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The reconstruction of palaeoenvironment during development of the fourth palaeosol in the southern Loess Plateau of China

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ABSTRACT

The fourth palaeosol (S_4) of the Brunhes Epoch (780,000–0 years B.P.) at Shuangzhu, Tianjiapo, and Hejiacun in the Guanzhong Plain developed over about 40 ka and varies in thickness from 3.6 to 4.0 m. It consists of four horizons: the first (uppermost) is a well developed red–brown clay horizon (Bts), the second is a dark yellowish-brown weathering-cracked loess horizon (Cs) with red ferruginous argillans, the third is a yellowish-brown weathering-cracked loess horizon (Cl) without red ferruginous argillans, and the fourth consists of $CaCO_3$ nodules (Ck). The two weathering-cracked loess horizons, which are a major feature differentiating a pedocomplex from a palaeosol, have not been found previously in Chinese palaeosol. The ferruginous clay argillans are composed of montmorillonite–illite with some kaolinite minerals. The pedocomplex suggests that a moist subtropical climate prevailed between 420,000 and 360,000 years in the southern parts of the Chinese Loess Plateau. Its profile is Bts–Cs–Cl–Ck–Co. When the pedocomplex was developed, the mean annual temperature and precipitation were about 16 °C and 1000 mm respectively, about 3 °C higher and 400 mm more than at present in the Guanzhong Plain. The removal depth of $CaCO_3$ and the weathering-cracked loess layer indicate that the gravitational water reached a depth of at least 3.2 m, and the moisture content in S_4 would have been sufficient to sustain forest development at that time. In the typical interglacial in which S_4 was developed, the Qinling Mountains lost their function as the boundary between the subtropical and temperate zones of China, and water-bearing air masses resulting in rich rainfall could frequently reach the southern Loess Plateau.

1. Introduction

Aeolian loess and palaeosols are well developed in the Loess Plateau of China. The loess–palaeosol sequences are assumed to form a continuous record of the Quaternary although the rates of deposition and soil formation are variable. During the last 20 years, many studies have been done and various types of proxy data have been obtained from the loess–palaeosol sequences to reconstruct the monsoonal climate changes in East Asia. The magnetic susceptibility of loess–palaeosol sequences can indicate climatic change: low magnetic susceptibility represents weak soil formation and cold arid climate while high magnetic susceptibility represents strong soil formation and warm moist climate (Liu, 1985; Hell and Liu, 1986; Kukla et al., 1988; An et al., 1991; Maher and Thompson, 1991, 1995; Liu et al., 2008). The chemical composition showed obvious periodic climate change (Gellet et al., 1996; Kohfeld and Harrison, 2003; Zhao, 2005; Chen et al., 2006). The soil microstructure and chemical composition indicated that the soil types of red–brown palaeosol in loess were luvisol and eutric cambisol (An et al., 1985). Study results showed that the S_4 and S_5 developed best in the Chinese Loess Plateau (An et al., 1985; Guo et al., 1998; Zhao, 2002; Zhao et al., 2012). The particle size of loess in Luochuan, China, showed that the dust accumulation rate is slow during the interglacial stage but speeds up during the glacial stage (Bronger and Heinkele, 1989). On the basis of the study of the climatic change of the last glacial–interglacial cycle, it is known that a warm and moist climate is beneficial to the development of palaeosol and decreases the dust accumulation rate, while a cold and dry climate is beneficial to the development of loess and increases the dust accumulation rate (Porter, 2001; Rutter et al., 2003; Feng et al., 2004; Vidic et al., 2004). Changes in the dust accumulation rate are correlated with global ice volume cycles (Shackleton et al., 1995). Based on field spectroscopy research on loess stratigraphy, past monsoon variation was reconstructed (Mike et al., 2011).

The fourth palaeosol (S_4) in China's Loess Plateau was a luvisol with a Bt–Ck–C profile developed under a semi-arid (Zhu, 1965) or semi-humid climate (An et al., 1985; Chen et al., 2006). Some researchers consider that the vegetation during the formation of the S_4 of Guanzhong Plain was forest-steppe (Lin and Liu, 1992). Many other researches consider that because of the very large thickness of loess and the lack of a water-resistant layer, atmospheric precipitation can

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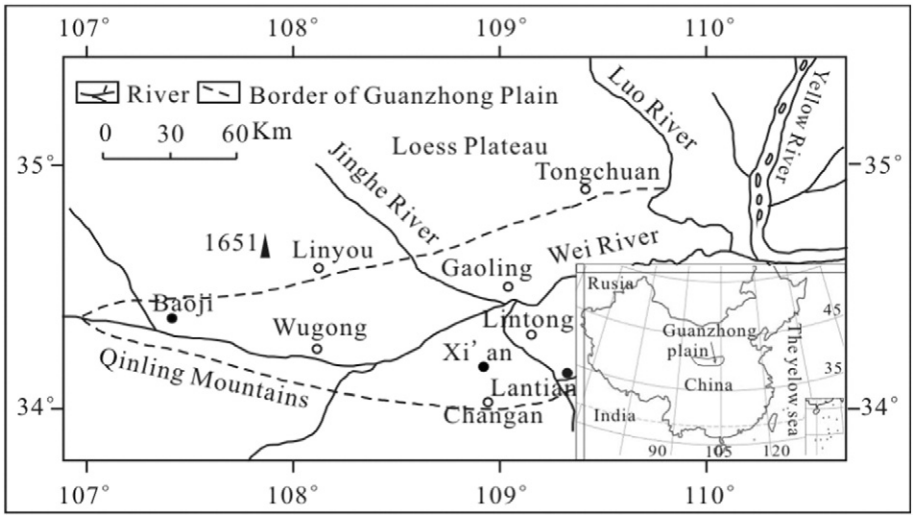

Fig. 1. Location of the Guanzhong Plain and profiles studied.

seep down to reach an underground water level 50 m deep, and thus due to the lack of soil water needed by forest during the formation of the S_4, no forest growth occurred (Zhang and An, 1994).

S_4 is corresponding to eleventh oxygen isotope stage of very warm climate in deep sea deposit (Ruddiman et al., 1989). S_4 developed also in loess profile in Czech Republic (Kukla, 1977), Federal Republic of Germany in Europe (Pecis, 1987), The United State in America (Kukla, 1987a), Central Asia in Asia (Bronger and Winter, 1995; Dodonov and Baiguzina, 1995), New Zealand in Australia (Eden, 1989). S_4 was studied for revealing Pleistocene climatic cycles, but its soil type, deep weathered layer, profile constitution, weathered degree, and soil palaeomoisture content during development of the palaeosol were not studied. For this reason, the studying of S_4 is of very important significance in the world.

However, a pedocomplex has not been found. Our investigations in the southeastern parts of the Loess Plateau indicate a pedocomplex at the elevation of S_4 in the Brunhes Epoch, which has not been reported previously. As mentioned after, the pedocomplex differs from other palaeosols in Chinese loess (An et al., 1985; Guo et al., 1996) and European loess (Pecis, 1987; Kukla, 1987a,b). In this paper, we shall discuss its profile subdivision and the palaeoenvironment during its development.

2. Materials and methods

2.1. Site description

The Shuangzhu and Tianjiapo profiles (34°10′ N, 109°58′ E) are situated about 5 and 40 km to the southeast of Xi'an City, respectively (Fig. 1), and the Hejiacun profile is situated about 2 km to the north of Baoji City. The three profiles are exposed along a high cliff of the loess tablelands 500–700 m above sea level. The stratigraphy was exposed by erosion caused by nearby rivers. The mean annual temperature and rainfall are 13 °C and 600–650 mm in Guanzhong Plain. The entire Quaternary loess profile is about 120 m thick in the area and consists of 38 loess layers and 37 reddish brown palaeosols (Table 1), with the upper 35 m belonging to the Brunhes.

2.2. Soil sampling and analyses

The pedocomplex was found at the elevation of S_4 within the Brunhes Epoch. Samples were taken at 20–25 cm through two profiles. Clay minerals were determined by X-ray diffraction. The microstructure was studied with an optical microscope and electronic microscope. $CaCO_3$ was analysed by the capacity method. The removal depth of $CaCO_3$ and Fe_2O_3 in the profile was measured in the field. The Fe_2O_3 and Al_2O_3 contents were determined by spectrophotometry (Li, 1991) at the Xi'an Institute of Geology and Mineral Resources of the Ministry of Land and Resources.

3. Experimental and observed results in the field

3.1. The profile divisions of the pedocomplex observed in the field and its age

The pedocomplex observed in the loess profile of the Brunhes Epoch in Guanzhong Plain occurs at the elevation of S_4 at a depth of 18.0–21.6 m. Thus its age and duration are considered to be the same as those of S_4. It was formed during a period of 40,000 years between 420,000 and 360,000 years B.P. (Kukla, 1987a,b; Ding et al., 1994). Field surveys show that it usually occurs in the southeastern parts of the Loess Plateau (Fig. 1) and is well developed in the Guanzhong Plain.

Most of the palaeosols, except the S_4 and S_5 identified in loess profiles of Guanzhong Plain, have two horizons: a reddish brown Bt horizon and a $CaCO_3$ nodule horizon beneath it. The S_4 in the Shuangzhu, Tianjiapo, and Hejiacun profiles consists of four horizons (Fig. 2a–c) from top to bottom as follows:

(1) Bright reddish brown clay horizon (Bts) 1.5 m thick: prismatic structure and ferri-argillans developed well on the pedological surface.
(2) Dark yellowish brown loess horizon (Cs) 0.6 m thick: the cracks form a network, creating blocks 10–30 cm wide. Some red ferri-argillans are seen on the loess surface (Fig. 3a, b). The horizon is 0.3 m thicker in Hejiacun and Liujiapo profiles than in Shuangzhu (Fig. 2).

Table 1
Pleistocene loess strata of the Guanzhong Plain in the southern Loess Plateau of China.

Geological period	Late Pleistocene	Middle Pleistocene	Middle Pleistocene	Middle Pleistocene	Early Pleistocene
Loess and palaeosol	L_1, S_1	L_2–L_4	S_4	L_5–S_7	L_8–L_{38}
Thickness (m)	5–8	13–15	3.6–5.0	16–18	65–75
Age (kyr)	10–128	128–360	360–420	420–780	780–2480