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POST-DEPOSITIONAL DETRITAL REMANENT MAGNETISATION IN CHINESE LOESS: PRELIMINARY RESULTS OF LABORATORY EXPERIMENTS

GREGG McINTOSH

Geomagnetism Laboratory, Oliver Lodge Laboratory, Liverpool University, Oxford Street, PO Box 147, Liverpool L69 3BX, UK

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Abstract: The role of water in the development of a post-depositional magnetisation in Chinese loess was investigated in a series of laboratory experiments. Both wetted and dry dissagregated loess samples developed a magnetisation related to the applied magnetic field. It was possible to distinguish between an unstable viscous magnetisation in the dry samples and a stable component developed in the wetted samples. This can be attributed to magnetic grain re-alignment in water-filled pore spaces. In the natural environment this process can occur during seasonal saturation of the top-most loess layer, giving rise to a zone of detrital PDRM development that migrates upwards with loess accumulation, producing a continuous record of geomagnetic field behaviour.

Key words: loess, China, palaeomagnetism, PDRM, detrital.

Introduction

The interpretation of palaeomagnetic studies of Chinese loess has been complicated by the lack of understanding of the mode of remanence acquisition, with both chemical (Heller & Liu 1984) and detrital (Kukla & An 1989) processes being proposed. Burbank & Li (1985) recognised the remagnetisation of unconsolidated loess upon wetting, a phenomenon identified in Belgian loess deposits (Hus & Geeraerts 1986). This paper reports the initial results of laboratory experiments to investigate this mechanism in Chinese loess.

The mean particle size and mineral distribution of the loess used in this investigation (Rolph et al. 1989) has quartz in the medium silt range (7ø) dominating, with upto 20 - 28 % clay size material present. The magnetic mineralogy of the loess includes magnetite, haematite and maghaemite (Liu et al. 1992), with a range of grain sizes of magnetite and maghaemite governing the remanent magnetic properties (Rolph et al. 1993). Based on magnetostratigraphic evidence (Rolph et al. 1989) it is approximately 0.9 My in age, and in-situ it is strongly compacted and cemented.

Sample preparation

The loess was initially mechanically disaggregated and the residue passed through a 125 μm sieve to remove any large unbroken fragments. Samples were prepared by pouring the loess powder into perspex cubes of side 2 cm. To encourage an initially random distribution of magnetic grain orientations this preparation was carried out in a low magnetic field area. The degree of packing of the samples was varied by gently tapping the sides of some of the cubes whilst filling, producing either loosely packed or closely packed samples. The samples were then placed in a controlled magnetic field provided by an orthogonal 3 pair Helmholtz coil configuration.

To investigate the influence of wetting, the samples were split into two groups, one of which remained dry throughout the experiment. A piece of filter paper was placed over the top of selected samples and 2 cm^3 of de-ionised water was added gradually to the paper. This ensured a more even distribution of water infiltrating the sample. Both the wetted and dry samples were kept in the controlled field for a set time, during which the water was allowed to evaporate. At the end of this time period the remanence of both groups of samples was measured using a 3-axis cryogenic magnetometer. This procedure was then repeated in a number of different applied fields.

Results

The wetted samples took upto 2 - 3 days to dry and on drying developed desiccation features which were more pronounced in the loosely packed samples. A degree of physical stability was evident in the wetted samples in that they could be removed from their holders in one piece. Scanning Electron Microscope (SEM) pictures revealed the development of clay bridges, which would act to hold the samples together. These samples were darker in colour than the dry samples as a result of the retention of a thin layer of water adsorbed onto grain surfaces.

The results of the magnetisation experiments are summarised in Tab. 1. Both the wetted and dry samples developed a magnetisation related to the applied field. The wetted, loosely packed samples developed intensities of magnetisation approximately three times greater than those of the equivalent, closely packed samples. However they also show a greater scatter of directions, as reflected in the larger α_{95} values. For both sets of samples the directional agreement of the remanence with the applied field is good, with no systematic inclination or declination errors, although for the samples magnetised in weaker fields (field 20.8 μT) the directional agreement is poorer. AF demagnetisation to

Table 1: Remanent magnetisation after application of controlled magnetic field.

Applied Field D,I,F	Sample type	Time in field (days)	No. of samples	Remanence D,I,IN,T,α_{95}
166,24,88.4	W / L	24	3	174,29,409,40
166,24,88.4	W / C	24	3	162,29,130,11
166,24,88.4	D / C	24	3	165,14,48,58
101,15,80.6	W / C	32	8	104,12,223, 5
101,15,80.6	D / C	32	7	109,19, 74, 9
98,30,20.8	W / C	20	7	89,27, 72,10
98,30,20.8	W / C	20	3	149,37, 30,42

Declination (D); Inclination (I); Field Strength (F) in μT and Mean Remanent Intensity (INT) in 10^{-8} Am^{2}kg^{-1}.
Remanence directions calculated using Fisher Statistics.

Sample type: W/L - sample wetted, loosely packed,
W/C - sample wetted, closely packed,
D/C - sample dry, closely packed.

Table 2: Comparison of remanence before and after AF demagnetisation to 10mT.

Sample type	Applied Field D,I,F	Initial D,I,INT,α_{95}	Remanence D,I,INT,α_{95}
W / C	101,15,80.6	105,15,208	103,17,127
W / C	101,15,80.6	103,12,215	104,10,129
W / C	101,15,80.6	97,16,217	96,18,139
W / C	101,15,80.6	114, 9,253	116, 8,171
FISHERMEAN		105,13,223,9	105,13,142,11
D / C	101,15,80.6	117,13,103	127,11,43
D / C	101,15,80.6	114,26,104	115,42,48
D / C	101,15,80.6	109,15, 77	120,16,16
FISHERMEAN		113,18,95,12	121,23,36,12

Declination (D); Inclination (I); Field strength (F) in μT and Mean Remanence Intensity (INT) in 10^{-8}Am^{2}kg^{-1}.

Sample type: W/C - sample wetted, closely packed,
D/ C - sample dry, closely packed.

10 mT removes 30 % of the remanence (Tab. 2), good directional agreement with the applied field being maintained.

For the dry samples, the directional agreement is less well defined than for the wetted samples, with much larger α_{95} values in evidence. Their intensities are approximately one third those of equivalent closely packed, wetted samples. They are also less stable to AF demagnetisation, losing 60 % of their remanence after demagnetisation at 10 mT (Tab. 2) and show decreased directional agreement.

A further series of experiments were undertaken to examine the viscous behaviour of the magnetisation in the wetted and dry samples. Two sets of samples were placed in the controlled field, one of which was wetted, and the magnetisation measured after a time of 32 days. The samples were then replaced in the applied field, rotated through 90°, and left for a further 17 days, after which the magnetisation was remeasured. No water was added during this stage. The samples were then subjected to AF demagnetisation to 10 mT, the results are given in Tab. 3.

From this it is seen that a secondary magnetisation is developed in the wetted samples that is almost completely removed on AF demagnetisation to 10 mT. The remaining magnetisation compares closely with the magnetisation acquired after wetting in the initial field, suggesting that this is a stable magnetisation. In the case of the dry samples, the initial magnetisation is completely overprinted by the secondary magnetisation, the AF demagnetisation providing a direction more consistent with the second applied field. This indicates that the magnetisation in the dry samples is dominantly viscous in behaviour.

These results were checked by investigating the decay of the magnetisation when stored in a magnetically shielded environment (Tab. 4). Samples whose magnetisation was acquired in a controlled field after 20 days were then stored in a low magnetic field for 17 days and their remanence remeasured. The wetted samples lose about 20 % of their magnetisation after an equivalant time in low field, whilst retaining consistent directions, although greater scatter is evident. The dry samples lose over 50 % of their remanence and directions show poor agreement, providing further indication of the strong viscous component.

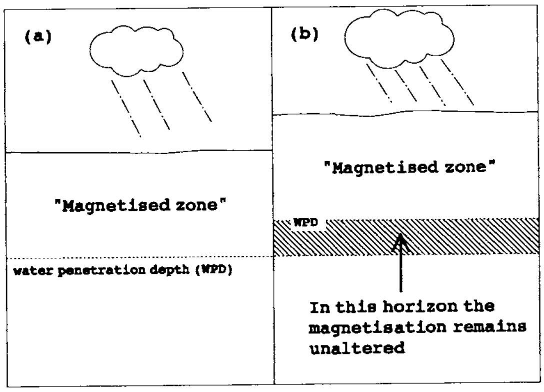

Fig. 1. a - Development of magnetised zone during saturation of top-most loes; **b** - after further accumulation.

Discussion

The physical coherence in the wetted samples is a consequence of the development of stabilising structures such as the clay bridges seen in SEM pictures. They act to brace the matrix of larger quartz grains and probably represent the first step in the "loessification" of the deposits (Liu et al. 1985). The thin water layer adsorbed onto grain surfaces will also act to enhance the cohesive forces between particles, helping to hold the samples together.

The dry samples develop a magnetisation that is unstable with time and readily realigns with successive applied fields. The presence of a significant viscous component is commonly reported in loess palaeomagnetic studies (eg. Burbank & Li 1985) and probably resides in the very fine-grain magnetite fraction. The wetted samples also develop this viscous component (they have the same magnetic grain size distribution) but in addition acquire a stable component as a direct result of the presence of water during the magnetisation process.

Table 3: Comparison of remanence before and after application of secondary field with subsequent AF demagnetisation to 10 mT.

Sample type	Initial Remanence D,I,INT,α_{95}	Remanence after 90° rotation D,I,INT,α_{95}	Remanence after 10mT AF demagnetisation D,I,INT,α_{95}
W/C	109, 8,229	135,11,184	117,12,131
W/C	99,14,248	117,19,182	100,18,157
W/C	106,17,239	124,22,182	111,21, 14
Mean	105,13,239,10	125,17,183,16	109,17,145,14
D/C	89,33,73	209,49,47	285,80,23
D/C	120,18,78	196,19,71	192,21,35
D/C	106,12,87	182,14,57	157,16,17
D/C	103,14,73	199,24,36	221,36,13
Mean	115,20,78,17	195,27,53,21	192,42,22,52

Declination (D); Inclination (I); Mean Remanent Intensity (INT) in 10^{-8}Am^{2}kg^{-1}.

Sample type: W/C - sample wetted, closely packed
D/C - sample dry, closely packed

Mean directions calculated using Fisher Statistics.

The relatively open microstructure in the loess (Tan 1988), along with the presence of water, provides the necessary conditions for the development of a detrital post-depositional remanent magnetisation or PDRM (see Verosub 1977; Tucker 1980). The magnetic grains are able to align themselves in the water-filled pore spaces and are "locked in" on drying of the sample. The net magnetisation associated with the action of water will be the resultant of this and the demagnetisation effect on drying (Henshaw & Merrill 1979). Another consequence of drying is seen in the loosely packed samples, where physical disruption, as evidenced by the development of large desiccation cracks, leads to an increased scatter in the remanence directions. The mean directions, however, still agree well with the applied field. The closely packed samples have less well developed desiccation features and lower α_{95} values, having undergone a lower degree of disturbance on drying.

The relationship between field intensity and remanence intensity is complicated by the role of the microstructural environment. The loosely packed samples display much larger intensities than their closely packed counterparts. One would expect that the relatively more open structure in these samples offer less physical restriction to grain realignment, thus leading to greater efficiency. Conversely, the closely packed (and hence more dense) samples offer increased constraints and reduce the opportunities for complete alignment. Any corresponding increases in α_{95} values due to this restriction are masked by the effect that drying has on the remanence directions. Therefore it is important to assess the extent of density variability at the time of PDRM acquisition. In the case of loess the typical uniformity of the deposit suggests that at any depth the variation will be minimal.

Conclusions

From these experiments it has been shown that it is possible to develop a stable PDRM that accurately records the ambient field when water is allowed to infiltrate, and then evaporate from, a disaggregated loess sample. In the natural environment this action of saturation - evaporation can be imagined to occur during rainfall and/or snowmelt. A "saturated zone", created below the loess surface, provides an area where a detrital PDRM can be developed, forming a "magnetised zone" recording the ambient field at the time of drying. The depth of this zone will be the depth to which sufficient water can penetrate to allow grain realignment (Fig. 1a). Upon re-saturation of the topmost loess a new magnetisation will be developed, recording the field at this new time of drying. As loess accumulation continues this cycle of saturation - magnetisation - accumulation is repeated, migrating upwards and creating sequential layers of magnetised horizons (Fig. 1b). Thus a coherent record of field behaviour is produced, the temporal resolution of which is dependant on the accumulation rate.

If there are any changes in the accumulation rate or properties of the loess, such as occur during soil-forming periods, then this will alter the resolution of the palaeomagnetic record. Therefore, records obtained solely from loess units, or from areas where the differences between soil and loess are minimal, would be expected to provide the best signal. Such areas are to be found on the NW fringes of the loess plateau, where poorly developed soils indicate reduced variations in climate. In this area accumulation rates reach upto 30 cm/ky so the potential for high quality palaeomagnetic records is great.

Table 4: Comparison of remanent magnetisations before and after time in low magnetic field.

Sample type	Applied field D,I,F	Remanence after 20 days in applied field D,I,INT,α_{95}	Remanence after 17 days in lowfield D,I,INT,α_{95}
W/C	98,30,20.8	88,25,83	80,21,65
W/C	98,30,20.8	81,36,61	66,33,48
W/C	98,30,20.8	97,13,63	87, 1,45
W/C	98,30,20.8	73,34,95	63,32,79
Fisher mean		85,27,76,16	75,22,59,21
D/C	98,30,20.8	131,58,33	222,77,17
D/C	98,30,20.8	137,29,31	163,12,13
Fisher mean		135,44,32,69	*

Declination (D); Inclination (I); Field strength (F) in μT and Mean Remanent Intensity (INT) in 10^{-8}Am^{2}kg^{-1}.

* Precision parameter, k, <3 so Fisher Test is invalid.

Sample type: W/C - sample wetted, closely packed
D/C - sample dry, closely packed

Further work

The proposed model is based on a limited data set and clearly requires further investigation. More specifically the efficiency of successive magnetisations needs to be considered in order to establish the feasibility of "resetting" the magnetisation with repeated wetting events. Also, as discussed earlier, the importance of physical restrictions on grain realignment has to be determined. An increase in compaction (due to burial) and cementation with age may act to define a maximum depth at which this type of

PDRM can be developed. These factors may also determine the long-term stability of the PDRM, effectively rendering the (magnetic) grains immobile. This work is currently in progress.

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