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Geochemical characterization of loess-paleosol sequences:

Comparison between the upper reaches of the Hanjiang and Weihe river valleys, China

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Abstract: This paper aims to compare the geochemical characteristics of loess-paleosol sequences in the upper reaches of the Hanjiang and Weihe river valleys, which are located in the semi-humid temperate zone and humid subtropical zone, respectively. The Mituosi (MTS) profile in the upper reaches of the Hanjiang River valley and the Yaohecun (YHC) profile in the Weihe River valley were selected for this comparative research. The stratigraphic characteristics, composition, chemical weathering intensity, leaching rates of Ca and Na, mobility of major elements, and transport features of Na and Fe were analyzed with respect to depth and compared between the two profiles. This study reached the following conclusions. (1) The composition of the loess-paleosol sequences in two regions are quite similar to the average composition of the upper continental crust (UCC), indicating that the loess in the two regions came from multiple sources and was mixed well. Therefore, the loess in the two regions is considered aeolian loess. (2) Compared with the loess-paleosol sequence in the Weihe River valley, the loess-paleosol sequence in the upper reaches of the Hanjiang River valley features a darker color; a higher chemical index of alteration (CIA) value; higher leaching rates of Na and Ca; higher migration ratio (relative to K) of Al, Si, Mg, and Na; and lower migration ratio of Fe and Ca. This evidence indicates that the loess-paleosol sequence in the humid subtropical environment experienced stronger chemical weathering intensity than the loess-paleosol sequence in the semi-humid temperate zone. (3) Both the YHC profile and MTS profile record a period of climate deterioration at 6000–5000 a BP. The period punctuated the mid-Holocene Climatic Optimum (8500–3100 a BP) in the study area.

Keywords: loess-paleosol sequence; geochemical characterization; Hanjiang and Weihe river valleys

1 Introduction

Revealing the mechanisms and causes of past global changes is the basic goal of researching

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global environmental changes. The climate variability of the last glaciation and the Holocene is the focus of the Past Global changes (PAGES) project (Oldpeld, 1999). Loess-paleosol sequences on the Chinese Loess Plateau have been regarded as one of the best media to reflect global paleo-climatic changes (Liu, 1988; Liu *et al*., 1990; Guo *et al*., 2000).The differences in weathering intensity between the loess and paleosols were essentially caused by element recombination and element transport. Chemical weathering is not only the main form of interaction between the spheres of the Earth on the continental surface and the geochemical circulation of supergene elements but also a record of the paleo-climatic and paleo-environmental changes (Chen *et al*., 2008). Numerous field studies on both chemical and physical weathering have been performed in various parts of the world (Stallard and Edmond, 1981; Meybeck, 1987; Amiotte Suchet and Probst, 1993; Land *et al*., 1999; Dalai *et al*., 2002; Singh *et al*., 2008; Zhang *et al*., 2013). These studies were mainly directed at: (1) calculating chemical weathering rates; (2) understanding the biogeochemical cycles of major and trace elements; (3) estimating the role of major parameters, such as terrain, climate, lithology, vegetation, and soil erosion, in the chemical weathering processes; and (4) quantifying the potential climate change caused by the chemical weathering of rock (Viers *et al*., 2000).

Geochemical studies of loess-paleosol sequences in recent years have mainly been conducted in semi-humid temperate zones, such as the Loess Plateau, Xinjiang Uygur Autonomous Region, and western Sichuan province, China. Much fewer studies have been conducted in the humid subtropical climate zone, and few studies have compared the geochemical differences and similarities between the two zones (Sun, 1994; Pang and Huang, 2006; Chen *et al*., 2008). The Mituosi (MTS) profile in the upper reaches of the Hanjiang River valley and the Yaohecun (YHC) profile in the Weihe River valley were selected to study the geochemical differences and similarities between the upper reaches of the Hanjiang River valley and the Weihe River valley.

2 Geographic setting

The Weihe River valley and Hanjiang River valley are located on two sides of the Qinling Mountains. The upper reaches of the Hanjiang River valley are located in the southern Qinling Mountains and feature a humid subtropical monsoonal environment (Figure 1). The mean annual temperature varies from 14–18°C, and the mean annual precipitation is 873 mm, with a dust storm frequency of approximately 30 days per year. Yellow cinnamon soils (Claypani-Udic Argosols) are spread throughout the region. The Weihe River valley is situated in the northern Qinling Mountains and features a semi-humid temperate monsoon environment. The mean annual temperature varies from 6–14°C, and the mean annual precipitation is 577.8 mm, with a dust storm frequency of approximately 45 days per year. Cinnamon soils (Hapli-Ustic Argosols) are widely distributed in the Weihe valley.

3 Methods

To perform a scientific comparative study of the loess-paleosol sequences in the upper reaches of the Hanjiang and Weihe river valleys, extensive field investigations were conducted in the study area during the years 2010–2013. Representative profiles were chosen

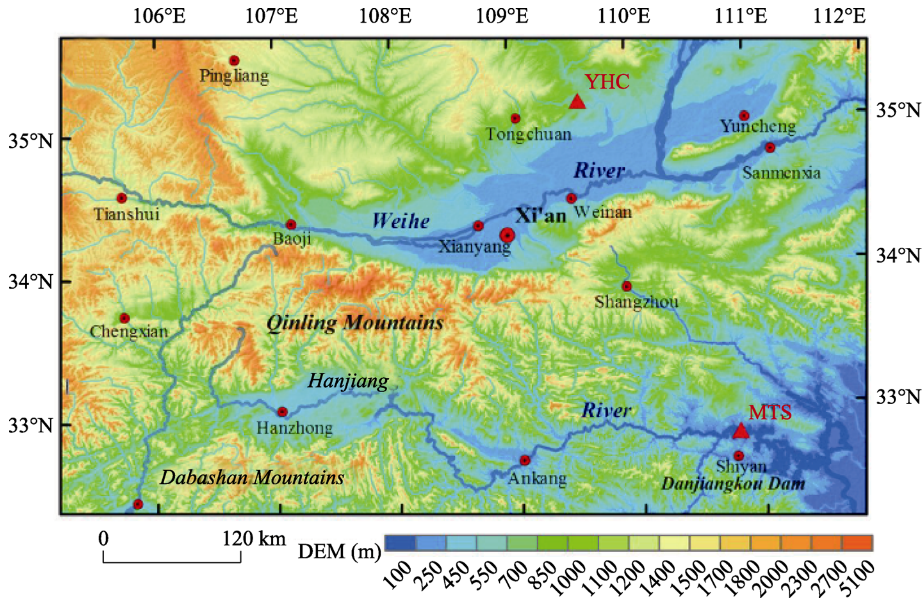

Figure 1 Site map showing the position of the Weihe River valley and the upper reaches of the Hanjiang River valley. The locations of the studied loess-paleosol sequences in the upper reaches of the Hanjiang and Weihe river valleys are marked with "▲".

based upon the following criteria: (1) The terrace/tableland surface is wide and flat, ensuring that the process of dust deposition was not affected by soil erosion. (2) The sampling area has not been disturbed by human activity, ensuring dust accumulation was mainly affected by the evolution of the natural environment. (3) The thickness of the profile is > 1.5 m and the pedo-stratigraphy of the profile does not contain hidden layers. Based on detailed observations, the Mituosi profile (MTS, 32º49′23″N, 110°34′46″E, 170 m asl) and Yaohecun profile (YHC, 35º15′57″N, 109°29′5″E, 960 m asl) were selected as representative profiles (Figure 1).

Samples were taken at depth intervals of 2 cm in the MTS profile, and 300 samples were collected in total. Samples were taken at depth intervals of 5 cm in the YHC profile, and 150 samples were collected for major element and magnetic susceptibility analysis. At the critical depth in the MTS profile (Figure 2), 10 samples were taken for the optically simulated luminescence (OSL) dating at the same time and tightly packed with lightproof materials. Magnetic susceptibility was measured using a Bartington MS2 magnetic susceptibility meter (0.47/4.7 kHz). Fe, Al, Si, K, and Na were analyzed using a PANalytical X-ray fluorescence spectrometer (XRF). Blue lighting-stimulated OSL dating was performed on a Risø-TL/OSL-DA15 Dating System using the fine-grain regeneration method in the TL/OSL Dating Laboratory of Shaanxi Normal University, China.

4 Stratigraphy and chronology

Both the MTS and YHC profiles are well preserved. They were identified as accretionary profiles of aeolian origin based on their colors, texture and stratigraphic structure, and they share the same stratigraphic characteristics: Ts-L_0-S_0-Lt-L_1 (Figure 2). Compared with the YHC profile, the topsoil layer (Ts) of the MTS profile has a darker color and more well-rounded spherical pellets; the aeolian loess layer (L_0/L_1) and transitional layer (Lt) of the MTS profile have similar textures and colors; and the paleosol layer (S_0) of the MTS profile has a darker color and more red-brown ferri-argillans on structural surface (Table 1).

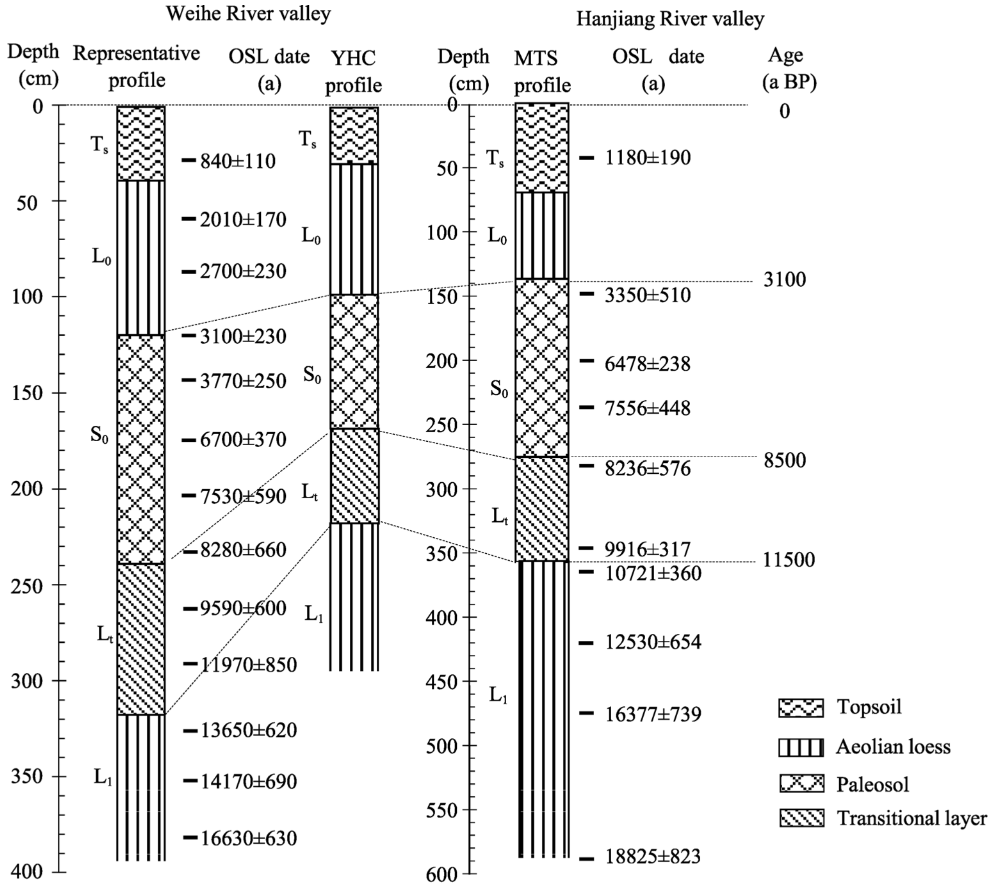

Figure 2 Pedo-stratigraphic correlations of the studied loess-paleosol sequences in the upper reaches of the Hanjiang and Weihe river valleys, China

Table 1 Pedo-sedimentary descriptions of the loess-paleosol sequences at the MTS and YHC sites

Stratigraphy	YHC profile in the Weihe valley	MTS profile in the upper reaches of the Hanjiang valley
Topsoil (Ts)	0–30 cm, pale orange (10YR6/4), silt, medium granular-blocky structure, friable, some bio-pores	0–70 cm, pale brown (7.5YR/5/4), silt, medium granular-blocky structure, friable, some bio-pores, moderately abundant well-rounded spherical pellets
Upper loess (L_0)	30–100 cm, pale orange (10 YR 6/3), silt, blocky structure	70–140 cm, pale orange (10YR/6/4), silt, blocky-massive structure, weak pedogenesis
Paleosol (S_0)	100–170 cm, pale brown (5YR 6/3), clay silt, blocky structure, relatively firm, some secondary calcite deposits	140–280 cm, dull brown (7.5YR/3/4), clayey silt, prismatic, angular blocky structure, firm, abundant bio-pores, abundant red-brown ferri-argillans on structural surfaces
Transitional loess (Lt)	170–220 cm, pale orange (10YR 7/3), blocky structure, silt, abundant secondary calcite deposits (pseudo-mycelia)	280–360 cm, pale yellow orange (10YR/7/4), silt, blocky structure, few red-brown ferri-argillans in the fissure plane
Malan loess (L_1)	220–300 cm, pale orange (10YR 7/4), silt, constant massive structure, very friable, uniform structure	360–600 cm, pale yellow orange (10YR/7/3), silt, constant massive structure, very friable, few bio-pores, thickness greater than 3.0 m, covering a riverbed phase layer of coarse gravel

The field observations indicate that the Ts layer and the paleosol S_0 layer of the MTS profile experienced stronger weathering intensity than those of the YHC profile, but this conclusion should be supported by more experimental data.

The chronological framework of the pedo-stratigraphy in the profiles was established using the OSL dating method and stratigraphic correlation method (Figure 2). Although the OSL age of the YHC loess-paleosol sequence was not experimentally determined, it was obtained indirectly via correlation with the representative pedo-stratigraphy in the Weihe River valley (Huang *et al*., 2000; Wang *et al*., 2012; Zhang *et al*., 2012). The OSL age of the pedo-stratigraphy at the MTS site in the upper reaches of the Hanjiang River valley was close to the calibrated age of the representative loess-paleosol sequence in the Weihe River valley. The pedo-stratigraphic boundary between the Malan loess (L_1) deposited during the last glaciation and the lower Holocene transitional loess (Lt) in the MTS and YHC profiles was dated to be 11,500 a BP. The paleosols (S_0) in the two profiles were dated to the mid-Holocene Climatic Optimum (8500–3100 a BP). In other words, the chronological frameworks of the loess-paleosol sequences in the Weihe and Hanjiang river valleys were essentially consistent.

5 Results and interpretations

5.1 Major element compositions

The average contents of major elements in the YHC and MTS profiles are listed in Table 2. The data show the following characteristics. (1) The main components of the loess-paleosol sequences are SiO_2, Al_2O_3, and Fe_2O_3, together comprising 83.24% and 77.41% of the MTS and YHC profiles, respectively. The order of the major element concentrations in the two profiles is Si > Al > Fe > K > Mg > Na > Ca. The coefficient of variance (CV) values for Si, Al, Fe, K, Mg, and Na in the two profiles are all lower than 11%, which indicates that the major elements are consistent throughout both profiles. These data support the hypothesis

Table 2 Comparison of the major element contents, magnetic susceptibility, CIA and CIW between the MTS profile in the upper reaches of the Hanjiang valley and the YHC profile in the Weihe valley, China

Profile	Stratigraphy	Sample	SiO_2	CaO	Fe_2O_3	Al_2O_3	MgO	K_2O	Na_2O	X_{lf}	CIW	CIA
		Quantities	‰	‰	‰	‰	‰	‰	‰	$\times10^{-8}$ m^3/kg		
MTS profile	TS	36	620.4	10.9	59.2	150.9	20.2	32.8	11.2	313.44	80.28	67.50
	L_0	35	630.3	11	54.1	143.9	20.6	31.1	13.6	192.5	77.26	65.10
	S_0	70	630.5	10.8	57.3	146.6	19.8	31.7	12.3	271.6	79.46	67.09
	Lt	40	633.1	10.7	55.6	146.1	21.6	30.7	12	67.61	78.80	66.79
	L_1	58	640.8	11.5	52.6	140.7	21.4	29.9	14.2	54.11	74.01	64.36
	CV	—	1.36	7.21	5.2	3.02	4.18	3.62	10.2	—	—	—
YHC profile	TS	15	541.4	13.6	46.7	130.2	24.6	23	13.6	110.7	74.85	65.15
	L_0	40	551.2	13.5	48.2	131.5	25.4	23.7	13.5	115.8	74.64	65.28
	S_0	40	597.6	12.9	49.1	138	24.2	24.4	12.9	127.9	75.92	66.68
	Lt	10	561	13.5	46.5	130.8	24.5	23	13.5	78.3	75.81	65.38
	L_1	20	591.2	13.9	44.7	129.2	24.6	22.7	13.9	51.2	73.59	64.69
	CV	—	4.29	27.17	4.05	2.96	3.51	3.18	3.42	—	—	—

that the loess in both the Hanjiang River valley and the Weihe River valley is aeolian in origin. (2) Comparing the concentrations of mobile elements (MgO, Na_2O, and CaO) and immobile elements (Fe_2O_3, Al_2O_3 and K_2O) between the MTS profile and YHC profile, the mobile element concentration is lower in the MTS profile than in the YHC profile. The immobile element concentration is higher in the MTS profile than in the YHC profile. This pattern implies that the soluble elements were leached more extensively (thereby enriching the insoluble element) with depth in the loess-paleosol sequence in the upper reaches of the Hanjiang River valley, which experienced relatively stronger weather intensity than the profile in the Weihe River valley.

Compared with the average chemical composition of the upper continental crust (UCC) (Gallet, 1998), the major element distribution patterns are almost flat and close to those of the UCC, with the exception of Na and Ca in the two representative profiles (Figure 3). These patterns indicate that the loess of the Hanjiang River valley and the Weihe River valley is from multiple sources and is well mixed. The concentrations of Na and Ca deviate from the average concentration of the UCC, which might be attributable to the chemical weathering during the process of pedogenesis, as Na and Ca are prone to leaching in warm and humid climates and enrichments in cold and arid regions. Compared with data of Ca in the paleosol (S_0)/Malan loess (L_1) layers between the two study areas, the concentration of Ca in paleosol (S_0)/Malan loess (L_1) layers of the Hanjiang River valley is much higher. This is possibly attributable to a different paleoclimate; the Hanjiang River valley is warmer and more humid than the Weihe River valley. In addition, the leaching rate of Na in the Hanjiang River valley was similar to that of the Weihe River valley, indicating that Na might have been leached out in the source area and was little affected by the process of pedogenesis.

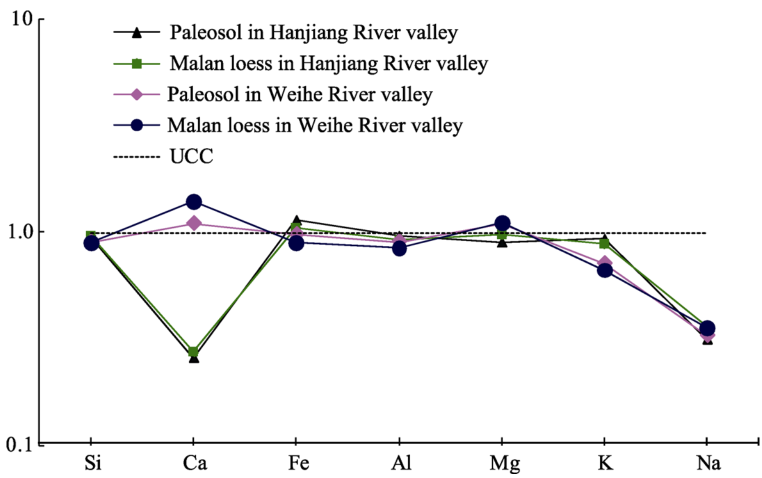

Figure 3 The UCC-normalized pattern of major elements of the loess-paleosol sequences in the Weihe River valley and upper reaches of the Hanjiang River valley

5.2 Chemical weathering intensity

5.2.1 Chemical indices (CIA and CIW)

The upper crust is dominated by plagioclase and K-feldspar-rich rocks and their weathering products, clay minerals (Nesbitt and Young, 1984, 1989). Plagioclase and K-feldspar account for 41% and 21% of the mineral composition of the crust, respectively (Wedepohl, 1969). Feldspar is the main mineral affected by chemical weathering in the upper crust. Alkali metal elements are leached out of feldspar in ionic form and participate in the formation of clay minerals. The molar fraction of Al_2O_3 (the main component in the weathering products) varies with the chemical weathering intensity. Thus, the chemical index of alteration (CIA) was proposed by Nesbitt and Young to evaluate the degree of chemical weathering (Table 2):

$$CIA=[Al_2O_3/(Al_2O_3+CaO^*+K_2O+Na_2O)]\times 100 \quad (1)$$

Several papers on the geochemistry of sedimentary rocks and paleosols have reported that K is typically more abundant than might be predicted based on the basement sources, which led Harnois (Harnois, 1988) to propose a new weathering index, the chemical index of weathering (CIW):

$$CIW= [Al_2O_3/ (Al_2O_3+CaO^* +Na_2O)] \times 100 \quad (2)$$

The two indices are calculated using molecular proportions, in which the CaO* represents the content of CaO in silicates, excluding the CaO in carbonates and phosphates. Generally, the ratio of CaO to Na_2O in silicate rocks is 1:1. Therefore, McLennan suggested that if the concentration of CaO is higher than that of Na_2O, one can assume $m_{CaO^*}=m_{Na_2O}$; otherwise, $m_{CaO^*}=m_{CaO}$ (McLennan, 1993). All values of m_{CaO^*} in this paper are calculated according to this method. According to the research of Li and Feng (Feng *et al.*, 2003; Li *et al.*, 2007), a CIA value between 50 and 65 indicates that the aeolian dust experienced a degree of weak weathering intensity under cold and dry climate conditions. If the CIA value is between 65 and 85, the aeolian dust experienced a moderate chemical weathering intensity under a warm and moist environment. If the CIA value is between 85 and 100, the loess experienced a strong weathering intensity under hot and humid climate conditions.

The CIA values of different layers in the MTS loess-paleosol sequence range from 64.36 to 67.50, and the values in the YHC profile are somewhat lower than those of the MTS profile, ranging from 64.69 to 66.68 (Table 1). Both the CIA values of the YHC and MTS profiles are significantly higher than that of the UCC (47.92) and approach the moderate chemical weathering intensity. Compared with the YHC profile, the CIW value of the MTS is slightly higher, and the mean values of CIW at YHC and MTS sites are 74.885 and 77.9, respectively. These values indicate that the loess-paleosol profile of the Hanjiang valley experienced stronger chemical weathering than that of the Weihe valley. In the two profiles, the different layers of the loess-paleosol sequence exhibit the following order in terms of chemical weathering intensity: Malan loess (L_1) < transitional loess (Lt) < upper loess (L_0) < paleosol (S_0). Comparing the chemical weathering intensities of the same layer in the two profiles, the difference in the Malan loess was minimal, whereas the difference in the paleosol was the greatest. Therefore, the parent rocks of the two profiles were compositionally similar to the Malan loess (lowest CIA value), and the differences in temperature and humidity were most obvious during the period of paleosol formation.

5.2.2 A–CN–K diagram

Nesbitt and Young (1982) developed the A–CN–K (Al_2O_3–CaO^*+Na_2O–K_2O) ternary diagram to predict the continental chemical weathering trend. This diagram can reflect the chemical weathering trend and changes in the main components and minerals during the chemical weathering process. Terrestrial shale is the typical chemical weathering product of the UCC. Thus, the direction from UCC to terrestrial shale on the diagram represents the typical trend of continental chemical weathering.

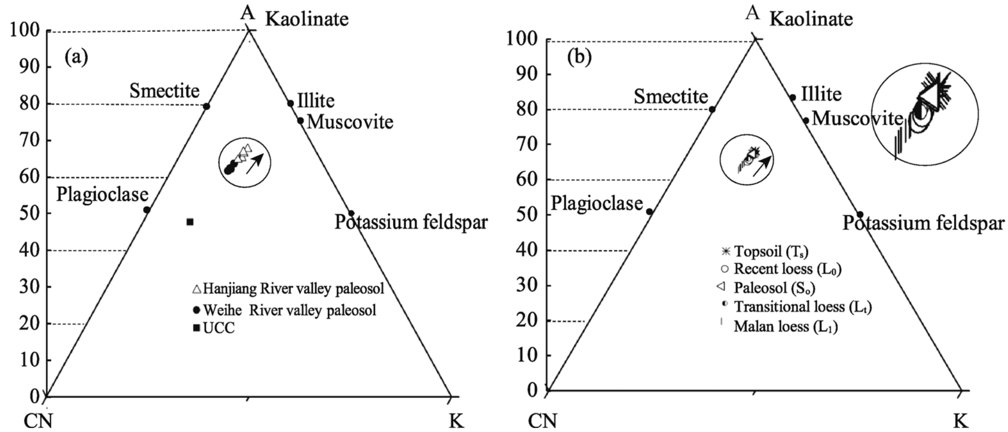

Figure 4 A-CN-K ternary diagrams of the loess-paleosol sequences (the arrows indicate the weathering trend) (a) Comparison of the paleosol layers between the Hanjiang valley (MTS site) and the Weihe valley (YHC site); (b) The different layers of the MTS site in the upper reaches of the Hanjiang River valley. A=Al_2O_3; CN=CaO^*+Na_2O; K=K_2O

Both the MTS and YHC loess sediments are plotted along the chemical weathering trend line of UCC to terrestrial shale (Figure 4a). This pattern demonstrates that both the sediments of the two regions are derived from rocks with an overall composition similar to the UCC. The weathering trend line of the loess sediments parallels the CN–A boundary, which means that plagioclase weathered first, thereby rapidly releasing Ca and Na, whereas potassium feldspar was relatively stable. In the MTS profile (Figure 4b), the leaching rate of Na and Ca increases in the order of Malan loess (L_1) → recent loess (L_0) → transitional loess (Lt) → paleosol (S_0). Compared with the paleosol in the Weihe River valley, the data points from the Hanjiang River valley are plotted closer to the A–K boundary. Therefore, the silicates have experienced stronger weathering intensity, and plagioclase was weathered into smectite and illite via Ca and Na leaching, whereas K was not leached, and little kaolinite was produced.

5.3 Mobility of major elements

5.3.1 Mobility sequence of major elements

The major element absolute concentrations are somewhat variable due to differences in active element transport. However, their removal increases the proportion of stable elements during chemical weathering, which confuses the true characteristics of element migration. Thus, the variation ratio of an element compared to a stable element was selected to show the real features of element migration and enrichment. The formula is as follows:

$$\triangle=[(Xs/Is)/(Xp/Ip)-1]\times 100\%$$

where *Xs* and *Is* represent the concentrations of element *X* and stable element *I* in the paleosol, respectively; and *Xp* and *Ip* represent the concentrations of element *X* and stable element *I* in the parent rocks, respectively (Malan loess was used as a substitute for unweathered rock). When △<0, *X* is relatively leached compared to *I*. If △>0, element *X* is relatively enriched. The variation percentage of each element is calculated by using *K* as the stable element (Figure 5).

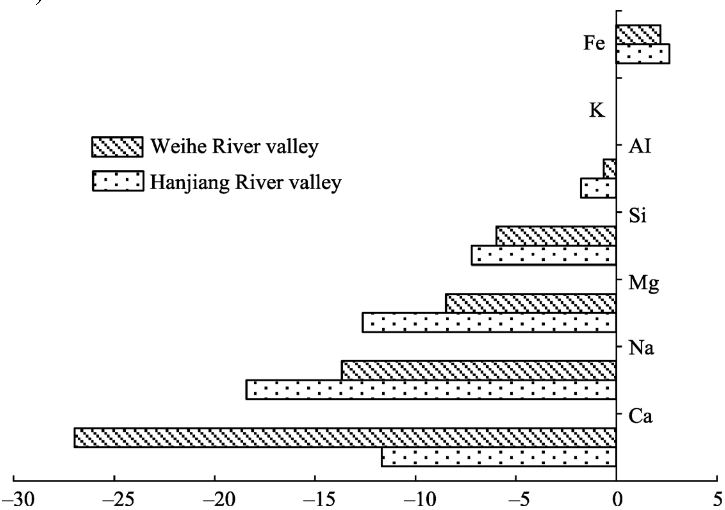

Figure 5 Comparison of the migration ratio of major elements in the paleosol layer between the upper reaches of the Hanjiang valley (MTS site) and the Weihe valley (YHC site) calculated relative to the stable element K

According to Figure 5, the major element migration characteristics of the paleosol layer in the Hanjiang River valley are very similar to those of the Weihe River. (1) The △ of most elements, such as Ca, Na, Mg, Si, and Al, is <0, which demonstrates that these elements were leached during the chemical weathering. In contrast, the △ value of Fe is slightly greater than 0, suggesting that Fe_2O_3 is relatively stable and inactive in the profile. Consequently, the relative concentration of Fe increased in the two profiles. (2) The activity and mobility sequence of the major elements in the Hanjiang River valley is as follows: Na>Mg>Ca>Si>Al>K>Fe. According to mobility, the major elements, listed in descending order, in the Weihe River valley exhibit the following order: Ca>Na>Mg>Si>Al>K>Fe. (3) Compared with the Weihe River valley, the △ values of Al, Si, Mg, and Na are obviously higher, indicating that the active elements in Hanjiang were leached to a greater degree during aeolian dust deposition and pedogenesis. The paleosol layer in the Hanjiang River valley has experienced stronger chemical weathering than the paleosol layer in the Weihe River valley.

5.3.2 Geochemical characteristics of the loess-paleosol sequences

We choose four representative geochemical indices (the migration ratios of Fe and Na calculated relative to the stable element K and the values of CIA and CIW) and magnetic susceptibility to discuss the differences and similarities of the geochemical characteristics of the loess-paleosol sequences at the MTS site and YHC site (Figure 6).

The immobile element Fe and the most mobile element Na were selected to explore their migration behaviors in the different layers.The most mobile element is Na, which is easily leached in the humid and warm environments. In terms of the mobility of Na, the different layers in the Weihe and Hanjiang river valleys exhibited the following descending order: paleosol (S_0) > transitional loess (Lt) > recent loess (L_0) > Malan loess (L_1). The mobility ratio of Na is really higher in the paleosols, demonstrating that the environment was

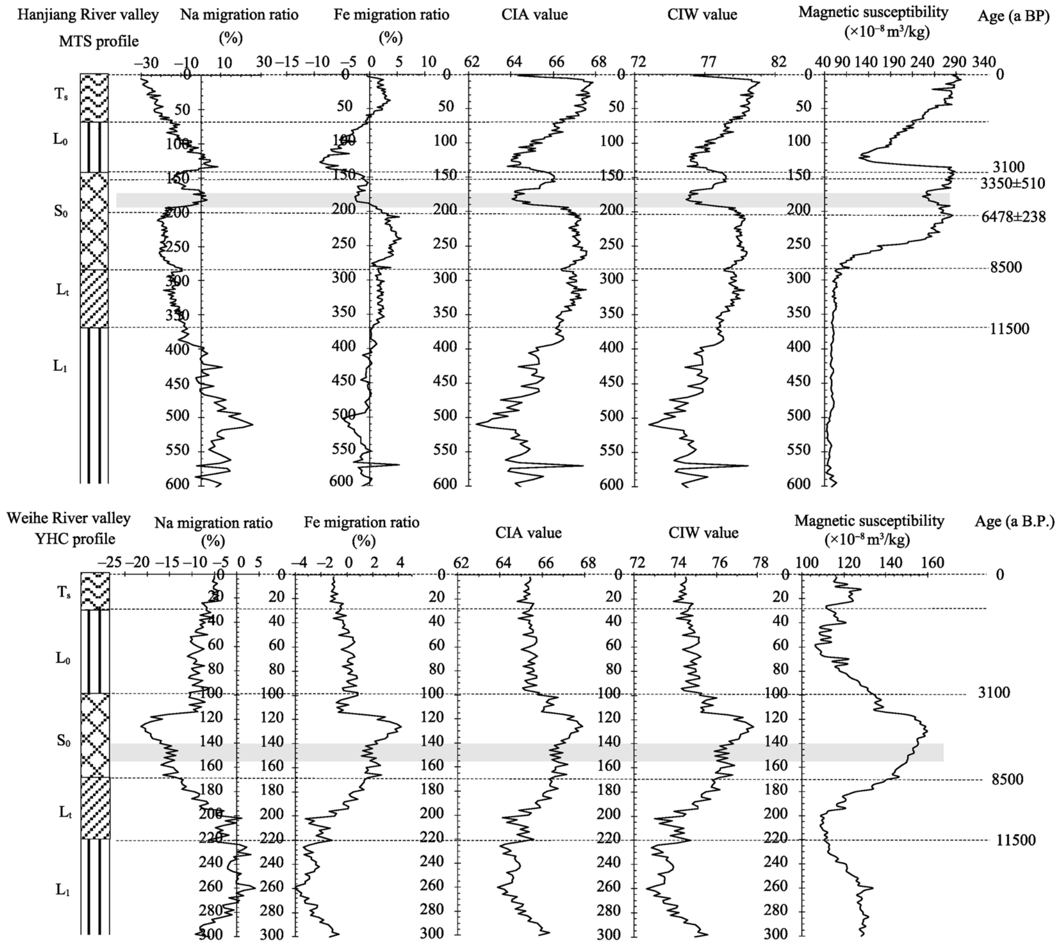

Figure 6 Comparison of the variations in CIA, CIW, magnetic susceptibility and migration ratios of elements Fe and Na throughout the loess-paleosol sequences in the Hanjiang valley (MTS site) and Weihe valley (YHC site)

warm and humid during paleosol formation. Thus, a certain amount of Na was leached out as the aeolian dust interacted with biologic and pedogenic processes. In contrast, the mobility of Na is lower in the loess layer, which indicates that the environment was cold and dry during the period of dust accumulation and that the dust experienced weak chemical weathering. Compared with the YHC site, the mobility ratio of Na in the MTS site is significantly higher. The average migration ratios of Na in the MTS and YHC sites are –11.9% and –5.9%, respectively, indicating that the aeolian loess experienced stronger chemical weathering in the Hanjiang River valley. The variation curve of Fe with depth in the profile is contrary to the pattern of Na in the YHC and MTS profiles. Fe is stable; thus, when active elements are leached out of the system, the concentration of Fe relatively increases; otherwise, the migration ratio of Fe would decrease. Therefore, Fe is relatively enriched in the paleosol layer, and the mobility is relatively low in the loess layers (including the Malan loess, recent loess, and transitional loess). These patterns indicate that the paleosol layer developed in a warm and humid environment and that the loess formed in a dry and cold environment. According to the enrichment ratio of Fe, the layers in the Weihe and Hanjiang river valleys can be listed in the following descending order: paleosol (S_0) > transitional loess (Lt) / recent loess (L_0) > Malan loess (L_1). The variations in the migration ratio of Fe in the two profiles agrees with the morphological characteristics and structures, such as the layer of paleosol composed of dull brown clayey silt with abundant red-brown ferri-argillans on the structural surfaces and the layers of loess composed of pale yellow-orange silt with porous structures and few ferri-argillans on the structural surfaces. The CIA and CIW values are widely used to interpret the chemical weathering intensity of feldspar in modern and ancient sediments (Nesbitt and Young, 1982). The variation curves of the CIA and CIW values synchronously change with the element migration and magnetic susceptibility variations. These patterns show that the paleosols (S_0) of the YHC and MTS sites experienced moderate chemical weathering intensity and a degree of chemical weathering that is significantly higher than that of the topsoil and loess layers (Lt, L_0, and L_1). Comparing the CIW value and magnetic susceptibility values of the MTS and YHC sites, the values of the MTS site are significantly higher than those of the YHC site. Therefore, the loess-paleosol sequence in the upper reaches of the Hanjiang River valley experienced stronger chemical weathering than that in the Weihe River valley.

Notably, at the depth of 170–190 cm in the paleosol layer (S_0) at the MTS site, the four geochemical indices of this section exhibit obvious fluctuations that indicate that the pedogenic environment of this section was cold and dry. Compared with the MTS site, the chemical index fluctuations in response to climate are not particularly evident at the YHC site. This may be due to micro-topographic and micro-climatic factors. However, at the depth of 140–150 cm, the data still effectively indicate that this section experienced weak chemical weathering. According to the OSL ages of the MTS profile and the interpolated ages of the YHC profile (Figure 6), the sections with weak pedogenesis were dated to 6000–5000 a BP. This period has been shown to feature a period of climate deterioration that resulted in a section of weak pedogenesis in the midst of the paleosols (S_0) in the two profiles. This period of climate deterioration was also recorded by various climatic proxies, including ice cores, pollen, peat and marine sediments. Bond observed an ice-rafted debris (IRD) event at 5900 a BP in a North Atlantic deep-sea core (Bond G *et al.*, 1997). O'Brien found that the concentration of sea salt and dust increased during the period of 6100–5000 a BP (O'Brien, 1993). Studying worldwide Holocene glacier fluctuations, Denton proposed a third major interval of glacier advances at approximately 5800–4900 a BP (Denton and Karlén, 1973). Many lines of evidence, including climate proxies based on ice cores, peat, pollen, and marine sediment, suggest that drought and flood events occurred during 6000–5000 a B P in Jilin, Qinghai, Sichuan, Guangdong, and Qinghai provinces and in the South China Sea (Wang *et al.*, 1999; Hong *et al.*, 2005; Liu *et al.*, 2000; Zhou *et al.*, 2001).

5.4 The controlling factor of chemical weathering

The chemical composition and CIA value of the Malan loess in the Weihe River valley and Hanjiang River valley were very similar, suggesting that the parent rocks of the two regions were very similar. However, the weathering intensities of their paleosols exhibit obvious differences. Compared with the paleosol in the Weihe River valley, the paleosol in the upper reaches of the Hanjiang valley experienced stronger pedogenesis, based on the geochemical indices (CIA and CIW), A–CN–K diagrams, and major element mobility data. The factors that usually influence chemical weathering include topography, drainage conditions, soil erosion, environmental conditions, etc. The selection process of the studied profiles has avoided some influencing factors, such as topography, drainage conditions, and soil erosion; therefore, the factor controlling the chemical weathering intensity differences is the environment. According to the doctrine "the present is the key to the past", the precipitation and temperature values of the upper reaches of the Hanjiang River valley are clearly higher than those of the Weihe River valley and may be the two important factors influencing the pedogenic intensity.

The mobility characteristics of Fe and Na with depth in the YHC and MTS profiles indicate that the period of paleosol (S_0) formation (8500–3100 a BP) was humid and warm, whereas the periods of loess deposition (3100–1500 a BP, 11,500–8500 a BP, and >11,500 a BP) were relatively cold and dry.

6 Conclusions

A comparative study of the chemical weathering intensity and element transport features of loess-paleosol sequences in the upper reaches of the Hanjiang River valley and the Weihe River valley was conducted. This research has reached the following conclusions.

(1) The main components of the loess-paleosol sequences in the Hanjiang and Weihe river valleys are SiO_2, Al_2O_3, and Fe_2O_3, and the major element compositions are consistent throughout the profiles. Furthermore, these compositions are quite similar to the composition of the upper continental crust, indicating that the loess of the two regions came from multiple sources and was well mixed. Thus, these sediments are interpreted to be aeolian loess.

(2) The loess-paleosol sequences in the Hanjiang and Weihe river valleys both experienced moderate chemical weathering. The chemical index values (CIA and CIW), the leaching rates of Ca and Na, and the mobility of the major elements were obviously higher in the paleosol layer. Thus, the chemical weathering intensity of the paleosol is stronger than the loess layers. The mobility of the elements in the paleosol layer was as follows: Fe<K<Al<Si<Mg<Na.

(3) Compared with the morphological and color characteristics, magnetic susceptibility, chemical index values (CIA and CIW), and major element mobilities of the Weihe River valley profile, the profile in the upper reaches of the Hanjiang River valley experienced stronger chemical weathering. The precipitation and temperature differences between the Hanjiang River valley and the Weihe River valley are the primary controlling factors that explain the differences in pedogenic intensity between the two regions.

(4) Both the YHC and MTS profiles record a period of climate deterioration at 6000–5000 a BP based on the variations in Fe and Na mobilities, CIA and CIW values, and magnetic susceptibility at the depth ranges of 140–150 cm and 170–190 cm, respectively.

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