Fossil gastropods from the MGS3 stratigraphic segment in the Salawusu River Valley and their climatic and environmental implications

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Contemporaneous with MIS3, the MGS3 segment of the Milanggouwan stratigraphic section in the Salawusu River Valley, Mu Us Desert, China contains fossil gastropods (terrestrial and freshwater snails) in strata 33LS, 35LS, 37FL and 39LS. Examination of these fossils revealed 11 species belonging to 8 families and 10 genera. They can be classified as: (1) assemblage of Gyraulus and Galba mainly consisting of Gyraulus convexiusculus, Gyraulus sibiricus, Galba pervia and Galba superegra Gredler, etc. (2) assemblage of Vallonia mainly consisting of terrestrial snails, such as Vallonia patens, Pupilla muscorum and Discus paupe, etc. Based on the dating results, and the living habits, living conditions, and geographic distribution of their extant species, we suggest that: the ages of 33LS, 35LS, 39LS are 26000, 29000, 33000 and 38000 a, respectively, corresponding well to the interstadial period in GRIP 4, 5, 6 and 10 in terms of chronology and climatic characters; 33LS, 35LS and 39LS represent very warm-humid periods, while 37FL represents a less warm-humid period; the four periods of climatic fluctuations recorded in MGS3 were related to the strong impact of the summer monsoon in East Asia in Mu Us Desert of China during the interstadial of MIS3 on a global climatic background.

Salawusu River Valley, Milanggouwan Section, MGS3 stratigraphic segment, fossil gastropods, climatic environment

Terrestrial mollusk fossils are good indicators for paleoecology and thus were used for reconstructing paleoclimate and paleoenvironment in the Past Global Changes Project (PAGES) for their low ability to migrate, good preservation, huge numbers and ample species. Based on examination and analyses of their species assemblages, configuration features, embedding conditions, and contents of carbon and oxygen isotopes, and comparison of their living habits with those of their extant species, paleo-sedimentary environment were reconstructed qualitatively or quantitatively. Such a method has come to Neocene, especially Quaternary, researchers’ attention. Half a century ago, Leonard1,2 and Frankel3 classified the aeolian sediments in the Great Plains of North America into two biostratigraphic units, Inowan and Tazewellian, based on the distribution of fossil terrestrial mollusk species and their abundance variation. Successively, new advances were made from 1960s to 1980s in the study of fossil mollusks and the paleoecology they indicated in the European conti-
nent\textsuperscript{[4–6]}. In 1990s, Rousseau et al. discovered another two faunas, \textit{P. loessica} and \textit{V. tenuilabri}, and suggested that these two faunas and \textit{Vertigo genesii} were crucial indicator fossils for biogeography and biostratigraphy in the Pleistocene in the European continent\textsuperscript{[7,8]}. Recently, fossil terrestrial snails were more widely used in the research on environment evolution of Pleistocene and Holocene in both Europe and America.

Early researchers emphasized the depiction and classification for the genera and species of fossil terrestrial snails, and stratigraphic division in China\textsuperscript{[9–13]}. In 1980s, one of the authors examined the fossil terrestrial snails from the Luochuang loess section and suggested that \textit{Cathaica} and \textit{Metodontia} represented the cold-dry and warm-moist climates under the control of monsoon activities\textsuperscript{[14,15]}. However, fossil terrestrial snails were not taken as an important proxy for sedimentary environment until the middle 1990s and since then increasingly more studies in this area have been reported, among which the research of Quaternary loess has been especially noteworthy\textsuperscript{[14–20]}. Since the beginning of the 21st century, scholars have come to focus on the Neogene red clay and made some progress in it\textsuperscript{[21–23]}.

All the achievements show that researches on fossil terrestrial snails are very helpful for the understanding of some important scientific problems since Neogene, such as the evolution of monsoon environment, and even the correlative events such as the uplift of the Qinghai-Tibet Plateau, the East Asian monsoon circulation and global climatic correlations.

However, little has been studied on the abundant fossil freshwater snails imbedded in the Quaternary fluviolacustrine facies in deserts and their paleo-ecological and environmental implications. However, the evidences on the desert-lake environmental evolution are fairly credible, as can be seen in the researches of the “Megalake Tengger period” in the Tengger desert in MIS3\textsuperscript{[24]}, and the ebb and flow of lakes during the Holocene megathermal period in the Badainjaran desert\textsuperscript{[25,26]}.

Situated on the southeastern fringe of the Mu Us Desert, on the Ordos Plateau of Inner Mongolia (37°20′–37°58′N, 108°8′–108°48′E), the Salawusu River Valley preserves stratotype-stratigraphic sections of the late Pleistocene in north China\textsuperscript{[27]}. One of the most striking biostratigraphic phenomena is that fossil mollusks are abundant in the Upper Pleistocene series. In the early 1920s, French paleontologist Teilhard de Chardin and his colleagues marked the position of a fossil bivalve “\textit{Sphaerium}” when they studied the late Pleistocene lacustrine facies around Yangsigouwan site in the Salawusu River valley\textsuperscript{[28]}. Since then, and especially since the 1980s, though the fossil freshwater snails have been reported successively in the stratigraphic research\textsuperscript{[29–31]}, there has been no systematic study of the climatic and environmental implications of these fossils. Therefore, we have been there several times and collected some samples of fossil gastropods (terrestrial and freshwater snails) from the MGS3 stratigraphic segment in the Milanggouwan section. In this paper, ecological and environmental conditions are discussed based on systematic study of fossil mollusks, with reference to the analyses of grain-size, contents of SiO$_2$ and Al$_2$O$_3$, and Al$_2$O$_3$/SiO$_2$ ratio.

1 Features of the MGS3 segment in the Milanggouwan stratigraphic section and the assemblage of fossil gastropods

The Milanggouwan section is located on the left bank of the Salawusu River’s middle reaches (Figure 1), about 500 m northeast of the village of Milanggouwan (108°33′05.4″E, 37°45′47.2″N), with the top part of the section at the elevation of 1290 m above sea level. The MGS3 stratigraphic segment, also named as “the middle part of Chengchuan Formation”, corresponds to the last interstadial (MIS3), at depths ranging from 13.63 to 28.42 m\textsuperscript{[30]} (Figure 2). According to a recent investigation, it contains 19 layers of sedimentary units in this segment: 9 layers of aeolian-paleo-mobile dune sands, 4 layers of fluvial facies, 4 layers of lacustrine-swampy facies, and 2 layers of paleosols. To find out the lithologic features for the sedimentary facies of MGS3, we collected 299 samples at an interval of 5 cm (a few samples at an interval of 3 or 7 cm) from the top downwards to the bottom, and analyzed their grain-sizes with a Malvern Mastersizer 2000M analyzer in a measuring range of 0.02 to 2000 μm. The experimental procedure was based on that of the loess grain-size\textsuperscript{[32]} and the results were plotted in Figure 2.

As shown in Figure 2, the paleo-mobile dune sands are almost all sandy deposits mainly consisting of fine sands, loose and evenly sorted. Except for a few samples in some horizons, the silt and clay contents of most samples are very low and even zero. Relatively, the fine