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MAGNETIC HYSTERESIS PARAMETERS OF BULK SAMPLES AND PARTICLE-SIZE FRACTIONS OF THE LOESS/PALAEOSOL SEQUENCE IN CENTRAL CHINA

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Abstract: Measurements of the magnetic hysteresis parameters on bulk samples from different units of the Malan and Lishi Formations of the loess/palaeosol sequence in Potou (Luochuan) and Jiacun (Baoji), confirm the enrichment of magnetites with sizes near the SP/stable SD boundary in the soils. The magnetic properties of particle-size fractions of a sample from S3 and of L4 in Jiacun show a bimodal distribution.They also indicate the large contribution of the clay fraction to the magnetic properties in the palaeosols and hence of the pedogenic contribution. The total amount of hard imperfect antiferromagnetics is more or less the same in both loess and soils, but enriched in the clay fraction of the soils. Their contribution to the magnetic properties is negligeable in the soils, but clearly evidenced in the coarse and silt fraction of the loess.

Key words: rock magnetism, palaeomagnetism, hysteresis parameters, loess/palaeosol sequence, Central China.

Introduction

The strong resemblance and high degree of correlation between the magnetic susceptibility (κ)-signature of the loess/palaeosol sequence in Central China and the oxygen-isotope variation in deep sea and deep ocean cores, lead to the acceptance that κ in these continental deposits is a proxy indicator of past climatic changes (Heller & Liu 1986; Kukla 1987; Maher & Thompson 1991).

The κ-signal in this unique sequence can be used to reconstruct past climatic and environmental changes, once the link between them is well established. It also enables us to control the presence of cyclicities in the climate if a time scale is available (Wang et al. 1990).

Different models have been proposed to explain the κ-variation in the loess/palaeosol sequence of Central China and in particular the strong κ-enhancement witnessed in the palaeosols:

- the alteration and compaction model of Heller & Liu (1984) proposes a relative enrichment of the detrital magnetites in the soil horizons due to compaction, weathering, and alteration caused by pedogenic processes. The latter would result in a reduction of the carbonate content and the porosity.
- the dilution model of Kukla (Kukla 1987; Kukla et al. 1988, 1990; Kukla & An 1989) explains the κ-contrast and κ-climate linkage through the dilution of a relatively constant flux of fine-grained dust from remote sources, including particles of volcanic and meteoritic origin, by a variable, climatically modulated deposition of weaker magnetic eolian silt of local sources.
- the pedogenic model of Maher & Thompson (Liu et al. 1990; Zhou et al. 1990; Maher & Thompson 1991) considers the neoformation of magnetite in the soils as the major contributor to the κ-enhancement.

Indeed, pedogenic processes, and hence climatic changes, are the main origin for the κ-changes observed. However, important spatial variations in κ occur and different sources contribute to the still poorly understood κ-variance (Han et al. 1991; Hus & Han 1992). For instance, the κ -variance may reflect changes in :

- the sediment source, the weathering regime, grain size, the degree of dilution level of non-magnetic components and magnetic minerals, the rate of authigenic or pedogenic growth of secondary magnetic minerals.

Consequently, it is important to determine the mineralogy and magnetic state of the magnetic carriers present in the loess and soils. Loess, and soils formed in them, are typical examples of a diluted mixture of magnetic minerals in different magnetic states. Because the magnetic fraction occurs in low concentrations (%), and as very fine particles (mainly below 0.1 μm) they are difficult to identify directly by X-ray diffraction or optical microscopy. Large magnetite grains, which are strongly oxidized near the rims, were observed by Heller & Liu (1984) in polished sections. More recently, scanning and transmission electron microscopy by Maher & Thompson (1992) of soil magnetic extracts, identified magnetites of distinct shape and size. The coarse-grained fraction above 2 μm is dominated by lithogenic magnetites. The fraction below 2 μm contains particles resembling magnetites produced by inorganic precipitation as well as, although less abondant, some magnetites probably of bacterial origin. Magnetite and hematite could be detected in the loess and soils and maghemite in the soils by X-ray analysis (Kukla et al. 1988; Han et al. 1991).

The magnetic minerals present were also determined and characterized by different rock magnetic methods, including Mössbauer analysis, which allow to detect small changes in the magnetic mineralogy. Measurements of the saturation magnetization and saturation remanent magnetization show that magnetite is the predominant magnetic carrier in the loess and the soils, but strongly enriched in the latter (Han et al. 1991). Mag-

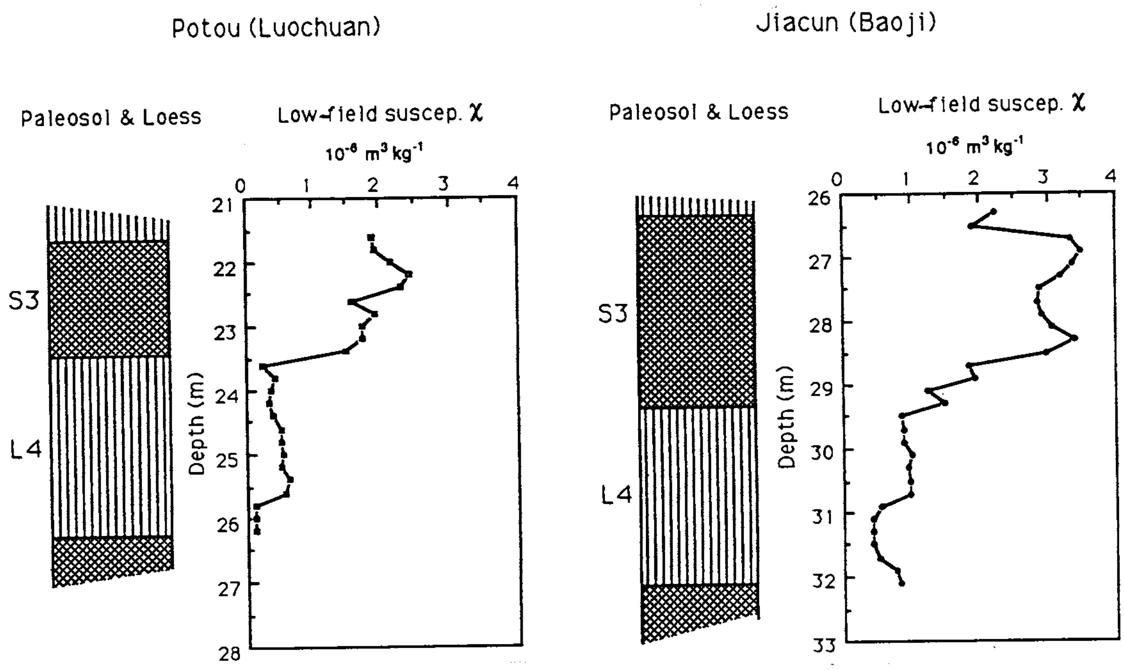

Fig. 1. Low-field susceptibility profile of soil unit S3 and its parent loess L4 in Potou (Luochuan) and Jiacun (Baoji), in the loess/palaeosol sequence in Central China.

netic measurements also suggest that the soils are enriched in fine-grained magnetites near the superparamagnetic/stable single-domain boundary (SP/stable SD boundary) (Zhou et al. 1990; Hus & Han 1991). Thermomagnetic analysis (Maher & Thompson 1991; Han et al. 1991; Hus & Han 1992; Heller et al. 1991) and Mössbauer analysis (Vandenberghe et al. 1992; Han et al. 1991; Xu Li et al. 1991) proved the presence of maghemite and weak magnetic minerals, such as the imperfect canted antiferromagnetics hematite and goethite, in the soils.

As secondary pedogenic magnetites are expected to occur in the clay fraction of grain sizes, it is indicated to examine the magnetic properties of grain size particles and in particular to determine the contribution of each in the total susceptibility. We measured the hysteresis parameters of samples retrieved from several units of the Malan and Lishi Formations in the Potou section in Luochuan and the Jiacun section in Baoji (both in the Shaanxi Province), as well as particle-size fractions obtained for soil unit S3 and loess unit L4 of the Jiacun section.

Methods

The bulk low-field magnetic susceptibility (κ) was measured with a Kappabridge in a field of 80 Am^{-1} at 970 Hz and determined on a mass specific basis. Hysteresis parameters of disaggregated samples were obtained with a PAR/PM-1 vibrating sample magnetometer. The hysteresis parameters given in the text, and which reflect the response of the samples in different applied magnetic fields, are defined as follows :

κ_l ($m^3 kg^{-1}$) = low-field magnetic susceptibility on a mass specific basis or ratio of the magnetization induced to the intensity of the inducing magnetic field. It is a measure of the magnetizability of the sample.

κ_h = high-field magnetic susceptibility, here the slope of the initial magnetization curve between 0.70 and 0.85 T.

Ms ($Am^2 kg^{-1}$) = saturation magnetization.

Msr or SIRM = saturation remanent magnetization. It is the remanence obtained when the sample is saturated in high forward fields, followed by a decrease of the applied field to zero. In our case it represents the maximum remanence that can be given to a sample in a field of 0.85 T.

(Bo)c = back field or reverse field needed to bring the magnetization to zero.

(Bo)cr = back field required to bring the saturation remanence to zero.

IRM .../SIRM = ratio expressing the loss in remanence when a back field is applied.

The procedure to obtain grain size fractions is the same as the one followed by Oldfield et al. (1985):
- a weighed dried and disaggregated bulk sample was dispersed ultrasonically with a 25 cc solution of 3.3 % w/v sodium hexametaphosphate and 0.7 % w/v sodium carbonate and 25 cc deionised water;
- the dispersed sample was wet-sieved through a 53 μm brass sieve;
- the sieve content, or coarse fraction above 53 μm, was washed several times and oven dried at 50 °C;
- the finer fraction below 53 μm (silt and clay) was separated into grain size fractions by the pipette method.

The finer grade was shaken end-over-end for one night. It was then transferred to a settling cylinder, filled with deionised water up to 500 ml, and kept in a constant temperature water bath of 25 °C. Eleven millilitres of the suspension was pipetted according to the settling times based on Stokes' law. The pipetted samples were finally oven dried at 50 °C and weighed.

Hysteresis parameters of bulk samples

Comparison of the low-field magnetic susceptibility (κ_l)-signature of the Malan and Lishi Formations of the loess/palaeosol sequence in Potou (Luochuan) and Jiacun (Baoji) reveals im-

Table 1: Hysteresis parameters of bulk loess and soil samples of the Potou (Luochuan) and Jiacun (Baoji) sections.(sample code gives also depth of samples; for explanation symbols see text).

	Ms Am^2Kg^{-1}	Msr Am^2Kg^{-1}	$\frac{Msr}{Ms}$	(Bo)c mT	(Bo)cr mT	$\frac{(Bo)c}{(Bo)cr}$	κ_h $10^{-8}m^3Kg^{-1}$	κ_l $10^{-8}m^3Kg^{-1}$
				Potou (Luochuan)				
S1-10.1	0.105	0.0166	0.15	6.9	24.4	3.5	6.3	252
S2-16.9	0.098	0.0160	0.16	6.9	24.9	3.6	6.5	228
S3-22.2	0.102	-	-	6.8	24.0	3.5	5.7	257
S4-27.2	0.099	-	-	5.2	19.6	3.8	6.3	230
S5-33.6	0.103	0.0171	0.17	6.3	22.2	3.5	6.7	268
S7-48.0	0.063	0.0120	0.19	7.3	26.7	3.6	6.1	145
S14-73.6	0.068	0.0120	0.18	7.1	25.4	3.6	5.2	150
L2-12.7	0.039	0.0065	0.17	11.9	44.5	3.7	5.3	56
L3-20.7	0.043	0.0068	0.16	9.9	37.9	3.8	4.8	80
L4-25.0	0.034	-	-	11.4	44.4	3.9	4.4	58
L5-30.3	0.031	-	-	9.9	40.3	4.1	5.2	56
L6-39.1	0.029	0.0060	0.21	12.6	50.5	4.0	4.4	49
L8-49.4	0.018	0.0056	0.30	10.8	44.0	4.1	5.0	53
L9-56.1	0.021	0.0059	0.28	15.8	64.6	4.1	4.3	18
L15-76.7	0.014	0.0040	0.28	18.3	62.3	3.4	4.3	12
				Jiacun (Baoji)				
S1-07.9	0.113	0.0199	0.18	6.5	22.1	3.4	7.0	314
S2-19.1	0.120	0.0194	0.16	6.1	22.8	3.7	7.8	308
S3-26.9	0.128	0.0202	0.16	5.9	22.0	3.7	6.5	348
S5-39.1	0.078	0.0157	0.20	6.6	22.3	3.4	8.0	241
S8-60.5	0.033	0.0077	0.23	8.9	32.4	3.6	7.3	86
S14-87.3	0.049	0.0100	0.21	7.3	25.6	3.5	6.7	121
L1-06.1	0.030	0.0076	0.25	9.1	38.5	4.2	7.3	145
L2-11.5	0.033	0.0071	0.21	12.1	48.5	4.0	6.2	53
L3-25.1	0.054	0.0107	0.20	7.7	28.8	3.7	6.7	126
L4-31.3	0.019	0.0064	0.34	13.1	54.0	4.1	6.8	43
L6-49.1	0.018	0.0062	0.34	13.1	57.0	4.3	6.3	46
L9-63.9	0.012	0.0028	0.24	17.1	65.1	3.8	3.0	23
L15-89.1	0.014	0.0040	0.28	18.0	66.2	3.7	4.5	22
				Huangling				
S4								
Bulk	0.045	0.0069	0.15	73	265	3.6	4.5	131
20Šm	0.079	0.0126	0.16	71	236	3.3	5.8	146
1Šm	0.078	0.0109	0.14	41	177	4.3	10.4	236
L5								
Bulk	0.049	0.0075	0.15	92	362	3.9	4.4	70
20Šm	0.053	0.0071	0.13	83	315	3.8	4.4	75
1Šm	0.048	0.0050	0.10	46	197	4.3	6.3	112

portant spatial differences. While κ_l is systematically lower in the palaeosols S4 until S15 in the Jiacun section, the opposite is true in the upper part for S1, S2 and S3. This is clearly seen for S3 and its parent loess L4 in Fig. 1, where the difference in average κ_l for the soil and loess unit is respectively 27 % and 17 %.

Initial magnetization curves, remanence magnetization curves and the most important hysteresis parameters were measured on disaggregated samples of about 0.5 g for several loess/palaeosol doublets. The shape of the magnetization and remanent magnetization curves are very similar for all the loess samples and for all the soil samples but the variance in Ms and Msr is high in the soils (Tab. 1). A few examples are given in Fig. 2 where the magnetization curves represent the induced magnetization and remanence normalized to the uncorrected saturation magnetization in function of the applied field. The isothermal remanence (IRM) acquisition curves of the soil samples display a sharp increase in low fields. In a forward field of 30 mT more than 95 % of the saturation remanence is attained in both the loess and soil samples. The average saturation magnetization Ms and saturation remanence Msr are respectively more than 3 times and about 2.5 times higher in the soils compared to the loess. From Tab. 1 we see that the highest values for Ms (which is grain size independent and corrected here for the paramagnetic and/or antiferromagnetic contribution) as well as the highest values for Msr (which is grain size dependent) occur in the soils with the highest κ_l-values. The

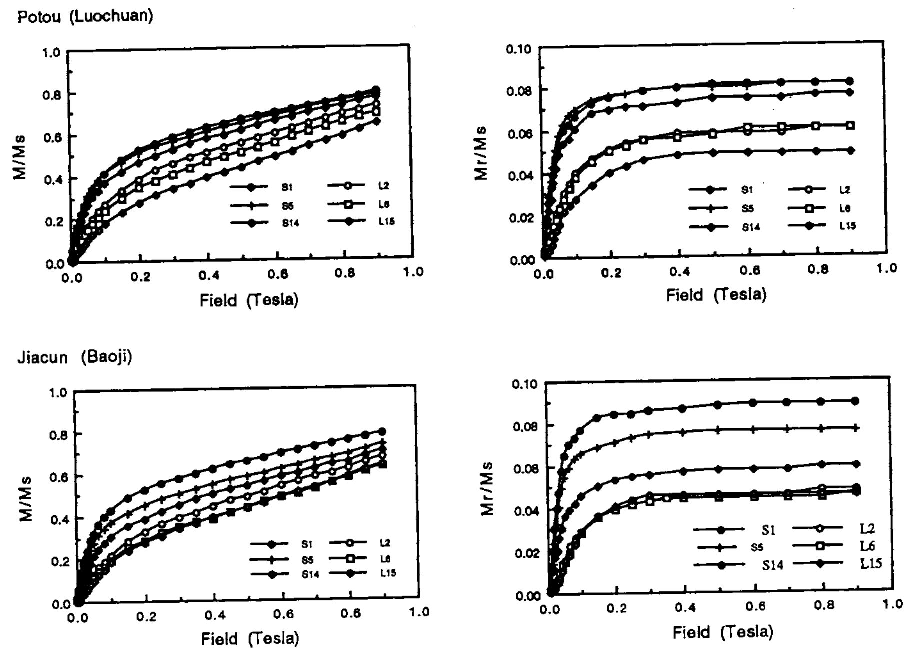

Fig. 2. Initial magnetization and remanent magnetization curves, normalized with the saturation magnetization, of different soil and loess units in the Potou (Luochuan) and Jiacun (Baoji) sections.

lowest values are found for the most sandy and less weathered loess L9 and L5, which also have the lowest κ_l-values. This suggests that the bulk magnetic mineralogy in both loess and soils is very similar, but with a higher concentration of strong but soft ferrimagnetic minerals in the soils.

In fields higher then 0.3 T, the initial magnetization curves become a straight line (Fig. 2). The slope of this straight line, the so-called high-field susceptibility κ_h, can be mainly attributed to the presence of paramagnetics and/or hard imperfect antiferromagnetics. The parameter κ_h is higher in the soils compared to their parent loess (Tab. 1) which indicates that the former contain a higher amount of paramagnetics and/or imperfect antiferromagnetics. The high-field susceptibility κ_h follows the same trend as κ_l and is high when κ_l is high. The relative contribution of the paramagnetics and/or imperfect antiferromagnetics to κ_l is however smaller in the palaeosols compared to their parent loess. This follows from the field-dependent susceptibility κ_f which is the normalized difference between the low- and high-field susceptibility. The field-dependent susceptibility κ_f, which reflects the ferrimagnetic contribution to κ_l, attains values higher than 95 % in the soils, but much lower ones in the loess, and only 65 % in L15. The high κ_f-values in the palaeosols and weathered loess, or loess with evidence of some degree of soil formation, is not the result of depletion in paramagnetics and/or imperfect antiferromagnetics but is due to an enrichment in the ferrimagnetic mineral content. This is confirmed by the high Ms values in the palaeosols, as we saw earlier.

Except for Ms, all the other hysteresis parameters are grain size dependent. The variations in coercive force (Bo)c and coercivity of remanence (Bo)cr are negatively correlated with Ms, Msr and κ_l. The low values in the palaeosols suggest a higher content of either multidomain (MD) or superparamagnetic (SP) magnetite. The highest values occur in the loess, especially in L9 and L15, where the contribution of the hard imperfect antiferromagnetics is clearly evidenced.

The domain state can be better appreciated if Msr/Ms is plotted against (Bo)c/(Bo)cr according to Day et al. (1977).

In this diagram (Fig. 3) the soil and loess samples form two groupings but mainly fall in the pseudo-single-domain range (PSD-range) but with either MD or SP affinities for the soil samples.

The ratios are: 0.16<Msr/Ms <0.34 and 5.9<(Bo)cr/(Bo)c <18. The same classification is found if we plot SIRM/κ_l against (Bo)cr according to Bradshaw & Thompson (1985).

The SIRM/κ_l ratio varies more or less between 5 and 33, with the lowest values corresponding to the soils and the highest value for L15. The foregoing diagrams have diagnostic value but are of limited use when we are dealing with admixtures of different magnetic minerals in different magnetic states.

The investigation of the hysteresis parameters of the bulk samples leads to the conclusion that we have an admixture of magnetic grains in the loess and soils with a larger concentration

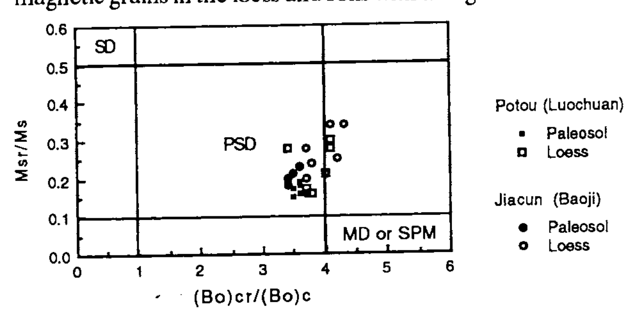

Fig. 3. Magnetic state of loess and soil samples of the Potou (Luochuan) and Jiacun (Baoji) sections in terms of the saturation remanence to saturation magnetization ratio (Msr/Ms) and remanence coercive force to the saturation coercivity ratio (Bo)cr/Bo, according to Day et al. (1977).

(full symbols = soil; open symbols = loess; ■, □ = Potou section; ●, ○ = Jiacun section)

Table 2: Hysteresis parameters of grain-size fractions of a sample of soil unit S3 and its parent loess L4 of the Jiacun (Baoji) section. (For explanation symbols see text).

	Ms Am^2Kg^{-1}	Msr Am^2Kg^{-1}	$\frac{Msr}{Ms}$	(Bo)c mT	(Bo)cr mT	$\frac{(Bo)c}{(Bo)cr}$	κ_h $10^{-8}m^3Kg^{-1}$	κ_l $10^{-8}m^3Kg^{-1}$
				Jiacun (Baoji)				
S3								
Bulk	0.128	0.0203	0.16	5.9	21.9	3.7	6.5	348
53Šm	0.057	0.0078	0.14	6.6	23.4	3.5	2.0	119
40Šm	0.135	0.0178	0.13	5.1	20.0	3.9	7.1	328
20Šm	0.145	0.0208	0.14	5.1	18.6	3.6	8.0	364
10Šm	0.159	0.0222	0.14	4.9	19.0	3.9	9.3	442
5 Šm	0.160	0.0243	0.15	4.8	17.9	3.7	10.9	475
2 Šm	0.144	0.0194	0.13	3.5	17.3	4.9	11.7	507
1 Šm	0.151	0.0164	0.10	2.9	16.5	5.6	10.6	494
L4								
Bulk	0.019	0.0064	0.34	13.1	54.0	4.1	6.8	43
53Šm	0.007	0.0012	0.17	9.3	41.8	4.5	3.3	-
40Šm	0.022	0.0045	0.20	10.9	50.0	4.6	6.7	40
20Šm	0.040	0.0062	0.15	10.8	51.3	4.7	5.7	43
10Šm	0.016	0.0045	0.28	10.1	46.6	4.6	8.7	45
5 Šm	0.025	0.0041	0.16	7.5	37.0	4.9	8.6	48
2 Šm	0.023	0.0021	0.09	5.0	27.7	5.5	8.8	47
1 Šm	0.022	0.0023	0.10	4.2	26.6	6.3	8.5	48

and number of either MD or SP grains in the soils. Differentiation between the latter is difficult as the effect of both is to enhance κ and also to soften the magnetic properties.

A higher frequency dependence of low-field susceptibility (κ_{fd}) of several % in the palaeosols compared to the loess, is often taken as a strong argument in favor of a high SP contribution to the former (Zhou et al. 1990; Xiuming Liu et al. 1992; Maher & Thompson 1991). Although Néel's „thermal fluctuation fieldÃ theory predicts a decrease of about 4 % in κ_{fd} in MD magnetite for a tenfold increase in frequency (Vincenz 1965), this has not been observed. On the contrary, the strongest κ_{fd} in magnetite, with values of 7 - 11 %, occurs in samples of 0.022 - 0.023 μm grain size, close to the SP/stable SD-boundary (Maher 1988).

The observation of the behaviour of κ_l at low and high temperatures may be of great help te decipher the magnetic state. With decreasing temperature below room temperature, κ_l is expected to decrease in SP and SD grains and to increase in paramagnetic particles. The presence of MD grains gives rise to a maximum in κ_l at about 130 K (Senanayaka & Mc Elhinny 1981), where the magnetocrystalline constant κ_l changes sign (Bickford et al. 1955). The low-field κ_l between room temperature and 77 K of different loess and soil samples given by Xiuming Liu et al. (1992), reflect well the competing effects between the κ_l-increase of the paramagnetic contribution and the reduction in κ_l caused by the SP to SD transition of grains during cooling. Complications occur due to the increase of κ_l in MD Fe_3O_4 at low temperatures, as κ_l is magnetostrictively controlled (Hodych 1986).

Hysteresis parameters of grain size fractions

It is expected that magnetic measurements on particle-size fractions provide more information of the detrital and pedogenic contributions to the magnetic content, compared to measurements on bulk samples, and hence of the source, weathering and climate related changes. Separation in different particle-size fractions is difficult to realize, and the classical pipette method, after wet sieving, was followed to make comparison with previous studies easier. One of the difficulties of this method is that the coarse fractions may still contain fine particles because of interaction between particles during sedimentation. Moreover, based on Stokes' law, magnetic particles which belong to the heavy fraction will settle more quickly than size equivalent lighther particles. A sample from soil unit S3 and of its parent loess L4 from the Jiacun (Baoji) section were splitted into 7 particle size ranges, from very coarse (>53 μm) to very fine (< 2 μm). The most important hysteresis parameters of these fractions are given in Tab. 2 and plotted in Fig. 4. Except for the ratios and coercive forces, the concentration dependent parameters in this diagram represent the magnetic properties of each grain size fraction per kg. These parameters depend mainly on the nature, concentration and magnetic grain size (magnetic state) of the samples. In Fig. 5 the concentration dependent parameters are plotted again, this time as the contributions of each fraction to the magnetic properties of 1 kg of bulk loess or palaeosol sample. It should be remembered that the particle sizes differ from the effective magnetic grain sizes and that several grain size ranges may contain particles of the same magnetic mineral in different magnetic states. If we refer to the experimental determination of the SP-SD threshold of Fe_3O_4, which is smaller than 0.036 μm (Dunlop 1973), and the SP-PSD threshold, which is below 0.1 μm (Day et al. 1977), then the fine particle range below 2 μm may contain SP, SD and PSD magnetite.

From Fig. 4 and Tab. 2 follows, that the concentration dependent parameters reach much higher values in the soil compared to its parent loess for each grain size fraction. This is in particular the case for the saturation magnetization Ms corrected for the paramagnetic and/or antiferromagnetic content, which is grain size independent. This can only be explained by a higher concentration of strong magnetic minerals in the soil compared to the loess. In the following we will distinguish be-

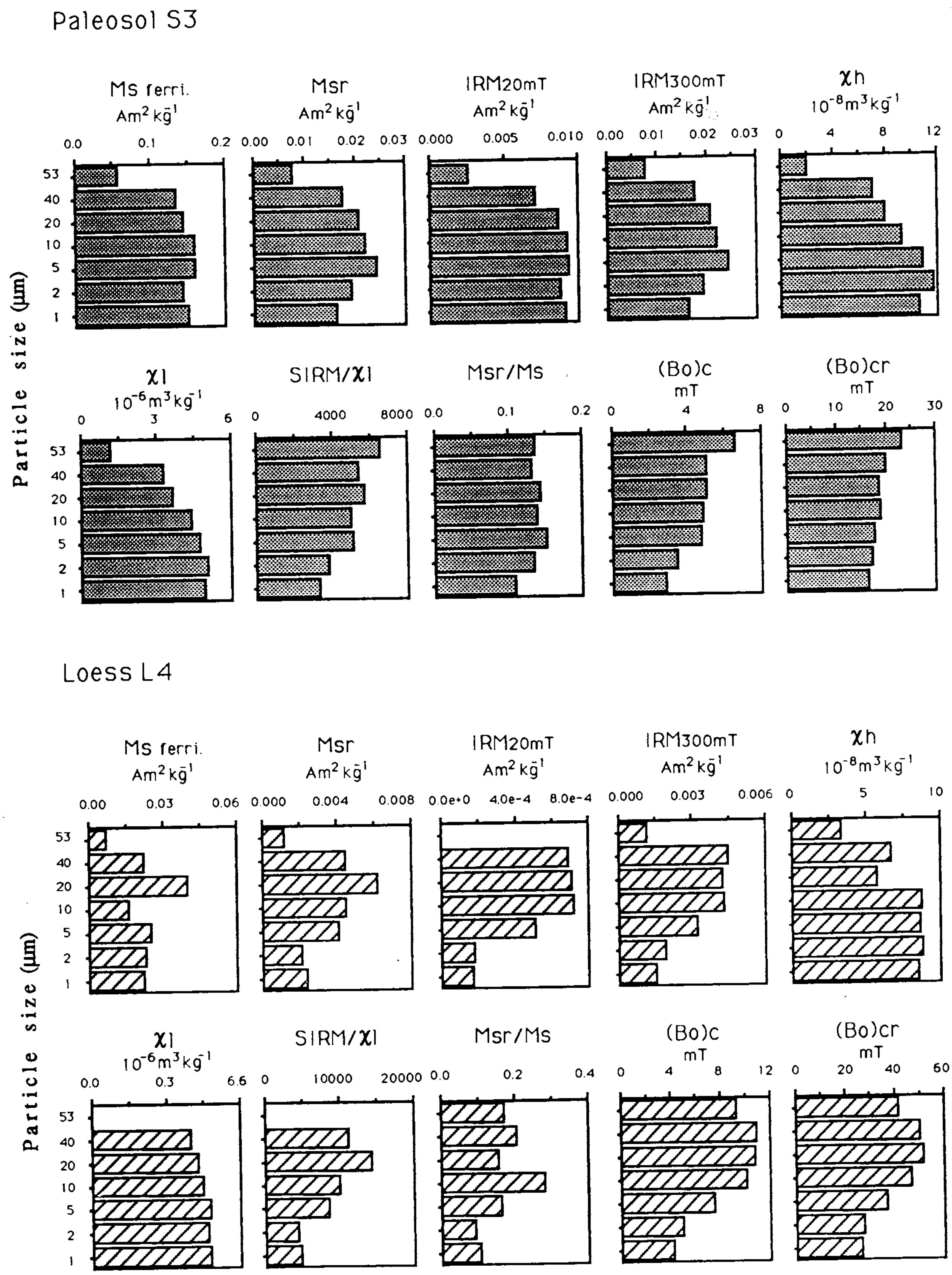

Fig. 4. Hysteresis parameters, saturation remanence to weak field susceptibility ratio (SIRM/κ_l) and saturation remanence to saturation magnetization ratio (SIRM/Ms) of particle size fractions of a sample of S3 and L4 from the Jiacun (Baoji) section.

tween the coarse fraction (>53 μm), the silt fraction (between 50 - 2 μm) and the clay fraction (<2 μm). The highest values of Ms and Msr occur in the silt fraction and for κ_h and κ_l in the silt and clay fraction. Both κ_h and κ_l have the tendancy to increase with a decrease in grain size. This suggests the presence of SP particles in the clay fraction, which would also explain the low values of (Bo)c, (Bo)cr and the Msr/Ms and SIRM/κ_l concentration independent ratios and in the clay Ms l fraction. There is a great contrast in IRM_{20mT} between the soil and loess in the clay fraction (Fig. 4). The behaviour and contrast is similar for IRM_{300mT} and thus in high fields. More than 95 % of the remanence is acquired in fields exceeding 300 mT in all the frac-

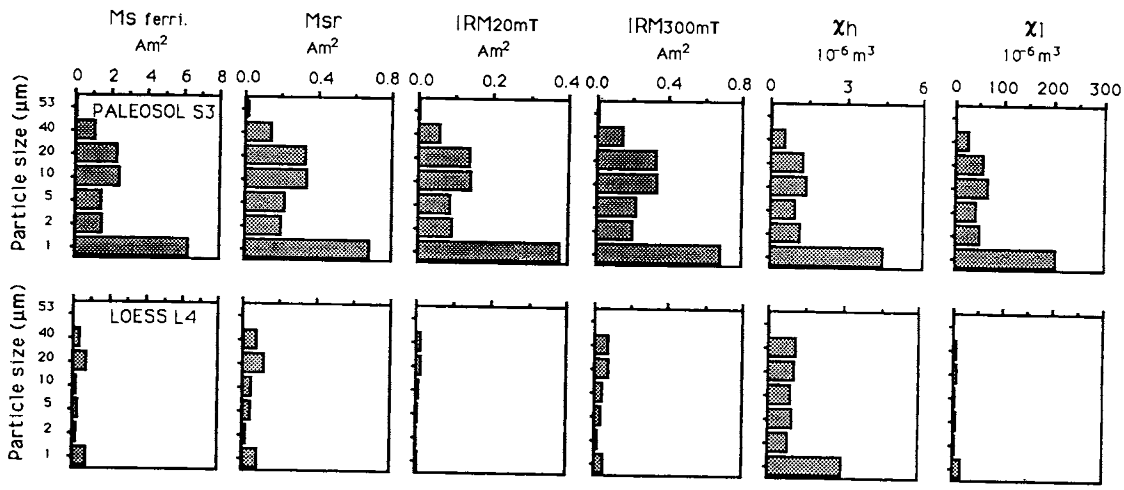

Fig. 5. The total contribution of the concentration dependent hysteresis parameters of particle-size fractions to the magnetic properties per kg of bulk sample, in soil unit S3 and its parent loess L4 from the Jiacun (Baoji) section.

tions, as can be seen from Fig. 6 where the magnetization curves of 2 fractions are compared with the bulk sample. The great similarity of the magnetization and remanent magnetization curves between all the fractions of the soil and loess sample point to a similar bulk magnetic mineralogy with magnetite as the dominant magnetic carrier.

Although it is important to know how the magnetic properties change with the grain size fraction they are difficult to interpret. They are of limited use, as they are controlled by different factors, mainly the nature, concentration and magnetic state of the magnetic minerals present. More enlightening is the contribution of each particle-size fraction to the magnetic properties of the bulk sample (Fig. 5). Striking is the bimodal character of all the magnetic properties, with the greatest contribution coming from the main silt and clay fraction and a minimum contribution from the lower end of the silt-size range between about 5 and 2 μm. This may be partially caused by some contamination of fines in the silt and coarse fractions, as explained earlier.

Without any doubt, there is an important relative contribution of the very fines to the magnetic properties in the soil sample and an important contribution of the silt fraction in the loess sample. This confirms the enrichment of SP/stable SD magnetites in the clay fraction of the soil compared to the loess.

Only for κ_h do we find an important contribution of the clay fraction in both the soil and loess sample. Moreover, the absolute contribution of all the particle-sized fractions to κ_h is not very different between the soil and loess sample. Exceptionally, S3 and L4 is the only doublet where κ_h is slightly higher in the bulk loess sample than in the bulk soil sample (see Tab. 1). From Tab. 1 follows that the paramagnetic and/or imperfect antiferromagnetic content of the palaeosols is of the same order but slightly higher than in the loess.

The results of the magnetic susceptibility measurements and other concentration related rock magnetic parameters on particle-size fractions from the doublet S3 and L4 can be immediately compared with those obtained by Zheng et al. (1991), on grain size fractions of a sample from S1 and L2 of the Luochuan section. The same conclusion is reached that the submicron clay fraction of the palaeosols examined are greatly enriched in fine-grained ferrimagnetic minerals. In both cases a bimodal distribution for the total contribution of each particle-size fraction to the magnetic properties of 1 kg is found. Zheng et al. (1991) interpret the bimodal distribution as due to a bimodal assemblage of magnetic particles of detrital and pedogenic origin. Interesting, but cumbersome, would be to separate and to examine the properties of the magnetic fraction of each particle-size range. In this case a difference in the magnetic properties per unit weight between loess and soil should be attributed to differences either in the nature of the magnetic minerals and/or to variations in the relative proportions of grains of the same magnetic mineral in different magnetic states. From low-field susceptibility measurements on different grain size fractions of concentrates of magnetic minerals, for different loess and soil units, Kukla et al. (1988) concluded that the main part of the susceptibility signal must be attributed to the fine-grained fraction with ultrafine magnetite. From the κ_l -diagram for L1 and S5 given by these authors the fine-grained magnetic concentrate contributes largely for about 50 %, the silt-sized fraction between 40 and 1 μm mainly for the remaining 50 %, while the contribution of particles larger then 40 μm can be neglected. Unexplained is the large unexpected difference in κ_l between the magnetic concentrates of loess and soil especially in the coarse fraction. No detail was given on the effectiveness of the magnetic separation, neither on the separation technique used. IRM_{100mT} From the S = ratio determined on loess and SIRM samples taken from S0 until L5 in Luochuan, Maher & Thompson (1991) concluded that the loess contains more imperfect antiferromagnetics, such as hematite, compared to the soils. They found an S ratio which varies from 0.7 to 0.8 in the soils and from 0.54 to 0.75 in the loess. Similar values for the S-ratio are found in this investigation (see Fig. 2). SIRM $/IRM_{300mT}$ The ratio, which represents twice the SIRM amount of the remanence that resists a back field of 300 mT, normalized for the saturation remanence, is higher in the coarse and silt fraction (between 0.12 - 0.18 in L4 and between 0.00 and 0.11 in S3), but lower in the clay fraction (between 0.23 - 0.30 in L4 and between 0.27 - 0.38 in S3) of L4 compared to S3. From this we conclude that the total amount of hard antiferromagnetics is more or less the same in both the loess and soil sample, but enriched in the clay fraction of the soil sample. The contribution of the antiferromagnetics is clear in the coarse and silt fraction of the loess sample. In the soil sample their contribution is less, as it is overwhelmed by the higher amount of strong ferrimagnetics. The enrichment in antiferromagnetics in the clay fraction of the soil sample is partially due to the presence of goethite, which could be detected by Mössbauer spectroscopy in

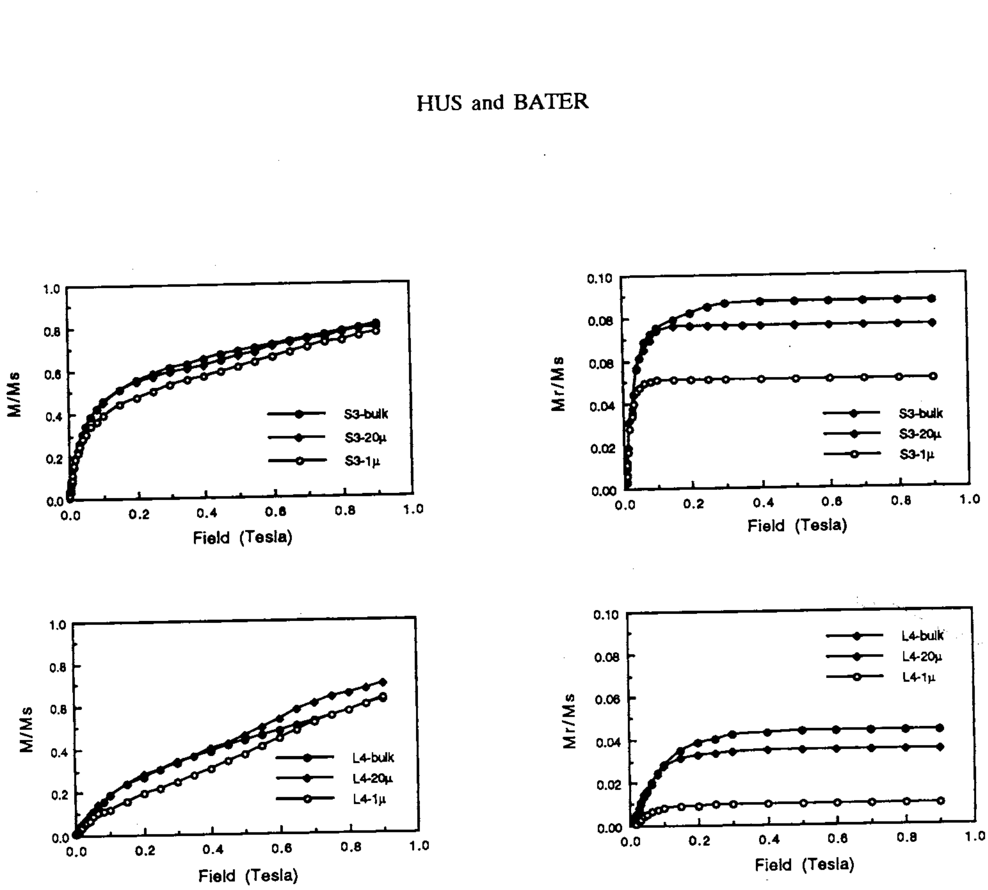

Fig. 6. Initial magnetization and remanent magnetization curves of some grain size fractions and bulk material, of a sample of soil unit S3 and its parent loess L4 from the Jiacun (Baoji) section.

other soil samples (Vandenberghe et al. 1992). Interesting to mention is that the hematite subspectra at 130 K indicate the presence of an antiferromagnetic and a weakly ferrimagnetic phase, in both loess and soil, typical for an inferior crystallinity and/or small amount of substitution for Fe by other elements.

Conclusion

Measurements of the most important hysteresis parameters on bulk samples and particle-size fractions from the loess/palaeosol sequence in Central China, confirm the higher concentration of „magnetitesÂ and especially a greater contribution of the fine-grained fraction to the magnetic properties of the palaeosols compared to the loess. This strongly supports the authigenic production of a large fraction of the fine-grained magnetites in the palaeosols.

The palaeosols contain more paramagnetic plus imperfect antiferromagnetics, but the loess a higher amount of imperfect antiferromagnetics. In the loess the contribution of the imperfect antiferromagnetics is clearly evidenced in the silt fraction. Although, their effect in the soils is masked by the high concentration of strong ferrimagnetics, their presence is well marked in the clay fraction.

The rock magnetic properties of grain size fractions may yield important information about the source, weathering and climate regimes during the building up of the loess/palaeosol sequence. The sedimentation method applied to obtain the grain size fractions suffers from interaction between the particles resulting in a contamination of the coarse fractions by finer particles. It would be very useful to combine the measurements on grain size fractions with measurements and other analysis on magnetic concentrates of the same fractions, as these may differentiate between the proportions of particles of the same magnetic mineral in different magnetic states.

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