THE MAGNETIC SUSCEPTIBILITY OF MODERN SOILS IN CHINA AND ITS USE FOR PALEOCLIMATE RECONSTRUCTION

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Summary: *Magnetic susceptibility of more than 160 modern silty soil samples in China was measured to assess the relationship between the magnetic susceptibility and modern climatic parameters. Correlation between magnetic susceptibility and mean annual temperature (MAT) or mean annual precipitation (MAP), shows a complex picture and no single function can be found to fit all the data on the national scale. In East China, where East Asian monsoon plays an important role for the climate conditions, magnetic susceptibility increases with the increase of MAT or MAP in temperate semi-arid regions of the Loess Plateau and surrounding areas. This can be attributed to increasing intensity of pedogenesis which would favor the formation of strongly magnetic minerals and/or reduce depositional rate of eolian dust. Magnetic susceptibility tends to decrease with the increase of temperature and precipitation in the tropical and subtropical warm and humid regions of the vast areas south of the Yangtze River. This may be explained by pedogenic transformation of iron-bearing minerals to weakly magnetic minerals. Between these two different correlation patterns, 15°C of MAT and/or 1200 mm of MAP seem to be the thresholds. In West China, the correlation becomes quite complex in the great mountains and vast sedimentary basins in the north-west. This may be due to the prevailing continental climate in this region and topographic contrast within short distance. The correlation for the Qinghai-Xizang (Tibetan) Plateau is not clear because very few samples were collected. Fluctuations of paleo-temperature and paleo-precipitation at Luochuan for the last 130 ka were estimated using the climofunction obtained from this study.*

Keywords: polynomial regression, climofunction, paleotemperature, paleoprecipitation, magnetic mineralogy, loess-paleosol sequence, the Loess Plateau, Louchuan

1. INTRODUCTION

Magnetic susceptibility records of the Chinese loess correlate well with oxygen isotope records obtained from the shells of foraminifera found in deep sea sediments (*Heller and Liu, 1986*). This indicates their great potential in the study of past global changes. Magnetic enhancement of paleosols compared to underlying loess layers have widely served as a proxy for paleoclimate change in the Chinese Loess Plateau. Several possible mechanisms for the magnetic enhancement of the paleosols have been suggested (*Heller and Liu, 1984; Kukla et al., 1988; Zhou et al., 1990; Han et al., 1991; Heller et al., 1991; Maher and Thompson, 1991; Hus and Han, 1992; Rolph et al., 1993*). All these hypotheses may be generally subdivided into depositional models and pedogenic models. The depositional model of *Kukla et al. (1988)* considered magnetic enhancement of paleosol horizons as a result of less dilution by a weakly magnetic eolian dust of a strongly magnetic "rain" during interglacial times than during glacial times. On the other hand, pedogenic models attribute magnetic enhancement of paleosol horizons to the formation of ultrafine (superparamagnetic and stable single domain) strongly magnetic minerals during the pedogenic

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process. Both depositional and pedogenic models are related to climatic change (*Kukla et al., 1988; Zhou et al., 1990; Heller et al., 1991; Maher and Thompson, 1991*). Some authors have further suggested that magnetic susceptibility is directly related to paleo-rainfall (*An et al., 1991*). A relationship between paleo-precipitation and the proportion of superparamagnetic (SP) particles (*Beer et al., 1993; Heller et al., 1993; Liu et al., 1995b*) was used to estimate paleo-precipitation. These studies were important steps in the spatial and temporal reconstruction of the past climate changes. In these attempts, a linear relationship between the magnetic susceptibility signal and precipitation was assumed. *Maher et al. (1994)* gave an alternative approach (the logarithm of magnetic susceptibility against annual rainfall) to calculating paleo-precipitation by using the difference in magnetic susceptibility between B and C horizons ($\chi_{B\text{-}C}$).

In this study, we measured magnetic susceptibility of 166 modern soils in China. The purposes of our study are (1) to find a better relationship between magnetic susceptibility of modern soils and present-day climate parameters, such as temperature and precipitation and (2) to estimate the paleoclimate parameters based on the magnetic susceptibility record of the loess-paleosol sequence in Luochuan using the climofunction obtained from the regression analysis of the modern analogue.

2. MATERIALS AND METHODS

166 samples were collected from many categories of the modern silty soils in China developed under different environments (Fig. 1). The climate conditions of the sampling sites range from −4 to 24°C in mean annual temperature (MAT) and from 10 to 2000 mm mean annual precipitation (MAP). Four principles were used in the sampling:

1. The sampling sites should be as far as possible away from industries and villages in order to avoid contamination from possible industrial pollutants;
2. Samples should be taken from the non-cultivated soils to avoid man-induced modification to soils;
3. Soils developed on eolian deposits or similar deposits and on flat geomorphic surface were preferentially sampled because the magnetic susceptibility of a soil may be influenced by the parent material and geomorphology, and
4. Real modern soils with a sufficiently long development time instead of the relic paleosols were sampled in order to be sure the soil sampled is in equilibrium with the present environment.

The sample at each site was a mixture of the top 5 – 10 cm in the soil profile. All samples were air-dried in the laboratory then ground-up gently. The measurements were carried out using a Bartington MS2 magnetic susceptibility bridge. Mass magnetic susceptibility was used to eliminate the effects of the soil density when comparing results from different sites.

MAT and MAP data for the sampling sites was from instrumental measurements obtained from local meteorological stations in each county. The duration of observation ranges from thirty to forty years. The observatory station was not at the place of the sampling site and the difference of the climatic parameters caused by the topography has not been taken into consideration. It is assumed that the local topographic effect is not significant in most cases except in the north-west territories.

3. RESULTS AND DISCUSSION

3.1 Variations of the Magnetic Susceptibility of Modern Soils in China

The important factors affecting the soil development are climate, vegetation, topography, parent material and time (*Jenny, 1941*). Following our preferential selection of sampling sites mentioned above, the most important factors are climate and climate-related vegetation. The climate conditions in East China (Fig. 1, regions I and II) are mainly controlled by the East Asian monsoon (*Ren, 1982*). There is a latitudinal gradient of MAT and a gradient of MAP depending on the distance from the oceans. So it tends to be warm and humid in the south-east and relatively cold and dry toward north-west. In West China, there are two topographical units, i.e. the Qinghai-Xizang (Tibetan) Plateau in the south (Fig. 1, region III) and the great mountains and large basins in the north (Fig. 1, region IV). The climate conditions there are quite different from that of East China. The Qinghai-Xizang Plateau is sometimes called as the "Third Pole" of the Earth. With high altitude (more than 4,000 m in average), the climate there is cold in winter and cool in summer (*Ren, 1982*). For the high mountains and large basins, it is controlled by the cold Siberian high pressure in winter and by the westerly jet system in summer. The moisture hardly reaches this region because it is located at the center of the Eurasian continent very far away from the oceans. Therefore, typical continental climate prevails

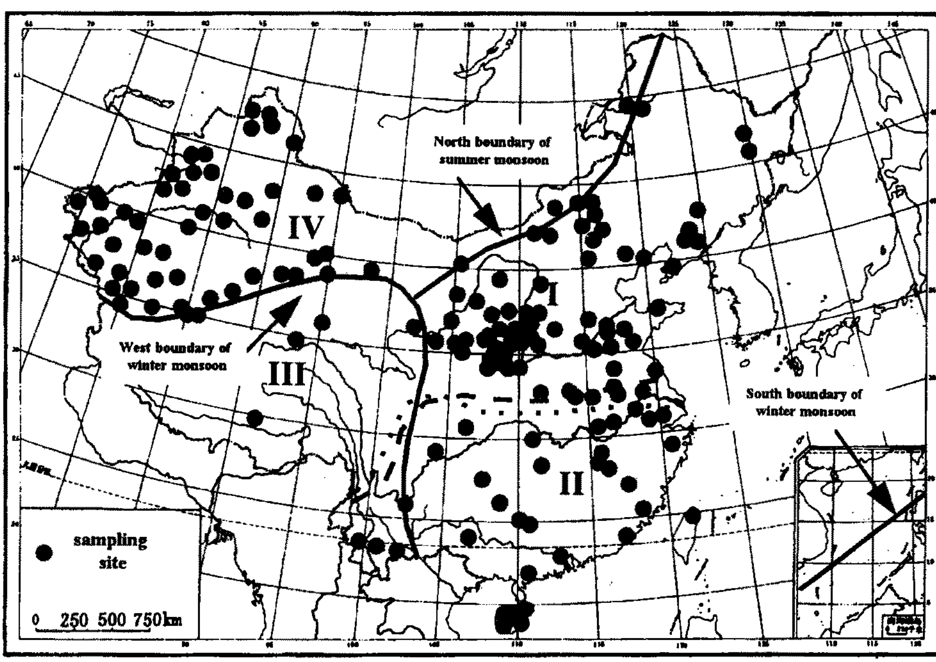


Fig. 1 Location map showing the extent of different regions and sampling sites. I: Loess Plateau and surrounding areas; II: South China; III: Qinghai-Xizang (Tibetan) Plateau; IV: North-west China; solid line: the boundary of winter and summer monsoon (after *Ren, 1982*); dashed line: isotherm of 15°C of MAT; dotted line: isoline of 1,200 mm of MAP

with large annual and daily variations of temperature and very little precipitation (*Ren, 1982*).

Magnetic susceptibility of a soil is dependent on the concentration, composition and grain size of magnetic minerals (*Thompson and Oldfield, 1986*). The variation of magnetic susceptibility of the collected modern soils, therefore, reflects the changes of magnetic minerals, their composition, concentration and grain size during depositional and pedogenic processes, all of which are closely related to the factors of soil development. For our samples in East China, the climate conditions determined by the East Asian monsoon are the main controls on soil development.

Fig. 2 shows the relationship of magnetic susceptibility, MAT and MAP. Data points are along with the down-left to up-right diagonal direction (Fig. 2a) because we do not have many samples taken from the sites with low temperatures but high precipitation and vice versa. Along this diagonal it is quite clear that soil magnetic susceptibility increases with increase of the temperature (or precipitation) when temperature (or precipitation) is lower than certain values (Fig. 2a and 2b). With further increase of the MAT (or MAP) there is a turning point for the variation of the magnetic susceptibility. The highest magnetic susceptibility values of the modern soils appear where MAT is about 15°C and MAP is about 1,200 mm. Overall, our magnetic susceptibility measurements from all over China show a relationship between the magnetic susceptibility of modern soils and MAP (or MAT), which is different from the patterns found in earlier studies (*Beer et al., 1993; Heller et al., 1993; Maher et al., 1994; Liu et al., 1995b*).

3.2 Regional Differentiation in East China

China with its vast territory and complex natural conditions shows great regional climatic differentiation as mentioned above. It is impossible to find a simple equation to express the relationship between the magnetic susceptibility of the soil and MAT (or MAP) for the whole country. Therefore in our study, four regions are distinguished (Fig. 1,

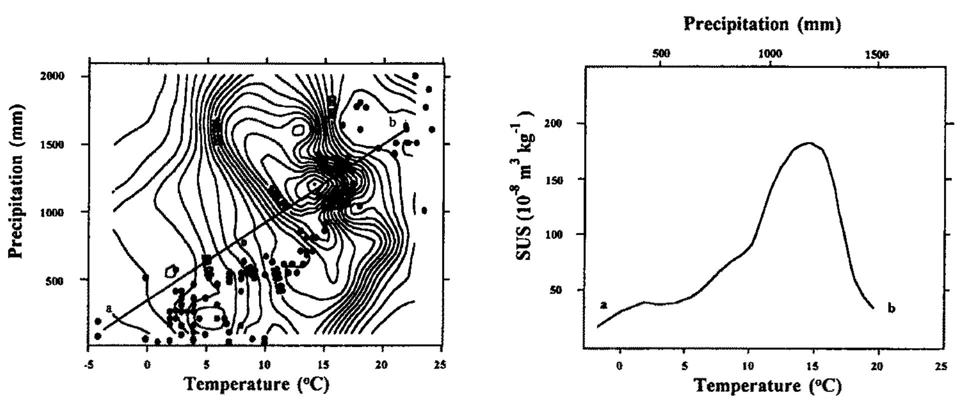
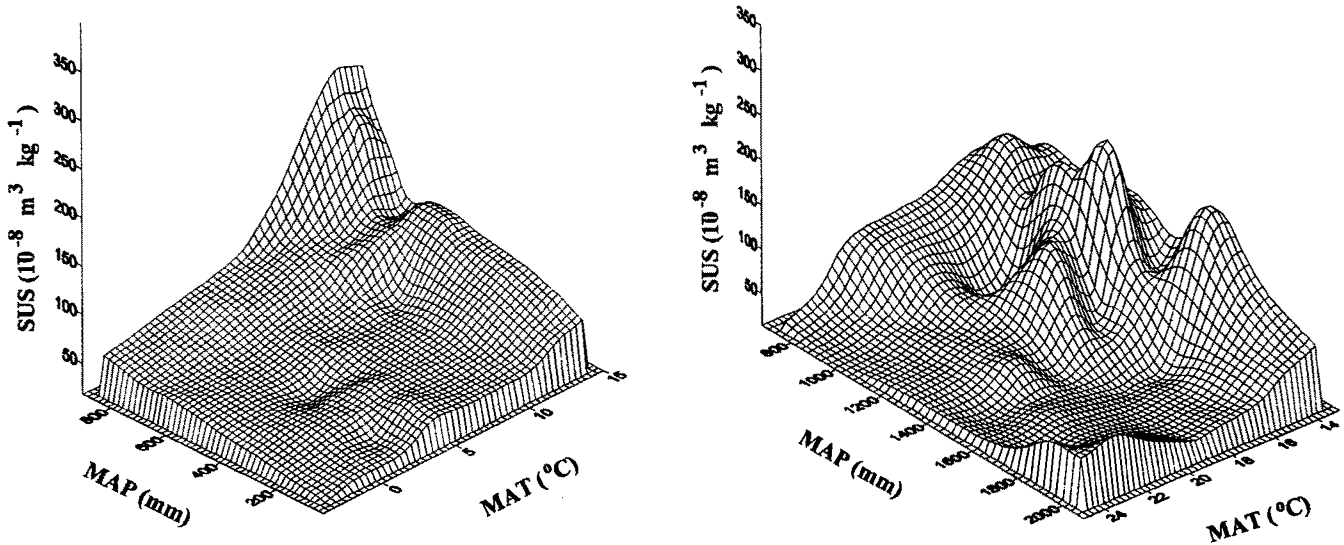


Fig. 2. Magnetic susceptibility variation of modern surface soils with local mean annual temperature and mean annual precipitation. (a) Two-dimensional diagram showing distribution of data points and the variation of the magnetic susceptibility (matrix smoothed) of modern soils in China with MAT and MAP. Line A-B indicates the direction of the magnetic susceptibility profile shown in Fig. 2b. (b) Magnetic susceptibility profile along the line A-B.

I - IV): I, the Loess Plateau (with surrounding areas), II, south China (south of the Changjiang (Yangtze) River), III, the Qinghai-Xizang (Tibetan) Plateau and IV, northwest China. Variations of magnetic susceptibility of loess-paleosol sequences in China are mainly controlled by the East Asian monsoon (*An et al., 1991*). Our main interest lies in the reconstruction of paleoclimate parameters based on the magnetic records of the loess-paleosol sequences. So, when correlating the magnetic susceptibility to MAT or MAP, only the data from East China will be discussed in detail in this paper. The isotherm of 15°C MAT and the isoline of 1,200 mm MAP are both quite near the channel of the Yangtze River (Fig. 1). Therefore roughly along these two lines, East China was separated into two units: south China (the south of the Yangtze River valley) as a unit with tropical and subtropical warm and humid climate and the Loess Plateau (with surrounding areas) as a unit with temperate semi-arid climate.

Three-dimensional diagrams of the relationship of modern soil magnetic susceptibility with MAT and MAP in East China are shown in Fig. 3. In the Loess Plateau and surrounding areas, magnetic susceptibility of the modern soils increases with the increase of temperature and precipitation (Fig. 3a). The three-dimensional picture in south China looks a little complex. It may be affected by some local factors. However, the main tendency is quite clear. Magnetic susceptibility of the modern soils decreases with the increase of temperature and precipitation (Fig. 3b).

The existence of a turning point in the magnetic susceptibility versus MAT (or MAP) should be taken into consideration in interpreting the magnetic susceptibility signal obtained from Chinese loess. As can be seen in Fig. 2b, with the increase of temperature or precipitation magnetic susceptibility may increase, but with further increase of temperature or precipitation over a certain value, magnetic susceptibility will decrease. The latter could explain the lower magnetic susceptibility values of some very well developed paleosols in the southern-most part of the Loess Plateau. The magnetic susceptibility of $S_{1\text{-}3}$ in Weinan, for example, is about 250 m^3kg^{-1} (maximum) and 102 m^3kg^{-1} (average), much lower than the values of 380 m^3kg^{-1} (maximum) and 336 m^3kg^{-1} (average) of $S_{1\text{-}1}$ and 395 m^3kg^{-1} (maximum) and 354 m^3kg^{-1} (average) of $S_{1\text{-}2}$ at the same profile (*Liu et al., 1995a*). $S_{1\text{-}3}$ in Weinan is a well developed paleosol with reddish brown color (5YR5/8) of the B_t horizon, from which carbonate was completely leached and clay coatings and Fe-Mn speckles were found (*Guo et al., 1994*). Usually $S_{1\text{-}3}$ is correlated with oxygen isotope stage 5e. Similar observations were made for the $S_{5\text{-}3}$ in other southern-most localities like Lantian (*Jia et al., 1992*). This raises a fundamental question if magnetic susceptibility can provide a proxy record of paleoclimate. Our results imply that MAT may be over 15°C and/or MAP over 1,200 mm in Weinan when $S_{1\text{-}3}$ was formed. This shows that great care should be taken when reconstructing the paleo-precipitation based on magnetic susceptibility data. The magnetic approach as previously used might lead to an inaccurate estimation of the paleo-precipitation for some best developed paleosols in the Loess Plateau.



(a) (b)

Fig. 3. Three-dimensional diagram showing the relationship of magnetic susceptibility (matrix smoothed) of modern surface soils with local mean annual temperature and local mean annual precipitation in different regions, China. (a) Loess Plateau and surrounding areas; (b) South China. In order to show the turning point, Fig. 3a includes some data points from south China (near the boundary of the two regions). So does Fig. 3b.

3.3 Regression Analysis for the Data from the Loess Plateau and Surrounding Areas

In previous investigations the magnetic susceptibility of the Holocene soil (S_0), instead of real modern soil, is sometimes used in correlating the magnetic susceptibility to present-day MAP (based on past 30 – 40 yrs instrumental measurements). In this study, the magnetic susceptibility of real modern soil was used because of the well known fact that at many places in the Loess Plateau the climate conditions during the Holocene were not always the same as those at present day. It is obvious that no valuable calibration of climate change will be obtained if a correlation between modern precipitation and the Holocene paleosol (S_0) is used to reconstruct paleo-precipitation.

Magnetic susceptibility enhancement in the paleosols is controlled by complicated factors. For this reason statistical analysis is usually used in estimating paleoclimatic conditions from magnetic susceptibility data. The accuracy of the analysis depends on the number of the samples used. *Liu et al. (1995b)* obtained a linear relation between magnetic susceptibility and precipitation from the data of six sites and *Maher et al. (1994)* obtained their climatofunction from 37 soil profiles from a restricted geographic area. Fig. 4 shows the changes of the magnetic susceptibility of modern surface soils with MAT and MAP, respectively, from 63 sites in the Loess Plateau and surrounding areas covering almost all the Loess Plateau and the regions with loess deposits outside the Loess Plateau in China. The magnetic susceptibility increases strongly with an increase of the temperature (or precipitation) at the beginning and then levels off. In our study, linear regression, polynomial regression, power regression, exponential regression, logarithmic regression and hyperbolic regression between magnetic susceptibility and temperature were carried out respectively in order to obtain the best correlation (with the largest correlation coefficient and the smallest regression deviation). Compared with other analyses, it was found that polynomial regression analysis produced the best fit with the largest correlation coefficient and the smallest regression deviation using real climate data (Table 1). This is also the case for the relationship between magnetic susceptibility and precipitation (Table 1). The equations obtained from the polynomial regression are as follows respectively:

$$Y = -2{\cdot}4 + 0{\cdot}2X - 1{\cdot}1 \times 10^{-3}X^2 + 2{\cdot}7 \times 10^{-6}X^3 - 2{\cdot}7 \times 10^{-9}X^4 \quad , \qquad (1)$$

and

$$Z = -22{\cdot}7 + 11{\cdot}6X - 6{\cdot}7 \times 10^{-2}X^2 + 1{\cdot}9 \times 10^{-4}X^3 - 1{\cdot}9 \times 10^{-7}X^4 \quad , \qquad (2)$$

here Y, mean annual temperature (MAT), Z, mean annual precipitation (MAP), X, magnetic susceptibility of the soil.

For the statistical analyses, statistical tests are always necessary. The correlation efficiency for equation (1) is $R^2 = 0{\cdot}718 > R_{0{\cdot}01(61)} = 0{\cdot}325$, and the F test $= 156{\cdot}7 > > F_{0{\cdot}01(4{\cdot}58)} = 3{\cdot}71$. The correlation efficiency for equation (2), $R^2 = 0{\cdot}675 > > R_{0{\cdot}01(61)} = 0{\cdot}325$, and the F test $= 126{\cdot}8 > F_{0{\cdot}01(4{\cdot}58)} = 3{\cdot}71$ (*Davis, 1986*). The statistical test shows that equations (1) and (2) have a remarkable significance. The mean regression error is ±11·2% for estimating MAT using equation (1) if compared to the meteorological record, and ±10·8% for MAP using equation (2).

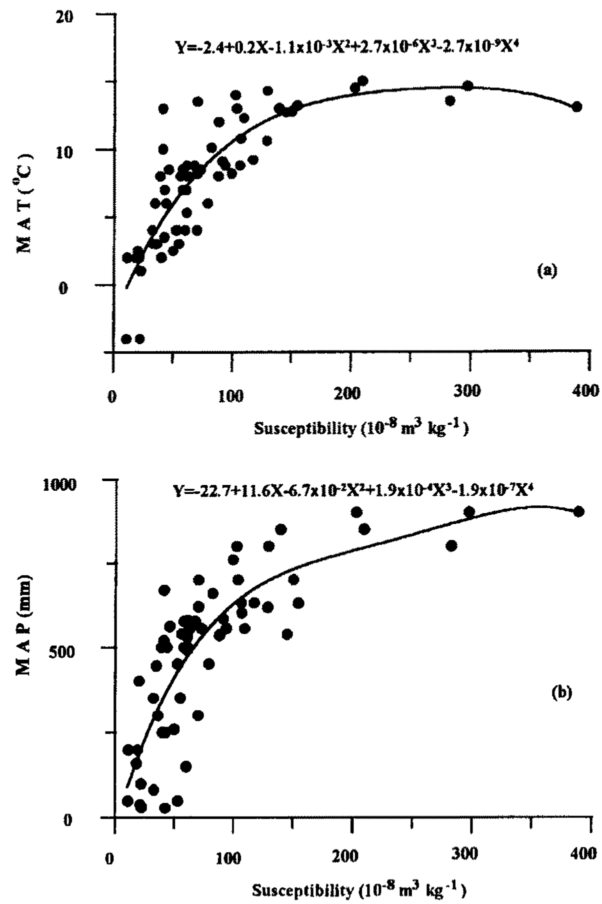


Fig. 4. Variations in magnetic susceptibility of modern soils with present-day climate conditions in the Loess Plateau, China. (a) with mean annual temperature; (b) with mean annual precipitation. It is clear that susceptibiltiy of modern soil in loess plateau is linear neither with MAT nor with MAP.

3.4 Paleoclimate Reconstruction in Luochuan for the last 130000 yrs

Heller et al. (1993) estimated the average paleo-precipitation values of 600 mm/yr for S_0, 310 mm/yr for L_1 and 540 mm/yr for S_1 at Luochuan, respectively. This is a useful attempt to estimate paleorainfall quantitatively. However, the inference that the precipitation during S_0 formation is higher than that of S_1 is not quite in line with other geological evidence (*Liu, 1985*). *Liu et al. (1995b)* used the slope of present-day precipitation plotted against the SP fraction of the early Holocene soil (S_0) at six sites and obtained paleo-precipitation values of 150 – 250 mm/yr for $L_{1\text{-}1}$, $L_{1\text{-}3}$ and L_2 (stages 2, 4 and 6), 300 – 500 mm/yr for $L_{1\text{-}2}$ (stage 3) and 550 – 700 mm/yr for S_1 (stage 5) at

Table 1. Correlation coefficients and the sum of square deviation of different regression analyses.

	χ–MAT		χ–MAP	
	θ	R	$\theta(10^7)$	R
linear regression ($y = a + bx$)	561	0·71	1·7	0·71
power regression ($y = ax^b$)	2074727	0·33	2·3	0·74
exponential regression ($y = a^x$)	1834437	0·22	6·1	0·54
logarithmic regression ($y = a + b \log x$)	345	0·83	1·2	0·81
hyperbolic regression ($y = 1/(a + bx)$)	4915	0·19	1·5	0·25
polynomial regression ($y = a + bx + cx^2 + dx^3 + ex^4$)	318	0·85	1·1	0·82

x: magnetic susceptibility (χ), y: MAT (°C) in χ–MAT and MAP (mm) in χ–MAP, respectively $\theta = \Sigma (y_m - y_c)^2$, y_m is the MAT (or MAP) value from meteorological station and y_c is the MAT (or MAP) value calculated from the equation obtained from each regression analysis, respectively. θ is the sum of the square deviations ($(y_m - y_c)^2$) of 63 samples for all the regression analyses except the logarithmic regression of χ–MAT. In the logarithmic regression 2 samples with negative MAT values were discarded. So, θ is the sum of the square deviations of 61 samples.

Xifeng. The validity of the estimation within the Holocene based on a correlation between modern precipitation and the Holocene paleosol (S_0) has been discussed above. The estimation of an increase in rainfall of up to 215 mm/yr during S_0, a similar increase during the S_1 development in the west of the Loess Plateau and a smaller increase in the east was made by *Maher et al. (1994)*. However, the L_9 loess at each site was assigned as the parent material in their paleoprecipitation reconstruction. It apparently differs from that of $\chi_{B\text{-}C}$ they used for obtaining the relationship between annual precipitation and pedogenic magnetic susceptibility. A deviation may be introduced in this way, especially for those paleosols developed on strongly weathered loess layers. On the other hand, it has been assumed that all of the magnetic susceptibility enhancement is due to pedogenesis (*Maher et al., 1994; Maher and Thompson, 1995*). However, the true pedogenic component should be determined and used for paleo-precipitation reconstruction as pointed by *Banerjee (1995)*.

Based on our regression analysis, a new method can be used in reconstructing paleo-temperature and paleo-precipitation directly from magnetic susceptibility data. Fig. 5 shows the fluctuations of temperature and precipitation at Luochuan for the last 130,000 yrs. Table 2 lists the ranges and the average values of MAT and MAP of each stratigraphical unit in Luochuan loess section calculated from equations (1) and (2). The results are quite similar with those estimated from other geological evidence (*Liu, 1985*). MAT and MAP during S_1 development were 3°C and 120 mm higher than present-day in Luochuan. Average MAT and MAP during the whole period of S_0 development are quite similar to those of present day, but the maximum MAT may be about 2°C more and maximum MAP mm about 75 mm more than present day. MAT and MAP are both quite low when typical loess accumulated, for example, during L_2 (oxygen isotope stage 6) 4·8°C in MAT, more than 5°C lower than present-day and 350 mm in MAP, about 300 mm lower than present-day.

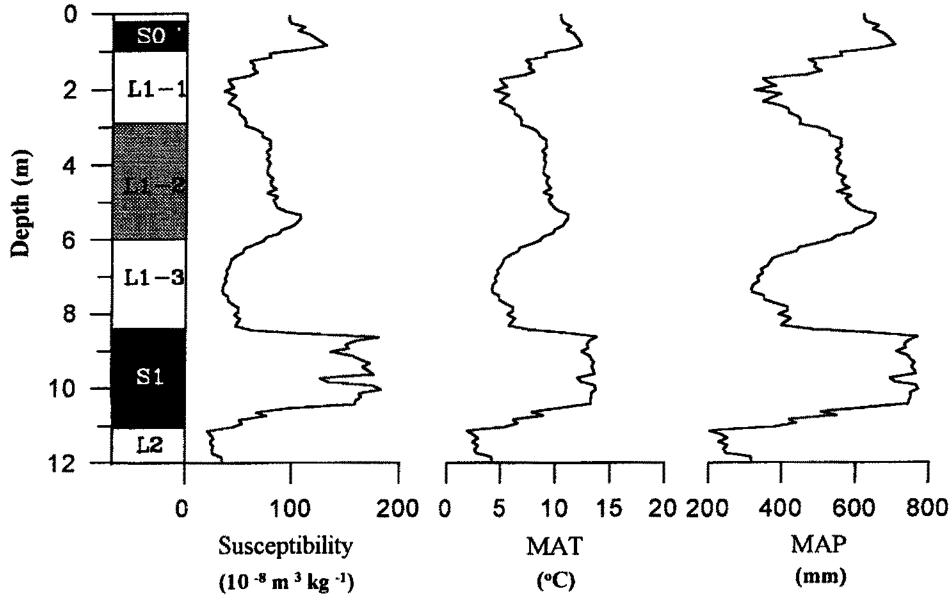


Fig. 5. Reconstruction of paleotemperature and paleoprecipitation during the last 130 ka for the Luochuan area based on the climofunction equations 1 and 2, respectively.

3.5 Geochemical consideration of the evolution of iron-bearing minerals

Variation of the magnetic susceptibility of modern soils reflects the change of the magnetic minerals, their composition, concentration and grain size. The deposition model of *Kukla et al. (1988)* noted the effect of concentration. They proposed a strongly magnetic "rain" with less dilution by low-magnetic-susceptibility eolian dust during interglacial times. This model may be true in some circumstances but it cannot explain the observed lower magnetic susceptibility in some well developed interglacial paleosols in southern-most margin of the Loess Plateau. It is necessary to discuss the change of the magnetic minerals in difficult environments. Geochemically, the variation of the magnetic susceptibility is dependent on the evolution of iron-bearing minerals during soil forming processes. The paleosols are distinguished from loess layers by concentration, mineralogy and a much different (and much smaller) grain-size of the magnetic carriers (*Zhou et al., 1990; Heller et al., 1991; Maher and Thompson, 1991; Hus and Han, 1992*). Magnetic minerals in loess are mainly detrital magnetite and hematite (*Han et al., 1991; Hus and Han, 1992*). Neo-formed magnetite and maghemite were detected in the paleosols in addition to the detrital magnetic minerals (*Han et al., 1991; Hus and Han, 1992; Vandenberghe et al., 1992; Eyre and Shaw, 1994; Hunt et al., 1995*).

Table 2. Ranges and average of the magnetic susceptibility, MAT and MAP in Luochuan during the last 130,000 years.

Unit	Depth (cm)	Susceptibility ($10^{-8}m^3kg^{-1}$)		Mean Annual Temperature (°C)		Mean Annual Precipitation (mm)		Equivalent Oxygen Isotope Stage
		Range	Average	Range	Average	Range	Average	
S_0	0–120	78·1–116·2	105·2	8·9–12·2	10·8	550–700	640	1
$L_{1\text{-}1}$	120–310	36·7–66·5	52·1	4·2–7·8	6·2	320–500	420	2
$L_{1\text{-}2}$	310–610	71·7–108·1	83·7	8·3–11·1	9·4	520–650	570	3
$L_{1\text{-}3}$	610–850	36·0–64·0	46·2	4·1–7·6	5·5	320–490	380	4
S_1	850–1050	106·0–183·0	157·9	11·0–13·7	13·1	650–770	740	5
L_2	1050–1200	22·0–96·0	41·0	1·9–10·3	4·8	200–620	350	6

The Loess Plateau is located at the north-western part of the East Asian summer monsoon system at present. The MAT and MAP increase gradually toward south-east, giving rise to an increase of the pedogenic intensity. The precipitation is mainly concentrated in the summer months in the Loess Plateau. Warm, wet summers followed by cold, dry winters cause alternative reducing and oxidising conditions. Reduction-oxidation cycles favor the formation of microcrystalline maghemite or magnetite from the weathering products of iron-bearing minerals (*Thompson and Oldfield, 1986*). Based on micromorphological studies of several sections, *Guo et al (1991)* deduced that the profile of Holocene soils for the entire Loess Plateau were rarely water-saturated. In this case, near-absence of hydromorphic conditions occurred during the soil formation. This is also true for the most of the paleosol forming periods on the Loess Plateau. A number of rock magnetic studies (*Liu et al., 1992; Evans and Heller, 1994; Eyre and Shaw, 1994; Hunt et al., 1995*) have argued for the formation of magnetite and maghemite in paleosols.

In south China (south of the Yangtze River valley) MAT is over 15°C (15 – 28°C) and MAP ranges from 1200 – 1800 mm (both increase southward). Tropical and subtropical climate prevails in this region. From north to south yellow soil, red soil and latosol (equivalent to Acrorthox, Rhodudult and Hapludult respectively) developed (*Li, 1983*). In many reddish soil, goethite is associated with hematite (*Schwertmann and Taylor, 1977*). In acidic soils with strong hydrolytic and oxidative reactions in south China the resulting iron minerals is mainly weakly magnetic hematite and/or goethite (*Li, 1983*). As a result, the magnetic susceptibility becomes lower. This is supported by increase in the content of Fe-Mn speckles in the soil profile of the region. Abundant Fe-Mn speckles were observed in the very well developed paleosols, such as $S_{1\text{-}3}$ and S_5 in Weinan and Lantian. It indicates that very warm and humid conditions prevailed in the southern-most part of the Loess Plateau during the development of these paleosols.

More work on iron-bearing mineral geochemistry in loess during weathering is needed.

4. CONCLUSIONS

1. Linear correlation between magnetic susceptibility and MAT (or MAP) is not the best fit based our data from modern soils all over China. An apparent turning point can be seen in the diagram of magnetic susceptibility verses MAT (or MAP). It is about 15°C for MAT and 1,200 mm for MAP, respectively.
2. Magnetic susceptibility increases with increasing MAT and/or MAP is seen for the Loess Plateau and its surrounding areas. A contrary relationship exists for south China where MAT exceeds 15°C and MAP exceeds 1,200 mm. The equations obtained from the polynomial regression analysis best reflect the relationship between the magnetic susceptibility and MAT or MAP in the Loess Plateau and surrounding areas.
3. Magnetic susceptibility variation in the Chinese loess-paleosol sequence is a good record of the past climate changes. Great care should be taken in reconstructing the paleo-precipitation and/or paleo-temperature using the magnetic susceptibility data. The estimation obtained from the linear and logarithmic climofunction coefficients between magnetic susceptibility and climate parameters may lead to an incorrect estimation of the paleo-precipitation in some very well developed paleosols.
4. The variation of magnetic susceptibility is closely related to the evolution of iron-bearing minerals in parent material during the soil development. The products are quite distinct under different climate conditions. Alternation of oxidation and reduction in the Loess Plateau during most of the interglacial times favors the neo-formation of strongly magnetic minerals. Conversely, relative weakly magnetic minerals may be formed in soils developed in the area to the south of the Yangtze River.

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