Climates of the Past

Editors
J. Meco and N. Petit-Maire

Proceedings of the CLIP meeting held June 2-7, 1995
Lanzarote and Fuerteventura (Canary Islands, Spain)

INTERNATIONAL UNION OF GEOLOGICAL SCIENCES
UNESCO

Earth Processes in Global Change

Universidad de Las Palmas de Gran Canaria
SERVICIO DE PUBLICACIONES

BEHAVIOUR OF THE GLACIAL INTERGLACIAL-GLACIAL TRANSITIONS RECORDED IN CHINA LOESS

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Abstract

Two loess sections in the central Loess Plateau in China are studied to characterise the behaviour of the climatic transition from the penultimate glaciation to the last interglacial and that of the subsequent interglacial-glacial transition. Measurements on free iron and total iron contents and micromorphological observations converge to demonstrate that both transitions were marked by a severe climatic event at millennial scale, which cannot be directly attributed to the orbitally induced insolation changes and ice-volume variations. During these events, the Loess Plateau region was characterised by destruction of vegetation and strong aeolian dynamics, probably in relation with strong winter monsoon winds. Natural fire may have played an important role in the destruction of the pre-existed vegetation.

Introduction

In the recent years, paleoclimatic studies in a number of regions tend to show that the transitions between glacial and interglacial periods were associated with some catastrophic and abrupt events. In the North Atlantic region, the transition from the last glacial period to the Holocene (the last deglaciation) experienced an abrupt and striking cooling event (the Younger Dryas; Overpeck *et al*; 1989) which has been also identified in many other parts of the world (Kudras *et al.*, 1991; Van Camp and Gasse, 1993; Yan and Petit-Maire, 1994), while the termination of the last interglacial (marine $\partial^{18}O$ stage 5) is marked by massive discharge of icebergs into the ocean (Heinrich event 6) associated with the decrease in atmospheric temperature in the circum-Atlantic region (Bond *et al.* 1992). A similar event may have occurred right at the termination of the penultimate glaciation (transition $\partial^{18}O$ stage 6 to 5; Broecker, 1994). The transition of $\partial^{18}O$ stage 5 and 4 was also synchronous with a major volcanic eruption (Toba eruption)

73,500 years ago, which is thought to have greatly influenced the global climates (Rampino and Stephen, 1992). A question arisen is if synchronous changes have been documented in the loess-soil sequence in the Loess Plateau of China, commonly regarded as a near continuous climatic record of Quaternary paleoclimates (Liu, 1985; Kukla, 1987; Kukla *et al.*, 1988). Based on geochemical and micromorphological studies from two loess sections in the central Loess Plateau, this paper aims to study the behaviour of the climatic transition from the penultimate glaciation to the last interglacial and that of the subsequent interglacial-glacial transition.

Materials and Methods

Two loess sections are studied, located at Luochuan (35°45' N, 109°25' E) and Yichuan (36°03'N, 110°10' E) in Shaanxi Province. A stratigraphic summary is given in Figure 1, which is quite similar to that of the other loess sections (Liu, 1985; Kukla, 1987, Kukla *et al.*, 1988; Liu *et al.*, 1995). Since magnetic susceptibility is widely used in characterising the stratigraphic boundaries of the loess-soil sequence in China (Kukla et *al* 1988), it is also measured on dry samples taken at 10 cm intervals using a Bartington susceptibility meter and expressed in SI units (Fig. 1).

In earlier studies (Liu, 1985; Kukla, 1987; Liu *et al*, 1995), the top soil (Holocene soil S0) was correlated with marine $\partial^{18}O$ stage 1 (Fig. 1). The underlying loess unit L1 was correlated with $\partial^{18}O$ stages 2,3 and 4, the soil complex S1 with stage 5 and the loess unit L2 with stage 6. This correlation pattern has been confirmed by radiocarbon and thermoluminescense dating results from different localities (Liu et *al.*, 1988; Forman, 1991; Liu et *al.*, 1995).

In this study, two methods are used to characterise the behaviour of the climatic transitions. Firstly, bulk samples were taken at 10 cm intervals from the lower part of L1, the whole of the S1 soil and the upper part of L2, to measure the ratio of free iron and total iron contents (Fed/Fet, Fed and Fet are expressed as Fe_2O_3 weight percent). Fed is extracted by dithionite-bicarbonate-citrate method (Meha and Jackson, 1960). The ratio Fed/Fet, widely used by European pedologists, is a measurement of iron liberated from iron-bearing silicate minerals by chemical weathering (Duchaufour, 1983), and thus an indication of chemical weathering intensity which is in close relationship with paleoclimatic conditions. It should be mentioned that the possibility of iron translocation in loess can be basically excluded as non evidence of clay illuviation and hydromorphic features were identified. Secondly, thirty-two non-disturbed and oriented samples were taken from the transitional parts (about 1 m in thickness) covering the L1/S1 and S1/L2 boundaries for micromorphological studies. This method proved particularly useful in characterising the abrupt climatic changes recorded in paleosols and eolian sediments (Fedoroff, 1996).

Results and Discussions

Weathering intensity

The variations of the Fet/Fed ratio in the studied sections are shown in Figure 2. The values are much higher in S1 soil than in the overlying and underlying loess. It may be inappropiate to interprete the fluctuations of the ratio within S1 soil since the last one in the Loess Plateau is a soil complex having been affected by three pedogenic

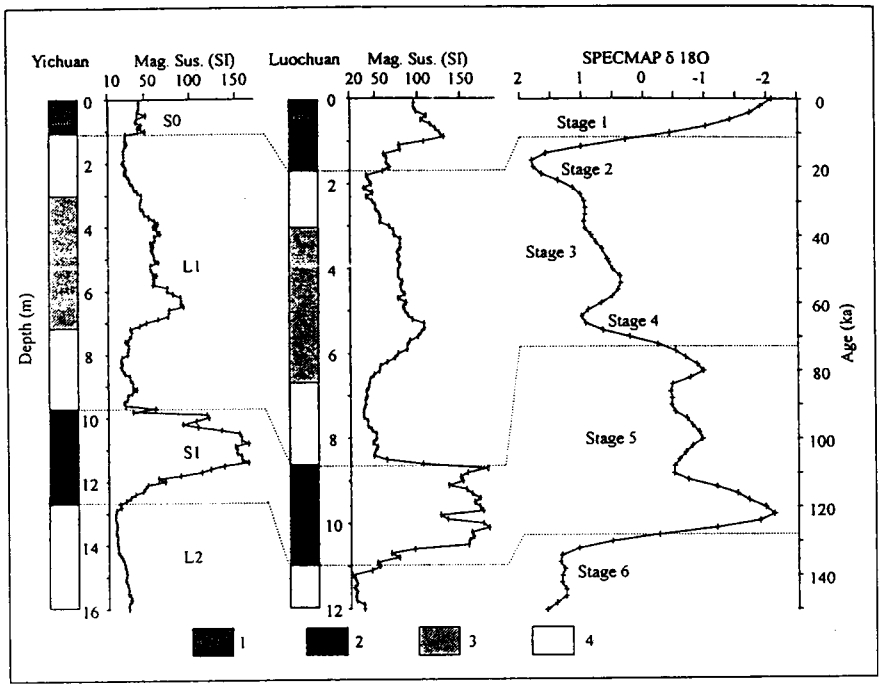

Figure 1 Stratigraphy and magnetic susceptibility of the Yichuan and Luochuan sections and correlation with SPECMAP marine $\partial^{18}O$ record ($\partial^{18}O$ data from Imbrie *et al.*, 1984). 1, Disturbed horizon; 2, palaeosol; 3, weakly developed palaeosol; 4, loess.

stages (Guo *et al.*, 1994; Liu *et al.*, 1995). The pedofeatures produced during the different pedogenic stages were overlapped, and, thus, influence the Fet / Fed ratio. In addition, the S1 soil experienced clay illuvial process, and translocation of iron along the profiles, can be expected.

The most significant features are the two peaks with lower values (Fig. 2). One locates just above the L1 /S1 boundary and another just below the S1 /L2 boundary. These peaks are clearly expressed in both sections, suggesting that they are climatically significant. The Loess Plateau is located within the east Asian monsoon zone and the modern climate is mainly controlled by two seasonally alternative monsoons, i.e. the warm-humid summer monsoon and the cold-dry winter monsoon (Liu *et al.*, 1995). Since the average soil temperatures in the region are below 0°C from late autum to early spring, under the modern interglacial conditions, chemical weathering of loess mainly depends upon the summer temperatures and precipitation, associated with the summer monsoon intensity, or / and dust accumulation rate associated with the winter monsoon intensity. Consequently, high Fet / Fed ratio can be interpreted as an indication of a strengthened summer monsoon or / and a weakened winter monsoon, and lower values indicate the inverse. The low Fet / Fed peaks therefore imply a significant weakening of summer monsoon or / and a strengthening of the winter monsoon.

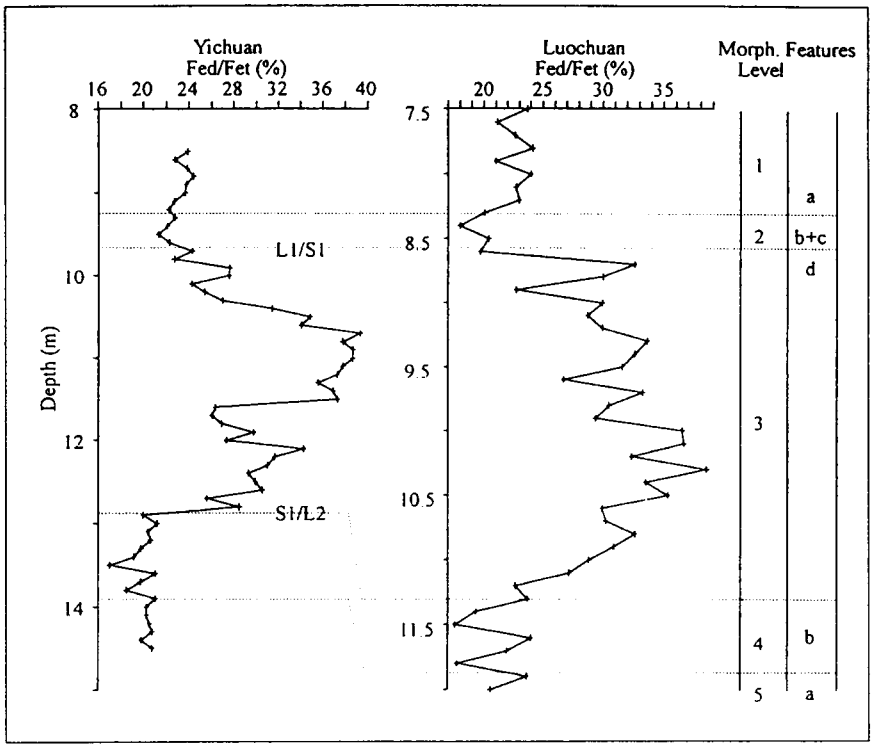

Figure 2. Variations of Fed/Fet ratio and ocurrence of selected micromorphological features in Yichuan and Luochuan sections. a. Loess with spongy microstructure; b, Loess with pseudo-sand microstructure; c, Charcoal particles; d, Fine silty textural feature.

Morphological features

The following morphological features have been identified. They are highly significant to the studied topics. Their stratigraphic occurence is shown in Figure 2.

(1) Abrupt L1 /S1 boundary: In both sections, the top of the S1 soil is truncated as indicated by an irregular and abrupt L1 / S1 boundary. Some soil fragments randomly distribute in the loess inmediately overlying the boundary. However, non water-reworked features are observed. Truncation of the profiles was therefore related with aeolian erosion, suggesting strong aeolian dynamics and probably also a landscape with a very sparse vegetation cover, which is favourable to aeolian erosion.

(2) Loess with pseudo-sand microstructure: They are observed at the positions inmediately overlying the L1 / S1 boundary and underlying the S1 / L2 boundary. In the field, they are massive with very few canalicular pores. Under the microscope, the groundmass contains a large amount of sand-sized (50-300 μm), rounded-subrounded aggregates (pseudo-sands) consisting of silty mineral grains and clay fraction. Some soil fragments are also observed. According to the experiments of Pye and Tsoar (1987), particles larger than 100 μm are unable to be transported by wind as suspended dust for long distance, and most of them would be deposited within 30 km from the source. The pseudo-sands were evidently derived from local materials, rather than typical aeolian

dust particles. Since non waterreworked feature is observed in these loess, the pseudo-sands must have been produced by aeolian erosion and transportation in saltation state, as is also supported by the rounded sharps. Consequently, the loess with this type of microstructure suggest a landscape with sparse vegetation cover and strong winds, thus dry-cold conditions.

(3) Charcoal particles: In the groundmass of the loess with pseudo-sand microstructure immediately overlying the L1 /S1 boundary, some (>1%) randomly distributed charcoal particles (generally >100 μm) are observed. The presence of charcoal particles has been reported from the aeolian sediments in tropical and temperate zones and is commonly regarded as evidence of natural fire (Fedoroff and Goldberg, 1982; Fedoroff, 1996). A question arisen is whether the fire is causally related with climatic change. The fact that charcoals particles are identified at L1 / S1 boundary in the loess with pseudo-sand microstructure may imply that natural fire preferably occurred during climatic deterioration and that natural fires may have played an important role in the degradation of the vegetation cover.

(4) Fine silty textural features: At the top part of the S1 soil in both sections, some silty textural features are observed, juxtaposing over all the other pedofeatures, suggesting that they were formed in the latest stage. They are similar to clay coatings in sharps, but with much lower transparency. They mainly consist of 2-5 μm sized silty particles, including some fine carbonate grains and charcoal particles. This type of textural feature in modern soils have been studied by many authors and are mainly found in soils with a surface crust, like soils denuded of vegetation (Courty and Fedoroff, 1985; Macphail *et al*, 1987). In paleosols, they are usually associated with climatic aridification and sometimes with natural fires (Courty and Fedoroff, 1985; Fedoroff, 1996). Consequently, the presence of these features at the top part of S1 soil can be interpreted as evidence of vegetation destruction during the climatic transition from Interglacial conditions to glacial conditions. Moreover, the fine charcoal particles in the textural features and those in the overlying loess may indicate a vegetation destruction, in relationship with natural fire.

(5) Loess with spongy microstructure: The groundmass of loess is characterised by a large amount of animal excrement and interconnected channels, mainly resulted from strong biological activity. This type of loess identified in both L1 and L2, but is more typical in L1 (Fig. 2). This microstructure evidently implies that the land surface was covered by a significant steppe since organic matter is indispensable for soil fauna living. These loess can be therefore regarded as weakly developed soils, thus evidencing more humid conditions. In fact, spongy microstructure is typical of steppe soils in semi-arid environments (Pawluk and Bal, 1985).

Behaviour of the climatic transitions

The significant morphological features of loess in the studied sections are summarised in Figure 2 and compared with the variations in Fet / Fed ratio (weathering intensity). It shows that the results provided by the two methods are highly consistent. Level 1, characterised by spongy microstructure and relatively higher Fed / Fet values, suggests relatively humid conditions during which the land surface was covered by a significant steppe cover. This level is stratigraphically correlated to the middle part of marine $\partial^{18}O$ glacial stage 4, (Fig. 1). Level 2, a loess layer with pseudo-sands microstructure and very low Fed / Fet values, indicates severe climatic conditions with sparse

vegetation cover and strong winds. It immediately overlies the L1 /S1 boundary and correlates with the earliest part of marine $\partial^{18}O$ stage 4, thus marks the termination of the last interglacial ($\partial^{18}O$ stage 5) . The aeolian truncation of the S1 soil and the formation of the fine silty textural features in the top part of S1 were apparently occurred during this episode. The charcoal particles suggest that natural fire may have played an important role for the vegetation destruction. Level 3 corresponds to the entire S1 soil complex formed during the last interglacial (marine $\partial^{18}O$ stage 5). Paleopedological study in Xifeng (Guo, 1990), where modern climate conditions are somewhat similar to those for Luochuan and Yichuan, suggested a steppe-forest landscape for the early part, semi-arid warm steppe for the middle part and a dry steppe for the lastest part. Level 4, inmediately underlying the S1 /L2, marks the termination of the penultimate glaciation (marine $\partial^{18}O$ stage 6) . This episode is characterised by climatic conditions comparable to those for Level 2. The lowest Level 5 is comparable to Level 1, but suggests slightly less humid conditions according to the less developed spongy microstructure.

The transition from the penultimate glaciation to the last interglacial and the subsequent interglacial-glacial transition were therefore marked by a severe climatic episode in the Loess Plateau region, characterised by destruction of vegetation probably associated with both intensive aridification and natural fires. During these episodes, aeolian dynamic was particularly strong as indicated by the truncation of the S1 soil and the aeolian saltation process resulting in the pseudo-sand microstructure of loess. On the contrary, the preceeding episode (Level 5) and the following episode (Level 1) were characterised by more humid conditions resulting in a significant steppe cover although they still correspond to glacial stages. It should be mentioned that in the Xifeng section (Guo, 1990), two layers evidencing relatively weak cryogenic process were identified corresponding to the stratigraphic positions of Level 2 and 4 in this study, indicating strongly cold conditions.

According to the land-sea correlation pattern (Fig. 1), the ages of the S0 / L1, L1 / S1 and S1 / L2 boundaries should be ≈ 73 and ≈ 128 ka, respectively. Using these ages as control points and the magnetic susceptibility data, we have developed the time scales for the studied sections according to the method of Kukla et al. (1988). They dates the low Fed / Fet peak above S1 soil at ≈ 67-73 ka, lasting about 5,000 years. Assuming a similar accumulation rate for L2 loess, the low Fed / Fet peak below S1 should be ≈ 128-131 ka in age, lasting ≈ 3,000 years. Evidently, these events, occurred at the transitions between glacial and interglacial periods. They cannot be directly explained by either the orbitally induced insolation changes or the ice-volume variations. However, the age of the event at the termination of the penultimate glaciation may be correlated with that of an unnamed Heinrich layer in the North Atlantic, mentioned by Broecker (1994), while the one following the formation of the S1 soil is more or less synchronous with the Heinrich event 6 or the Toba super volcanic eruption. A very important question has therefore arisen for future studies: are these events dynamically linked and by what mechanisms?

Conclusions

(1) Geochemical and micromorphological studies converge to demonstrate that the transition from the penultimate glacial period to the last interglacial, and the one from the last interglacial to the last glacial period were marked by a severe climatic event at

millennial scale, which cannot be directly explained by either orbitally induced insolation changes or ice-volume variations, as reflected by marine $\partial^{18}O$ record.

(2) During these events, the Loess Plateau region was characterised by denudation of vegetation and strong aeolian dynamics, probably in relation with strong winter monsoon winds. Natural fire may have played an important role in the destruction of the vegetation.

Acknowledgements

This work was supported by the National Natural Science Foundation of China and is also a contribution to the IUGS-UNESCO Programme Climates of the Past (CLIP). The author is grateful to Drs. Wu Naiqin and Lu Houyuan for their collaboration for investigation and for the magnetic susceptibility data.

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