New developments in the study of loess in China

Loess in China provides a good record of global change and has drawn extensive attention from geologists all over the world. By strengthening such research it may be possible to make new contributions to the study of global change.

Loess in China provides perhaps the most complete Quaternary continental record in the world. Among the most important past achievements are: compilation of typical profile maps in various areas; successful correlations between rock stratigraphy, biostratigraphy, climatostratigraphy and magnetostratigraphy; discovery of palaeoclimate cycles of loess-palaeosol dated at 2.5 Ma and correlated with deep-sea oxygen isotope records; establishment of a loess-palaeosol stratigraphic time scale tied to palaeomagnetic events and using improved dating techniques; and determination of the environmental evolution of the Loess Plateau.

In recent years, new understanding of loess stratigraphy has been obtained and short-term palaeoclimatic changes have been thoroughly studied. The semi-quantitative study of palaeoclimate has been successful and some initial progress has been made in the study of spatial palaeoclimate variation based on studies of specific palaeosol layers.

New understandings

Based on recent research on two loess profiles in Huangling and Baoji, Shaanxi Provinces respectively, a stratigraphic classification and correlation according to magnetostratigraphy, spore-pollen biostratigraphy, soil climate stratigraphy, rock stratigraphy and chronostratigraphy are proposed (Figure 1).

Magnetostratigraphy

This is basically identical with the previously reported conclusions (Liu Tungshen et al., 1985; Zhang Zonghu et al., 1983). The main magnetostratigraphic boundaries are:

- The Brunhes/Matsuyama (B/M) boundary is in the lower part of loess layer L₈;
- The top of Jaramillo event in the Matsuyama reversed epoch is near the juncture of palaeosol S₁₀ and loess L₁₁ and its bottom is in the middle of loess layer L₁₃;
- The other boundaries are as previously reported.

In addition, at the top of Matsuyama reversed epoch (upper L₉) there is a polar abnormal zone which received little attention in the past. Through analysis, it can be correlated with the 'B/M precursor'. In the upper part of L₁₅, there is another short-term polar abnormal zone, which may be equivalent to the 'Cop Maintain'. The detection of these short-term abnormal phenomena is of great help in deter-

Figure 1 Stratigraphic divisions of a typical loess profile, Shaanxi, China.

mining the absolute time scale of loess sequences and making global comparisons of palaeoclimate and palaeoenvironment.

Spore-pollen biostratigraphic divisions

Four spore-pollen biological climate zones have been designated as follows:

- 1 from the top of profile to the top of palaeosol S₄;
- 2 from palaeosol S₄ to the bottom of palaeosol S₈;
- 3 from L₉ to S₂₀, and
- 4 from L₂₁ to the bottom of whole loess profile.

Table 1 Dominant soil types in various soil climate zones.

Order	Dominant soil	Colour	Structure	Clay skin	Pore space	Representative bed
1	black loam	dark greyish brown				S ₀
2	deep-brown earth	deep brownish yellow	columnar	abundant	more	S ₄₋₇ , S ₅
3	brown earth	brownish yellow deep brown	lump	less	less	S ₆ , S ₈
4	brown earth	brownish yellow	granular	least	more	S ₁₄
5	brownish red soil	brownish red		none	less	S ₂₀

The numbers in column 1 are equivalent to those in Figure 1, column 6.

Soil climatic stratigraphic divisions

Palaeosols are important components of loess sequences and contain a great amount of information about palaeoclimatic and palaeoenvironmental change. From the view point of soil climate stratigraphy, five soil climate zones have been recognised. From the top to the bottom they are:

- 1 S₀ (near the ground surface is a black loam layer);
- 2 from L₁ to the middle of S₄;
- 3 from the middle of S₄ to the top of S₉;
- 4 from the top of S₉ to the bottom of S₁₅; and
- 5 from the bottom of S₁₅ to the bottom of whole loess sequences.

The soil characteristics of each zone are shown in Table 1.

Rock stratigraphic divisions

Loess in China is transported and accumulated by various geological agents under certain climatic conditions and formed through loessification. The rock stratigraphic units have been divided on the basis of rock, loess and palaeosol properties.

- 1 Holocene series: composed of black loam layer (S₀);
- 2 Late Pleistocene series: from the top of L₁ to the bottom of L₄;
- 3 Middle Pleistocene series: from S₄ to the bottom of L₉;
- 4 Early Pleistocene series:
upper part: from S₉ to the bottom of L₁₅;
lower part: from S₁₅ to the bottom of loess accumulation.

Chronostratigraphic divisions

The chronostratigraphic divisions have been set according to the time scale determined by the magnetostratigraphic analysis and international correlation principles:

- 1 The Q₄/Q₃ boundary is at the bottom of S₀, at about 10 Ka;
- 2 With regard to the Q₃/Q₂ boundary, so far there is no clear evidence. It is temporarily placed somewhere between S₂ and S₄ based on rock- and biostratigraphy. A precise age for this boundary has yet to be determined;
- 3 The Q₂/Q₁ boundary is determined to be at the top of S₈ by magnetostratigraphic chronology, about 0.73 Ma;
- 4 The Q₁/N boundary is at the bottom of the loess sequence, coincident with the Matsuyama/Gauss polarity boundary of 2.48 Ma.

New progress

Palaeoclimate research on loess in China began several decades ago and some advances in the understanding of Quaternary climatic changes have been made. For example, the use of high-precision dating techniques, have led to the establishment of short-duration palaeoclimatic changes. By means of correlation analysis, past climatic change has been quantified, and based on a study of time

sequences, the spatial regularities of palaeoclimatic evolution have been probed.

Further understanding of past global changes requires a strengthening of research on the last glacial-interglacial cycle and on post-Holocene continental records to complement the palaeoclimatic interpretation of loess in China for these time periods.

It is well known that the magnetic susceptibility of loess strata can reflect climatic changes and this has already been used in correlation between land and ocean and in research into past global changes (Heller et al., 1984;

Kukla, 1987). With this index and high-precision dating method, the climatic evolution since the Holocene epoch in the Loess Plateau has been analysed and it is found that there were low-frequency climatic fluctuations of relatively short span in the Holocene (Figure 2). The analysis shows that the climate in the Loess Plateau began to become warmer after the last pleniglacial. During that period, around 10.3 Ka, a sudden drop in temperature within a very short time, occurred, possibly in the Younger Dryas stage. Afterwards, the temperature continued to rise very slowly. At approximately 9.3 Ka, the speed evidently quickened, heralding a postglacial optimal period which lasted until 6.7 Ka. However, this high-temperature period was not stable. There were three relatively cold periods, and two small fluctuations of cold climate, that is to say, during the period 9.3–6.7 Ka there were second-order low-frequency fluctuations in climate against a general warm-humid background and also the climate became warmer and warmer reaching a peak around 6.7 Ka. After that, the postglacial optimal period ended and the temperature began

Figure 2 Holocene magnetic susceptibility curve for loess of the Loess Plateau. Y.D. = Younger Dryas

to fall until 5.5 Ka. Since then, the climate has fluctuated frequently against a background which was cooler than in the optimal period. Two more evident cold periods occurred around 4 Ka and 3 Ka respectively.

These basic features of Holocene climate recorded by the loess, including the instability of climate in the warm period 9.3–6.7 Ka and the cold periods in 4 Ka and 3 Ka, can be correlated with the Holocene climate records in other regions of China (Kukla, 1987; Wu Xihao et al., 1994) and also with the cold periods divided by glaciers since the Holocene epoch in the Northern Hemisphere (Denton et al., 1993).

Palaeoclimatic research on loess in China occupies an important place in the study of global change. From the loess-palaeosol sequences, many indices reflecting palaeoenvironmental change can be obtained and analysis of these indices can provide concrete evidence of past environmental change. The annual average temperature and the annual average precipitation in the last interglacial stage of some areas of the Loess Plateau has been investigated in accordance with the relationship between modern surface spore-pollen and climate. At the same time, an equation describing the relationship between the ferric oxide content in the profiles and local modern average precipitation and temperature has been obtained:

- $Y = (245.675)(X) - (648.787)$ (fitting degree 0.779)
 - $Y^1 = (5.8)(X) - (32.99)$ (fitting degree 0.759)
- where Y is the annual average precipitation (mm);
Y¹ is the average temperature (°C) in January, and
X is the percentage of ferric oxide.

Figure 3 Compound palaeosol section through the Huangling profile S1. L Loess; S Palaeosol

Calculated from the above equations, the annual average precipitation in the Holocene high-temperature period in the central Loess Plateau was 200 mm more than it is nowadays and the average temperature in January was 3°C higher.

The pedological study of loess-palaeosol sequences and the analysis of palaeoclimatic changes from pedogenic data have met with further success in China in recent years. The climate conditions in various regions have been compared through the first palaeosol layer of the Loess Plateau. The results show that this palaeosol is composite and formed during successive periods in which various pedogenic processes operated (Figure 3).

Judged by observations in the profiles of factors such as the leaching and precipitation of CaCO₃, the precipitation of ferric oxide and ferric hydroxide and the distribution of clay skin etc., there were two periods of pedogenesis with contrasting climates. The contents of Al₂O₃, Fe₂O₃ and FeO in the soil during the first period were evidently higher than in the second period and the B layer in the first period became completely decalcified. The soil in the first period was mainly argillic (Bt) while that in the second period was still at the leaching stage (A). This fully demonstrates that temperature and humidity in the first period were markedly higher than in the second one. Further, the climatic conditions in different areas in the same period were also different. For instance, during the first pedogenic period, the climate indicated by the Huangling S1 profile was northern sub tropical while the Xifeng S1 profile indicates southern warm moderate conditions.

For a long time, particular emphasis was laid on time sequences in palaeoclimate research on loess in China. However, such research may also lead to an understanding of the spatial distribution of climatic zones in a specific period. How to further understand these spatial patterns and their mechanisms of formation is no doubt the main challenge to be faced in the future.

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