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Chronology of loess-paleosol sequences at Weinan section, Central China

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Abstract: The loess profile at Weinan (34°12'N and 109°31'E), Central China, with good stratigraphic stability and well developed paleosols, was systematically sampled and dated by AMS radiocarbon and TL methods. The preliminary high-resolution time scale of this section has been tuned. Based on this time scale and other climatic proxies such as susceptibility curve and grain-size curve, the author summarizes several for the last 150,000 years age results regarding some important stratigraphic boundaries and established a time scale.
According to this time scale, the basal age of S_0, located at 143 cm below the top of section, corresponding to the boundary between S_0/L_1 is 11,980 yr cal BP, this is the age of the beginning of Holocene.
The age of the boundary between L_1 and S_1 is dated 74,220 years B. P. at 854 cm, which shows the ending age of the last interglacial stage is about 74,000 cal BP. S_1 is highly pedogenised paleosol with dark brown color and 361 cm in thickness. It can be divided into three sub-layers, corresponding to the last interglacial stage. the real S_1/L_2 boundary islocated in 1,180 cm depth and has an age of 128,870 years B. P. It may be correlated with the deep-sea oxygen-isotopic stage 5. The Last Glacial Maximum (LGM) reflected in Weinan loess section by grain size curve and susceptibility curve is from about 20,000 cal BP to 18,000 cal BP. A rapid deposit period from 300 cm to 196 cm lasted a time span from 20,200 cal BP to 19,800 cal BP. The deposit rate of this segment is over 20 times than the average deposit rate of Chinese loess.

Key words: Loess section, 14C and TL dating, time scale.

Introduction

Chinese loess sequences typically contain alternating loess (L) and paleosols (S). Previous studies (Liu 1985; Kukla 1987) argued that loess horizons have formed during the glacial epochs, whereas formation of soils corresponded to interglacial period. By now, there have been two kinds of chronology for the Chinese loess deposits. The first is the paleomagnetostratigraphy(An *et al.* 1977; Heller & Liu 1982, 1984; Liu 1985; Kukla 1987; Kukla & An 1989; Liu *et al.* 1991; Rutter *et al.* 1991; Zhu *et al.* 1994), which yields ages by using the paleomagnetic polarity events; the other one is the orbital tuned-time scale by using climatic proxy parameters, such as particle size (Ding *et al.* 1994) and magnetic susceptibility (Kukla *et al.* 1988). However, both of these two methods only focus on the long-term chronology, especially on the orbital time scale, and they can only provide relative time controls, but no actual dates.

In recent years several authors have used the thermoluminescence (TL) dating technique to date the Chinese aeolian sediments (Lu *et al.* 1987; Forman 1991; Sun *et al.* 1998). However, there has no systematic accelerator mass spectrometry (AMS) ^{14}C dating on the Chinese loess. The purpose of this paper aims to develop a new time scale over the last 150,000 years by using the AMS^{14}C and the TL dating techniques.

Geological setting

Weinan loess section (34°21'N, 109°31'E, Fig. 1) is located at Yangguo Town, southern Loess Plateau. At this section, the loess-paleosol sequences of above S_5 are well exposed, however, only the upper part of the section (from L_2 to S_0, Fig. 2) was studied.

S_0 is the top soil, 143 cm thick, and with a A/AC/C soil profile. There is a sharp boundary between this soil and the underlying loess layer (L_1). L_1 is 712 cm thick, consisting of five subdivided units, among them, L_{1-1}, L_{1-3} and L_{1-5} are loess beds, whereas L_{1-2} and L_{1-4} are weakly developed soils (Fig. 2). The transition between L_1 and the underlying paleosol (S_1) is gradual. S_1 is a well-developed soil, 361 cm thick, it cannot be easily subdivided in the field. Below S_1, there is a loess bed of L_2.

Sampling and dating

From the top to the bottom of the Weinan section, 9 pieces of ^{14}C samples and 11 pieces of TL samples were gathered. Additionally, samples for particle size magnetic susceptibility analysis were taken at 2 cm intervals. The particle size was measured by using a laser sizemeter, and the susceptibility was measure by using a Bartington M. S. 2 instruments in our laboratory.

The humic acid and humins fractions for radiocarbon dating were separated from the samples by repeated treatments with hydrochloric acid and alkaline solution in laboratory. Furthermore, the organic materials were converted into graphite in special vacuum system. This graphite is the target material for

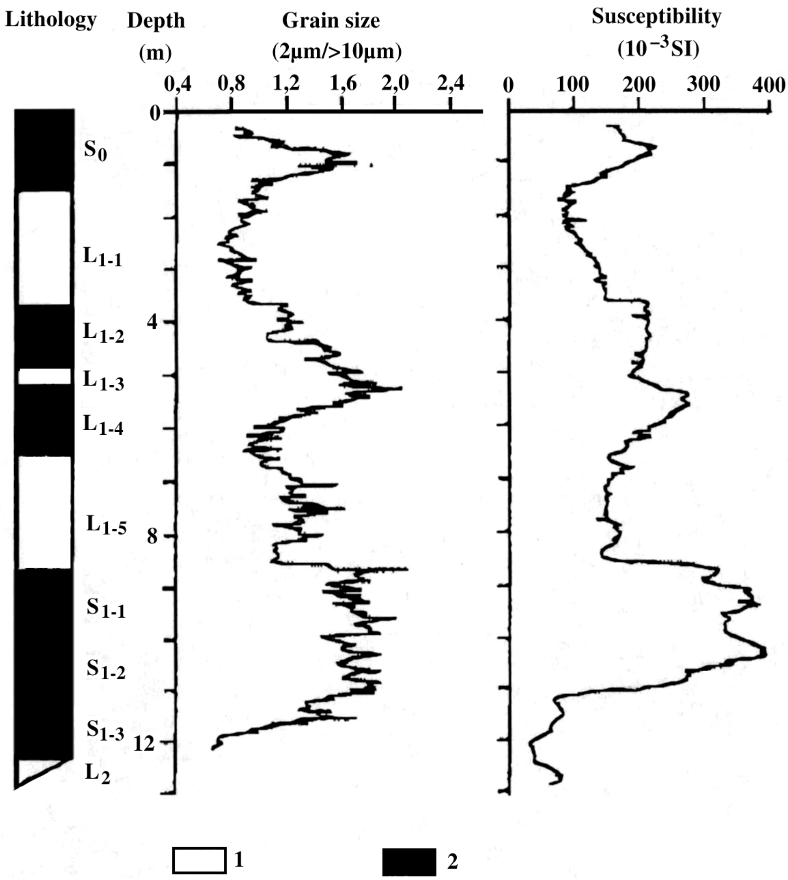

Fig. 1. The grain size curve and susceptibility curve of Weinan loess section.
1 – Loess, **2** – Paleosol.

AMS^{14}C dating. The radiocarbon measurements were carried out in the AMS laboratory of Peking University. The half-life of 5568 years was used and dating results of Weinan loess section are shown in Table 1. All original ^{14}C ages were corrected for isotopic fractionation, and of which is younger than 20,265 yr BP were converted into calendar ages using the INTCAL98. ^{14}C calibration data set (Stuiver *et al.* 1998b), included as part of the CALIB3.03 software (Stuiver & Reimer 1993).

TL dating was also carried out in the TL laboratory of Peking University by using Oxford 185 instrument the fine grain method, and they are corrected by UV light bleaching. The linear heating was applied for TL observation from 50 to 500°C with a heating rate of 20°C per second. A plate source of ^{90}Sr–^{90}Y was used to provide beta radiation dose in the TL experiment. The TL dating results of Weinan loess section are shown in Table 2.

Time series reconstruction

From above dating results, we can compare the TL ages with AMS^{14}C ages. For example, the C_{16} sample, which was located at 143cm below the top of the section, has an AMS^{14}C age – 10,270±380 BP and a calendar age of 11,980 cal BP. Whereas a TL sample TL_1, 10 cm below C_{16}, yielded an age of 11,740±3,280 BP, which showed the consistent of AMS^{14}C age and TL age within evident errors.

The ^{14}C ages of ten samples shown in Table 1 contain two groups: one is humic acid ages and the other is humins ages. Since humins neither dissolves in acid nor alkaline solution, it has been considered to be the most stable organic material in soil, thus its age probably represents the age of soil formation.

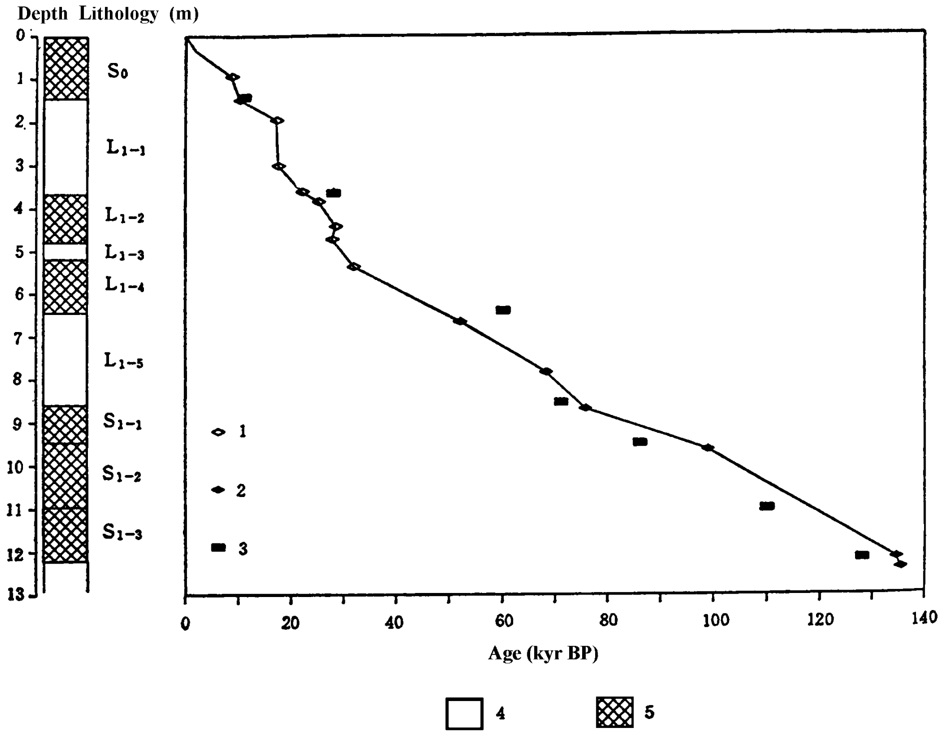

Fig. 2. Comparison the curve of depth versus age in Weinan loess section with SPECMAP.

1 – AMS^{14}C age, **2** – TL age, **3** – the age based on SPECMAP, **4** – loess, **5** – paleosol.

Though some TL ages (for example, TL_{26}) need to be reconfirmed, the others seem to be in good agreement with the stratigraphic sequence. Therefore, they were used to establish the time scale too. After picking out unreasonable data, we reconstructed the paleoclimatic time scale of loess and paleosol sequences with calendar-corrected ages of humins and TL dating results. Comparing the curve of ages vs depth of Weinan loess section with SPECMAP curve, it indicates that they can be generally correlated (Fig. 2), which probably suggest the ages obtained by both AMS^{14}C and TL are reliable.

The major stratigraphic boundaries and climate events in Weinan loess section

Based on above data, a time scale of the past 150ka in Weinan section is developed. We use the AMS^{14}C calendar ages and TL ages as the time controls, then calculate a rough depth-time scale with a 2 cm interval by depth linear interpolation between every two close time controls. By using FFT (Fast Fourier Transform) analysis based on grain-size curve vs this rough depth-time scale, we get three dominant cycles from grain-size curve that are 128 ka, 39.3 ka and 20.5 ka (Fig. 3). This suggests that these three dominant cycles are similar to the periods of the earth's orbit parameters of 100 ka, 40 ka and 20 ka. So we tried to tune a preliminary time scale for Weinan loess section since 0.15 Ma by ETP (Eccentricity Tilt Precession) filter following Ding's method (Ding *et al.* 1991). Fig. 4 showed the results comparing the ETP curve and the grain-size curve and susceptibility after ETP filter. In our tuning process, only the susceptibility curve was used to tune. Finally, we obtained a preliminary orbit-tuned time scale.

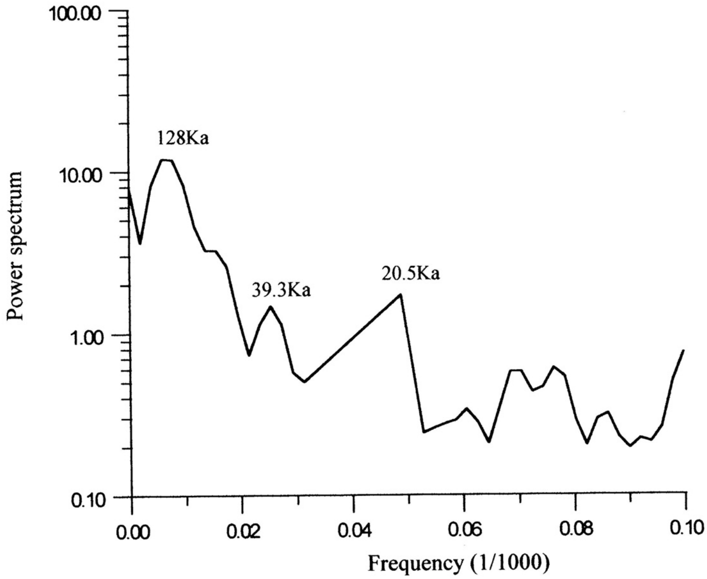

Fig. 3. FFT (Fast Fourier Transform) analysis of grain-size curve based on the rough depth-time scale.

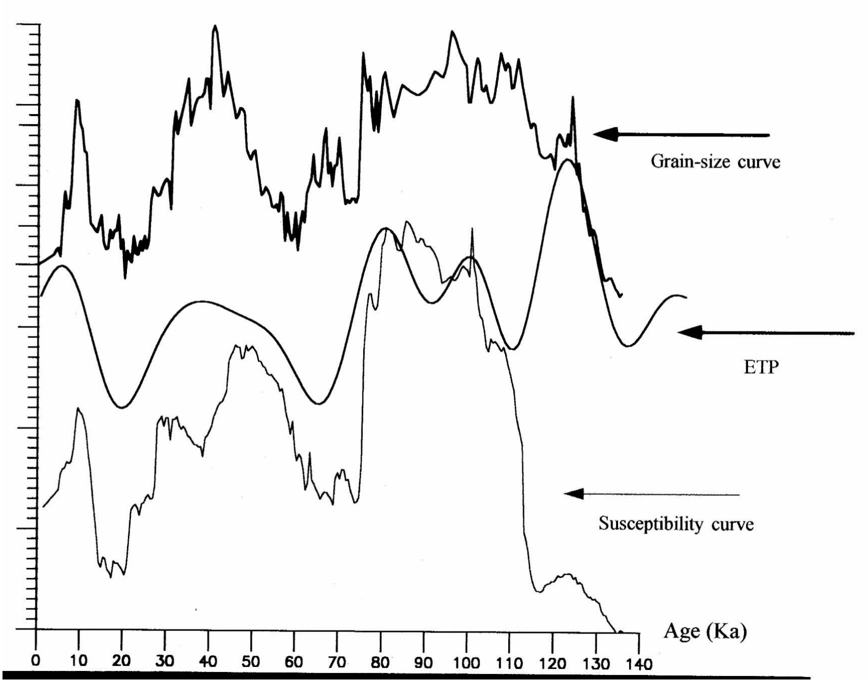

Fig. 4. Comparison of ETP (Eccentricity Tilt Precession), grain-size and susceptibility curve of Weinan loess section since 0.15 Ma BP.

Considering detailed analysis on this orbit-tuned time scale and other climatic proxies such as susceptibility curve, etc., we summarized several important age results regarding some stratigraphic boundaries since 150,000 yr BP as following:

(1) S_1/L_2 boundary

Two samples located at 1,216 cm (TL29) and 1,240 cm (TL30) below S_1 were dated by TL method. The results were to be about 134,500±17,700 BP and 135,400±23,250 BP respectively. The apparent basal age of S_1 was suggested 134,500 BP at 1216 cm in depth. In previous study, S_1 was considered to be correlated with stage 5 of the deep sea oxygen isotope record, the latter has a basal age of 128,000 BP. Therefore, we can find a difference between the initial age of the last interglacial period and the age of bottom of S_1. Based on the pedogenesis study in Weinan loess section, Guo *et al.* (1994) considered that the S_1/L_2 boundary should be located at depth of 1180 cm rather than 1216 cm, which means the layer between 1180 cm to 1216 cm was L_2 loess but weathered by the later soil forming processes. So, the real S_1/L_2 should be located at 1180 cm depth with an age of 128.87 kyr BP determined by the tuned time scale which is corresponding to the beginning of the last interglacial epoch (Fig. 5).

(2) L_1/S_1 boundary

A sample at the bottom of L_1 in depth of 785 cm (TL 17) yielded an age of

68,100±3,780 BP, another sample at the top of S_1 in depth of 870 cm (TL 20) gave an age of 75,620±10,540 BP. The boundary between L_1 and S_1 at depth of 854 cm may suggest an age 74,220 BP from this time scale (Fig. 5), which corresponds to the age of 72,000 BP at Luochuan section suggested by Forman (1991) and the age of about 73,000 BP in the SPECMAP curve within error limitation. From above ages, we speculate that L_1 could be generally correlated to stages 2, 3, 4 of the marine oxygen isotopes and the end of the last interglacial stage was about. 74,000 BP.

(3) S_0/L_1 boundary (Holocene)

The basal age of S_0, i.e. the beginning of Holocene, is an important age. According to our dating results, sample C16, which is located between bottom of S_0 and top of L_1, had an AMS^{14}C age of 10,270±380 BP. We speculate the age of C16 representing the beginning age of Holocene (Fig. 5). The calendar age is 11,980 cal BP.

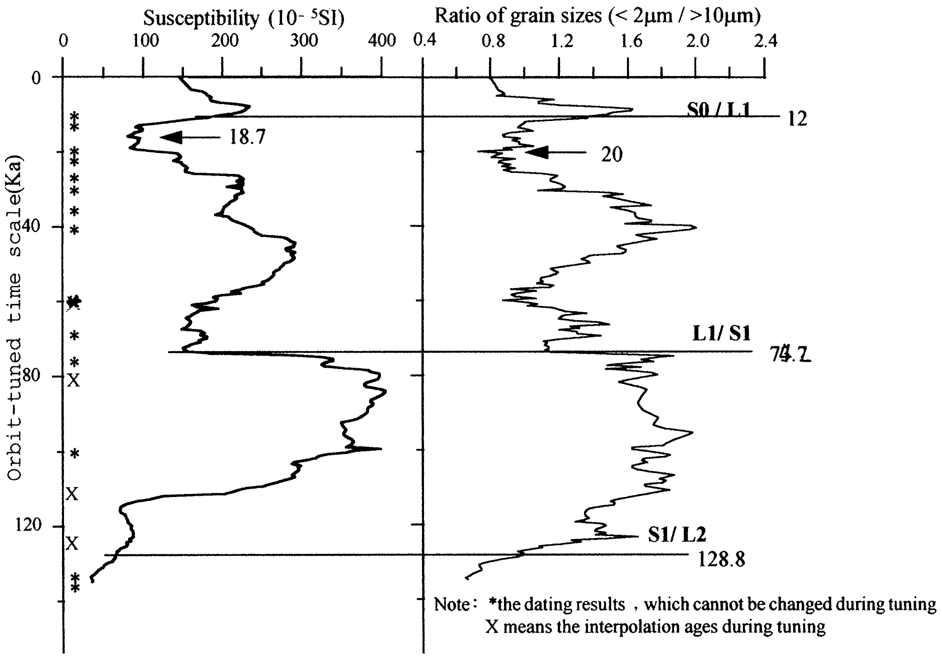

Fig. 5. Ages of some important boundary and events in Weinan loess section.
*: location of sampled level, x: interpolation age.

(4) The Last Glacial Maximum (LGM)

It is known that the Last Glacial Maximum occurred at about 18,000 BP. determined by SPECMAP curve. By using AMS^{14}C dating data, this event reflected in Weinan loess section has a different fact. The Last Glacial Maximum was 20,000 BP in grain size curve and 18,700 BP in susceptibility curve (Fig. 5).

Both ages were not the same because grain size of dust changed more quickly than susceptibility when climate changed. It can be speculated that the maximum of the Last Glacial Maximum had an age from about 20,000 BP to 18,000 BP and different climatic proxies may show different ages of event because of different dynamic mechanisms.

(5) A rapid deposition period

Based on the time scale, we can get an averaged deposition rate in Weinan loess section for the past 130 ka with a sedimentation rate of about 9.16 cm/kyr. Loess deposited at a rate of 11–13 cm/kyr, greatly exceed that of the paleosol, which has a sedimentation rate of about 6–8 cm/kyr. There existed a rapid deposition part from 300 cm to 196 cm of Weinan loess section, the time span from 20,200 BP to 19,800 BP. It just happened within the Last Glacial Maximum, the deposit rate of 260 cm/kyr during this period was over 20 times than the averaged deposition rate of Chinese loess.

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