Loess and early land use: Geoarchaeological investigation at the early Neolithic site of Guobei, Southern Chinese Loess Plateau

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Abstract

Prehistoric land use at the Guobei site and its relationship with the local environment are examined by applying OSL dating, micromorphological examination and geo-physical analysis. The majority of the OSL dates are of early to middle Holocene ages and are thus comparable to many OSL dates derived from other studies in the same region. According to the particle size analysis, silt-sized particles (2-60μm) were predominant throughout the profiles examined. However, there are spatial and temporal variations of different size groups of particles throughout the profiles, which provide complementary information for the micromorphological interpretation. The total organic component of the samples examined through LOI is relatively high (all > 2%), with those of the overlying Holocene deposits higher than those of the underlying Malan loess by about 0.2%. Moreover, in all three profiles, the highest organic contents appear in the palaeosols, confirming that there was greater organic accumulation during soil formation periods. The groundmass of most slides collected from the early to middle Holocene horizons displays a very homogeneous pattern, while the abundance and distribution of different kinds of pedo-features, mainly including clay textural, calcitic, iron/Mn and crustal features, vary greatly temporally and spatially. These different lines of information demonstrate diversified pedo/sedimentary processes due to variations in micro-environmental conditions and cultural activities. We discuss the importance of a palaeo-ecological perspective, allowed by the geoarchaeological study, to an improved understanding of the relationship between loess, changing hydrology, prehistoric farming practice and land use, and long-term landscape change in the Chinese Loess area. This will thus contribute to a comparison on the dynamic relationship between loess and prehistoric farming in other regions of the world such as Europe and North America.

Key words

Loess, early farming, micromorphology, OSL dating, geoarchaeology, China

1. Introduction

Loess is widely distributed in North China, Central and Eastern Europe and Central North and South America and has been considered as fertile land for farming (Liu, 1985; Schaetzl and Anderson, 2005). This importance to agriculture in Europe and the formation of loessic landscapes has been intensively researched (~~Catt, 2001;~~ Doolittle, 2002; Pulleman, 2002). Richthofen, the great geographer who introduced Chinese loess to the west, for instance, noted the long history of crop cultivation in North China "without use of manure" and attributed this sustainable agriculture to the "porosity of loess" (cited from Catt, 2001). This opinion was adopted and further elaborated by many agronomic scientists who tried to explain why this porous structure of loess is important and how loess supported sustainable farming without manuring (Catt, 2001).

The physical and chemical properties of loess are proved to be vital to the development of farming practices (Catt 2001). The key to disentangle the long-term interaction between loess, agriculture and prehistoric societies lies in an in-depth understanding of the palaeo-ecology and landscape of prehistoric farming through interdisciplinary inquiry. Agriculture has a long history in the Chinese loess area, yet there has been a pronounced lack of such interdisciplinary investigations, unparallel with the great achievement in modern agronomic research in the loess area (Li, 2007). There is thus a pressing need to examine the palaeo-ecology and environmental backgrounds of early farming and associated land use in the Chinese loess area.

This paper is concerned with the earliest Neolithic Culture, the Laoguantai Culture (c. 8000-7000 BP) in the Western and Southern Chinese Loess Plateau (CLP) (Bettinger et al., 2010a, 2010b; they provide evidence of earlier origins of agriculture in this region, but it remains controversial), a culture first recognized in 1950s (Wei and Yang, 1986) with its distinctive pottery assemblage. While years of excavations and research in other parts of North China have unearthed remains of contemporary cultures and investigated the similarity and difference between them, the ecological diversity and importance of local environments in the Laoguantai Culture are rarely addressed. A geoarchaeological survey was carried out at the Guobei site and its vicinity in the Southern CLP. Optimal Stimulated Luminescence (OSL) dating was applied to aid stratigraphical interpretation based on field observation. Within this basic chronological framework, soil micromorphology and geo-physical analyses were used to obtain detailed information of sedimentary and pedogenetic processes and long-term land use history. The results from the case study are then discussed with archaeological discoveries and environmental data derived from other studies in the same region.

2. Site, material and methods

2.1 The site and the fieldwork

Guobei is located on the alluvial plain of the Taipingyu River in the Southern CLP, 416 meters above sea level and only about 4km to the north of the Qinling Mountains (Figure 1). The surrounding landscape is typical in the Southern CLP, that is, a flat alluvial plain is situated immediately next to the foothill of the Qinling Mountain, with topography quickly descending from more than 2000 meters to around 400-500 meters above sea level. A rough estimation of the size of the site is around 60000 m^2. The site was found in 2008 in a regional archaeological survey. After the pilot fieldwork in 2009, two more fieldwork seasons were carried out at Guobei in 2010 and 2011. Ceramics of Laoguantai culture (c.8000-7000 BP) and Longshan culture (c.5000 BP) were found from the surface and collected from exposed profiles. A deep, continuous section was dug for mud-brick manufacture, which provides an excellent overview of the stratigraphy at the site, and from which artefacts and archaeological features (e.g., pits) of the Laoguantai culture and Longshan period can be seen.

Unfortunately, the upper part (of Late Holocene age) of the wind-blown and reworked loess and the palaeosol has been removed in some localities. Detailed description in the field of the sediments is provided in Table 1. Nine sections were cleaned and examined (Figure 2), all showing comparable stratigraphies (Figure 3 and Table 1). 25 micromorphological, 14 OSL dating and 59 bulk samples were collected from five profiles (Profiles 5-9, Figure 2). Below is a brief summary of the collection, processing and analysis of the samples; more details are given in the appendix.

2.2 Sampling, processing and analyses of geo-physical and micromorphological samples

Undisturbed soil samples were collected by using knives and other tools, from the examined sections after fresh section walls were cleaned and clear stratigraphies displayed. Bulk samples were normally collected with 10cm intervals, from bottom to top and with the top 30-50cm neglected to avoid contamination. Micromorphological samples were manufactured at the McBurney Laboratory for Geoarchaeology at the University of Cambridge following the method described by Murphy (1986) with modification by Julie Boreham, Charles French and Tonko Rajkovaca. These thin sections were analysed using a polarizing microscope, with microstructures, coarse and fine fractions of groundmasses, anthropogenic and heterogeneous inclusions and pedo-features examined and semi-quantified (after Bullock et al., 1985; Stoops 2003). Very often one slide is divided into different units as changes in textures and abundance of key pedo-features are observed. The geophysical analyses were processed at the Laboratory for Physical Geographic Science, Department of Geography, University of Cambridge, under the supervision of Dr. Steve Boreham and Mr Chris Rolfe. The processing methods follow the standard protocols described by the Laboratory for Physical Geographic Science (http://www.geog.cam.ac.uk/facilities/laboratories/techniques/)

2.3 Collection and processing of OSL dating samples

Special metal tubes (c.30cm long) with one end sealed were made to collect OSL samples. These tubes were entirely hammered into cleaned profiles. After the tubes were taken out of the profiles, the other end of the tubes was quickly sealed by sponge and paper. They were then labeled and wrapped with black plastic bags and tapes. Wet bulk samples were also collected to measure water contents for dose rate calculation and calibration.

The pre-treatment, dating of these OSL dating samples and measurement of water contents for dose rate calibration were completed at the TL and OSL Dating Laboratory at the School of Archaeology and Museology, Peking University, following standard single-aliquot regenerative dose methods described by Duller et al. (2003). All procedures were completed in the dark room of the laboratory. U, Th and K for dose rate calculation were measured at the China Earthquake Administration.

In the dark room, samples in the two ends of the tubes were first removed into self-sealing bags with knives for dose rate measurement. This rules out the possibility of partial exposure to sunlight during sampling, which may significantly affect dating results. About 100g of the sediments in the middle of each tube were placed into glass beakers before being dried in the oven with 40°C overnight. The dried samples were slightly grounded in an agate mortar to break down small aggregates. They were then sieved using 200, 125 and 20μm mesh sieves, with each separated fraction packed into different self-sealing bags. The 20μm samples were used for the obtainment of fine quartz grains for OSL dating. These 20μm sediments were first added with 30% HCL and 30% H_2O_2 to remove carbonates and organic material, respectively. They were then immersed in hydrofluorosilicic acid, H_2SiF_6 (30%), in tubes for 4-5 days to obtain fine-grained quartz. All measurements were performed using an OSL reader (produced by the Riso National Laboratory, Denmark) with blue-light-emitting diodes (LEDs). Details of the determinations of De, dose rates and errors will be discussed separately in future work. This paper only presents the results and discusses some preliminary observations.

3. Results

3.1 Results of OSL dating

The results of OSL dating at Guobei (Table 2), except for the GBP6:4 which has a very high dose rate (≈6.7 Gy/Ka), vary slightly within the range of 3.3-4.0 Gy/Ka. These dose rates are also comparable to dose rates obtained from other similar studies in the same area (Lai and Wintle, 2006; Lu et al., 2007; Zhao et al., 2007). Such consistent dose rates indicate that the sediments of the examined profile at Guobei were not exposed to abnormal radiations and the calculations here are reliable. The equivalent doses (De) were divided by the dose rates. This gives the OSL ages (ka). GBP6:8 and 9 were collected from the Late Pleistocene Malan loess (Figure 3). This is corroborated by the age of GBP6:8, 20,910±1300 BP, although this age is in fact older than the preliminary date drawn from our field observations. Assuming the sedimentation rate remained roughly constant since the Late Pleistocene to the beginning of the Holocene, the OSL age at GBP6:8 thus helps to calculate the sedimentation rate at Guobei since 20,910±1300 BP. With the depth of about 30cm from GBP6:8 to the possible Pleistocene/Holocene boundary (1.6m or more below modern surface) (Figure 3) and divided by 10000 yr, a sedimentation rate about 3cm/ka can be obtained. This is almost negligible compared to a 60cm/ka sedimentation rate of the Late Pleistocene period calculated by Lai and Wintle (2006) in their study of a loess section at the Yuanbao site in the Western CLP. There was probably surface truncation which removed much of the Late Pleistocene – Early Holocene deposits. This date thus needs to be re-examined and cross-checked with results from other samples (e.g., GBP6:9).

GBP6:7 is located within the Pleistocene/Holocene boundary. The OSL age is 7440±270 BP, which is possibly younger than its real sedimentation age. The micromorpholoical examination of thin sections collected from the same levels (Figure 3 and below) confirms the evident impact of farming and/or related activities on the soil and the boundary here might have also been disturbed. These might affect the OSL dating results. A pilot OSL test was completed in 2009 on a sample collected from this boundary or slight above (from the location of GBP3:2, Figure 3 and Table 2). Dose rate measurement was not carried out, but an average value of 3.3 Gy/ka is adopted (Lai and Wintle, 2006), which gave an OSL age of 9730±400 BP. This result suggests at least some of the tested fine-grained quartz were deposited at the beginning of the Holocene.

GBP6:6 and 5 were collected from the early Holocene palaeosol. More pronounced impact of farming and other disturbance on soils is observed in micromorphological examination. Such disturbance causes mixture and re-deposition of materials of different dates and was probably responsible for the date reverse seen here. In theory, every single event of sunlight exposure due to sedimentation processes or disturbance can be detected by OSL dating if sufficient dates are obtained. But this is not possible for the study at Guobei. In their detailed study of the OSL ages of a soil sequence which received disturbance due to terracing and agricultural activities, Roberts et al. (2001) was able to identify these cultural activities by the procurement of OSL ages from a sequence. The future work should thus also focus on the identification of abnormal exposure events due to cultural activities. This will provide valuable information for micromorphological examination.

3.2 Results of geo-physical analyses

3.2.1 Particle size distribution

Silt-sized particles (2-60μm) were predominant throughout the profiles (Profiles 6, 5 and 7), a pattern which has been seen in many previous studies of particle size distribution in the CLP (Liu, 1985, 2009; Sun et al., 2000). The spatial and temporal variations of different size groups of particles provide important complementary information for the micromorphological interpretation (Figure 4).

Firstly, the relative percentage of clay minerals is a useful indicator of post-depositional modification and soil development in the CLP (Liu, 1985; Sun et al., 2000; Sun et al., 2002). With the exception of two bulk samples (GBP6:16, GBP6:21) from which an elevated clay-sized material content can be seen (to about 27%), the proportion of clay-sized material mainly falls between 16% and c. ≈20%. The high percentage of clay in GBP6:16 may have resulted from clay illuviation with translocated clay minerals derived from the overlying levels, due to increasing surface runoff. Dramatic changes in the proportion of clay-sized particles can be seen from samples collected from the early Holocene palaeosol at Profile 7. As with GBP6:16, the high percentages of clay at the very upper and very lower parts of the sequence may also have derived from clay illuviation. This resonates with the abundance of clay textural features in the slides taken from contemporary levels (GBP7:1 and GBP8:2, these are slide numbers rather than bulk sample numbers).

Secondly, despite their small proportion, the very fine sand particles (88-125μm) display vertical variation. A common trend is that the loess layers contain slightly more very fine sand than the palaeosols. Besides the frequent changes in direction and strength of the winds that were responsible for the deposition of coarse wind-blown materials (Sun et al., 2000; Sun et al., 2002; Xin, 2005; Zhang et al., 2005), this might also be related to ongoing soil formation and mineral weathering processes (Stoops and Schaefer, 2010; Zauyah et al., 2010) which disintegrate coarse minerals (e.g. feldspar) into finer particles.

Lastly, very fine sand particles are the coarsest particles recorded by particle size analysis by which the occasional occurrence of coarse sand particles along large voids seen in micromorphological examination is not reflected. This, however, further supports the interpretation that these coarser materials along voids might have resulted from rooting or similar activities (Goldberg and Macphail, 2006: 198-201) which only took place sporadically.

3.2.2 Loss-on-ignition

The carbohydrate, carbon, total organic and $CaCO_3$ (%) contents of the examined bulk samples are presented in the Table S1. The total organic component of the samples examined is relatively high (all > 2%), with those of the overlying Holocene deposits higher than those of the underlying Malan loess by about 0.2%. Moreover, in all three profiles, the highest organic contents appear in the palaeosols, confirming that there was greater organic accumulation during soil formation periods (Connor et al., 2011: 175). Also, a higher organic content is not seen in those levels where slides with cultivated features were collected, implying that the farming activities did not have a significant impact on organic accumulation, or that cultivation caused the relatively quicker loss of organic matter.

There is a widely-recognized positive correlation between clay minerals and organic content (Konen et al., 2002; Lagaly, 1984; Pulleman, 2002). This is perfectly demonstrated by the synchronously high content of both clay particles and organic matter in GBP7:2-4 (Table S1). The reason for such a correlation might be that clay-minerals provide enormous surface areas where organic materials, particularly humus or organic pigments, can bond (Connor et al., 2011: 175; Sui, 2006).

In all three profiles, the $CaCO_3$ contents remain relatively high in their lower parts (the Malan loess), in accordance with field observations and many studies suggesting that the Malan loess represents one of the driest events in the Pleistocene of North China (Kemp, 1995, 2001; Zhao, 2002). In Profile 7, the $CaCO_3$ content abruptly reduces from 18.6% to 7% at the transition from the Malan loess to the overlying early Holocene palaeosol. Such a contrast in $CaCO_3$ contents must be the result of decalcification of the early Holocene palaeosol with the help of frequent water movement which leached $CaCO_3$ out of the profile. Such a sudden change is also seen in both Profiles 5 and 6. In Profile 6, the change took place within the early Holocene palaeosol, suggesting that the groundwater table was probably not as deep as it was at Profile 7 and led only to the re-precipitation of $CaCO_3$ within the soil profile. This result thus clarifies the fact that the sharp boundary observed in the field is perhaps not an actual boundary (from the sedimentation viewpoint) (Lai and Wintle, 2006), but one caused by $CaCO_3$ precipitation.

The carbon content of the examined profiles is generally very low, around or less than 1%, which is consistent with the findings of other studies in the CLP (Wu et al., 2003). However, there is spatial variation amongst these profiles. Throughout the profile, the carbon content in Profile 5 remains constant (0.84-1%), which might be closely related to the land use here (see below). Stable grassy vegetation may have been conducive for the maintenance of soil carbon (Li et al., 2007). The carbon values in Profile 6 range mostly 0.6-0.8%, with two exceptions appearing in the Malan loess and the early Holocene palaeosol. This relatively lower quantity of soil carbon might be attributed to the effect of farming, as suggested by some studies (Wu et al., 2003). Farming not only reduces plant debris input (because of land clearance and the removal of plant remains), but the resultant bare surface might also accelerate the mineralization process. However, the effect of farming on organic accumulation is not linear (Li et al., 2007; Wu et al., 2003). Also, after the land has been left fallow for a few years, soil carbon can reach the same level as in natural grassland (Li et al., 2007). All these factors complicate the interpretation of organic contents using LOI results.

3.3 Results of micromorphological examination

In line with the particle size distribution shown above, the groundmass of most slides collected from the early to middle Holocene horizons displays a very homogeneous pattern: dominated by silt-sized particles of loess, reworked loess or alluvial sediments, with noticeable contributions of both coarser and finer (clay-sized) particles due to changes in sedimentation regimes and pedogenetic processes. The results of micromorphological examination and interpretation are briefly summarized below, with an emphasis on the Early to Middle Holocene horizons. Full details are given in Table S2.

3.3.1 Profile 6

The bottom of the profile (GBP6:5 and upper part of the GBP6:4, typical Bk horizons, of Late-Pleistocene age), is dominated by calcitic pedofeatures and abundant inherited calcite nodules, and developed excremental granules/structures. These calcitic pedofeatures appear as micritic granular, needle-shaped calcite or larger calcitic coatings and nodules either along root channels or well embedded within the groundmass. They are mostly the product of calcium carbonate dissolution and re-precipitation in soil solution percolating along soil pores or fissures (Durand et al., 2010: 158-159) under relatively dry conditions with only pores and adjacent areas seasonally wetted by capillary or plant root water (Alonso-Zarza, 1999; Jaillard et al., 1991; Wright et al., 1995). Occasionally, there are very thin and discontinuous dusty clay pedo-features and micro-charcoal, representing slight surface disturbance such as natural firing events. There is a sharp boundary between the Late-Pleistocene horizons and its overlying horizons.

The groundmass of the slides collected from the Early to Middle Holocene horizons (upper part of GBP6:4, GBP3:2 and GBP6:3) is highly disturbed, characterised by the abundance of large, amorphous or sub-rounded aggregates. They are darker in colour compared to the adjacent groundmass. These heterogeneous aggregates are sometimes better preserved within the calcareous groundmass, but more often they are disintegrated into smaller granules and mixed up with the light yellowish groundmass materials (Figure 5a). In the latter case, calcitic features are also involved, coating or mixing with these aggregates (Figure 5b).

Abundant clay pedofeatures are present. They are either formed in situ or appear as disrupted fragments of previously formed features. These textural features are roughly divided into three categories. The first include limpid clay coatings and infillings, which show typical bright reddish colours and strong birefringence with layered structures (Figure 5c). The second category, dusty and silty clay coatings and translocated papules (3-4%), is most abundant (Figure 5d, 5e and 5f). Disrupted fragments of clay/silty features constitute the third category (1-2%) (Figure 5g and 5h). According to their forms and colours, especially the distinctive dividing lines in the middle of some fragments, it is clear that some are derived from the second type. In addition, two types of compound pedofeatures are found. The first type is silty clay coatings superimposed on limpid clay coatings and infillings (Figure 5c). The second type, which is more common, is darkish-red clay pedofeatures with low birefringence superimposed on calcitic features (Figure 5e and 6a). Abundant micro-charcoal and organic matters were deposited during this time, of which about 1% or less are very coarse and amorphous charcoal (Figure 6b and 6c) with plant-tissue structures often visible, and the rest are fine micro-charcoal and organic matter.

The heterogeneous aggregates probably result from physical disturbance by tilling or similar activities capable of mixing up the aggregates, allowing them to be re-deposited in deep depths and creating the sharp boundary. This serious physical disturbance caused by tillage has been recorded in many places (Macphail, 1998; Huang et al., 2002; Lewis, 2012). They then underwent bioturbation and further ploughing which caused them to disintegrate into smaller granular aggregate. Those disrupted clay pedofeatures well incorporated into the groundmass. They might be also caused by repeated tilling or physical disturbance.

The biological activities were encouraged by the presence of abundant organic materials which themselves may have been added into the groundmass deliberately, perhaps as soil amendment. This is further supported by the presence of very coarse and angular minerals, being brought into the soil deliberately.

In two micromorphological studies of ancient and modern cultivated soil in the same areas, Pang et al. (2006; 2007) terms the dusty/silty clay features “residual clay” features (see section 4.2.1). They are different from typical illuvial/argillic clay features, as they are only moved within Ap horizons. The smooth wall of the voids might have also derived from irrigation or related activities (Pang et al., 2007) with standing vegetation on the surface. Such hydrological conditions also lead to ongoing internal slaking in the groundmass, as evidenced by the clay depletion and concentration areas (these are called "redox depletions and concentrations" in (Schaetzl and Anderson, 2005:494-495) which encourage physical movement and chemical break-down of soil minerals under frequent wet-dry alternations). The abundance of calcitic features and the presence of compound pedofeatures, which show calcitic features superimposed onto clay textural features.

3.3.2 Profiles 5

GBP5: 6 and GBP5:5 collected from the bottom of Profile 5 possess typical C/Bk-horizon characteristics, similar to the contemporary part in Profile 6 just described. The granules are mostly very coarse, have a reddish or yellowish colour and sometimes contain abundant calcite. Abundant calcitic features, including coatings, nodules and infillings, are present. These calcitic features are undergoing severe bioturbation, appearing as disrupted aggregates filling in channel voids or being highly mixed up with other granular (Figure 8a and 8b).

Clay textural features are also very abundant (5%). Limpid clay coatings and infillings are often layered and show bright reddish color (Figure 6d and 6e). Some dusty clay coatings are layered, while others are generally very thin (Figure 6f and 6g). In addition to these are sparsely distributed dusty clay concentration features, often appearing in channels (Figure 6h). The clay textural features are often bioturbated and mixed with disrupted soil aggregates. Occasionally, dusty clay features are found juxtaposed with calcitic coatings (Figure 6g). Abundant very fine sand and silt-sized organic materials and micro-charcoal are present.

A few major episodes of pedogenic processes are observed based on the above descriptions. First, clay textural features, when the soil was relatively Ca^{2+} free, were probably formed first, followed by the formation of the other types of clay pedofeatures. These clay pedofeatures are connected in the groundmass, representing probably a grassland vegetation under periodic disturbance with seasonally wet conditions. The succeeding period witnessed the formation of calcitic features, possibly through the quick re-precipitation of calcium carbonate rich water when a seasonal wet-dry water regime was dominant (Durand et al., 2010). The surface stability facilitated biological activities, which mixed up the soil groundmass, and created the developed granular microstructure. The bioturbated aggregates are smaller and more homogeneous in size, compared with those caused by physical disturbance (e.g. GBP6:4 and GBP3:2). This is a typical type of microstructure observed in grassland soils (Liu, 2009).

3.3.3 Profile 7 and 8

Horizons located in the transitional position from the Late Pleistocene to the Early Holocene have enriched manganese and iron nodules (GBP7:3 and GBP7:2). The formation of these typical dendritic manganese nodules may have been facilitated by a period of high water saturation (Kovda and Mermut, 2010; Schaetzl and Anderson, 2005: 495) (Figure 7a), suggesting prevailing wet conditions (Bánesz et al., 1995) after the dry period characterized by the formation of typical calcitic features. This happened during the Early-Middle Holocene on the overlying level after the palaeosol of earlier age was covered. However, such saturation may have not lasted for too long, as “long periods of saturation lead to the removal of manganese from the profile” (Gerrard, 1992: 96).

Further up-profile in the typical dark Early to Middle Holocene palaeosol (GBP7:1, GBP8:2 and GBP8:1), clay textural features are very abundant (10%). Limpid and layered clay coatings are very common (Figure 7b-f). The majority of them are dusty or silty clay coatings, infillings and concentration features, also with a layered structure (Figure 7e-h) and containing a large amount of silt-sized particles (minerals and fine charcoal). In situ or disrupted surface crustal features are also present (Figure 8c and d). About 4-5% of very fine charcoal is present throughout the slides.

The limpid or less-dusty clay coatings and infillings were probably first formed under relatively stable surface conditions and a mild surface run-off regime with grassland-forest vegetation. Their layered features suggest this process was frequently repeated. The predominance of dusty or silty clay coatings and related features, however, suggests longer and stronger surface disturbance, which must have provided abundant movable particles (minerals and micro-charcoal) for the ensuing illuviation. The poor sorting of these coarse particles indicates quick penetration of surface run-off within the soil. It is possible that the surface was covered by sparse vegetation and experienced frequent disturbance (or clearance) and burning over a prolonged period.

4. Discussion

4.1. Sedimentary and pedogenetic processes and land use changes throughout time

Through the detailed micromorphological and geo-physical analyses, we are able to reconstruction four major stages of pedo/sedimentary formation in these profiles described above.

Stage one coincides with the loess accumulation during the Pleistocene/Holocene transitional period (Figure 9). During this stage, weak calcium carbonate dissolution and re-precipitation were taking place, possibly during summer rainfall, although the amount of precipitation was probably very low. Very sparse grassy vegetation may have grown on the surface, promoting downward biological activities as evidenced by the developed bioturbated microstructure. However, the profile aggradation rate exceeded the rate at which the pedogenetic process was capable of incorporating newly-arrived materials into soil horizons.

In stage two, the dust-accumulation rate was significantly reduced (Tang and He, 2004; He et al., 2004), allowing soil formation processes to actively participate in the establishment of the distinctive Early-Holocene palaeosol. This is characterised by a typical "upbuilding" pedogenetic process with its products (clay textural and calcitic features and iron-nodules) invading the underlying parent material, the Malan loess. The processes seen in Profiles 5- 8 are, however, different. In Profile 6, there is a clear, physically-disturbed boundary between the Early Holocene palaeosol and the Malan loess, probably caused by tilling activities, although the possibility that it was truncated by other physical activities could not be entirely ruled out. A ploughed, clay enriched argic horizon/calcitic-clay enriched ploughsoil (Ap-Bt/Bk-Bt-Ap) is formed, representing the combined effect of continuous but reduced dust input, farming activities and ameliorating climatic conditions (mainly increased precipitation). In Profile 5, firstly the Early-Holocene palaeosol/Malan boundary seen in the field is as clear as it is in Profile 6. But this boundary is reflected in micromorphological examination more by the forms, quantities and depths of some diagnostic pedofeatures (e.g. calcitic features) rather than a very clear-cut boundary, implying it is more a colour difference rather than a real geomorphological boundary (Lai and Wintle, 2006). However, at the beginning of the development of the calcitic/clay enriched/calcitic/clay enriched (Bk-Bt-Bk-Bt) sequence, there is also evidence of physical disturbance that mixed up aggregates from the underlying and overlying horizons. Such disturbance seems to be quite tenuous. Therefore, the predominant disturbance was probably bioturbation, which is mostly likely facilitated by a stable grassland surface. The formation of the sequence is therefore the result of grassland development, continuous dust input and pedogenetic processes encouraged by improved climatic conditions. In both Profiles 6 and 5, some well-impregnated iron-nodules are present in the lower half of the sequence, suggesting that the soil was wetted at some point after burial.

In Profiles 7 and 8, firstly, the boundary is quite diffuse, based on both field observations and micromorphological examination. A typical Bk horizon then developed. Immediately after the Bk horizon was covered by continuous dust input, there was probably a short period of water saturation, favouring the formation of iron-oxide/sesquioxide features along voids. This gave way to the formation of a relatively thicker (argic) clay enriched or Bt horizon compared to the contemporary levels at Profiles 5 and 6. This is characterised by the abundance of dusty or silty clay features, which are rich in silt-sized particles (minerals and micro-charcoal), along with lesser amounts of limpid or slightly-dusty clay features. Some clay features have typical reddish colours, which are sometimes attributed to the contribution of fulvic acid from coniferous trees (Fedoroff and Goldberg, 1982; Liu, 2009), and a layered structure is often present. Bioturbation and developed calcitic features are rarely observed here. These together suggest a steady development of Bt horizon under a sparse tree-covered surface which received regular disturbance and experienced seasonal wet-dry alternations. It seems, therefore, that the development of the Early Holocene palaeosol here witnessed dramatic hydrological changes through time (dry-wetted-wet/dry) and there were many micro-scale variations. This sequence is completed by the formation of a weak calcitic Bk horizon, marking the return of dry conditions.

Pedogeneteic and sedimentary processes in stages three and four are of Middle to Late Holocene age and are discussed elsewhere.

To sum up, although the upbuilding model applies to the development of the Early-Holocene palaeosol in most periods, there is also spatial diversity mainly due to different vegetation cover, hydrological conditions and land use. It should be mentioned that the common occurrence of compound pedofeatures consisting of clay textural, calcitic and iron-rich features indicate that there were short-term environmental fluctuations which created short but perhaps frequent alternations of dry-wet, acid-alkaline soil forming conditions, often seen in the palaeosols of the loess areas (An and Wei, 1980; Hu and Lu, 2004; Tang, 1981).

4.2. Early Neolithic land use and the environment

Below we discuss in detail some important aspects of early land use in the CLP and how these contribute to the rethinking of some long-lasting views on the relationship between land use and the environment.

In addition to the physical properties of loess discussed in section 3, two other favourable properties of loess for agriculture are: continuous dust input rich in calcium carbonate and many other mineral elements (e.g. K, Mg and S) (Connor et al., 2011: 327-331) in the form of water solution travelling through the soil aggregates and thus facilitating direct nutritional uptake of plants; and porous conducive to long-term farming. Without intensive manuring, early millet farming would have benefited from these properties.

In section 3.3, we have shown that physical disturbance and related activities at Guobei had brought evident changes to the Early-Holocene palaeosol. Many studies in the same region have also presented similar evidence of the soil modification caused by early farming. At a site located on the loess tableland between the Wei River and the North Mountains in Zhouyuan (120km to the west of Xi'an City, also well known as the early capital of the Western Zhou Dynasty), Huang et al. (2002: 35) identify a type of micromorphological feature, 'well-rounded spherical pellet', that is commonly present in the horizon overlying the level with 'initial clearance', and suggest that this resulted from churning by cultivation starting from c. 7500 BP. This is corroborated, in Huang et al. (2002), by the peak of microscopic charcoal concentration in the corresponding level. Similar features are also present at sites near Xi'an (Pang and Huang, 2002). Pang and colleagues, in their comparative and experimental studies on modern and ancient cultivated and forest soils, find abundant dusty clay textural features (termed 'residual clay') in organic-rich groundmass and argue that such are diagnostic features resulting from the combined effect of farming, surface disturbance and water saturation. The last accelerates mineral weathering, generating a large amount of clay particles which are available for translocation (Pang and Huang, 2002; Pang et al., 2006; Pang et al., 2007).

Other indirect evidence of the adverse agricultural impacts is the presence of surface crustal features, which have been commonly seen in modern agricultural soils (Pagliai and Stoops, 2010, and references therein). These appear to be either in situ or eroded and re-deposited, implying the impact of water on bare surfaces in the field. These re-deposited, sub-rounded disrupted-crustal features are usually well incorporated into soil profiles (Figure 8c and d). Coupled with the compaction caused by physical pressure discussed above, they together may have had a strong impact on the structure of the soil groundmass and may have been in the long run harmful to the maintenance of soil structural stability, although it is argued that other soil characteristics of the loess may have offset such impacts.

It should be therefore admitted that the extent to which the soil was modified was probably small and very localized (Zhuang and Kidder, 2014). Early farming did not yet significantly change the properties of the loess and soils formed out of it (Huang et al., 2002). During the Early to Middle Holocene, the continuous dust accumulation was well incorporated into the ongoing soil formation process and often contributed to the thickening A and deepening B horizons. In other words, this aggrading land surface and might erase imprints of early farming as well.

4.3. Ecology for early farmers

The early Neolithic in North China represents a interesting case for the emergence of an entirely new type of interaction between people and the landscape. Domestication of key cultivars was completed, but an intrinsic diversity in local subsistence strategies was maintained. It is a period when human activities began to play an increasingly critical role in the formation of local landscapes. Here we use 'ecology' as a concept to further synthesize the afore-mentioned physical-environmental aspects for early farmers and the long-term interaction between people and the environment in the CLP.

A positive correlation between charcoal concentration and the onset of early farming in the Southern CLP has been confirmed by recent studies (Huang et al., 2006; Li et al., 2009; Tan, et al., 2011). Some of the sites with the increase of charcoal abundance occurring from 7800 or 7500 cal. BP are situated on the typical loess tableland which undergoes severe ongoing surface erosion, whereas others are located in the lowland areas, on either upper edge of river terraces or next to river floodplain. If the changes of charcoal abundance were indeed human-induced, diversified environments in this region were explored by the people during this period.

Fire was used in combination of simple farming tools (e.g., stone or bone spades or hoes) to clear lands in the nearby slopes and terraces where the hydrological conditions were most optimal. But both fire and physical clearance by using tools were probably kept minimum. For the latter, although the impact at the beginning was very patchy, gradually this had modified the ecosystem of the farming fields that were becoming more and more adaptive and vulnerable to human disturbance. Most notably, with the formation of typical cultivated soils, after repeated cultivation and disturbance, in the CLP, the water infiltration of soils in the farming fields became lower. This means the field would have become seasonally dry and an optimal habitat for dry-loving plants including millets and their relatives was formed. Indeed, with dry-land farming spread across North China, more and more lands were dominated by weeds and dry-loving grassy plants as by-products of farming.

The use of fire was not exclusively for agricultural purposes, however. It can also promote animal grazing or greatly change the habitats of some herbivores that were the key target for hunters. A good example for this is the quick colonization of grassy plants with the help of fire. This would have promoted the grazing of deer, a species that was intensively hunted during this time.

A strong degree of mobility was maintained amongst the early Neolithic settlements in North China (cf. Zhuang et al., 2013), but the distance of movement for obtaining a variety of foods varies from place to place, depending on the availability of resource in local environments, occupation patterns and subsistence.

Therefore, instead of sticking to the traditional view which tends to look at the patterns of prehistoric agriculture and life as a clear-cut model, being either swidden (slash and burn) or permanent, we propose an ecological perspective, in that the temporality and moving patterns of the prehistoric agriculture life were intricately intertwined with local environments, prehistoric farming regimes and social environments in a long-term process.

5. Conclusion

Focusing on the early land use on the Southern CLP, this article uses a variety of methods (soil micromorphology, OSL dating, geo-physical analysis) to obtain high-resolution information from on- and off-site contexts for a robust reconstruction on the relationship between long-term land use and landscape change.

a) While soil evidence concerning early farming activities is present at the Guobei and other sites in the region, a diversity of the land use patterns was maintained, which has been supported by the soil evidence.
b) The environmental conditions on the CLP were unique for early farmers. The soil properties and hydrological regimes in the region played an especially important role in the development of early farming. The reconstructed hydrology and detailed scrutiny of the soil evidence, combined with the examination of the regional environmental datasets, lead to a rethinking on the traditional opinion on slash and burn (swidden) farming. Whilst it is the case that the early farming communities in North China were continuously moving around in their local landscapes for various reasons (Zhuang et al., 2013), this does not necessarily mean the farming regime adopted by these communities would resemble the fallowing pattern often seen in the typical slash and

burn farming in prehistoric Europe. Rather, the current evidence does not allow any of such conclusions to be drawn.

c) As well as the need to carry out large-scale and systematic surveys, we also propose to study the ecology and landscape of early farming to better understand the long-term interaction between people and the landscape. Fire, long-term land use, and occupational patterns all played a crucial role in the formation of early Neolithic landscape and in modifying the ecosystem towards one more and more managed by humans. Indeed, studies integrating site-based information with regional datasets will contribute to disentangle the interplay between different activities and conditions and the prolonged and increasing engagement between people, culture and the environment.

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Table 1 Sediment descriptions of Profiles 5 and 6 at Guobei

Profile 6		Profile 5	
Unit	**Description**	**Unit**	**Description**
d	Yellowish silty deposits; abundant plant roots; moderately developed vertical structure	**d**	Same as unit d in profile 6
c	Grey brownish silty clay deposits, the lower part has a brighter colour than the upper part; abundant plant roots; display angular blocky structure when it is dry; contain charcoal and pottery sherds	**c**	Same as unit c in profile 6, but has a more homogeneous colour throughout the horizon
b	Brown yellowish silty-clayey deposits; abundant plant roots; developed soil structure; contain some calcium carbonate nodules, charcoal and pottery sherds; a thin layer of silty deposit with rich calcium carbonate nodules; a sharp boundary with the underlying level	**b**	Brown yellowish silty deposits; abundant plant roots; highly bioturbated; contain some calcium carbonate nodules and pseudohypha, some charcoal and very rare pottery sherds
a	Yellowish silty deposits; abundant plant roots; abundant calcium carbonate pseudohypha and nodules; developed granular structure	**a**	Similar to unit a in profile 6, but in the mid-lower part, contains a thin layer of greying silty deposits, decalcified, with few charcoal embedded

Table 2 Results of OSL dating of samples collected from Profile 6

Sample number and depth	dose rate (Gy/ka) (a=0.035)	*De*(Gy)	OSL age(ka)	Age(BP)	Age error
GBP6:1(20cm)	4.00 ± 0.10	2.67	0.67 ± 0.02	670	20
GBP6:2(50cm)	3.61 ± 0.09	13.68	3.79 ± 0.13	3790	130
GBP6:3(90cm)	3.48 ± 0.09	16.48	4.73 ± 0.24	4730	240
GBP6:4(128cm)	6.71 ± 0.17	13.79	2.06 ± 0.14	2060	140
GBP6:5(163cm)	3.79 ± 0.10	25.98	6.85 ± 0.25	6850	250
GBP6:6(180cm)	3.51 ± 0.09	15.26	4.35 ± 0.20	4350	200
GBP6:7(200cm)	3.31 ± 0.08	24.59	7.44 ± 0.27	7440	270
GBP6:8(232cm)	3.20 ± 0.08	66.89	20.91 ± 1.30	20910	1300
GBP6:9(262cm)	3.48 ± 0.10	Not completed			

GBP3: 2(c. 210cm)	3.30	32.10	9.73 ± 0.4	9730	400

Figure 1 Locations of the Guobei site

Figure 2 Examined profiles at Guobei and their locations. Profiles 7 and 8 are close to Profile 9 to its left. Scale: the distance between profiles 5 and 4 is about 100m.

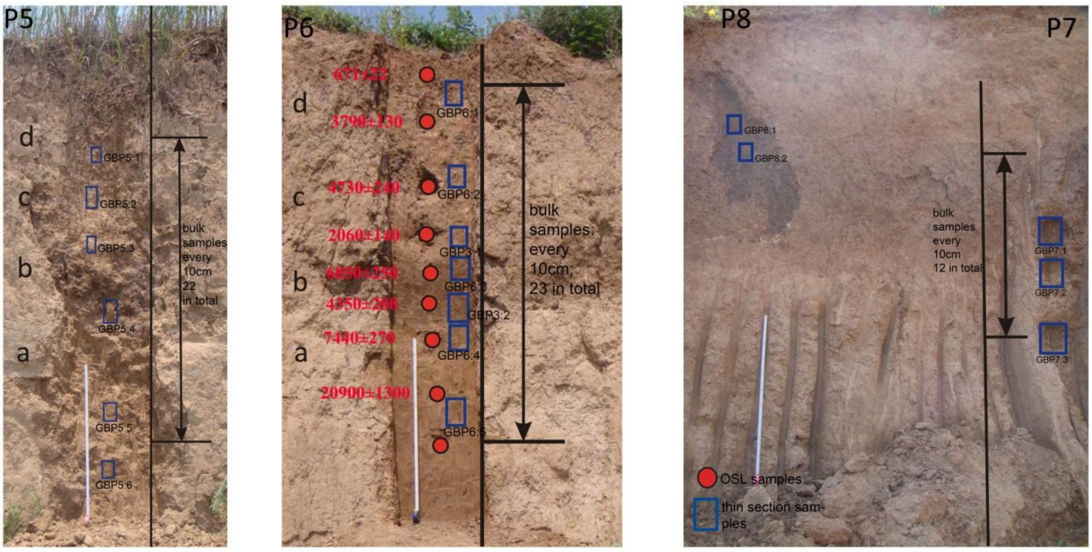

Figure 3 Strategraphies, sampling locations and OSL dating results of profiles examined at Guobei. Detailed sediment descriptions are given in Table 1. Note the boundary between the Pleistocene and the Holocene about 5cm below the location of the OSL dating sample GBP6:7.

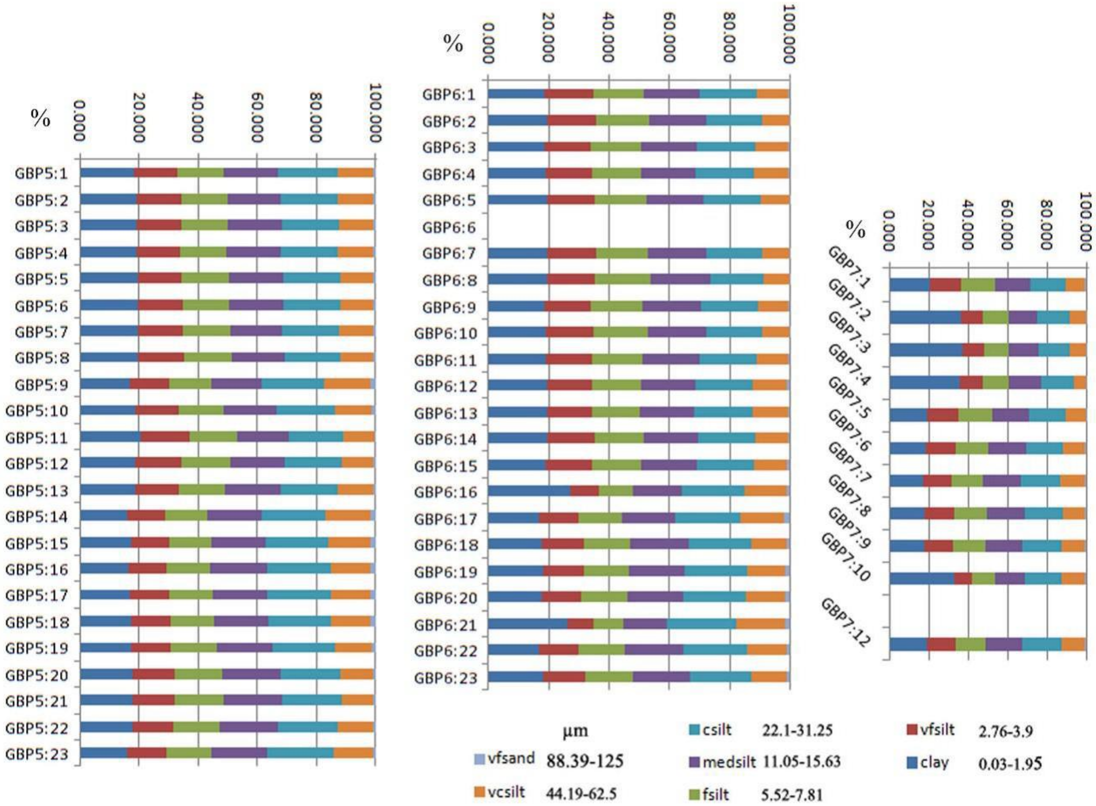

Figure 4 Results of particle-size distribution of Profile 5, 6, and 7at Guobei. GBP5:1-23, top to bottom, so are GBP6:1-23 and GBP7:1-12. GBP6:6 and GBP7:11 are missing. vfsand: very fine sand; vcsilt: very coarse silt; csilt: coarse silt; medsilt: medium silt; fsilt: fine silt; vfsilt: very fine silt

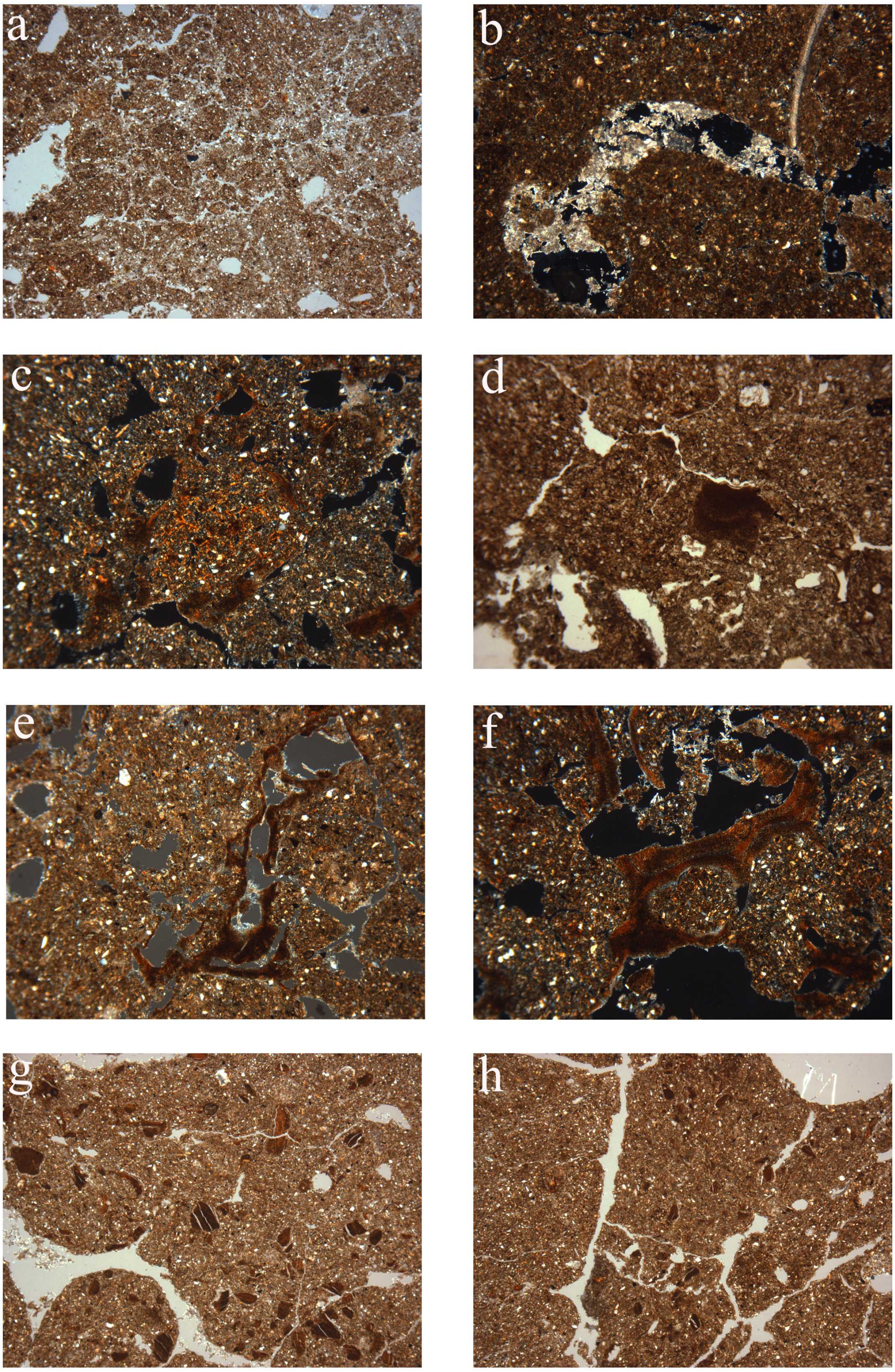

Figure 5
a: GBP6:4 up, granular microstructure consisting of small granules, mixed up with the light yellow groundmass (scale) (XPL);
b: GBP6:4 up, calcitic infillings, also note the shell fragment (XPL);
c: GBP3:2, compound pedofeatures. Dusty clay features superimposed on limpid clay coatings and infillings and calcitic features (arrow) (XPL);
d, e, and f: GBP3-2. They show darkish-grayish colours under XPL and have moderate or weak birefringence. Some of the dusty, silty clay coatings formed along voids have the

tendency of particle fining-up towards the voids. d: dusty, translocated clay papule (PPL); e: dusty clay coatings superimposing on calcitic features (XPL); f: layered dusty clay coatings and hypo-coatings, also note the growth of needle-shaped calcite (XPL); g and h: GBP3-2, disrupted clay pedofeatures with sharp boundaries. Note the line in the middle of most fragments (XPL).

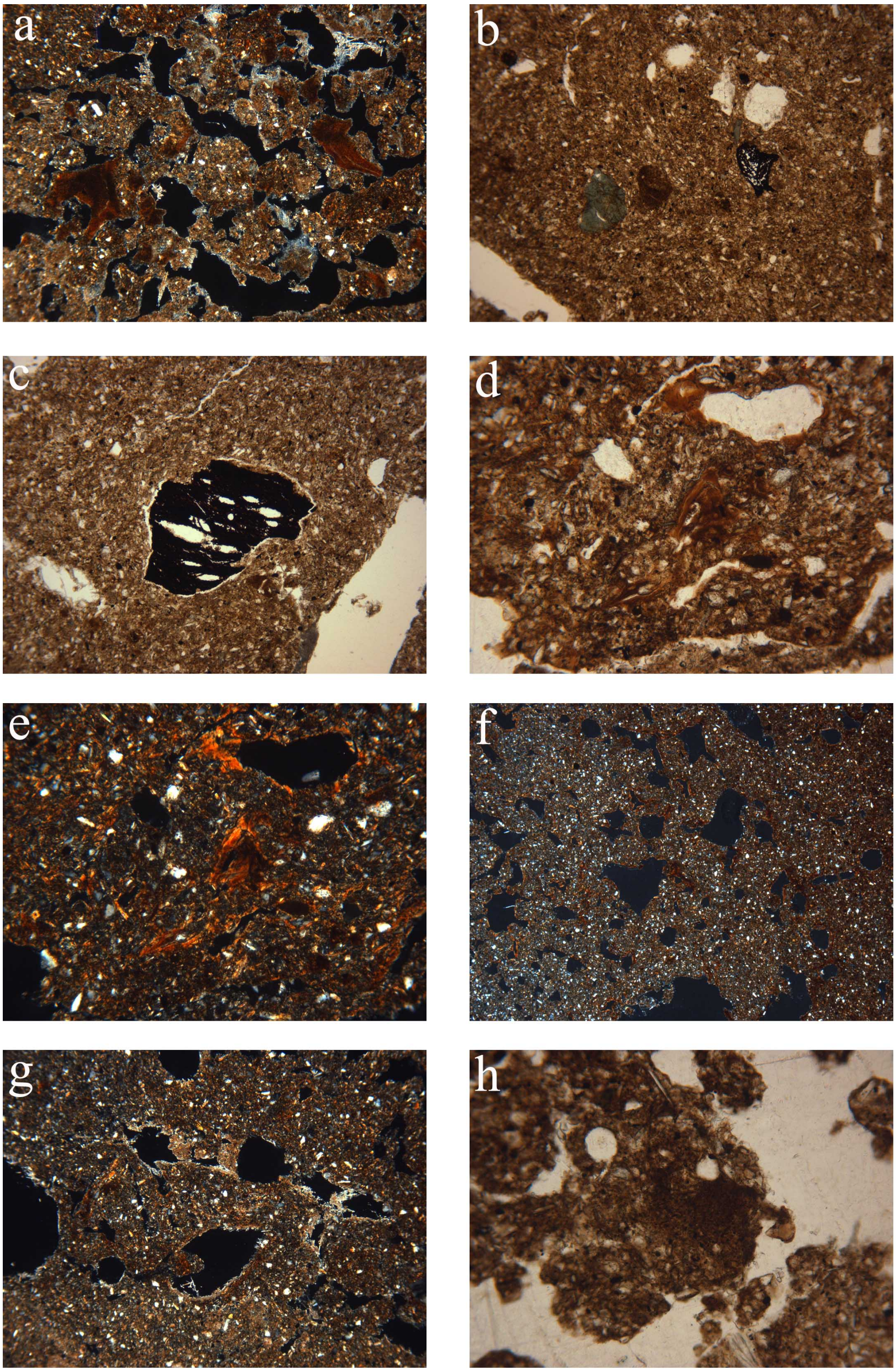

Figure 6
a, b and c: GBP3-2; a: Layered dusty clay features. Disrupted with superimposing on calcitic features (XPL);

b: coarse mineral, coarse amorphous charcoal and dusty clay aggregate (PPL);
c: coarse, amorphous charcoal with plant-tissue structure preserved (PPL);
d and e: GBP5-4, layered, limpid or less-dusty clay coatings. Also note the iron-rich nodules covering on these clay textural features (PPL); e: same as c in XPL. Note the distinctive birefringence;
f: GBP5-4, abundant thin dusty clay coatings and hypo-coatings (XPL);
g: GBP5-3, needle-shaped calcitic coatings and micritic calcitic infillings. Note the former are covered by dusty clay hypo-coatings; the latter contain minerals (XPL);
h: GBP5-4, silty clay concentration feature (or crustal feature?) along the void with a very diffuse boundary with the groundmass (PPL).

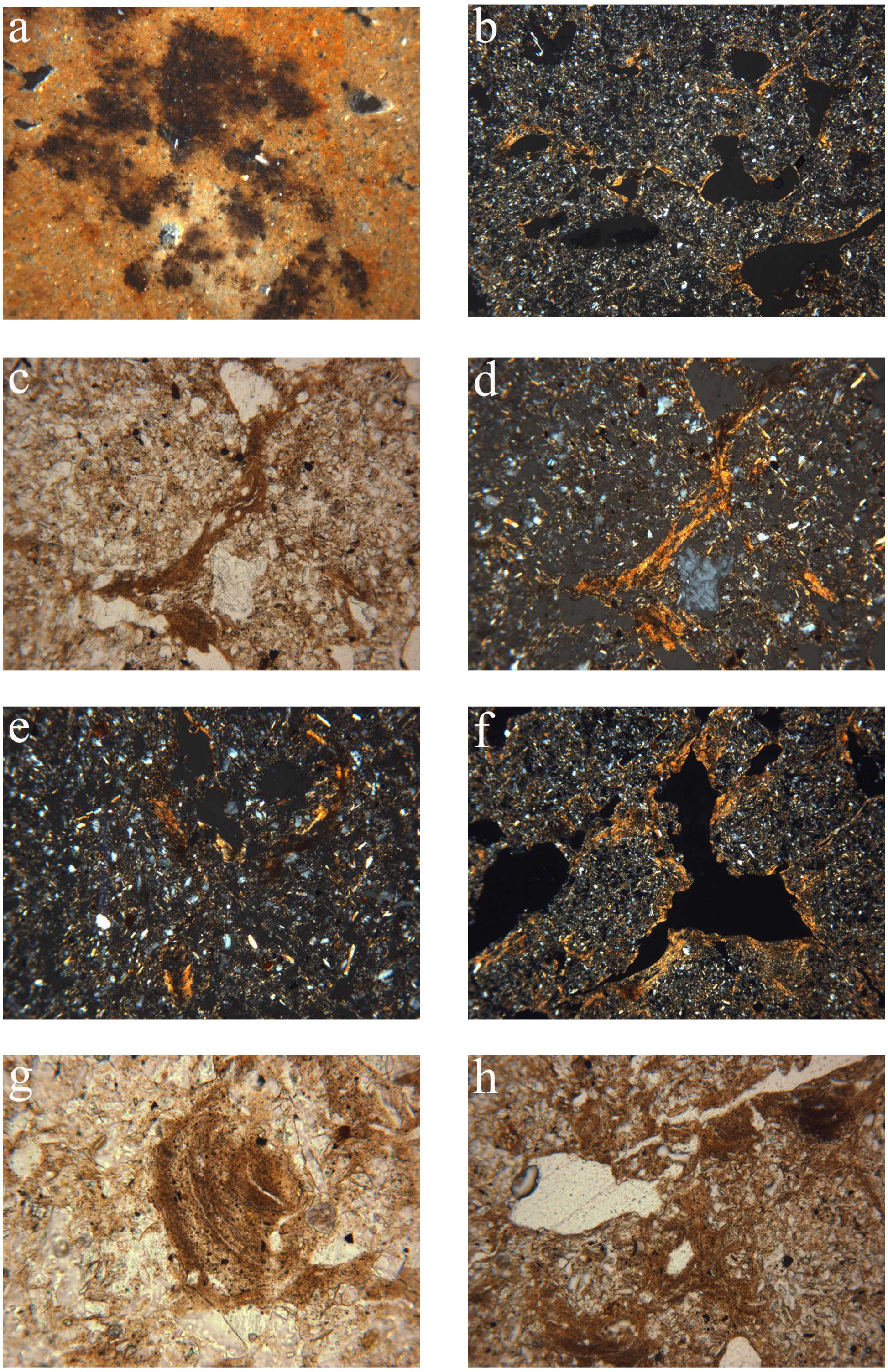

Figure 7

a: GBP7-2 down, dendritic manganese nodules (XPL), also note that iron minerals surrounding the nodules;

b: GBP8-2, layered, limpid clay coatings (XPL);

c: GBP8-2, layered, limpid or slightly dusty clay coatings and infillings and coarse minerals (PPL);

d: same as c in XPL;

e: GBP8-2, layered (arrow), limpid and dusty clay coatings and infillings (XPL);

f: GBP8-2, layered, dusty or silty clay coatings (XPL);
g: GBP8-2, layered, dusty or silty clay infillings (PPL), note that fine materials alternate with the coarse-fraction materials of the groundmass;
h: GBP8-2, layered, limpid to dusty clay coatings (PPL).

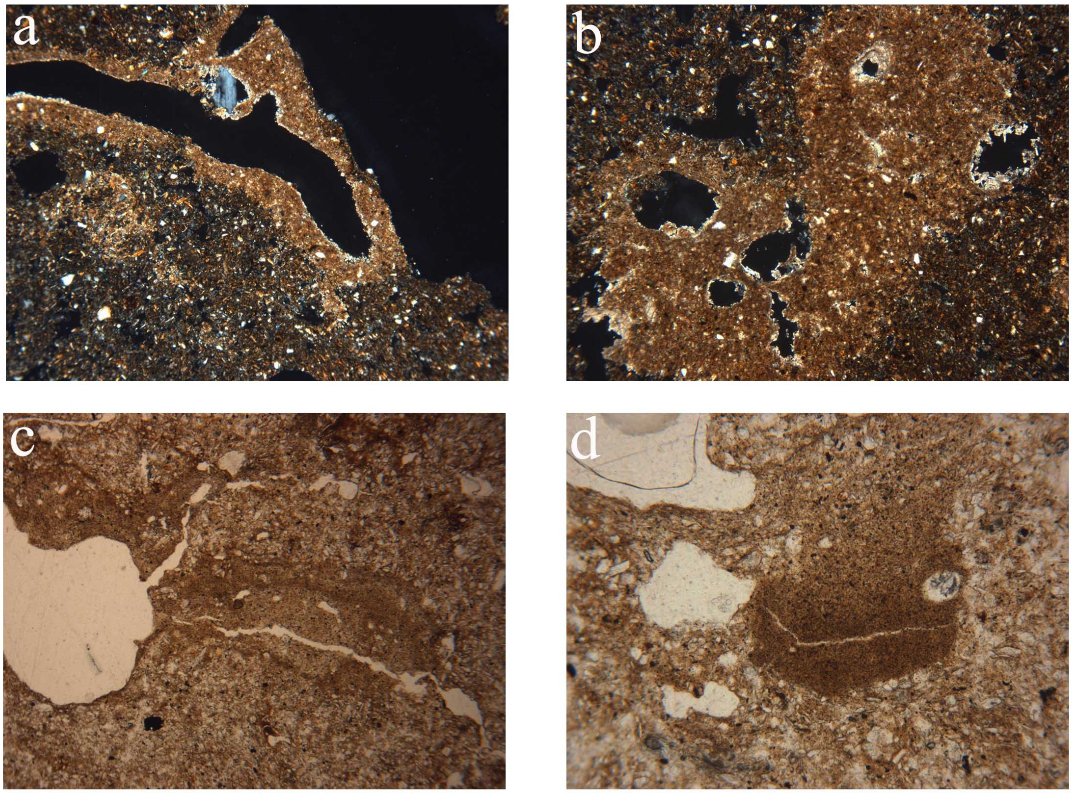

Figure 8
a and b: GBP5-6 and GBP5-5, calcitic coatings and infillings; made of both micritic and needle-shaped (arrow) calcite (XPL). Most of them are dense complete or incomplete and formed of micritic calcite with very fine sand-sized mineral inclusions, but loose incomplete infillings made of needle-shaped calcite are also present;
c: GBP8-2, in-situ surface crustal feature (PPL);
d: GBP8-1, in-situ surface crustal features (PPL);

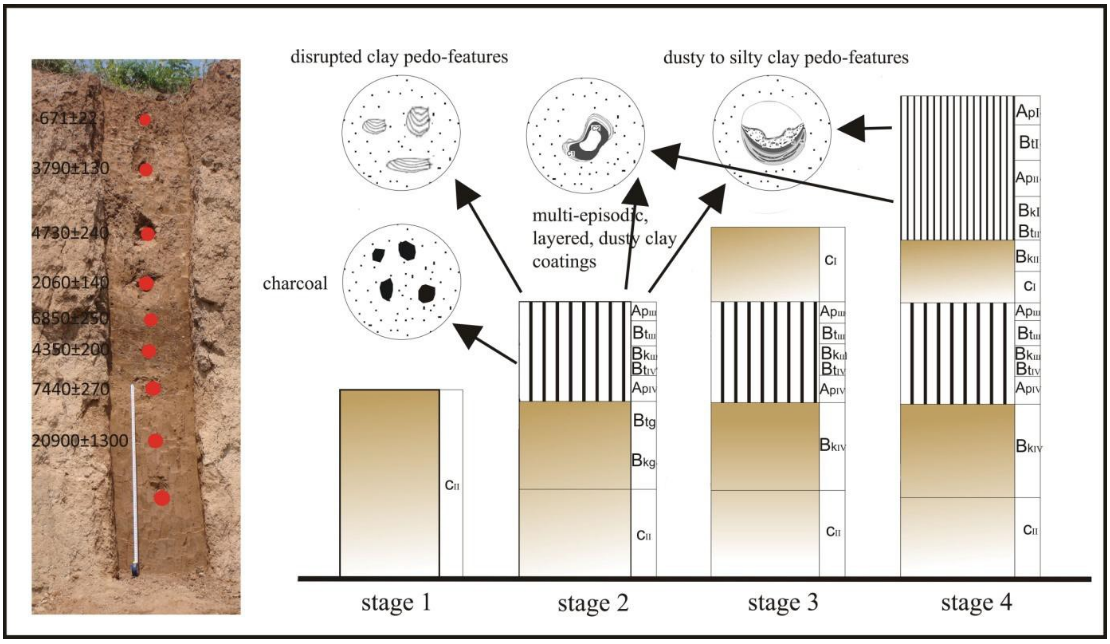

Figure 9
Reconstructed pedo-complex at Guobei. The soil horizons are mainly based on the analysed thin-section samples from Profile 6. Detailed sediment descriptions see Table 1.