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Age of the fossil Dali Man in north-central China deduced from chronostratigraphy of the loess–paleosol sequence

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Abstract

Dali Man, an archaic type of early *Homo sapiens*, is of great significance to the origin of *Homo sapiens*. Achievements have been made during the past decades in the understanding of the fossil human skull as well as the accompanying mammalian fossils and stone artifacts. However, the absolute age of the fossil Dali Man still remains unclear. Based on the magnetic susceptibility of loess sediments and the relationship of terracing process with climatic condition, we correlated the loess sequence and the subjacent terrace alluvium at the Dali Man site with the well-studied loess–paleosol sequence at Luochuan in the central part of the Chinese Loess Plateau. The correlation indicates that the loess–paleosol sequence at the Dali Man site extends down to the paleosol S2, and the underlying fluvial deposits correspond to the loess L3. Because the Dali Man skull appears in the basal gravel layer of the terrace, and because the deposition of the terrace gravels would occur during the transition from S3 paleosol formation to L3 loess accumulation, the age of the fossil Dali Man is inferred to be ca 270 ka, which is equivalent to the age of the boundary between the loess L3 and paleosol S3 on the magnetic susceptibility time series of the Luochuan loess–paleosol sequence.

1. Introduction

In 1978, Shuntang Liu, a geologist from the Shaanxi Bureau of Geology and Mineral Resources, discovered an almost complete fossil human skull from a terrace alluvium in Tianshui gully near Jiefang village (34°52′ N, 109°44′ E), Dali County, Shaanxi Province in north-central China (Figs. 1 and 2). Wang et al. (1979) first observed the fossil human skull and designated it Dali Man. Based on the morphologic features and stratigraphic horizon of the fossil skull, Wang et al. (1979) suggested that Dali Man may be a representative of the transition from *Homo erectus* to *Homo sapiens neanderthalensis*, and probably is a type of late *Homo erectus* due to many *Homo erectus* traits, but more progressive than *Homo erectus pekinensis*. After re-investigating the Dali Man site and re-observing the fossil skull, Wu and You (1979) argued that Dali Man characterizes early *Homo sapiens*, and morphologically intermediates between *Homo erectus* and *Homo sapiens* and differs from Neanderthals in racial character.

Furthermore, Wu (1981) carefully compared morphologic features of the Dali Man skull with those of fossil skulls of Peking Man from China, Ngandong Man from Indonesia, western early *Homo sapiens*, Liujiang (Liukiang) Man from China, and modern humans. These features include cranial length (g–op), width (eu–eu) and height (ba–b), orbital height (r) and width (mf–ek, r), cranial length–width, length–height and width–height indices, thickness of cranial bones, inclination angles of the frontal bone and others (Wu, 1981). Most of the measurements and indices of the Dali Man skull fall within the range of variation of western early *Homo sapiens*, and some features are very close to those of *Homo erectus pekinensis* (Wu, 1981). In addition, the Dali Man cranium is different from *Homo sapiens neanderthalensis* found in Europe and western Asia in a number of racial characteristics, such as the thickness of brow ridges, lowness of the skull vault, orientation of the fronto-sphenoidal process of the zygomatic bone, the angled junction between the maxilla

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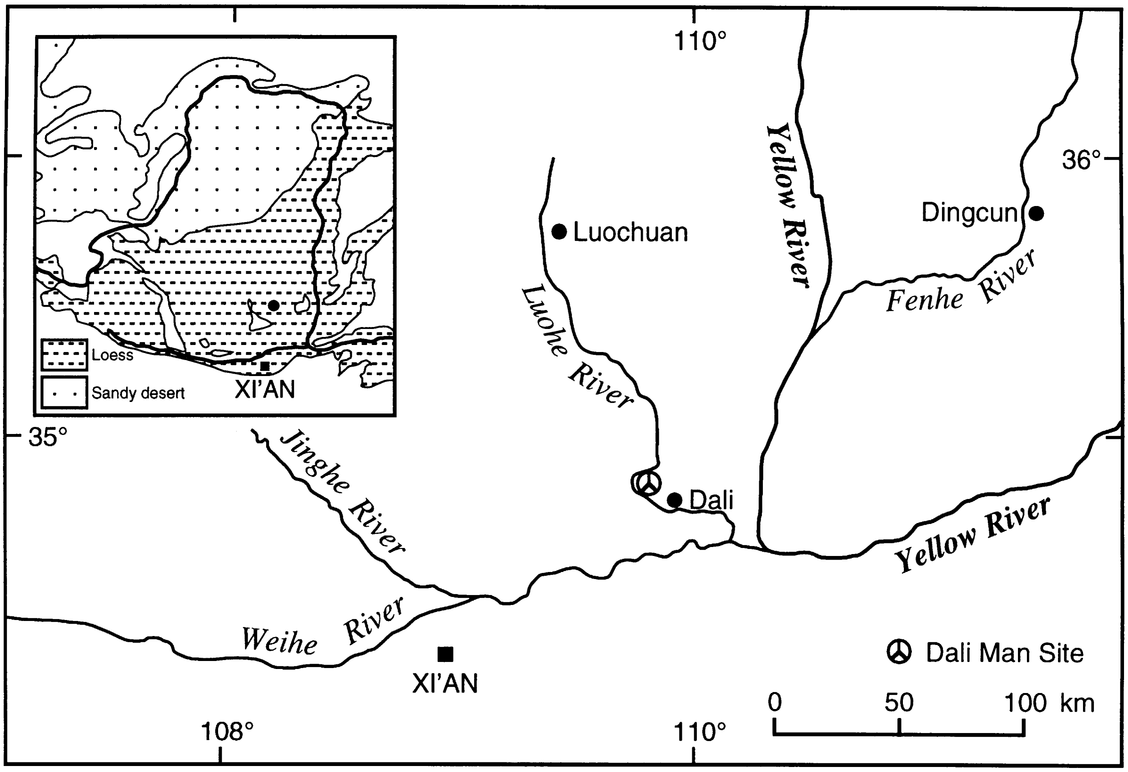

Fig. 1. Map showing the location of the Dali Man site. Locations of the Luochuan loess section and the Dingcun Man site are shown. Inset map shows the distribution of loess in the region of the Loess Plateau in north-central China and the location of Luochuan section.

and the zygomatic bone in basal view, lowness and less protrusion of the facial bone, and the shape of the orbits (Wu, 1981). Consequently Wu (1981) and Wu and Poirier (1995) suggested that the Dali Man skull is intermediate between *Homo erectus* and modern humans, and represents an archaic type of early *Homo sapiens*.

Several excavations were carried out at the Dali Man site after the discovery of the fossil human skull. Some mammalian fossils and a great number of small stone artifacts were found with the human fossils (Wang et al., 1979; Wu and You, 1979; Zhang and Zhou, 1984). The fauna mainly includes *Palaeoloxodon naumanni*, *Palaeoloxodon* sp., *Megaloceros pachyosteus*, *Megaloceros* sp., *Pseudaxis* cf. *grayi*, *Bubalus* sp., *Equus* sp., *Rhinoceros* sp., Castoridae, *Struthio anderssoni*, Cypriniformes, and siluroidea (Wang et al., 1979; Wu and You, 1979). The stone tools are dominated by small scrapers, and points, a stone awl, and burins are also included (Wu and You, 1979; Zhang and Zhou, 1984). Most of the tools were made by hammering, and the manufacture is simple and rough (Wu and You, 1979; Zhang and Zhou, 1984).

A large number of human fossils have been found in China over the past several decades (Wu, 1981; Wu and Poirier, 1995). Until now, however, most of them have been confined to *Homo erectus* or late *Homo sapiens*, and less is known about early *Homo sapiens*. Therefore, Dali Man, an archaic type of early *Homo sapiens*, would provide a great potential for understanding the process of evolution from *Homo erectus pekinensis* (*Sinanthropus*) to late *Homo sapiens* in China. Middle Pleistocene cranial specimens as complete as the Dali Man skull have been seldom found anywhere else (Wu, 1981; Wu and Poirier, 1995). Thus Dali Man is of great significance in seeking for the origin of *Homo sapiens*.

Remarkable achievements have been made in the study of the Dali Man skull as well as the accompanying mammalian fossils and stone artifacts. However, the absolute age of the fossil Dali Man still remains unsure. In the present study, we correlate the sedimentary sequence of the Dali Man site with the well-studied loess–paleosol sequence at Luochuan in the central part of the Chinese Loess Plateau. We attempt to offer convincing evidence for the age of the fossil Dali Man based on the chronostratigraphy of the Chinese loess–paleosol sequence.

2. Lithostratigraphy of the Dali Man site section

The Dali Man site is located at the juncture of the Loess Plateau to the north and the Weihe valley to the south (Fig. 1). The section crops out on the left bank of

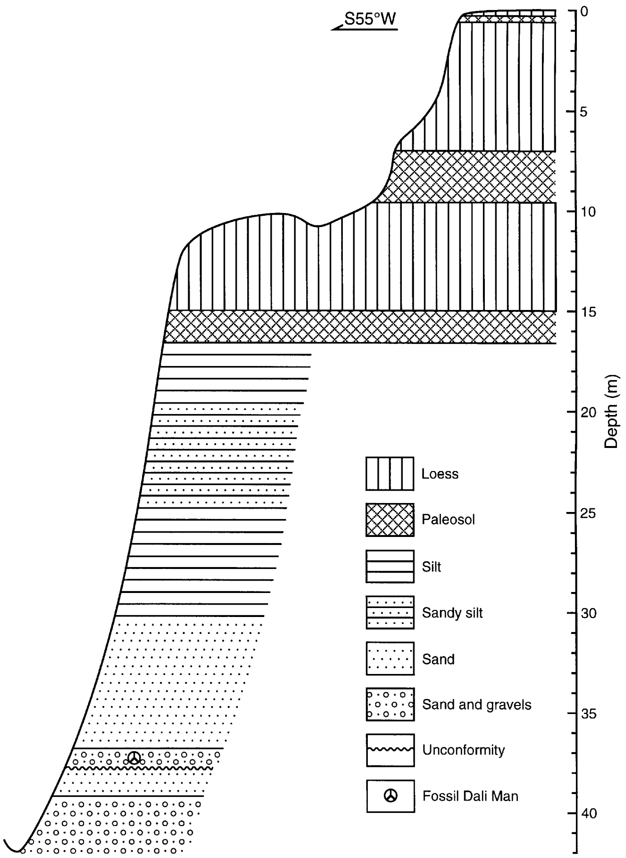

Fig. 2. Profile of the Dali Man site, plotted against depth below the platform. The section is located on the left bank of the Luohe River. The Dali Man skull was found in the top of the gravel layer of the third terrace (Wang et al., 1979).

the Luohe River, a first-order tributary of the Weihe River which flows into the Yellow River (Fig. 1). Terraces are well developed along both sides of the Luohe River. In the area of the Dali Man site, three terraces are developed with surfaces of about 5, 30, 45 m above the riverbed. The outcrop of the Dali Man site is part of the third terrace of the Luohe River.

The Dali Man site section is about 42 m thick, and can be divided lithologically into two parts, i.e., the upper loess sequence and the lower fluvial deposits (Fig. 2). The upper loess sediments are yellowish, massive, porous, and calcareous, and reach a thickness of 16.7 m. It is difficult with the naked eye to distinguish immature paleosols from loess units.

The fluvial deposits below the depth of 16.7 m can be subdivided into three parts, i.e., the upper silt, middle sand, and lower gravel units (Fig. 2). The upper silt unit at depths of 16.7–30.2 m consists of greyish-yellow silt of floodplain facies (Fig. 2). A sandy silt bed between 19.6 and 24.9 m subdivides an upper silt bed from a lower one. The upper silt bed shows insect and worm burrows, and the lower one contains snail fossils. Horizontal beddings are developed in both silt beds. The in-between sandy silt layer was occasionally interbedded with mm-thick laminae of yellowish-brown slity clay.

The middle sand unit at depths of 30.2–36.9 m is composed of greyish-yellow fine to medium sands of river-bank facies (Fig. 2). Sands of the upper part are finer and display occasional horizontal beddings; whereas the lower part consists of coarser sands and show developed cross beddings.

The lower gravel unit below the depth of 36.9 m is dominated by well-rounded pebbles of river-bed facies (Fig. 2). An intervening bed of coarse sands separates it into the upper and lower gravel beds. Both of the gravel beds contain lenses of coarse to medium sands. An unconformable contact of the upper gravel bed with the underlying coarse-sand bed can be seen clearly (Fig. 2).

The fossil Dali Man skull was discovered in the top of the gravel unit (Wang et al., 1979). During the subsequent excavations, some mammalian fossils (Wang et al., 1979; Wu and You, 1979) and a great number of stone artifacts (Wu and You, 1979; Zhang and Zhou, 1984) were found both from the skull-bearing gravel bed and from the lower part of the sand unit.

3. Previous studies on the age of the fossil Dali Man

Wang et al. (1979) collected several samples from the middle sand unit and the sand bed intervening in the gravel unit (cf. Fig. 2) for paleomagnetic measurements, and all the samples show normal polarities. In addition, Wang et al. (1979) recognized a soil unit at depths of 7–10 m (cf. Fig. 2), and took several samples from this soil unit for thermoluminescence (TL) dating. The TL dates span from 41 to 71 ka BP (Wang et al., 1979). Based on results from paleomagnetic polarities and TL datings, Wang et al. (1979) assigned the fossil Dali Man to late Middle Pleistocene, no later than early Late Pleistocene. Subsequently, Wu and You (1979) proposed an age of late Middle Pleistocene to the fossil Dali Man, because the fossil skull was yielded from the lower part of the third terrace of the Luohe River. Mammalian fossils from the skull-bearing bed include both old mammals, such as *Sinomegaceros* cf. *pachyosteus* and *Equus* cf. *sanmeniensis*, and relatively younger mammals, such as *Gazella prezewalskyi* and *Equus* sp. similar to *Equus hemionus* and *Equus caballus* (Zhang and Zhou, 1984). Accordingly Zhang and Zhou (1984) suggested that the age of the fossil Dali Man would be *Middle Paleolithic*.

A buffalo tooth from the skull-bearing bed and a horn of red deer from the base of the middle sand unit (cf. Fig. 2) were dated by the uranium-series method, and yielded an age of 209 ± 23 ka and an age range of 182–226 ka, respectively (Chen et al., 1984). Based on both U-series datings, Chen et al. (1984) suggested that the horizon bearing the fossil Dali Man skull would span an interval of 180–230 ka BP. Another buffalo tooth collected from the skull-bearing bed was dated with ^{230}Th method, and gave an age range of 190–232 ka (Sun and Zhao, 1991). Sun and Zhao (1991) also took a sample from the base of the upper silt unit (ca 7 m above the skull-bearing horizon; Fig. 2), and dated with TL technique to 183 ka BP. Due to the close proximity of the ^{230}Th ages and the TL dating, Sun and Zhao (1991) assigned the fossil Dali Man to ca 200 ka BP. Recently, Yin et al. (2001) collected shells (*Lamprotula antiqua Odtiqua Odhner*) from the skull-bearing bed for electron spin resonance (ESR) and ^{227}Th/^{230}Th datings. The ESR technique yielded four ages of 282.5 ± 116.6, 279.5 ± 110.7, 267.1 ± 72.2, and 246.6 ± 65.6 ka, while the U-series method gave a ^{227}Th age of 192^{+27}_{-22} ka (Yin et al., 2001). From these dates, Yin et al. (2001) came to the conclusion that the fossil Dali Man would be older than 250 ka.

4. Loess–paleosol sequence of the Chinese Loess Plateau

Loess, a wind-deposited silt, covers an area of about 500,000 km^2 in north-central China and began to accumulate about 2.5 Ma ago (Liu et al., 1985; Kukla and An, 1989; An et al., 1990; Ding et al., 1992). The total thickness of the sequence decreases from northwest to southeast with increasing distance from the deserts in northwestern China, and attains up to 135 m at Luochuan (35°45′ N, 109°25′ E) in the central part of the Loess Plateau (Liu et al., 1985; Kukla and An, 1989) (Fig. 1). The loess sequence is generally interstratified with soils, and assumes alternations of loess and soil units. Starting from the top, each of the units has been assigned a stratigraphic designation in consecutive order, i.e., L1, L2, …, to loess units; S1, S2, …, to paleosols (Liu et al., 1985; Ding et al., 1992).

The loess–paleosol sequence on the Loess Plateau of central China has long been regarded as an excellent proxy record of global glacial/interglacial climatic cycles over the past 2.5 Ma (Sasajima and Wang, 1984; Liu et al., 1985; Kukla and An, 1989; An et al., 1990; Ding et al., 1992, 1995). It demonstrates a good correlation with the standard oxygen-isotope record of deep-sea sediments (Heller and Liu, 1984; Liu et al., 1985; Kukla et al., 1988). Loess (L) units mark times of increased dust flux under glacial conditions, and correspond to even stages of marine oxygen-isotope records. Paleosols (S), by contrast, represent periods of intensified pedogenic activity under interglacial conditions, and coincide with the odd stages. Therefore, the loess–paleosol sequence can be employed to relate and date sediments in the region of the Chinese Loess Plateau, as in the same way that the marine oxygen-isotope record can be used to correlate and date Quaternary sediments in deep-sea cores.

Magnetic susceptibility (MS) is a measure of induced magnetization in an artificial low-frequency magnetic field. The MS intensity depends on the concentration and grain size of magnetic minerals (Maher, 1986; Kukla et al., 1988). The magnetic susceptibility of the Chinese loess–paleosol sequences is high in soils and low in loess units (Heller and Liu, 1984; Kukla et al., 1988). Even incipient soils which are distinguished with difficulty by the naked eye still show relatively higher MS values than does the loess (Kukla and An, 1989; An et al., 1991). Thereby, the magnetic susceptibility is not only a useful aid for discriminating paleosols from loess units, but can also serve as a primary criterion for delimiting and correlating loess and soil units (Kukla and An, 1989; An et al., 1991). Moreover assuming a quasi-constant deposition rate of magnetic minerals, Kukla et al. (1988) proposed a magnetic susceptibility time formula to compute absolute ages of each loess and paleosol unit of the loess–paleosol sequences with interpolation between the fixed-age reference points of paleomagnetic reversals. The 135-m loess–paleosol sequence at Luochuan in the central Loess Plateau has been dated by using the MS time formula, which can be closely compared with the SPECMAP marine δ^{18}O time series (Kukla et al., 1988; Kukla and An, 1989). Although it was argued that the magnetic susceptibility signal of the loess and paleosols is determined primarily by pedogenesis (Maher and Taylor, 1988; Zhou et al., 1990; Maher and Thompson, 1991; Verosub et al., 1993), the MS time scale would be practicable to estimate, on the glacial/interglacial time scale, reasonable ages for the loess and paleosol units (Kukla et al., 1990).

5. Loess–paleosol sequence at the Dali Man site

The loess sequence at the Dali Man site has been described differently by different investigators because of the difficulty in discerning, with the naked eye, the paleosols from loess units. The magnetic susceptibility cannot only be used to distinguish paleosols from loess units but also to correlate loess and soil units (Kukla and An, 1989; An et al., 1991). We have made continuous field measurements of magnetic susceptibility (MS, SI units) of the upper 20 m of the section at the Dali Man site by using a portable Bartington susceptibility meter and a MS2F probe (Figs. 2 and 3). The faces for measurements were cleared to expose the unweathered sediment with the original texture, structure and bulk density, and were cut flat. The MS was measured at a vertical interval of 10 cm. At each level, ten independent readings were taken, and averaged. The

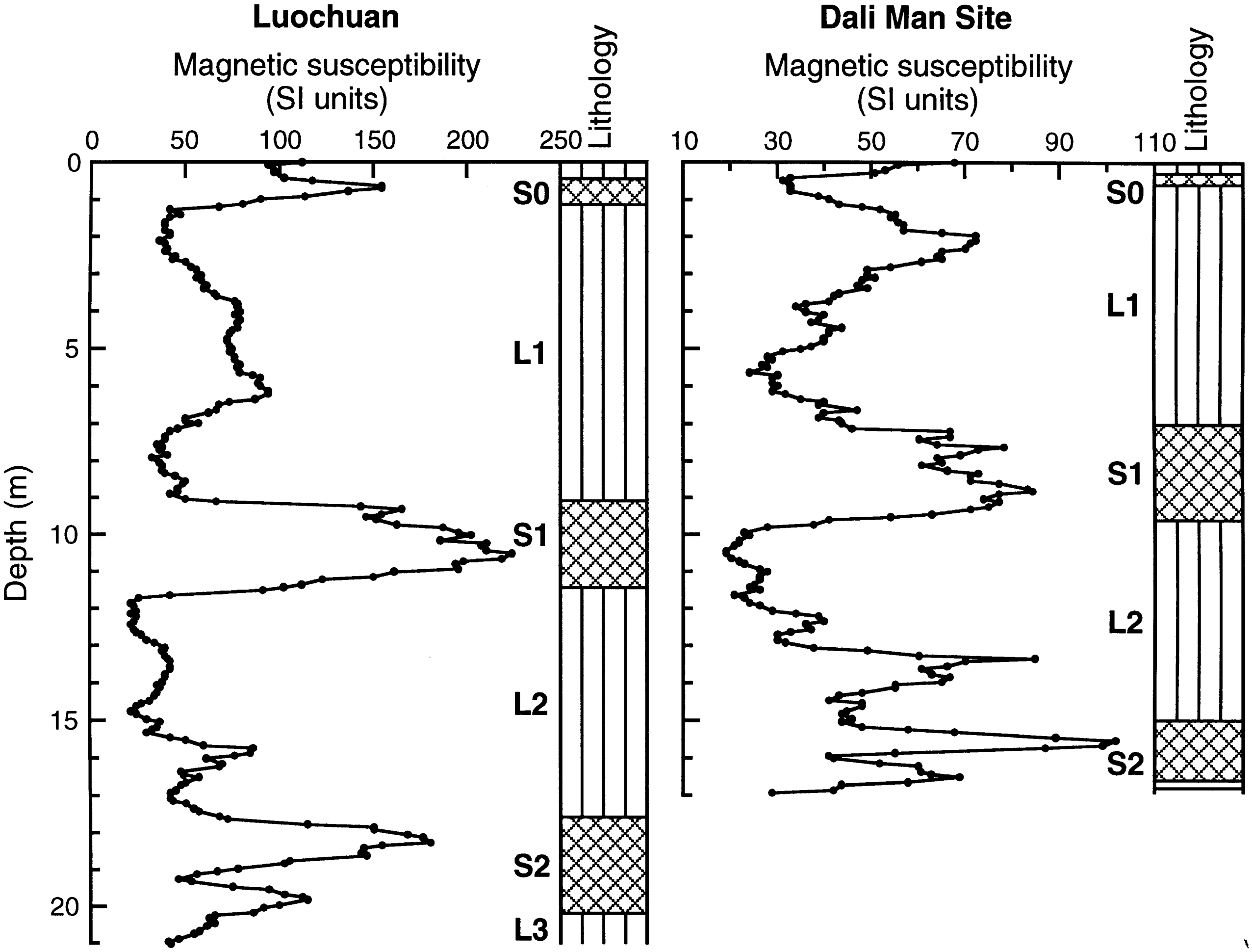

Fig. 3. Correlation of the lithostratigraphy and magnetic susceptibility (SI units) record of the loess–paleosol sequence at the Dali Man site with those at Luochuan in the central part of the Loess Plateau (Kukla et al., 1988). Symbols are the same as in Fig. 2. L1, L2, and L3 are loess units; S0, S1, and S2 are paleosols.

depth below the platform was measured with an optical level.

As shown in Fig. 3, the MS record of the upper 16.7-m loess sequence at the Dali Man site displays six intervals during which the MS values were greater than 50 SI units. The longest interval with MS values > 50 SI units lies at depths of 7.3–9.5 m. Two of the intervals concentrated between 15.2 and 16.7 m.

The MS record of the loess sequence at the Dali Man site can be correlated with that of the Black Loam S0 to paleosol S2 of the loess–paleosol sequence at Luochuan in the central Loess Plateau (Kukla et al., 1988) (Fig. 3). The interval at depth of 7.3–9.5 m apparently coincides with the paleosol S1 at Luochuan. The segment between 15.2 and 16.7 m, characterized by double peaks with MS values > 50 SI units, corresponds to the Luochuan S2 paleosol complex. Based on this correlation, we infer that the loess–paleosol sequence at the Dali Man site contains three soils and two loess units. From the surface downward, these are: soil S0 (Black Loam), loess L1 (Malan Loess), paleosol S1, loess L2, and paleosol S2 (Figs. 2 and 3).

On the other hand, the Dali Man site is located at the southern margin of the Loess Plateau (Fig. 1). The Malan Loess L1 at the Dali Man site is thinner than that at Luochuan in the central part of the Loess Plateau (Figs. 1 and 3). The fact that the thickness of the Malan Loess L1 decreases gradually from northwest to southeast (Liu et al., 1985; Xiao et al., 1992) gives counter-evidence for such a correlation.

It is worth mentioning that (1) some of the previous investigators described the sediments at depths of 9.5–16.7 m (Figs. 2 and 3) as fluvial deposits rather than loess sediments (e.g., Wang et al., 1979), and (2) some of them related the segment between 15.2 and 16.7 m (Figs. 2 and 3) to the paleosol S1 rather than S2 (e.g., Sun and Zhao, 1991). Such provisional stratigraphic correlations might have led to inaccurate estimates of the age of the fossil Dali Man.

6. Discussion and conclusions

Correlation between magnetic susceptibility records of the loess–paleosol sequence at the Dali Man site and Luochuan in the central Loess Plateau suggests that the boundary between the upper loess sequence and the lower fluvial deposits (i.e., the base of the paleosol S2) at the Dali Man site corresponds to the base of the paleosol S2 of the loess–paleosol sequence at Luochuan (Figs. 2 and 3). By using the magnetic susceptibility time formula, the base of the paleosol S2 of the Luochuan loess–paleosol sequence was dated to 245 ka BP (Kukla et al., 1988; Kukla and An, 1989; Kukla et al., 1990). Therefore the fossil Dali Man would be older than 245 ka, because the gravel bed bearing the fossil skull is more than 20 m below the paleosol S2 (Fig. 2).

Fig. 4 compares the magnetic susceptibility time series of the loess–paleosol sequence at the Dali Man site and Luochuan (Kukla et al., 1988) with the SPECMAP marine oxygen-isotope chronology (Martinson et al., 1987). The MS record of the loess–paleosol sequence at the Dali Man site was plotted against the MS time scale of Kukla et al. (1988). In view of the consistent relationship between MS records of the loess–paleosol sequence at the Dali Man site and Luochuan, the stratigraphic boundaries were used as the fixed-age reference points. These are: the S0/L1 boundary at 10 ka BP, L1/S1 at 75 ka BP, S1/L2 at 128 ka BP, L2/S2 at 185 ka BP, and the base of the S2 at 245 ka BP. Among them, ages of the L1/S1 and L2/S2 boundaries and the base of paleosol S2 were derived from the MS time scale of the Luochuan loess–paleosol sequence (Kukla et al., 1988, 1990; Kukla and An, 1989). Ages of measured horizons were calculated by following the MS time formula given by Kukla et al. (1988). It can be seen in Fig. 4 that the two MS records correlate broadly with the SPECMAP marine δ^{18}O record of Martinson et al. (1987). The paleosol S2 apparently corresponds to the SPECMAP δ^{18}O stage 7. The age of the stage 8/7 transition (event 8.0) was estimated at ca 244 ka in the marine oxygen-isotope chronology, supporting the inference that the fossil Dali Man would be older than 245 ka.

The Luohe River is one of the two longest first order tributaries of the Weihe River which flows into the Yellow River (Fig. 1). It rises in the Baiyu Mountains on the northern margin of the Loess Plateau about 200 km northwest of Luochuan, and flows southward through the Loess Plateau toward its confluence with the Weihe River (Fig. 1). An exposure in a narrow valley in the upper reaches of the Luohe River, north of Luochuan, illustrates a sandshale scarp capped by loess sediments (Liu et al., 1985; Yuan et al., 1987). The loess sequence in this profile extends down to the paleosol S5, suggesting that the sandshale scarp was downcut by the Luohe River about 500 ka ago (Liu et al., 1985; Yuan et al., 1987). Nearby this exposure, there is an outcrop showing that a terrace alluvium is overlain by the paleosol S1, and higher in altitude than the surface of the sandshale. The appearance that the young terrace lies higher than the old one implies that the alluviation and terracing of the Luohe River were dominantly controlled by climatic changes (Liu et al., 1985; Yuan et al., 1987). Moreover, most of the terrace sections in the region of the Loess Plateau show that accretionary soils were directly developed on the subjacent terrace alluvium (Yuan et al., 1987; Sun and Zhao, 1991). The presence of paleosols on terrace treads denotes that terracing occurred during intervals of soil formation (Yuan et al., 1987; Sun and Zhao, 1991). Based on this interpretation, Sun and Zhao (1991) and Porter et al. (1992) further suggested that episodes of stream aggradation in the region of the Loess Plateau correlate with episodes of loess deposition (glaciations), whereas intervals of degradation correspond with intervals of soil formation (interglaciations).

In the profile at the Dali Man site, the paleosol S2 accreted in the subjacent floodplain silt at the top of the terrace (Fig. 2). The section shows no signs of erosional hiatuses between the superjacent loess sediments and the underlying fluvial deposits. Thus, the transition from the preceding alluvial aggradation to the subsequent eolian accumulation could be thought to be continuous. Moreover, most of the terrace sediments in the region of the Loess Plateau display three stratigraphic units, i.e., the basal gravel, middle sand, and upper silt beds (Yuan et al., 1987). These three units represent three sedimentary facies of the river-bed, river-bank, and floodplain, and indicate a gradual decrease of the river flow with the onset of glacial conditions (Yuan et al., 1987). Consequently, the terrace alluvium at the Dali Man site would be correlated with the loess L3. In other words, the degradation of the third terrace occurred during the S3 paleosol formation, whereas the aggradational period corresponds with the L3 loess accumulation.

Because the gravel unit bearing the fossil Dali Man skull serves as the base of the third terrace (Fig. 2), the deposition of the gravels would have occurred during the transition from the S3 paleosol formation to the L3 loess accumulation. Based on the magnetic susceptibility time scale of the Luochuan loess–paleosol sequence, the L3/S3 boundary was dated to ca 270 ka BP (Kukla et al., 1988, 1990). The age of the fossil Dali Man is thus inferred to be ca 270 ka.

In addition, the marine isotope stage 9/8 transition, which is equivalent to the L3/S3 boundary, was estimated at ca 305 ka BP (Imbrie et al., 1984; Prell et al., 1986). This age appears to be 35 ka older than that of the L3/S3 boundary derived by calculating on the magnetic susceptibility time formula of Kukla et al. (1988). However, the Marine Isotope Stage (MIS)

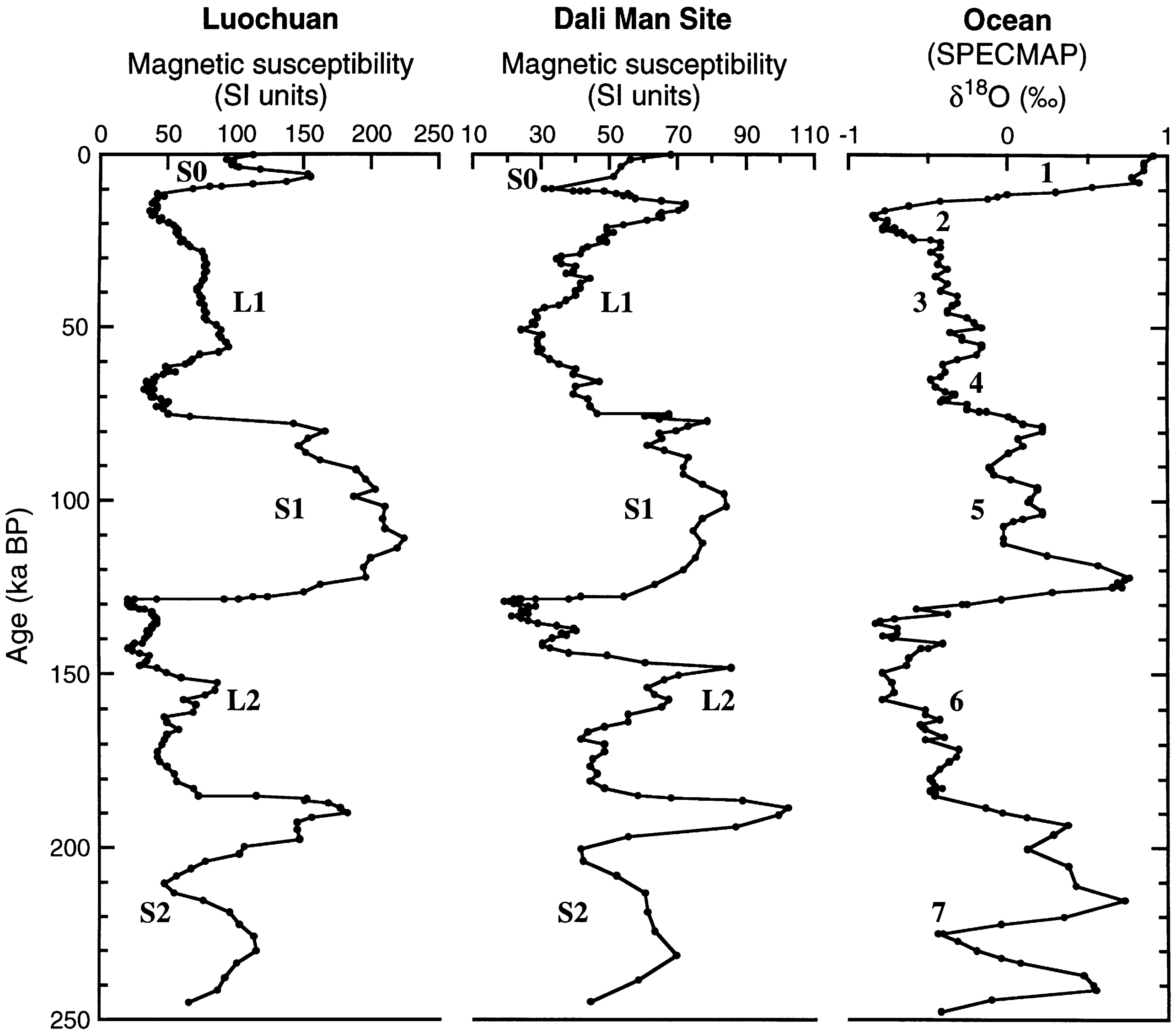

Fig. 4. Time series of the last ca 250 ka comparing magnetic susceptibility (SI units) records of the loess–paleosol sequence at the Dali Man site and Luochuan (Kukla et al., 1988) with the SPECMAP marine $\delta^{18}O$ record of Martinson et al. (1987). The chronology of the magnetic susceptibility records was derived by calculating on the magnetic susceptibility time formula of Kukla et al. (1988). L1 and L2 are loess units; S0, S1, and S2 are paleosols; 1–7 are marine oxygen-isotope stages.

8 displays a $\delta^{18}O$ peak during its early part, i.e., the event 8.5 (Imbrie et al., 1984; Prell et al., 1986; Martinson et al., 1987). Figs. 2 and 7 of Kukla et al. (1988) illustrate that the paleosol S3 corresponds with both the MIS 9 and the early part of the MIS 8 of the marine oxygen-isotope chronology. That is, the L3/S3 boundary correlates with the end of early part of the MIS 8 rather than the MIS 9/8 transition (Kukla et al., 1988). If this correlation is reasonable, the age of ca 275 ka of the end of the early MIS 8 in the marine oxygen-isotope chronology (Imbrie et al., 1984; Prell et al., 1986; Martinson et al., 1987) seems to be in support of our inference that the fossil Dali Man would be 270 ka BP.

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