Pergamon

Journal of Southeast Asian Earth Sciences, Vol. 13, Nos 3-5, pp. 341-346, 1996

0743-9547/96 $15.00 + 0.00

PII: S0743-9547(96)00041-4

Prehistoric vegetation on the Loess Plateau: steppe or forest?

Liu Tungsheng,* Guo Zhengtang,* Wu Naiqin* and Lu Houyuan†

*Institute of Geology, Chinese Academy of Sciences, PO Box 9825, Beijing 100029; and
†First Institute of Oceanography, State Oceanic Administration, PO Box 98, Qingdao 266003, China

Abstract-The paper aims to assess the Holocene natural vegetation on the Loess Plateau before human reclamation, a contentious point in paleo-environmental studies. Coordinated analyses on the soils, phytolith assemblage, organic carbon isotope composition and pollen data from selected sites suggest that the Holocene vegetation on the Loess Plateau was dominated by steppe. During the mid-Holocene, corresponding to the climatic optimum, the southernmost part of the Plateau (Weinan and Xian) was covered by an open meadow steppe with the presence of some coniferous species, while the middle part of the plateau (Luochuan) was covered by steppe. Our results do not support the notion that dense forest cover had developed on the Loess Plateau during the Holocene.

Introduction

The Loess Plateau at the middle reaches of the Yellow River (Huanghe) was the cradle of the ancient Chinese civilization (Liu 1985). For several thousands of years, human activity has caused extensive destruction of the natural vegetation cover and thus it is now impossible to find the virgin soil with climatic vegetation. In the modern geographical division schemes (CCVE 1980; Yang and Yuan 1991), the southern part of the Loess Plateau was classified as a broad-leaved deciduous zone while the northern part as a forest-steppe zone. The boundary in Shaanxi was delimited near Yan'an. It should be mentioned that disagreements still exist as the criteria for the division vary amongst the different authors (Yang and Yuan 1991).

The landscape evolution of the Loess Plateau has been a common objective in many paleo-environmental studies. However, interpretation of the Holocene natural vegetation before human reclamation is still controversial. Certain authors consider that at least the southern part of the Loess Plateau was covered by dense forest (Sun and Zhao 1991), while others infer that the dominant vegetation before the human-induced destruction was herbs (Lin *et al*. 1991; Zhu and Zhu 1991). Although many palynological studies have been carried out to assess the variability of natural vegetation, there are still considerable disagreements between the results obtained. This is probably due to the small amount and uncertain origin of pollen in loess (Kukla 1987). Moreover, it seems that the quantity and combination of pollens extracted from loess depend upon the protocols of analysis which vary for different laboratories.

The loess-soil sequence in China is one of the few continuous continental records of paleoclimate of the last 2.5 Ma (Liu 1985; Kukla 1987). Interpretation of the Holocene natural vegetation on the Loess Plateau is of special importance in loess-based paleo-climatological studies as it usually serves as the basis for interpreting the environmental conditions under which the older sequences were formed. It also provides the basic information for estimating the human impact on environmental changes.

In recent years, peleopedological evidence (Bronger and Heinkele 1989; Guo 1990; Guo *et al*. 1991; Guo *et al*. 1993a; Guo *et al*. 1993b), analyses of phytolith (Lu *et al*. 1991; Wu *et al*. 1992) and carbon stable isotope data (Lin *et al*. 1991) from the loess-soil sequence have provided valuable information on the landscape evolution of the Loess Plateau. The wide distribution of the Holocene soil on the Loess Plateau provides an opportunity to assess the spatial variability of natural vegetation cover. The major advantage of phytolith in loess, especially when preserved in large amounts, is that it facilitates the identification of the plants combination.

This paper aims to characterize the Holocene natural vegetation on the Loess Plateau, especially that covering the plain areas (*yuan* areas) through a multi-approach. Our study is based on: (1) paleopedological results from the loess sections of Weinan and Luochuan; (2) phytolith analyses from the Holocene soils of the Weinan, Baoji and Lanzhou sections; (3) carbon isotope data from Xian and Luochuan sites (Lin *et al*. 1991); and (4) selected Holocene pollen data reported in earlier works (Yang and Yuan 1991). Combination of these data provides a fair picture of the Holocene natural vegetation on the Loess Plateau before human reclamation. The location of the studied sites is shown in Fig. 1.

Soil evidence

The Holocene soils (SO) in Weinan and Luochuan were selected in this study because the geographic location of these sites allow a better inference on the natural vegetation on the entire Loess Plateau. The Weinan section is located at the southernmost part of the Loess Plateau (Fig. 1), climatically within the most temperate and humid region of the plateau. The Luochuan section is located at the middle part of the plateau, about 100 km south to the boundary between the inferred modern broad-leaved deciduous zone and the forest-steppe zone (Yang and Yuan 1991; Sun and Zhao 1991). A field description of the soils is given in Table 1 and the major chemical properties are listed in Table 2.

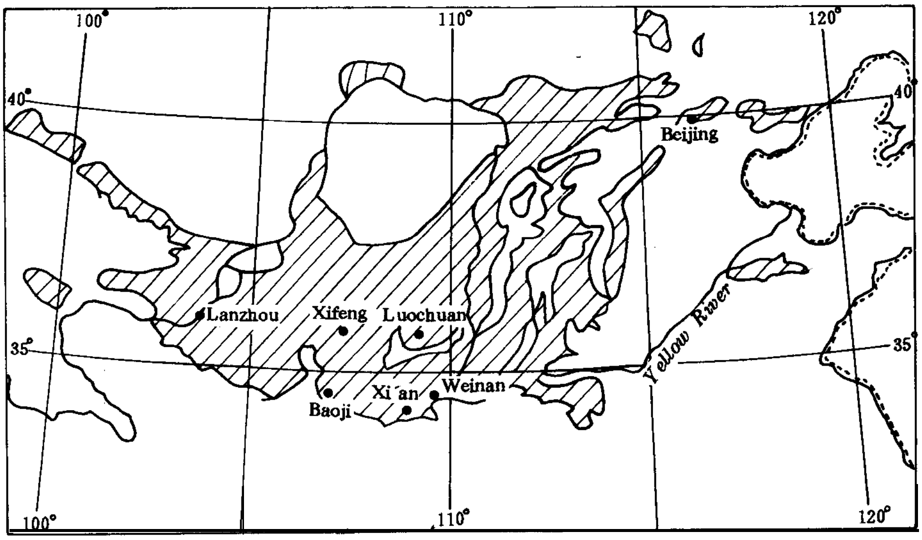

Fig. 1. Location of the studied sites.

Holocene soil in Weinan

The upper part (Ap) of the soil was strongly reworked by human activity as indicated by the abundant charcoals and brick pieces. An argillic horizon (Bt) is well preserved at the lower part, underlain by a Ck horizon (Table 1).

The pH values vary between 7.4 and 8.3, suggesting slightly alkaline environments. The exchangeable cations are dominated by Ca^{2+} and Mg^{2+} and the adsorb complex is saturated. The free iron content varies from 1.02 to 2%, indicating limited weathering degree. The decrease of SiO_2/Al_2O_3 ratio and the increase of free iron content in soils suggest weak pedological enrichment of Fe-Al oxides and hydroxides. Earlier study (Guo *et al.* 1993b) on the Holocene soil in the nearby Xian loess section (55 km west of Weinan) revealed that the clay mineralogy is dominated by 2: 1 type. The soil contains illites, kaolinite, chlorites, vermiculites, smectites and interstratified minerals. The major difference from the underlying loess layer is the slight increase in the content of vermiculites and the decrease of chlorites, suggesting that the weathering is in the stage of ***bisiallitisation*** (Pedro 1979).

Micromorphologic investigations show that all the soil horizons have dense incomplete excremental infilling microstructure with abundant biopores (12–15%), typical of steppe dominant soil with mollic epipedon (Pawluk and Bal 1985). The dense excremental infillings imply that the soil profile can be temporarily water-saturated (Courty and Fedoroff 1985). This is in agreement with the Fe-Mn hypocoatings (1–2%)

Table 1. Macromorphology of the Holocene soils at Weinan and Luochuan

Site	Depth (cm)	Horizon	Texture	Colour	Structure	Other characteristics
Weinan	0–20	Ap1	clayish silt	brown (7.5YR4/4)	moderate-large granular	some brick pieces and charcoals, abrupt lower boundary
	20–34	Ap2	clayish silt	brown (7.5YR4/6)	moderate-large granular	some brick pieces and charcoals, abrupt lower boundary
	34–70	Blt	silty clay	brown (7.5YR4/6)	strong-large granular, fine-loose granular substructure	high humus content, 5% carbonate specks some clay coating (5YR3/6), gradual lower boundary
	70-105	B2t	clayish	dark brown (7.5–5YR4/6)	strong-large granular	more humus, carbonate specks (5–7%) and clay coatings (5YR3/4), gradual lower boundary
	105-143	B3	clayish silt	brown (7.5YR4/6)	moderate-large granular	10% carbonate specks and ***pseudomycelia***
	143-153	Ck	silty	brown (10YR4/6)	massive to weak granular	20% carbonate ***pseudomycelia*** and specks
Luochuan	0-40	Ap	silty	brown (10RY6/3)	loose granular	massive structure at lower part, some brick and ceramic pieces
	40-85	AC	clayish silt	dark brown (10–7.5YR4/2)		some ***pseudomycelia*** at the lower part
	85-l 10	Ck	silty	brown (10YR7/4)	massive with biopores	abundant ***pseudomycelia***

Table 2. Chemical properties of the Holocene soils at Weinan and Luochuan

Site	Horizon	pH (water)	CEC (cmolc kg-' earth)	Exchangeable cations (cmolc kg- earth)				Free iron % (CBD method)	Clay SiO_2/Al_2O_3 molecular ratio
				Ca^{2+}	Mg^{2+}	Na^+	K^+		
Weinan	Blt	8.00	23.82	22.39	0.60	0.18	0.25	1.36	3.94
	B2t	7.90	27.92	26.74	0.55	0.23	0.32	1.92	3.68
	C	8.30	17.85	15.86	0.67	0.36	0.21	1.02	4.23
Luochuan	AC	8.75	18.50	15.30	2.20	0.23	0.27		
	Ck	8.65	13.40	8.40	4.45	0.20	0.35		
	C	8.50	8.25	5.15	2.35	0.45	0.35		

around the biopores. The fine fraction (< 5 m) is dark reddish-brown and humus-rich, containing some reddish-brown iron particles, indicating brunification and weak rubification of the fine fraction. The clay coating (~ 5%) are dark brown (humus-rich), slightly dusty and non-laminated with moderate birefringence. According to Fedoroff and Goldberg (1982), this type of humus-rich clay coating is usually associated with vegetation containing some species providing fulvic acid in relative abundance (e.g. coniferous trees). The above features, combined with the chemical properties suggest an ***ustic*** soil water regime and a ***mesic*** temperature regime (Soil Survey Staff 1975). This soil can be classified as ***Luvic phaeozem*** in the FAO classification system (FAO-UNESCO 1974), ***Argiustoll*** in the U.S.A. system (Soil Survey Staff 1975), ***Brunizem lessive*** in the French ecological system (Duchaufour 1983) and a transition type of ***Helu soil*** and ***Luvic thermo-black soil*** in the new Chinese soil classification system (STCRG 1991). The vegetation was dominated by dense steppe containing probably some coniferous species.

Holocene soil in Luochuan

Similar to Weinan, the upper part (Ap) of the soil was strongly disturbed by human activity. The lower part of the profile consisting of an AC-Ck horizon sequence is thought to be of virgin soil (Table 1).

Table 2 shows that the weathering environment was slightly alkaline. The exchangeable cations are also dominated by Ca^{2+} and Mg^{2+} and the adsorb complex is saturated. Earlier clay mineralogical study (Liu 1985) indicate that the soil and the underlying loess (Malan loess) have a very similar clay mineralogical association. They contain illites, kaolinites, chlorites and vermiculites. The difference between the soil and loess is expressed by the decrease of the crystallinity of illites in soil, suggesting that the clay minerals were mainly inherited from aeolian dust.

Micromorphological study showed that decalcification had been achieved totally in the upper part of the AC horizon, and partly in the lower part (2% primary carbonates). The fine fraction is humus-rich, containing a great amount of dark charcoal particles. The soil has a typical spongy microstructure resulting from strong biological activity, characteristic of steppe soils with mollic epipedon (Pawluk and Bal 1985). The well-preserved spongy microstructure, consistent with the absence of Fe-Mn, indicates that the water regime has been ***ustic*** and the profiles have rarely been water-saturated (Courty and Fedoroff 1985). The lack of rubification and the significant humus accumulation suggest a ***mesic*** temperature regime of the soil (Soil Survey Staff 1975).

The soil can be classified as ***haplic chernozem*** according to the FAO system, ***vermustoll*** to the U.S.A. system, ***steppe chernozem*** to the French system and ***chernozem*** to the new Chinese system. This type of soil is characteristic of dense steppe regions with semi-arid and seasonally contrasted climate. The dry season is usually too long for the development of forest cover (STCRG 1991).

Phytolith assemblage

Phytolith is a biogenic hydrated silica ($SiO_2.nH_2O$), deposited in epidermal cells of plants. It is resistant to weathering processes and is generally preserved in large amounts in loess. Most of the phytolith can be morphologically identified in line with plant classification (Lu ***et al.*** 1991). For example, dumbbell types of the phytoliths are mostly derived from ***Panicoideas;*** fan square and rectangular types can be produced by all the subfamily of ***Gramineae,*** but the high content of these types is statistically related to the warm and relatively humid conditions; saddle phytoliths are generally derived from ***Eragrostoideae;*** hat and tooth types are only identified in ***Festucoideae;*** and granular, irregular and rugose phytoliths were mainly found in ***Chenopodiaceae*** and some other plants in desertic steppe environments. The major phytolith types in loess in line with plant classification were schematically reviewed (Lu ***et al.*** 1991; Lu and Wang 1991).

The phytolith assemblages in the SO soils of Weinan and Baoji are much similar. During the Holocene climatic optimum, the association is dominated by square and rectangle (30–40%), bar and point (25%), and fan (15%) sharped phytoliths, combined with dumbbell (3–5%), hat and teeth types (5–10%). The irregular and granular types are in small amount. Wooden phytoliths are scarcely observed. This association suggests that the vegetation during the Holocene climatic optimum in Weinan and Baoji was dominated by ***Gramineae*** with an open meadow landscape dominant. In Lanzhou, the phytolith assemblage of the mid-Holocene is dominated by granular and irregular types (40–50%), characteristic of desertic steppe landscape. Bar and point phytoliths represent about 20–30%, combined with hat and tooth types (10–20%). Dumbbell, fan square and rectangular phytoliths represent a total amount of about 10%. Those from wooden plants were not observed. This association indicates an arid steppe vegetation cover.

Carbon stable isotope data

In the soil-loess sequence, the organic carbon stable isotope composition is not only related to climate conditions, but also to vegetation as the mechanisms of photosynthetic pathway vary for different plants (Deines 1980; Luo 1985). C3 plants prefer relatively humid environments and the slow rate of CO_2 uptake results in negative d13C values ranging from −22‰ to −33‰ PDB (Deines 1980). C4 plants adapt generally to the water-stressed environments with strong isolation and high temperature. The d13C values of C4 plants vary from −10‰ to −22‰ (Deines 1980). CAM plants are mainly found in arid environments and the d13C values vary from −9‰ to −34‰ following the environmental factors. The organic carbon isotope composition can, therefore, be regarded as an indicator of paleo-vegetation. The organic carbon isotope composition in the Xian (Duanjiapo, about 50 km southeast of Weinan) and Luochuan loess sections was measured by Lin *et al.* (1991). The d13C values in the Holocene soil vary from approximately −19‰ to −23‰ in Xian, from −19‰ to −22‰ in Luochuan. The results suggest that C4 plants were dominant during the Holocene at both the two sites.

Among the -6000 species of C4 plants, about 5000 species are those in the family of ***Gramineae.*** Other than these, about 1000 species of C4 plants were identified in ***Aceanthaceae, Arizoaceae, Compositae, Chenopodiaceae*** and ***Cyperacea,*** etc. (Wu *et al.* 1992). These results suggest that the vegetation in Xian and Luochuan during the Holocene was dominated by herbs.

Pollen records

Generally, pollen in loess is in small amounts and its origin is thought to be uncertain as loess is a wind-blown sediment (Kukla 1987). Moreover, the carbonate and the microorganism in loess are unfavorable for the preservation of pollen (Sun and Zhao 1991). The pollen records in loess are, therefore, thought to be tentatively significant, although better results from well-selected sites can still be expected.

Loess in the southern part of the Loess Plateau usually contains more pollens as the climate was favorable for greater pollen production. Moreover, the wind strength in the southern regions is weaker than in the northern part and therefore the origin of pollen should be less complicated. We quote here two published works (Yang and Yuan 1991; Sun and Zhao 1991) from the southern part of the Loess Plateau, one from Xian and another from Fuping.

The Xian section is located at the archeological site of Banpo. The Holocene pollen data are shown in Fig. 2, which can be divided into three pollen zones. The lowermost part of the profile (zone I) is dominated by herbaceous pollens (99.5%), among these, *Cruciferae* represents 50.6%, ***Leguminosae*** 10.2% and ***Caryophyllaceae* 7.4%.** The wooden pollens represent only 0.5%. This assemblage indicates a steppe vegetation, corresponding to the Early Holocene. The middle part of the profile (zone 111) is characterized by an increase of coniferous pollens (7.3–31.9%). The assemblage is, however, dominated by herbaceous species (77.7–91.5%). The broad-leaved wooden pollens were found, but in small amounts (1–3%). This zone, corresponding to the Holocene climatic optimum, suggests a dense steppe dominant cover with some coniferous trees. In the upper part of the profile (zone II2), the significant increase in ***Artemisia*** content and the decrease in wooden pollen average content (4.9%) provide evidence for a deterioration of climate during the Late Holocene. The above results indicate that the Holocene vegetation in Xian was dominated by steppe cover. The climatic optimum was characterized by an increase of coniferous species, which is in good agreement with the pedological interpretation.

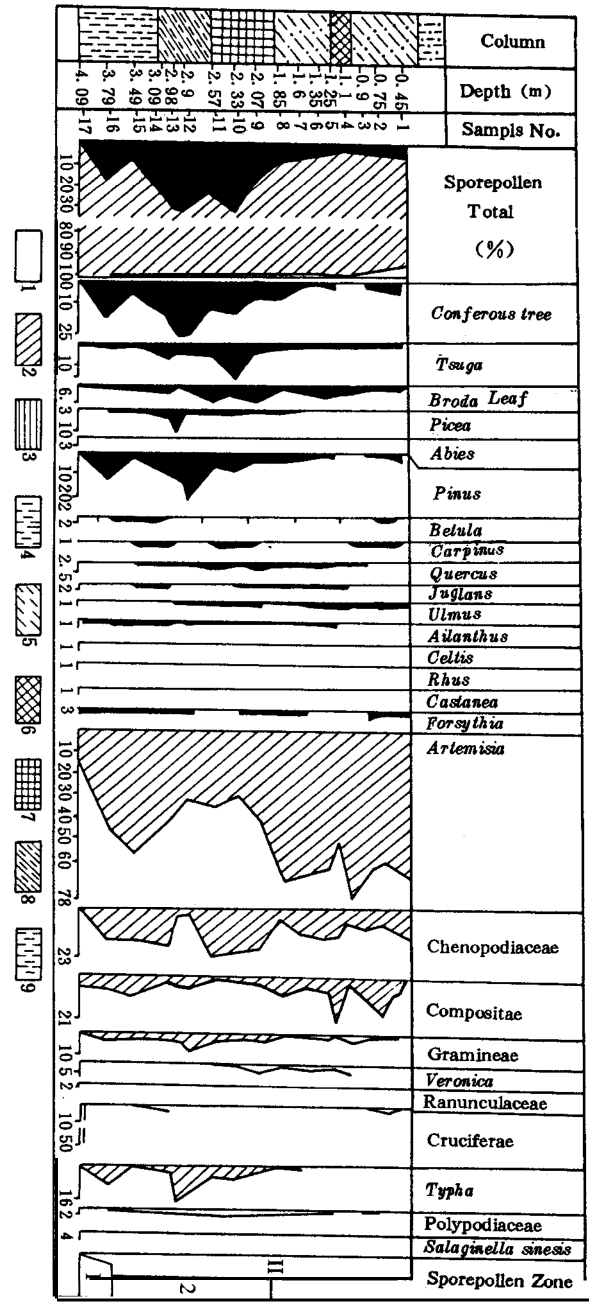

Fig. 2. Pollen diagrams of the Holocene profile in the Xian (Banpo) section (after Yang and Yuan 1991).
1 wooden pollens; 2 herbaceous and shrub pollens; 3 pteridophyte pollens; 4 cultivated horizon; 5 grey-brown loess-like earth; 6 yellow-brown loess-like earth; 7 reddish-brown-grey loess-like earth; 8 brown-grey silty clay; 9 grey-yellow silty clay.

The Fuping section is located at the Yaochun village, about 40 km northeast of Weinan city. The palynological analyses on the Holocene profile were reported by Yang and Yuan (1991) and Sun and Zhao (1991). During the Early Holocene, the pollen assemblage was dominated by *Artemisia* and other herbaceous species (92.3%), suggesting a steppe dominant vegetation cover. Wooden pollens dominated by Pinus represent only 5.9% in average. The mid-Holocene was still dominated by *Artemisia* and other herbaceous pollens (77.8–87.2%), combined with an increase in coniferous species (8.4% on average) and *Quercus* (5.3%). The assemblage of the Late Holocene is characterized by an increase in herbaceous species (83.4%) and a decrease in wooden pollens (9.4% on average), suggesting the deterioration of climate during the Late Holocene. These results allow us to conclude that the vegetation in Fuping during the Holocene was steppe-dominant. The Holocene climatic optimum was expressed by an increase in wooden pollen content, especially that of coniferous species, which is inconsistent with the interpretation of the Holocene soils.

Remarks and conclusion

The results from paleo-pedology, phytolith, organic carbon stable isotope analyses and pollen records suggest that the Holocene natural vegetation on the Loess Plateau was dominated by various kinds of steppes. During the mid-Holocene corresponding to the climatic optimum, the southernmost part of the Plateau (Weinan and Xian) was predominantly an open meadow steppe with the presence of some coniferous species, while the middle part of the plateau (Luochuan) was covered by steppe. Our results do not support the notion that dense forest cover was developed on the *yuan* areas (the plains of loess) of the Loess Plateau, even during the climatic optimum.

Our study does not exclude the possibility of the presence of dense forests in hill or mountain areas as well as in the valleys within the Loess Plateau, since the local ecological conditions could be very different from those of the *yuan* areas. It is commonly accepted that the restrictive factor for the landscape of the Loess Plateau is humidity rather than thermic conditions (An *et al.* 1993). According to our field observations, the presence of forest in the hill and mountain areas may be explained by the lower evapotranspiration at the shady sides favorable to water conservation. The presence of some wooden pollens (e.g. *Quercus)* in loess may be partly attributed to the forests in these areas. This is also consistent with the fact that the loess sections on the fluvial terraces and those close to the mountain areas usually contain more wooden pollens than those in the *yuan* areas.

Acknowledgements-This work was supported by the National Natural Science Foundation of China and the fund of the director of the Institute of Geology, Chinese Academy of Sciences.

REFERENCES

An Zhisheng, Porter, S., Wu Xihao, Kutzbach, J., Wang Sumin, Liu Xiaodong, Li Xiaoqiang, Wang Jian, Zhou Weijian, Xiao Jiayi, Liu Junfeng and Lu Jijun (1993) Holocene climatic optimum in central-eastern China and eastern Asian monsoon. Chinese *Sci. Bull.* **38,** 1302-1305 (in Chinese).

Bronger A. and Heinkele T. H. (1989) Micromorphology and genesis of paleosols in the Luochuan loess section, China: pedostratigraphic and environmental implications. Geoderma 45, 123-143.

Chinese Commission for Vegetation Edition (CCVE) (1980) ***Vegetations in China.*** Science Press, Beijing (in Chinese).

Courty M. A. and Fedoroff N. (1985) Micromorphology of recent and buried soils in a semi-arid region of Northwest India. ***Geoderma 35, 287-332.***

Deines P. (1980) The isotopic composition of reduced organic carbon. In ***Handbook of Environments. Al: Isotope Geochemistry, The Terrestrial Environment*** (edited by Fritz P. and Fontes J. C.), Vol. 1, pp. 329–406. Elsevier, Amsterdam.

Duchaufour Ph. (1983) ***Pedologie, Tome I: Pedogenese et classification.*** Masson, Paris, New York, Barcelone, Milan, Mexico, São Paulo.

FAO–UNESCO (1974) ***Soil Map of the Word.*** Vol. 1, Legend. Paris.

Fedoroff N. and Goldberg, P. (1982) Comparative micromorphology of two late Pleistocene paleosols (in the Paris basin). ***Catena*** 9, 227-251.

Guo Zhengtang (1990) Succession des paleosols et des loess du centre-ouest de la Chine: approche micromorphologique. Ph.D. Diss. University Pierre & Marie Currie, Paris, France.

Guo Zhengtang, Fedoroff N. and An Zhisheng (1991) Genetic types of the Holocene soil and Pleistocene paleosols in the Xifeng loess section in central China. In ***Loess, Environment and Global Change*** (edited by Liu Tungsheng), pp. 93-l 11. Science Press, Beijing.

Guo Zhengtang, Liu Tungsheng, Fedoroff N. and An Zhisheng (1993a) Shift of monsoon intensity on the Loess Plateau at ca. 0.85 Ma BP. ***Chinese Sci. Bull. 38, 586591.***

Guo Zhengtang, Fedoroff, N. and Liu Tungsheng (1993b) Paleosols as evidence of difference of climates between Holocene and the Last Interglacial. ***Quaternary Sci. 1,*** 41-55 (in Chinese with English abstract).

Kukla G. (1987) Loess stratigraphy in China. Quaternary ***Sci. Rev.*** 6, 191-219.

Lin Benhai, Liu Rongmo and An Zhisheng (1991) Preliminary research on stable isotopic composition of Chinese loess. In ***Loess, Environment and Global Change*** (edited by Liu Tungsheng), pp. 124-131. Science Press, Beijing, China.

Liu Tungsheng (1985) ***Loess and the Environment.*** China Ocean Press, Beijing.

Lu Houyuan and Wang Yongji (1991) A study on phytoliths in loess profile and paleoenvironmental evolution at Heimugou in Luochuan, Shaanxi Province since late Pleistocene. ***Quaternary Sci. 1,*** 72-84.

Lu Houyuan, Wu Naiqin, Nie Gaozhong and Wang Yongji (1991) Phytolith in loess and its bearing on paleovegetation. In ***Loess, Environment and Global Change*** (edited by Liu Tungsheng), pp. 112-123. Science Press, Beijing, China.

Luo Yuehua (1985) Ecological significance of C3, C4 and CAM pathways. ***Chinese J. Ecol. 5, 15-27*** (in Chinese).

Pawluk S. and Bal S. (1985) Micromorphology of selected mollic epipedons. In ***Soil Micromorphology and Soil Classification*** (edited by Douglas L. A. and Thompson M. L.), pp. 63-84, SSSA Madison, U.S.A.

Pedro G. (1979) Les conditions de formation des constituants secondaires. In ***Pedologie 2: Constituants et Proprietes du Sol*** (edited by Bonneau M. and Souchier B.), pp. 58-72. Masson, Paris.

Soil Survey Staff (1975) Soil taxonomy: a basic system of soil classification for making and interpreting soil surveys. USDA-SCS Agric. Handb. 436, U.S.A., Government Printing Office, Washington, D.C., pp. l-754.

Soil Taxonomic Classification Research Group (STCRG), Institute of Soil Science, Academia Sinica and Cooperative Research Group on Chinese Soil Taxonomic Classification 1991, ***Chinese Soil Taxonomic Classification*** (1st proposal). Science Press, Beijing.

Sun Jianzhong and Zhao Jingbo (1991) ***Quaternary Geology of the Loess Plateau.*** Science Press, Beijing (in Chinese).

Wu Naiqin, Lu Houyuan, Nie Gaozhong, Wang Yongji, Men Yi and Gu Guoan (1992) The study of phytoliths in C3 and C4 grasses and its paleoecological significance. *Quaternary Sci.* 3, 241-251 (in Chinese with English abstract).

Yang Qinye and Yuan Baoyin (1991) *Environment on the Loess Plateau Regions and Its Evolution.* Science Press, Beijing (in Chinese).

Zhu Xianmo and Zhu Yizhi (1991) A preliminary study on the soil on the Loess Plateau and its environment-a comparison between earth and soil on the Loess Plateau. In *Quaternary Geology and Environment in China* (edited by Liu Tungsheng), pp. 273–279. Science Press, Beijing, China.