studied sequence implies that a summer monsoon reached the Loess Plateau at that time (Wu et al., 1996, 2001, 2002; Rousseau and Wu, 1997; Rousseau et al., 2000).

As presented herein, the mollusk fossils preserved in the Dongwan section are undisturbed assemblages. The original environments in Dongwan during the late Miocene–Pliocene were definitely terrestrial in terms of mollusk composition. Such interpretation rejects previous speculation of alluvial and lacustrine origins (Bureau of Geology and Mineral Resources of Gansu Province, 1989; Editorial Committee of Stratigraphy of Gansu Province, 1980; Li, 1984) for the Gansu Group deposits in this region. The striking similarity of species composition between the Dongwan section and the Quaternary loess sequence mollusk fauna indicates that analogue sedimentary environments and ecological conditions existed to allow identical mollusk species to live and develop in different periods and areas. The late Miocene–Pliocene deposit at Dongwan section is therefore a typical loess-paleosol sequence, similar to the Quaternary loess-paleosol sequences in the Loess Plateau. Our mollusk results support the eolian origin, which can also be confirmed by sedimentological and geochemical properties (Hao and Guo, 2004). A continuous eolian deposition prevailed from 7.1 to 3.5 Ma in the Qinan region in the western Loess Plateau.

CONCLUSIONS

Our detailed investigation of mollusk fossils from the late Miocene–Pliocene Dongwan section in Qinan yields the first continuous biological record in the western Loess Plateau for this interval. All of the mollusks are terrestrial species, and no freshwater and paludal taxa were found at all in the sequence. The representation of identified individuals supports that the mollusk populations were preserved in their original environment. The similarity of the mollusk compositions between the Dongwan late Miocene–Pliocene section and the overlying Quaternary loess sequence clearly shows the same origin in a sedimentary environment. Thus, the results of our mollusk study support that the late Miocene–Pliocene deposit at Dongwan is a typical loess-paleosol sequence like the Quaternary loess deposits in the Loess Plateau, and thus is of a wind-blown origin, which can also be verified by sedimentological and geochemical properties (Hao and Guo, 2004).

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