Color reflectance of Chinese loess and its implications for climate gradient changes during the last two glacial-interglacial cycles

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[1] To examine the relationship between color changes of loess deposits and paleoclimate conditions, a north-south transect consisting of twelve loess sections were studied. Color reflectance was measured on loess-paleosol samples from the loess transect which accumulated over the last two glacial-interglacial cycles. The redness value, a*, shows an overall southward increase for both loess and soil units, coinciding with the pattern of a southerly increase in pedogenic development and the present north-south climatic gradient. The redness of loess deposits is linearly correlated with latitude values, implying that this parameter is an efficient proxy for the weathering intensity of loess deposits. The gradient of weathering intensity is much steeper during interglacials than in glacials, by comparison with color records for different time interval. INDEX TERMS: 3344 Meteorology and Atmospheric Dynamics: Paleoclimatology; 1886 Hydrology: Weathering (1625); 9604 Information Related to Geologic Time: Cenozoic; KEYWORDS: Chinese loess, Color reflectance, Glacial-interglacial cycles, Weathering intensity. Citation: Yang, S. L., and Z. L. Ding, Color reflectance of Chinese loess and its implications for climate gradient changes during the last two glacial-interglacial cycles, Geophys. Res. Lett., 30(20), 2058, doi:10.1029/2003GL018346, 2003.

1. Introduction

Recent quantitative studies of loess color have attracted much attention [Yang et al., 1999; Porter, 2000; Chen et al., 2002]. Portor [2000] first reported grayscale intensity of Chinese loess as a useful tool for rapid characterization of loess-paleosol stratigraphy. Then, Chen et al. [2002] further associated changes in whiteness of loess with paleoclimate conditions. Although color measurements have been done on several loess sections [Yang et al., 1999; Porter, 2000; Chen et al., 2002], the detailed pattern of spatial changes in color records and their potential as a proxy for paleoclimate require further study. Here we present the redness record of a north-south loess transect for the last two glacial-interglacial cycles, with the objective of examining the relationship between redness and paleoclimatic conditions. Changes in climate gradients between glacial and interglacials are also addressed, by comparison of color records for different time interval.

2. Site Locations and Lithostratigraphy

The north-south loess transect studied here runs from Hongde, about 88 km south of the Mu Us desert margin, to Yangling in the southernmost part of the Loess Plateau. Twelve loess sections, located at Hongde, Huanxian, Mubo, Quzi, Qingyang, Baimapu, Xifeng, Ningxia, Binxianbei, Binxian, Yongshou, and Yangling (Figure 1), were logged and sampled. At present, the mean annual temperature at Hongde is 8.5°C and the annual precipitation 380 mm, the values for Yangling being 13°C and 570 mm. Both mean annual temperatures and rainfall increase southwards along the loess transect (Figure 1). All loess sections except Quzi consist of the loess(L)-soil(S) sequence S0, L1, S1, L2, and S2. In the Quzi section, only loess units above S1 are exposed.
The Holocene soil, S0, is dark in color because of its relatively high organic matter content. The upper part of the Holocene soil has been partly eroded or disturbed by agricultural activities at some sites along the transect. The loess units L1 and L2, ranging in thickness from over 20 meters in the north to several meters in the south (Figure 2), were deposited during the last and penultimate glacial periods, respectively. The L1 loess unit can generally be subdivided into five sub-units, termed L1-1, L1-2, L1-3, L1-4, and L1-5 (Figure 2). L1-2 and L1-4 are weakly developed soils, and the other sub-units are typical loess horizons. Previous studies [185Kukla, 1987; Kukla et al., 1988] have shown that L1-1 is correlated with ocean oxygen isotope stage 2, L1-5 with stage 4, and L1-2, L1-3 and L1-4 together with stage 3. The L2 loess unit is also composed of three typical loess layers (L2-1, L2-3 and L2-5) and two weakly developed soils (L2-2 and L2-4). The L2 loess unit is correlated with marine oxygen isotope stage 6. The soil units S1 and S2 developed in the last and penultimate interglacial periods and correlate with marine oxygen isotope stages 5 and 7, respectively [186Kukla, 1987; Kukla et al., 1988]. The thickness of S1 at Hongde is 6.5 m, and two thin loess layers can be seen within S1. At Yangling, the southernmost site of the transect, the thickness of S1 decreases to 1.8 m, and no loess units are visible within it. Soil unit S2 is composed of two soils (S2-1 and S2-2) and a thin intervening loess horizon. Only the upper soil (S2-1) was sampled in this study.

3. Spatial Changes in the Redness Record of Loess Deposits Along the North-South Transect

For the twelve loess sections along the north-south transect, we took samples at 5 to 10 cm intervals, with a total of 6694 samples collected. Bulk magnetic susceptibility was measured for all samples using a Bartington MS2 susceptibility meter. For color measurement, samples (~1.5 g) were first dried at 40°C for 24 h and then were crushed to dust without destructing their grain size. Finally, color reflectance was measured using a handheld Minolta-CM2002 spectrophotometer. The color reflectance of all samples are given by the spherical L*a*b* color space. We use red-green chromaticity a* (+a* is the red direction, –a* is the green direction) to characterize the loess transect in this study (Figure 2). Recurrent analyses (n = 10) show that the standard deviation for this measurement is 0.22 and 0.21 for loess and soil samples, respectively.

The susceptibility and redness (a*) records of the twelve sections along the north-south transect are shown in Figure 2. All samples from the transect have positive a* values, varying from 3.9 to 12.1. Paleosols are consistently characterized by higher a* and susceptibility values, compared to the loess horizons above and below them. The fivefold subdivision of L1 and L2 is also clearly expressed in the magnetic susceptibility and color reflectance curves, as suggested by three valleys (typical loess units) and two peaks (weakly developed soils).

The color reflectance records from the loess transect (Figure 2) clearly display an overall southward increase in redness in the case of both loess and soil horizons, indicating loess deposits in the south are much redder than those in the north. From Hongde southward to Yangling, the a* value increases from 4.0–5.0 to 6.0–7.0 for the typical loess units within L1 and L2. For the soil units S1 and S2-1, the a* value shows a more rapid southward increase along the north-south transect, i.e., from 5.5–7.0 at Hongde to 10–12 at Yangling.
Figure 3. Redness (a*) changes versus latitude in six units of the loess transect. The stratigraphic positions of the selected samples from the loess transect are indicated in Figure 2.

[10] In order to examine variations in the redness (a*) along the north-south climatic gradient (Figure 1) during different periods, five adjacent samples were selected from typical loess layers (L1-1, L1-5 and L2-5), weakly developed soil unit (L1-4), and paleosol units (S1 and S2-1). The basis of this sample selection was the color reflectance record shown in Figure 2. For typical loess units, samples were consistently selected from units with lowest a* values, whereas samples from soil units were taken from the highest a* value units (as indicated in Figure 2). The a* values of the five adjacent samples in each unit were then averaged. It is assumed that this set of samples was deposited at approximately the same time in each of the loess and soil horizons. The redness changes versus latitude are shown in Figure 3.

[11] Along the loess transect, the value of redness (a*) shows an overall southward increase for both loess and soil units (Figure 3). The a* value increases more rapidly southwards in the soil units compared to the loess layers. For example, the a* values of typical loess units (L1-1, L1-5 and L2-5) gradually increase from 4.2–4.8 to 5.9–6.9, with decreasing latitude from 36.8° to 34.3°–34.7°N. For the soil units S1 and S2-1, however, the a* values increase rapidly from 6.0–6.6 to 11.0–11.6 between 36.8° and 34.3°N. In addition, the redness values (a*) of typical loess units on the southern part of the transect are similar to those of the soil units on the northern part of the transect.

[12] To further test the relationship between redness and latitude, correlation coefficients for the six units along the transect were calculated (Figure 3). There is a good linear correlation between redness and latitude for loess units L1-4, L1-5 and L2-5 (R² around 0.70) and a strong linear correlation for soil units S1 and S2-1 and loess unit L1-1 (R² ≥ 0.85). The redness gradient of paleosol units is over twice steeper than that of loess units, as suggested by changes in the slope of the fitted lines (Figure 3).

4. Discussion and Conclusions

[13] Color changes are one of the most striking features of loess-paleosol sequences. The loess bed is yellowish and the interstratified paleosol is reddish. This color difference is an important criterion for distinguishing and correlating loess stratigraphy. As shown in Figure 2, the alternation of loess and soils, even the weakly developed soil units within loess beds, is clearly expressed in the redness curves. Thus the redness, like the previously studied grayscale [Porter, 2000] and whiteness [Chen et al., 2002] parameters, is an efficient proxy for characterizing loess-paleosol stratigraphy. In fact, the redness proxy is perhaps better than grayscale and whiteness in characterizing loess stratigraphic patterns, because it is much closer to a researcher’s impressions in the field.

[14] To some extent, soil color is a cumulative property which derives, by varying degrees, from all the solid components that comprise the soil. For loess-paleosol sequences, although color is affected by several factors such as grain size, iron oxide minerals, organic matter and carbonate content, the fine-grained iron oxide minerals, especially hematite, are the major pigments [Schwertmann et al., 1982; Torren t et al., 1983; Liu et al., 1999; Chen et al., 2002]. These iron oxides are mainly a product of pedogenesis [Eyre and Dickson, 1995; Liu et al., 1999; Chen et al., 2002]. Field observations show that the intensity of pedogenesis increases for both loess and soil units from Hongde to Yangling. Various proxy records from loess deposits have demonstrated that the monsoonal rainfall and temperature over the plateau significantly increase from north to south both in glacial and interglacial periods, in accordance with the present pattern (Figure 1) [Liu and Ding, 1998]. In this study, the redness (a*) of loess deposits shows an overall southward increase during both glacial and interglacial periods, coinciding with both the pattern of north-south pedogenesis and the present climatic gradient (Figure 1). Therefore, the redness (a*) can serve as a rapid and non-destructive proxy for weathering intensity of loess deposits. Specifically, higher redness values indicate stronger weathering intensity of loess deposits and wetter and warmer climate conditions.

[15] It should be noted here that quantitative reconstruction of paleoclimate using a color record must be based on the relationship between modern soil color and climate. On the Loess Plateau, it is hard to find true modern soils because of natural erosion and agricultural activities. However, the relative changes of paleoclimate conditions between glacial and interglacial can still be inferred. As mentioned earlier, the redness values of glacial loess units on the southernmost Loess Plateau approximate those of interglacial soil units to the north. A tentative interpretation of this fact, pending more evidence, is that the climate conditions on the southernmost plateau during glacial periods are similar to those on the northernmost part during interglacials. In addition, a much steeper gradient of weathering intensity during interglacials than in glacials over the Loess Plateau is inferred, by comparison of the redness gradient for different time intervals. These information will provide valuable records for ground truthing GCM models of ancient climate change.

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