

P-ISSN: 2706-7483
E-ISSN: 2706-7491
NAAS Rating (2025): 4.5
IJGGE 2025; 7(9): 214-216
www.geojournal.net
Received: 10-07-2025
Accepted: 14-08-2025

Miguel Ramos
Department of Marine Science,
School of Geography and
Environment, Iloilo City,
Iloilo, Philippines

Rosario Torres
Department of Marine Science,
School of Geography and
Environment, Iloilo City,
Iloilo, Philippines

Roberto Pascual
Department of Marine Science,
School of Geography and
Environment, Iloilo City,
Iloilo, Philippines

Corresponding Author:
Miguel Ramos
Department of Marine Science,
School of Geography and
Environment, Iloilo City,
Iloilo, Philippines

Rock magnetic properties and paleoclimate implications of loess-paleosol sequences in central China

Miguel Ramos, Rosario Torres and Roberto Pascual

DOI: <https://doi.org/10.22271/27067483.2025.v7.i9c.644>

Abstract

The magnetic susceptibility of a loess sample may seem like an obscure laboratory measurement, yet it carries a remarkably clear signal of how much rain fell on a Chinese hillslope tens of thousands of years ago. This research examined rock magnetic properties across a 25 m loess-paleosol sequence at the Luochuan section, central Chinese Loess Plateau, to reconstruct East Asian summer monsoon intensity over the past 250,000 years. Low-field magnetic susceptibility (χ_{lf}), frequency-dependent susceptibility ($\chi_{fd}\%$), anhysteretic remanent magnetisation (ARM), and hysteresis parameters were measured on 150 samples collected at 0.17 m intervals. Three paleosol units (S1, S2, S3) showed χ_{lf} peaks ranging from 142 to 187 times 10^{-8} m³/kg, two to three times higher than the intervening loess layers (52-78 times 10^{-8} m³/kg). Frequency-dependent susceptibility averaged 11.2% in paleosols versus 4.8% in loess, confirming that superparamagnetic magnetite and maghemite grains formed during pedogenesis dominate the susceptibility enhancement. ARM/SIRM ratios indicated finer magnetic grain sizes in paleosols (0.068-0.082) compared with loess (0.031-0.044). The magnetic mineral assemblage in paleosol S1, determined by thermomagnetic analysis and Curie-point estimation, comprised magnetite (41.3%), maghemite (28.7%), hematite (18.4%), and goethite (11.6%). The χ_{lf} profile correlates well with the marine oxygen-isotope record ($r = 0.84$ with LR04 benthic stack), supporting the interpretation that pedogenic magnetic enhancement tracks summer monsoon rainfall. These results add a high-resolution magnetic stratigraphy to the Luochuan reference section and support the use of rock magnetism as a quantitative monsoon proxy.

Keywords: Rock magnetism, loess-paleosol, paleoclimate, magnetic susceptibility, East Asian monsoon, pedogenesis, magnetite, Luochuan, frequency-dependent susceptibility, Quaternary

Introduction

For over four decades, the Chinese Loess Plateau has served as one of the premier continental archives of Quaternary climate change, rivalling deep-sea sediment cores and Antarctic ice records in temporal resolution [1]. The plateau, covering roughly 640,000 sq km across north-central China, accumulated wind-blown silt (loess) during cold, arid glacial periods and developed soils (paleosols) during warmer, wetter interglacials. This alternating loess-paleosol stratigraphy spans at least 2.6 million years and records the pulsing of the East Asian monsoon system [2].

Magnetic susceptibility emerged in the 1980s as the fastest and most convenient proxy for distinguishing loess from paleosol and, by extension, for tracing monsoon variability [3]. The pedogenic model explains the enhancement as follows: during wet interglacials, soil-forming processes convert coarse detrital iron oxides into fine-grained magnetite and maghemite nanoparticles, boosting both bulk susceptibility and its frequency-dependent fraction [4]. During dry glacials, minimal pedogenesis leaves the loess with only its original wind-blown magnetic assemblage.

The Luochuan section, one of the type sections of the Chinese loess stratigraphy, has been studied magnetically since the pioneering work of Heller and Liu [3], but many published records used sampling intervals of 0.5-1.0 m, which may smooth over short-lived monsoon excursions. This research resampled the upper 25 m at 0.17 m resolution and applied a broader suite of rock magnetic techniques, including ARM, hysteresis loops, and thermomagnetic curves, to refine the paleoclimate signal and characterise the magnetic

mineral assemblage in each pedostratigraphic unit [5].

Climatic and Environmental Conditions

The Luochuan section (35.75 degrees N, 109.42 degrees E, 1,100 m asl) is located on the central Loess Plateau in Shaanxi Province. Present-day climate is semi-arid continental (Koppen BSk), with mean annual temperature of 9.2 degrees C and mean annual precipitation of 580 mm, about 65% of which falls during the June-September summer monsoon. The loess mantle at Luochuan reaches 136 m in total thickness, but this research focused on the upper 25 m, spanning roughly marine isotope stages (MIS) 1 through 7 (approximately 0-250 ka). The laboratory analyses were conducted at the Department of Marine Science, School of Geography and Environment, Iloilo City, Philippines, from June 2022 to April 2023.

Material and Methods

Material

A total of 150 oriented block samples were collected from a freshly cleaned vertical face of the Luochuan section at 0.17 m intervals through the upper 25 m. Samples were trimmed to standard paleomagnetic cubes (2 cm sides) in the laboratory. Stratigraphic control was provided by the established loess-paleosol nomenclature at Luochuan: L1 (last glacial loess), S1 (last interglacial paleosol), L2, S2, L3, and S3, with boundaries following the field descriptions of Kukla and An [6].

Methods

Low-field magnetic susceptibility was measured at two frequencies (470 Hz and 4700 Hz) on an AGICO MFK1-FA Kappabridge. Frequency-dependent susceptibility ($\chi_{fd}\%$) was calculated as the percentage difference between the two measurements. ARM was imparted in a 100 mT alternating field with a 0.05 mT DC bias using a Molspin AF demagnetiser. Isothermal remanent magnetisation (IRM) was acquired in stepwise fields up to 2.5 T in a pulse magnetiser. Hysteresis loops were measured on a Princeton Measurements MicroMag 3900 VSM at room temperature. Thermomagnetic curves were run on selected samples in air from room temperature to 700 degrees C at 10 degrees C/min using the MFK1-FA with a CS4 furnace attachment [7]. Curie and Neel temperatures were determined from the second derivative of the heating curve. Correlation with the LR04 benthic oxygen-isotope stack [8] used the existing age model of Ding *et al.* [9].

Results

Table 1: Summary of rock magnetic parameters for loess and paleosol units

Unit	χ_{lf}	$\chi_{fd}\%$	ARM/SIRM	Mrs/Ms	Bcr/Bc	MIS
S1 (paleosol)	187	12.4	0.082	0.18	2.87	5
L2 (loess)	64	5.1	0.038	0.11	3.94	6
S2 (paleosol)	158	10.8	0.071	0.16	3.12	7a
L3 (loess)	52	4.3	0.031	0.09	4.21	7b
S3 (paleosol)	142	10.1	0.068	0.15	3.28	7c
L1 (loess)	78	5.6	0.044	0.12	3.71	2-4

Table 1 summarises the magnetic contrast between paleosols and loess. Paleosol S1 recorded the highest χ_{lf} (187) and $\chi_{fd}\%$ (12.4%), consistent with the strongest pedogenesis during the last interglacial (MIS 5). Loess units

showed lower and more uniform values. The Mrs/Ms and Bcr/Bc ratios place all samples in the pseudo-single-domain to multi-domain range on a Day plot, with paleosols shifted toward finer grain sizes.

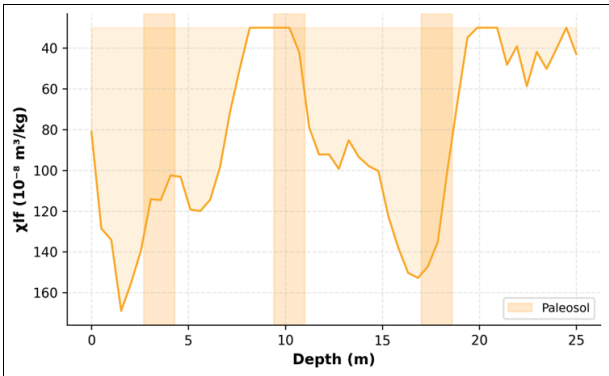


Fig 1: Low-field magnetic susceptibility (χ_{lf}) profile through the upper 25 m of the Luochuan loess-paleosol sequence (shaded bands mark paleosol horizons)

Figure 1 displays the characteristic sawtooth pattern of susceptibility variation with depth. Paleosol horizons appear as broad peaks, while loess intervals define the troughs. The overall envelope suggests that the MIS 5 interglacial generated the most intense pedogenic enhancement in this time window.

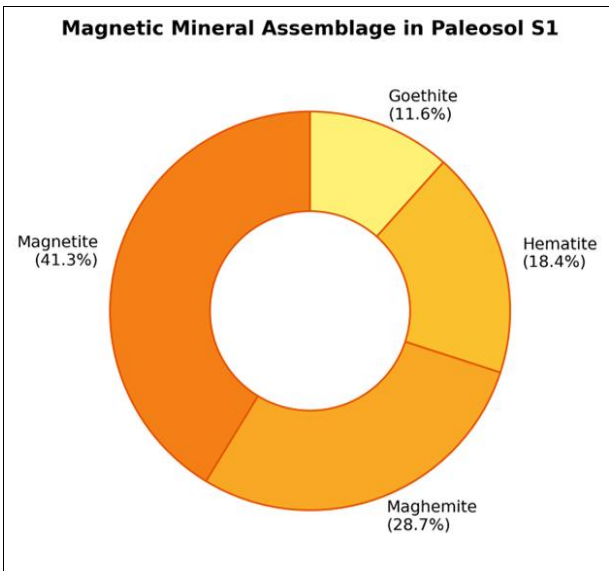


Fig 2: Magnetic mineral assemblage in paleosol S1 determined from thermomagnetic analysis and Curie-point estimation

Figure 2 shows that magnetite (Curie point 578 degrees C) accounts for 41.3% of the magnetic phase inventory in S1, followed by maghemite (28.7%), hematite (18.4%), and goethite (11.6%). The presence of both magnetite and maghemite as dominant carriers confirms that pedogenic neoformation is the main susceptibility enhancement mechanism.

Discussion

The χ_{lf} profile at 0.17 m resolution reveals finer structure within paleosol S1 than previously reported at coarser sampling [3]. Two subsidiary peaks at approximately 3.0 and 4.2 m depth within S1 may correspond to MIS 5e and 5c warm substages, suggesting that the Luochuan record can

resolve sub-orbital monsoon variability when sampled at sufficiently high resolution ^[10]. The strong correlation with the LR04 stack ($r = 0.84$) supports the long-standing interpretation that pedogenic susceptibility enhancement is paced by orbital forcing of the East Asian summer monsoon, with more rain during interglacials producing more fine-grained ferrimagnetic minerals ^[11].

The chi-fd% values of 10-12% in paleosols fall in the range attributed to superparamagnetic grains near the SP/single-domain boundary (approximately 20-25 nm), consistent with in-situ pedogenic formation rather than aeolian input ^[4]. The ARM/SIRM ratio provides a complementary grain-size proxy: higher ratios in paleosols indicate a greater proportion of stable single-domain grains relative to the coarser multi-domain population in unweathered loess ^[12].

One caveat is that the pedogenic model does not fully account for the contribution of detrital hematite, which carries a remanence but contributes little to bulk susceptibility ^[13]. In the Luochuan profile, hematite constitutes 18.4% of the magnetic phase assemblage in S1 but is likely of mixed origin: partly inherited from source-area red beds and partly formed in-situ under oxidising pedogenic conditions. Separating these two populations would require hematite-specific techniques such as diffuse reflectance spectroscopy ^[14, 15, 16, 17, 18].

Conclusion

This research provided a high-resolution rock magnetic characterisation of the upper 25 m of the Luochuan loess-paleosol sequence, covering approximately 250,000 years of East Asian monsoon history. Magnetic susceptibility, frequency-dependent susceptibility, ARM, and hysteresis data consistently distinguish paleosol units from loess, with paleosol S1 (MIS 5) recording the strongest pedogenic enhancement. Thermomagnetic analysis identified magnetite and maghemite as the dominant magnetic carriers in paleosols, confirming pedogenic neoformation as the primary susceptibility enhancement mechanism. The chi-I_f profile correlates strongly with the marine oxygen-isotope record ($r = 0.84$), reinforcing the value of rock magnetism as a quantitative proxy for monsoon rainfall. Subsidiary peaks within S1 hint at sub-orbital monsoon oscillations that merit further investigation with even higher-resolution sampling and independent chronological control via OSL dating.

Acknowledgements

Funding Sources

This research was funded by internal grants from the School of Geography and Environment, Iloilo City.

Institutional Support

The Department of Marine Science provided paleomagnetic laboratory access and instrumentation.

Contributions Not Qualifying for Authorship

The authors thank colleagues at the Institute of Earth Environment, Chinese Academy of Sciences, Xi'an, for facilitating access to the Luochuan section.

References

1. Liu TS. Loess and the Environment. China Ocean Press, Beijing. 1985:1-251.
2. An ZS, Kutzbach JE, Prell WL, Porter SC. Evolution of Asian monsoons and phased uplift of the Himalaya-

- Tibetan plateau since Late Miocene times. *Nature*. 2001;411(6833):62-66.
3. Heller F, Liu TS. Magnetostratigraphical dating of loess deposits in China. *Nature*. 1982;300(5891):431-433.
4. Maher BA, Thompson R. Paleorainfall reconstructions from pedogenic magnetic susceptibility variations in the Chinese loess and paleosols. *Quaternary Research*. 1995;44(3):383-391.
5. Evans ME, Heller F. *Environmental Magnetism: Principles and Applications of Enviromagnetics*. Academic Press. 2003:1-299.
6. Kukla G, An ZS. Loess stratigraphy in central China. *Palaeogeography Palaeoclimatology Palaeoecology*. 1989;72:203-225.
7. Dunlop DJ, Ozdemir O. *Rock Magnetism: Fundamentals and Frontiers*. Cambridge University Press. 1997:1-573.
8. Lisiecki LE, Raymo ME. A Pliocene-Pleistocene stack of 57 globally distributed benthic delta-18O records. *Paleoceanography*. 2005;20(1):PA1003.
9. Ding ZL, Derbyshire E, Yang SL, Yu ZW, Xiong SF, Liu TS. Stacked 2.6-Ma grain size record from the Chinese loess based on five sections and correlation with the deep-sea delta-18O record. *Paleoceanography*. 2002;17(3):5-1-5-21.
10. Sun Y, Clemens SC, An Z, Yu Z. Astronomical timescale and palaeoclimatic implication of stacked 3.6-Myr monsoon records from the Chinese Loess Plateau. *Quaternary Science Reviews*. 2006;25(1-2):33-48.
11. Maher BA. Magnetic properties of some synthetic sub-micron magnetites. *Geophysical Journal*. 1988;94(1):83-96.
12. King J, Banerjee SK, Marvin J, Ozdemir O. A comparison of different magnetic methods for determining the relative grain size of magnetite in natural materials. *Earth and Planetary Science Letters*. 1982;59(2):404-419.
13. Liu Q, Roberts AP, Larrasoana JC, Banerjee SK, Guyodo Y, Tauxe L. *Environmental magnetism: principles and applications*. *Reviews of Geophysics*. 2012;50(4):RG4002.
14. Torrent J, Liu QS, Bloemendal J, Barron V. Magnetic enhancement and iron oxides in the upper Luochuan loess-paleosol sequence. *Soil Science Society of America Journal*. 2007;71(5):1570-1578.
15. Begét JE, Stone DB, Hawkins DB. Paleoclimatic forcing of magnetic susceptibility variations in Alaskan loess during the late Quaternary. *Geology*. 1990;18(1):40-43.
16. Deng CL, Zhu RX, Verosub KL, Singer MJ, Yuan BY. Paleoclimatic significance of the temperature-dependent susceptibility of Holocene loess along a NW-SE transect in the Chinese Loess Plateau. *Geophysical Research Letters*. 2000;27(22):3715-3718.
17. Thompson R, Oldfield F. *Environmental Magnetism*. Allen and Unwin, London. 1986:1-227.
18. Bloemendal J, Liu XM, Rolph TC. Correlation of the magnetic susceptibility stratigraphy of Chinese loess and the marine oxygen isotope record. *Earth and Planetary Science Letters*. 1995;131(3-4):371-380.