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# The terrestrial mollusks as new indices of the Asian paleomonsoons in the Chinese loess plateau

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**Abstract**

This paper presents the results of a new malacological analysis of the last glacial cycle in the Luochuan loess sequence (China). A high-resolution study of the malacofauna, decomposed into ecological groups, allows the characterization of intervals of strong summer or winter paleomonsoons. The three occurrences of currently southeastern species in the sequence indicate that the climate conditions were warmer and wetter than today at about 88,000, 60,000, and 10,000 years BP. The main occurrence of xeric taxa between 75,000 and 65,000 years is interpreted as drier than today. This result is in good agreement with the variations of the summer and winter insolation at 30°N, as with other independent indices of the paleomonsoons yielded by pedogenic, sedimentologic and modeling studies. 

*Keywords:* paleomonsoons; loess; China; mollusks; last climatic cycle

## 1. Introduction

During the last decade, the Chinese loess sequences were intensively studied by numerous geoscientists. This allowed for the careful reconstruction of the climatic history recorded in these deposits (Heller and Liu, 1982; Kukla, 1987). Measurements of the magnetic susceptibility, for example, allowed to characterize the climatic changes by indicating strong values for the interglacial paleosols and lower values for the glacial loess units (Heller and Liu, 1982; Kukla and An, 1989). These interpretations led to establish some interrelationships between the continental record of the magnetic susceptibility and the eolian content in cores from the Pacific Ocean (Hovan and Rea, 1991), suggesting a close relationship between magnetic susceptibility and winter paleomonsoons records (An et al., 1991).

The study of the grain size of the Chinese loess sequences has allowed to determine that the loess

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material originated from the neighboring deserts (Gobi and Takla-Makan) on one hand, and also to recognize a certain periodicity, on the other hand, showing the influences of the parameters of the astronomical theory of climates (Ding et al., 1992). Recently, the grain size variations in Luochuan was also correlated with the oscillations corresponding to massive icebergs discharges in the North Atlantic during the last climatic cycle (Porter and An, 1995), and also with the variations of the winter paleomonsoon (Xiao et al., 1995).

All these studies highlight the importance of the Chinese loess sequences as a fundamental tool to better understand the paleoclimatology of eastern Asia during the last 130,000 years. Indeed, the loess plateau is, at present, at the northern limit of the Asian summer monsoon (Yoshino, 1978; Zhang and Lin, 1992). We decided thus to achieve a survey of

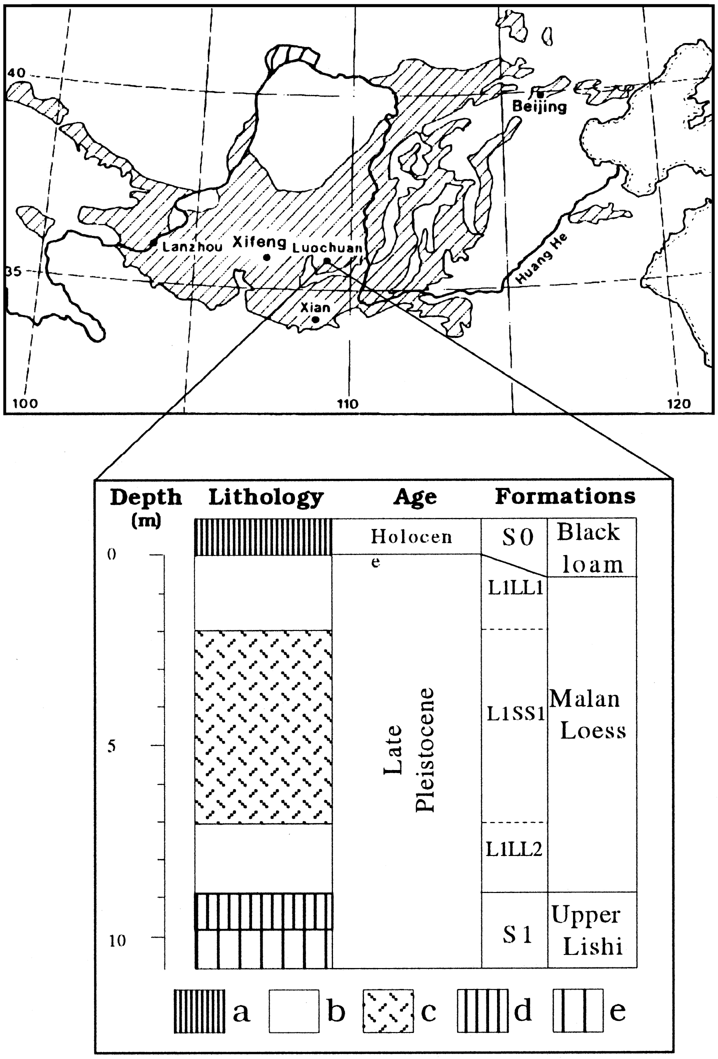


Fig. 1. Location of the studied section in the Chinese loess Plateau (after Kukla and An, 1989, modified). General presentation of the sequence of the last climatic cycle (Upper Pleistocene) in Luochuan. As indicated in the text, the base of the Holocene soil was taken as reference for the depth measurement. (a) Humiferous soil, (b) loess, (c) weathered loess, (d) bioturbated soil, (e) soil B with carbonate nodules at its bottom.

the terrestrial malacifauna of the Luochuan sequence in order to seek if the mollusks registered some synchronous variations to those indicated by other paleomonsoon indices.

## 2. Stratigraphy and method

The last climatic cycle in the Chinese loess sequence corresponds to the succession of a soil complex named S1, a loess L1 decomposed in a first loess sub-unit L1LL2, one weekly weathered loess L1SS1, and a second loess sub-unit L1LL1 (Kukla and An, 1989). A soil SO overlays this succession that occurs identical in all loess plateau. S1 belongs to the stratigraphic formation named Upper Lishi, L1LL2–L1SS1 and L1LL1 sub-units to the so-called Malan Loess formation, and SO to the Black Loam formation (Kukla and An, 1989). The numerous dates by thermoluminescence (Forman, 1991) and the interrelationships with the oceanic cores allow to establish the following chronolgy. S1 represents the continental equivalent of oxygen isotope stage (OIS) 5, L1LL2 stage 4, L1SS1, stage 3, L1LL1 stage 2 and SO, the stage 1 that is the Holocene (Kukla et al., 1990) (Fig. 1).

The town of Luochuan is situated 190 km to the northeast of Xian (Fig. 1). The sampled sequence is located near the Potou hamlet, at about 4 km southwest of Luochuan, on the slope of one numerous gullies bordering the Heimugou river. Luochuan (mean yearly precipitation = 500 mm, mean yearly temperature = 9°C; Liu et al., 1985) undergoes the impact of the summer monsoon characterized by strong precipitation, and the influence of the winter monsoon implying rigorous winters in relation with the displacement of cold air masses bound to Siberian high pressure cell (Zhang and Lin, 1992).

The studied section was prepared by cleaning a 2-m width column in order to clearly read the stratigraphy. The complex of brown paleosols S1 is then 1.9 m thick, the L1LL2 loess: 2.1 m thick, L1SS1 weathered loess: 4.9 m thick, and the L1LL1 loess: 1.8 m thick (Fig. 1). SO as measured on the studied section is 1 m thick. However, only the lower 70 cm could be considered as the human activity reworked strongly the upper part. This is why we interpreted the basis of SO as a stratigraphic reference.

The magnetic susceptibility (MS) was measured each 10 cm in the loess and each 5 cm in the soils, from the basis of S1. We used a portable suscepti-

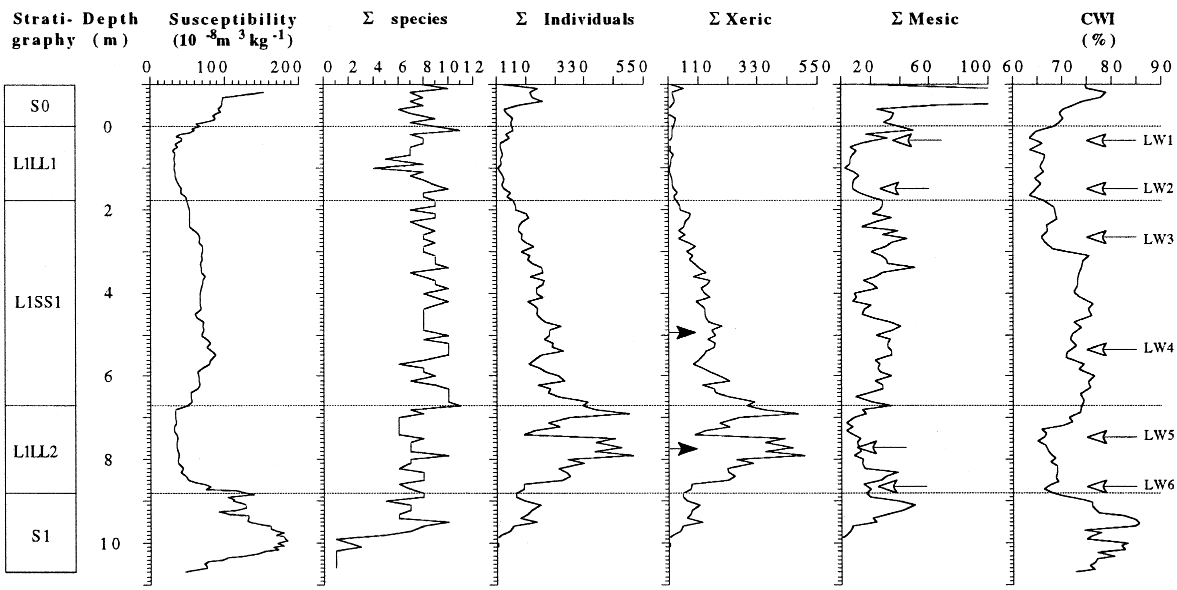


Fig. 2. Variation of the magnetic susceptibility in Luochuan during the last climatic cycle. On the left, Kukla's (1987) readings. On the left, this study.

bilimeter Bartington MS2 with a MS2F sensor operating a frequency 0.58 kHz. For every analyzed level, 10 measurements were taken and averaged. This allowed us to replace our readings with regard to the previous measurements achieved on the same section, with the same equipment, by George Kukla in 1987 (Fig. 2).

The occurrence of terrestrial mollusks had been indicated previously in Luochuan (Chen et al., 1982) but the particularly loose sampling interval did not permit any comparison with other paleoclimatic data. This is the reason why 118 samples of 10 l of sediment were taken continuously on the whole sequence, parallel to the magnetic susceptibility readings for the mollusk study. The samples were washed and sifted (the smallest mesh being 0.5 mm width), the mollusk shells (broken or complete) being pick out using a binocular. All the identifiable remains were considered for the counting of the number of individuals (NI) according to the procedure described by Puisségur (1976). Almost all the sampled levels contain some shells of terrestrial mollusks. However, NI number varies between 1 and 512.

## 3. Results and discussion

The values of the magnetic susceptibility (MS) vary between 30 and $190 \times 10^{-8}$ $m^3$ $kg^{-1}$ (Fig. 2). The strongest values are in the soil S1. From the basis of the studied section, MS quickly increases from 45.9 to $184.5 \times 10^{-8}$ $m^3$ $kg^{-1}$. The MS values decrease thereafter mostly relatively progressively to reach $31.4 \times 10^{-8}$ $m^3$ $kg^{-1}$ in L1LL2. The upper part of S1 is characterized by several oscillations corresponding to the soil succession characterizing the pedocomplex S1. The S1–L1LL2 transition is marked by a very abrupt lowering of the MS values. From the top of L1LL2, MS increase again. Within L1SS1, MS presents a minimum value of $60 \times 10^{-8}$ $m^3$ $kg^{-1}$ at a depth of 4.5 m, the lower and upper parts of L1SS1 indicating higher MS values. Finally, MS decreases again progressively in L1LL1 to reach $30.7 \times 10^{-8}$ $m^3$ $kg^{-1}$ at 0.6 m depth. Therefater, the values of MS increase and are of $104 \times 10^{-8}$ $m^3$ $kg^{-1}$ at 0.7 m above of the L1/SO limit (Fig. 2).

In the upper half of the S1 complex, NI varies parallel to MS (Fig. 3). From the S1/L1LL2 limit,

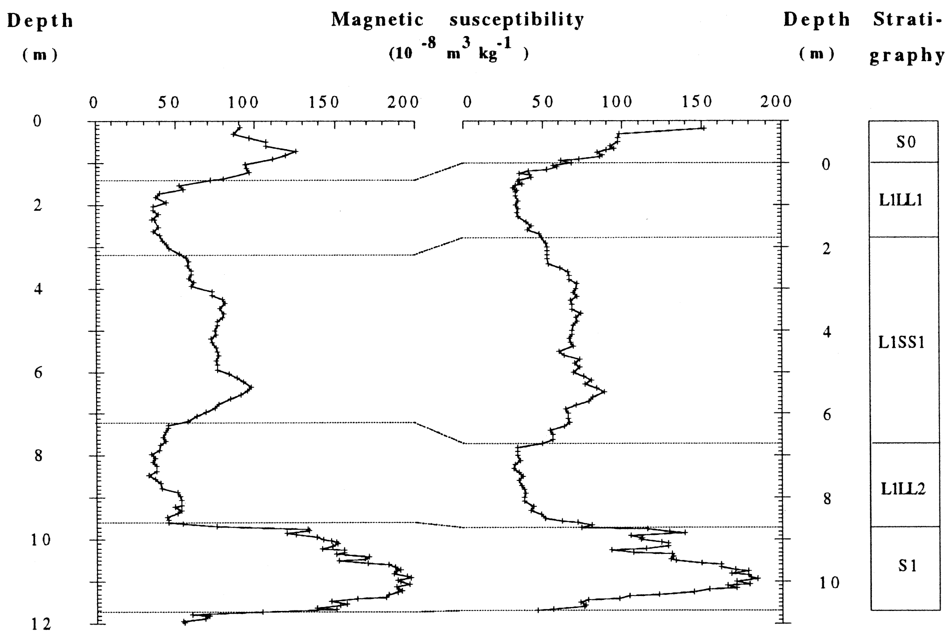


Fig. 3. Variation of the magnetic susceptibility, the total numbers of individuals, of species, of xeric, and of mesic taxa expressed vs. depth (counts are expressed in number per unit volume −10 l of sediment). Comparison with the CWI index (Guo et al., 1996, modified) with indication of the Low Weathered Intensity (LWI).

NI increases very quickly from 73 to more than 277 individuals per sample at 8.40 m depth. The sub-unit L1LL2 indicates the highest values of NI in the sequence: 512 at 7.90 m and 495 at 6.90 m with however a minimum of 103 individuals associated to low MS values. Thereafter, in the L1SS1 and L1LL1 sub-units, NI indicates a relatively regular trend to decreasing values reaching a minimum of seven individuals per sample at 1 m depth. NI increases to the top of L1LL1 and then in SO (Fig. 2). The variation in the number of individuals at Luochuan does not present therefore any parallel trend to the one of the magnetic susceptibility contrary to the results obtained for the glacial maximum loess sequence at Eustis (USA) (Rousseau and Kukla, 1994).

The mollusk species identified in the sequence of Luochuan are also present today in Asia. This allows for the interpretation of the variations of the fossil mollusk communities by using the present ecological characteristics and their present geographical distribution. Two main groups can be distinguished. The first gathers xeric taxa: *Vallonia tenera*, *Pupilla aeoli*, *Cathaica richtofeni*, *C. pulveratix*, and *C. pulveraticula*. The second corresponds to mesic taxa and includes *Macrochlamys angigyra*, *Opeas striatissimum*, *Vitrea pygmaea*, *Gastrocopta armigerella*, *Punctum orphanum*, *Metodontia yantaiensis*, *M. huaiensis*, *M. beresowski*, *Kaliella lamprocystis* and *Succinea* sp. If the paleomonsoons did exercise a similar control to the present on the environment, the variations of the two mollusk groups must be susceptible of characterizing some dominant paleomonsoons. Thus, winter paleomonsoons will be expressed through high number of xeric individuals on one hand, while dominant summer paleomonsoon would be characterized by high values of the mesic taxa on the other hand.

The variations of the xeric and the mesic taxa during the last climatic cycle seem to indicate alternating intervals of strong winter or summer monsoon (Fig. 3). Within L1LL2, the high number of xeric individuals corresponds to low values of the mesic counts. This shows that during the deposition of L1LL2, the environmental conditions were mostly driven by a dominant winter monsoon system preventing too much moisture to reach the studied area. On the contrary, L1SS1 is the better characterized by two maximums in the mesic taxa. In the meantime, the xeric taxa are not indicating any particular trend. Finally, L1LL1 loess sub-unit is marked by very low values of both indices indicating particularly strong conditions. On top, S0 is characterized by particularly strong mesic values. The comparison of the mollusk results with an independent indicator of the paleomonsoons determined from pedological investigations confirm our previous interpretations. CWI, the chemical weathering index (Guo et al., 1996), shows high values in the soils than in the loess.

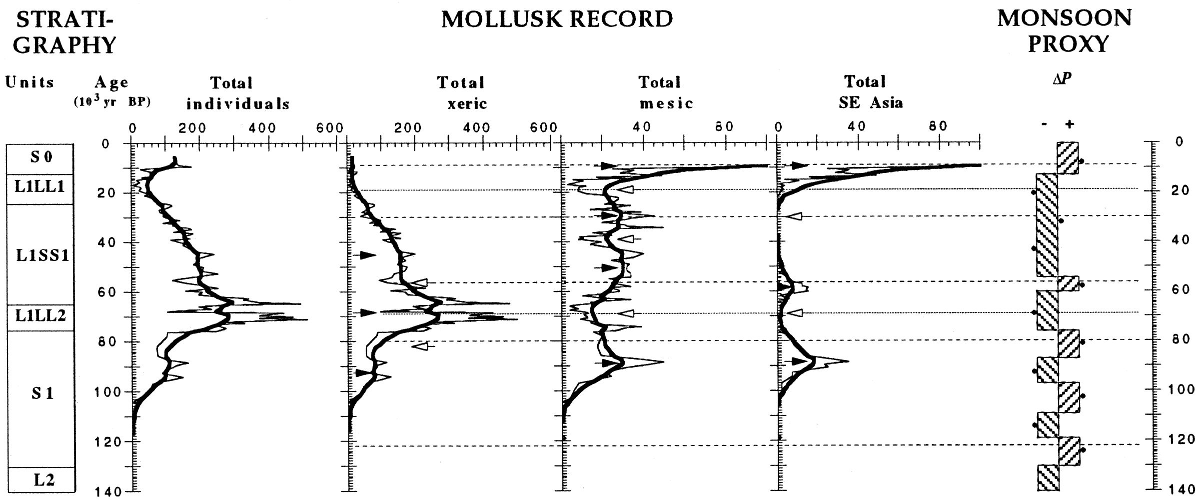


Fig. 4. Variation of the total numbers of xeric, mesic, and Southeast Asia individuals during the last 140,000 years BP. Comparison with the summer and winter insolation at 30°N (Berger, 1978) expressed as departures from the present values.

However, six intervals of particularly low weathering (LW1 to LW6) are determined during the last Climatic Cycle in Luochuan in relation with a decrease in the summer monsoon activity. The corresponding intervals are clearly identified within L1LL1 (LW1 and LW2) and L1LL2 (Wl5 and LW6) and are in agreement with the mollusk fluctuations. Some inconsistency still remains during L1SS1 although this could be due to a sampling procedure.

The trends in the magnetic susceptibility recognized during this study are in complete agreement with the variations previously determined by Kukla and An (1989) (Fig. 2). This will allow us to interpret our results by using the chronological scale based on the susceptibility age model (Kukla et al., 1990), interpreted to be more accurate (Guo et al., 1996). The variations of the two ecological groups is then compared, during the last 130,000 years, with those of the insolation at 30°N (Berger, 1978), interpreted as driving the variations of the paleomonsoons (Prell and Kutzbach, 1987).

The winter insolation (January, February and March) and the countings of the xeric taxa indicate a relative good agreement their respective variations (Fig. 4). Indeed, each maximum in the insolation, implying a reinforced winter monsoon, corresponds to a maximum in the xeric mollusk group. This expresses notably during the isotope stage 4 during

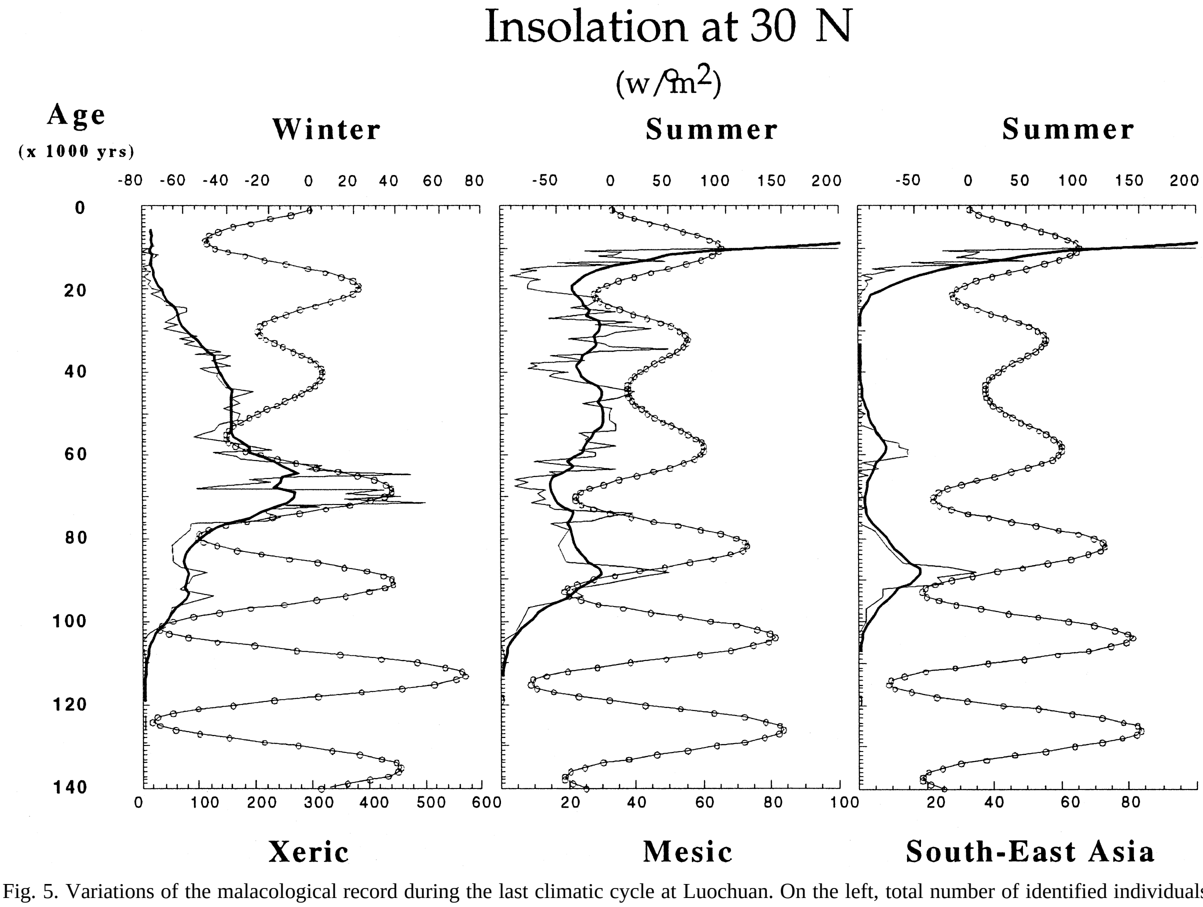


Fig. 5. Variations of the malacological record during the last climatic cycle at Luochuan. On the left, total number of identified individuals; center left, total number of xeric individuals; center right, total number of mesic individuals; right, total number of oriental (southeastern) individuals, all expressed as individuals per volume of sediment (10 l). The thick lines correspond to the respective smoothed curves. Comparison with the monsoon proxies deduced from modelling ($\Delta$P) (from Prell and Kutzbach, 1987),+and − indicate positive and negative values of the precipitation index. W and S indicate indices of strengthened winter or summer monsoon. The dark circles point the peak values for each proxy, while the arrows point the maximums (dark) and the minima (white) in the mollusk curves.

which xeric taxa indicate high counts. This interrelationship does not appear however valid for the last glacial maximum during which, on the contrary, a decrease in the total number of individuals is noticed (Fig. 3).

The comparison between the summer insolation (June, July and August) and the mesic taxa indicates also a relative good agreement between the two signals. However, toward 80 kyears a disagreement between both indices appears. The mollusk record seems to lead the insolation variation. On top of the sequence, the agreement between the two signals appears on the other hand particularly clear. Among the mesic taxa, *Macrochlamys*, *Opeas*, *Vitrea*, *Gastrocopta* and *Punctum* characterize warm and moist environments as their present Southeast Asia distribution indicates. The variation of this sub-group during the last cycle shows three maximums toward 88,000, 60,000 and 10,000 years BP, the last one being the most important. Except at 88,000 years, these maximums are in phase with the maximums of summer insolation (Fig. 4). This interrelationship indicates therefore that by three times during the last 100,000 years, the mollusks recorded particularly warm and humid climatic conditions allowing the south Asian species to develop and grow. This indicates a reinforcement of the summer monsoon toward 88,000, 60,000 and 10,000 years therefore. A similar interpretation can be suggested concerning the winter monsoon for which the mollusks recorded strengthened conditions toward 70,000 years.

The comparison of these results with other independent paleomonsoon indices, determined by GCMs (Prell and Kutzbach, 1987) or grain size studies (Xiao et al., 1995), allows to support the relevance of the mollusk interpretation (Fig. 5). Indeed, the variation of the different sub-groups previously defined is in agreement with the variations of this proxy-data. However, the grain size analysis of the sequence of Luchuan by Xiao et al. (1995) allows the characterization that the last glacial maximum was an interval during which the winter monsoon was particularly reinforced. Such a strength would imply particularly strong conditions of life expressed notably by some violent northeast winds during the last glacial maximum, which would have affected particularly the mollusk populations even among the most tolerant species to rough conditions which occurred. These organisms considerably reduced the number of individuals. This trend is also expressed through a drop in the total number of species (Fig. 3).

## 4. Conclusion

The study of the terrestrial mollusks of the sequence of the last climatic cycle in Luochuan (Chinese loess plateau) allows to indicate the presence of individuals in almost all the analyzed samples. The combined survey of the magnetic susceptibility and of the mollusks indicates an abrupt variation in the number of individuals at S1 interglacial soil complex—L1LL2 loess limit. The grouping of the species according to their ecological characteristics (xeric, mesic and Southeast Asia) allowed to present variations in the number of individuals in agreement with those of the winter and summer insolation at 30°N, main orbital parameter controlling the Asian paleomonsoons (Prell and Kutzbach 1987). These ecological groups indicate also some variations which are in agreement with other independent pedological, sedimentological or issued from GCMs. The mollusk analysis demonstrates that by three times the summer monsoon is reinforced permitting the immigration and the development of southern Asian taxa in the region of Luochuan. The mollusks also recorded a reinforcement of the winter monsoon during the isotope stage 4. A strong decrease of the total individuals and of the number of species during the last glacial maximum could correspond to particularly strong conditions linked to strongly windy winter monsoon during the isotope stage 2.

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