Chasing the Paleomonsoon over China: Its Magnetic Proxy Record

Subir K. Banerjee, Institute for Rock Magnetism, Department of Geology and Geophysics, University of Minnesota, Minneapolis, MN 55455

ABSTRACT
Magnetic susceptibility enhancements in Chinese paleosols compared to the underlying loess horizons can be explained by pedogenesis. In regions where variations in mineralogic composition and grain size are not large, the magnetic enhancement can serve as a proxy for paleomonsoon precipitation. Soil magnetization and current rainfall over many sites, plotted against each other, do provide a linear relation, a climofunction. When such climofunctions are used for old paleosols and loess, we can obtain relative variations in paleomonsoon precipitation that are comparable to general circulation model (GCM) estimates for these time periods.

INTRODUCTION
Climate change and the effects of climate change on society are interesting topics in their own right. Our concerns about them have taken on a much more urgent note, however, with the realization that increased emissions of greenhouse gases and the resultant induced warming may bring about a more rapid tempo of climate change than has been common in the past. Recent numerical modeling of the effects of global warming, using atmospheric general circulation models (GCMs) have shown that large greenhouse gases and the resultant induced warming may bring about a more rapid tempo of climate change than has been common in the past.

Magnetic susceptibility enhancement in Chinese paleosols compared to the underlying loess horizons can be explained by pedogenesis. In regions where variations in mineralogic composition and grain size are not large, the magnetic enhancement can serve as a proxy for paleomonsoon precipitation. Soil magnetization and current rainfall over many sites, plotted against each other, do provide a linear relation, a climofunction. When such climofunctions are used for old paleosols and loess, we can obtain relative variations in paleomonsoon precipitation that are comparable to general circulation model (GCM) estimates for these time periods.

THE ROCK MAGNETIC RECORD
The loess deposits of China represent eolian dust from the deserts of the north and northwest lifted by the winter northwesterlies and deposited on the loess plateau (Pye and Zhou, 1989). During glacial times, however, the input was much higher than during interglacial times. Except for the difference in color between buff-brown loess (glacial) and darker brown paleosols (interglacial), it has been difficult to study quantitatively the relative degrees of climatic change (or the precise ages of specific horizons of this uniform body) by the existing sedimentological and other methods. Magnetic stratigraphic dating by Heiler and Liu (1984, 1986) allowed the correlation of loess profiles from multiple sites. High sensitivity of the various rock magnetic parameters to climate change (through a change in the concentration, composition, and grain size of the magnetic minerals) has provided a high-resolution climatic proxy record.

The magnetic minerals responsible are magnetite, maghemite, and hematite; the first two are much more strongly magnetic and thus contribute greatly to the susceptibility signal. However, without a widely-accepted model for the changes in magnitude of all the magnetic parameters show that the climate at Xifeng and Xining was similar during both the early Holocene and last interglacial, about 9 and 120 ka, respectively. Photo by Christopher Hunt.

A vertical cut into the loess section near Xifeng, Gansu Province, China. Xifeng, which lies to the east of the Liupan Mountains, is currently warmer and wetter than sites to the west, as revealed by the vegetation and the magnetic properties of the youngest layers. Photo by Christopher Hunt.

Acknowledgments
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SUBSCRIPTIONS For 1995 calendar year, $45.00. Members sustained exceptional contributions to advancing science or a career distinguished both for achieve- ment and notable services to the scientific community. The Maryland Geological Survey in Baltimore remade its office building the Kenneth N. Weaver Building in honor of GSA Fellow Kenneth N. Weaver’s 29 years of service as director and state geologist. Weaver also received the John Wesley Powell Award for Citizen’s Achievement from the U.S. Geological Survey. The Meritorious Service Award, the second highest award given by the U.S. Department of the Interior, honored these U.S. Geological Survey employees and GSA Member Charles L. Rice, Reston, Virginia; Fellow Robert N. Oldale, Woods Hole, Massachusetts; Member

About People

GSA Member Raymond E. Beierdorfer, Youngstown (Ohio) State University, was recently awarded the 1995 Gustav Ohaus-NSTA (National Science Teachers Association) Award for Innovations in College Level Science Teaching.

GSA Member Timothy R. Carr, Kansas Geological Survey, Lawrence, has been appointed a co-director of the University of Kansas Energy Research Center.

Fellow Morris W. Leighton, chief emeritus of the Illinois State Geological Survey, Champaign, has received the Gaylord Donnelly-Nature of Illinois Foundation Award, for recognition of significant science and conservation efforts in Illinois.

The American Association for the Advancement of Science awarded its 1995 Philip Haas Abeleson Prize to GSA Fellow Frank Press, Carnegie Institution of Washington.

GSA on the Web

What’s new on the GSA home page on the World Wide Web? If you haven’t yet connected to the Web, the Universal Resource Locator (URL) is http://www.aeson.com/geosociety/index.html.

For current information for the 1995 Annual Meeting in Seattle, see GSA Meetings choose 1995 Annual Meeting. This area contains a listing of Symposia and Theme Sessions and has information about Field Trips, Continuing Education, Exhibits, and Lodging.

If you want to know more about the GSA Employment Service or about becoming a GSA Campus Representative, choose GSA Membership Section, which also has information on nominating a member to fellowship and on obtaining forms for applying to become a GSA Member or Student Associate.

See the Geoscience Calendar section for a listing of meetings of general geological interest.

The Publications section has a monthly table of contents and abstracts of articles for the GSA Bulletin and Geology. Also in this section is a guide for authors preparing manuscripts for submission to GSA publications.

For Congressional Contact Information, see the Administration section.

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Xifeng and Luochuan with the δ18O stratigraphy from SPECMAP, which represents the worldwide average changes in global ice volume measured through the variations in the oxygen isotope stratig- raphy. Because Xifeng and Luochuan are about 160 km apart, Kukla et al. (1988) concluded that the magnetic variations could not be due to pedog- enesis. The preferred model of Kukla et al. called for a relative weakening of γ in the loess layers and a strengthen- ing in the paleolayers, as a result of variable concentration of a global “rain” of strongly magnetic magnetite in a low-magnetic-susceptibility eolian dust (loess) prevalent during glacial times. During interglacial times, when soils formed slowly and dust arrival diminished, the magnetite rain from the troposphere was concentrated, thus preserving a relatively large mag- netic susceptibility to the observer. As proof, Kukla et al. (1988) presented a model in which the average magnetic susceptibility was multiplied by the thickness of the sediment column above the sample to produce a plot of magnetic mineral accumulation against inferred geologic age. It was observed that both Xifeng and Luochuan had the same magnetic accumulation rate for the past 800 k.y.

Robert N. Oldale, Woods Hole, Massachusetts; Member

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Figure 2. Kukla et al. (1988) comparison of the δ18O depth series from Zifeng and Luochuan with the SPECMAP series of globally averaged δ18O. Because δ18O values pro- vide global ice volume data, they indirectly pro- vide data on global tem- perature fluctuations which coincide in character with the δ18O depth series, provid- ing the first comparable scale comparison between oceanic and continental climates.

In Memoriam

Sturges Bailey
Madison, Wisconsin November 30, 1994
Russell C. Cutter
Ft. Lauderdale, Florida September 26, 1994
Richard M. Foose
Amherst, Massachusetts November 26, 1994
Mack Gipson, Jr.
Columbia, South Carolina March 10, 1995
Karl A. Naert
Ontario, Canada September 28, 1994

Correction

In GSA Today v. 5, no. 3, p. 4 (March 1995), Francis S. Birch was inadvertently listed among the deceased mem- bers. This was an error. We apologize to Francis S. Birch and his family and friends.

Charles L. Rice, Reston, Virginia; member John F. Slack, Reston, Virginia; and member Bruce R. Wardlaw, Reston, Virginia. ■
enhancement through the formation of ultramine (superparamagnetic and single domain, \( d < 0.1 \mu m \) smaller) magnetite. Later, Mahler and Thompson (1992a) attributed all \( g \)-variation to pedogenesis, as had been done earlier by An et al. (1991), and used a statistical sequence-slotted method to correlate susceptibility features with the \( SPECTAT \) \( P^2 \)O stratigraphy. Vero- sub et al. (1993) have also argued that all of the susceptibility enhancements above the loess background signal are due to pedogenesis. Pedogenesis may be driven by variations in summer monsoons, which may be the global climate signal, characterized by the similarity with \( 8{\delta}O \) data from ocean sediments. However, in the absence of a high-resolution chronology for the \( g \) stratigraphy, such correlations do not constitute a proof of the pedogenic hypothesis.

To test the model of Kukla et al. (1988), Horodyski et al. (1989) and Clemens and Prell (1992) tried to correlate directly the loess stratigraphy with the changes in the recent monsoon in the northwest Pacific and the Arabian Sea, respectively (and claimed success). However, Maher and Thompson (1992b) thought that such a correlation between magnetic susceptibility, which is a concentration-dependent parameter, should not be attempted with mass erosion parameter, which is a rate-dependent parameter. They emphasized that although both were ultimately responsive to climate change, the susceptibility in the Chinese loess plateau was more likely to be a derived pedogenic signal. In my opinion, both of the processes should be considered as the result of pedogenesis, as had been done earlier by An et al. (1991), and used a statistical sequence-slotted method to correlate susceptibility features with the \( SPECTAT \) \( P^2 \)O stratigraphy. Vero- sub et al. (1993) have also argued that all of the susceptibility enhancements above the loess background signal are due to pedogenesis. Pedogenesis may be driven by variations in summer monsoons, which may be the global climate signal, characterized by the similarity with \( 8{\delta}O \) data from ocean sediments. However, in the absence of a high-resolution chronology for the \( g \) stratigraphy, such correlations do not constitute a proof of the pedogenic hypothesis.

The second attempt was made by Vero- sub et al. (1993), who attributed the pedogenic component of \( g \) that part of the magnetic signal which is lost when a sample or a loess is treated with \( B \) citrate-bicarbonate-dithionite. Mahler and Thompson (1992b) thought that such a correlation between magnetic susceptibility, which is a concentration-dependent parameter, should not be attempted with mass erosion parameter, which is a rate-dependent parameter. They emphasized that although both were ultimately responsive to climate change, the susceptibility in the Chinese loess plateau was more likely to be a derived pedogenic signal. In my opinion, both of the processes should be considered as the result of pedogenesis, as had been done earlier by An et al. (1991), and used a statistical sequence-slotted method to correlate susceptibility features with the \( SPECTAT \) \( P^2 \)O stratigraphy. Vero- sub et al. (1993) have also argued that all of the susceptibility enhancements above the loess background signal are due to pedogenesis. Pedogenesis may be driven by variations in summer monsoons, which may be the global climate signal, characterized by the similarity with \( 8{\delta}O \) data from ocean sediments. However, in the absence of a high-resolution chronology for the \( g \) stratigraphy, such correlations do not constitute a proof of the pedogenic hypothesis.

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and by utilizing the average $\gamma$ values for $S_0$ (5–10 ka), $L_1$ (18–75 ka) and $S_1$ (75–130 ka), they obtained average paleorainfall values of 600 mm/yr, 310 mm/yr, and 540 mm/yr, respectively. The $S_0$ soil was used for calibration because Heller et al. believe current rainfall and early Holocene rainfall to be similar. It is immediately obvious, and odd, that while the $S_0$ value for the time interval associated with $S_1$ is known to be larger than $S_0$, the above procedure yields an $S_1$ rainfall that is smaller than that of $S_0$. Heller et al. also had to assume that the magnetic susceptibility of each layer, including $S_0$, had approached a steady-state value, which is contrary to what Singer et al. (1992) found, even for soils as old as 1 m.y. in California. Ongoing research by Zerubavel et al. (1994) may shed further light on this problem.

In the second attempt, Liu et al. (1994b), instead of using the $\gamma$ measurement, used the approach of low-temperature magnetic measurement, $S_0$, $L_1$, $T_1$ of Banerjee et al. (1993) to determine first the variation in pedogenic fraction or SP/total with time at Xifeng from closely spaced samples over the time period 0–130 ka. They then computed a constant of proportionality between the SP fraction and precipitation by plotting the present-day precipitation against SP fraction of the early Holocene ($S_0$) soil at six sites within the loess plateau. The early Holocene soil was used instead of a modern soil because Liu et al. could not be sure that the modern soil was totally free from anthropogenic disturbances (farming, grazing). The correlation between present-day precipitation and the SP fraction of this horizon ($S_0$) for the six sites was found to have a correlation coefficient of 0.95. Liu et al. (1994b) used the slope of this plot to convert the SP fraction to paleoprecipitation for the single high-resolution profile they had obtained at Xifeng. The paleoprecipitation curve thus obtained has a close similarity with the SPECMAP $\delta^{18}O$ record. For example, Liu et al. found that at Xifeng during glacial isotope stage 2 ($L_2$), 4 ($L_4$), and 6 ($L_6$), precipitation was about 200 mm/yr, i.e., 330 mm/yr less than today, whereas during the last interglacial, stage 6 ($S_6$), the precipitation was about 650 mm/yr—i.e., 100 mm/yr more than today. Unlike Heller et al. (1993), Liu et al. found that rainfall was 55% higher in stage 5 ($S_5$) than in stage 1, as would be expected from the SPECMAP data. Maher et al. (1994) gave what 1 perceive to be an improved approach to calculating paleoprecipitation. Following the method of Banerjee et al. (1992), Liu et al. first determined the $increase$ in susceptibility between the $B$ (weathered soil) and C (parent material) horizons at 36 modern soil sites located in eight different areas of the loess plateau. This relative enhancement was then correlated with the average rainfall between 1951 and 1980 in a regression analysis to establish a climation function coefficient. Like Heller et al. (1993) and Liu et al. (1994b), Maher et al. (1994b) obtained a correlation of only a few thousand years is enough for the magnetic susceptibility of the $B$ horizon to have achieved a steady state. Therefore, they convolved susceptibility enhancement to paleo- rainfall using the same coefficient for all the horizons. Rainfall $values$ for the $C$ horizon was approximated by the colder, least wetter $L_1$ horizon. For the last glacial ($L_1$) at 18 ka (dashed-line circles in Fig. 5) paleoprecipitation was less than at present all of the sites, and the maximum decrease was 266 mm/yr. In contrast, both during $S_5$ (isotope stage 1) and $S_1$ (isotope stage 5), the rainfall was much greater than today, and the largest values during both periods (200 mm/yr) were obtained from the western side of the loess plateau. During the early Holocene, the rainfall on the western side was much higher (+60%) not only during both periods (200 mm/yr) but to decalcification and collapse of soil layers (Heller and Liu, 1986), then the true pedogenic component can be determined, and only that should be reflective of paleoprecipitation.

**SUMMARY**

Although it is not yet known precisely how much of the susceptibility signal or SP/total fraction in the paleo- osols horizons (interglacial times) is strictly due to pedogenesis, and therefore, reflectively of summer monsoon, it has been possible to make a first approximation at calculating paleorainfall and hence paleo- monsoon intensity variations from magnetic data alone. Overall, the paleosol records (pollen, lake-level data) and climate model simulations for the loess plateau as a whole (Winkler and Wang, 1993) support the general increase and decrease of paleoprecipitation (0–130 ka) derived by the present method. Comparison with the results of Maher et al. (1994). However, both the study by Banerjee et al. (1993) and the study by Maher et al. (1994) pointed to an interesting regional event at 5–10 ka. Rainfall over current values in the northern part of the Chinese loess plateau was then quite high (+215 mm/yr) and comparable to the eastern part. However, this result should be compared with a much larger increase (+800 mm/yr) predicted by the atmospheric GCAM model for this area (Winkler and Wang, 1993). Improvements in spatial resolution and incorporation of additional model parameters (such as aerosol concentrations) in future studies may lead to a proper solution to the differences problem. Such improved paleo- rainfall time series from magnetic proxies for the Chinese loess plateau will provide the only high-quality continental analog of paleoclimate time series that may lead us to high-resolution spatial and temporal determination of comparative paleofall rainfall variations on a global scale.

**ACKNOWLEDGMENTS**

I thank my colleague Chris Hunt for help with review of the text and preparation of diagrams. Michele Elston and Diana Jensen provided valuable help with manuscript preparation. A.-M. Liu and H. J. Maher were kind enough to let me see their manuscripts in preparation. A. Roberts provided invaluable help in revising the first draft. This research was funded by the University of Minnesota Graduate School and by National Science Foundation grant EAR-9206024. This is contribution 9410 of the Institute for Rock Mag- netism, which is supported by the W. M. Rock Foundation and the National Science Foundation.

**REFERENCES CITED**

Crucial Environmental Issues: Fear and Loathing at the Leading Edge—
A Sample of the 1994 Institute for Environmental Education Annual Environmental Forum

PERSPECTIVE 1: Introduction
Bruce F. Molnia, Forum Editor

Mindful of its charge to promote the “application of geology to the wise use of Earth,” the GSA Institute for Environmental Education (IEE) sponsored a forum concerned with disasters affecting the “application of geology to the wise use of Earth” and the decisions that informed these issues from a number of perspectives, including how geoscientists can help improve the quality of the debate and the decisions that affect site selection. Many serious questions about the cost and effectiveness of possible solutions to these issues face the geoscientist-engineer and the public. The following three perspectives are samples of presentations from the IEE Forum.

PERSPECTIVE 2: Endangered Species, Ecosystem Management, and the Geological Sciences
David R. Montgomery, University of Washington, Seattle

One of the great social issues of the coming millennium will be reconciling the needs and desires of a burgeoning human population with the health and integrity of ecological systems. Even now this is an urgent problem, as current extinction rates resulting from human activity approximate those recorded during the mass extinctions at the close of the Paleozoic and Mesozoic eras. The process of species extinction now occurs in great part because society considers the needs of other species no more important to mankind than those on which it depends. Developing alternative approaches for geological research requires greater understanding of the factors that influence the structure and dynamics of many ecosystems.

An exponential increase in human population together with technological advances has accelerated landscape alteration to the extent that humans are the dominant geomorphic agent over most of the earth’s surface. In millions of years, the domination of nature has been the operative paradigm of many civilizations. In serving this mission, science has sought to mold landscapes to human desires or expectations, with little attention to knowledge of the long-term consequences. Now, our recognition of the human interdependence on and symbiosis with a complex web of ecological processes has led to political momentum for reversing the impacts of environmental degradation. The emerging philosophy of ecosystem management aims to maintain the integrity of ecological systems while deriving a sustainable level of benefits for human populations. If contemporary human societies are to adopt this approach, land management decisions must be based on an understanding of landscape-scale spatial and temporal patterns in habitat-forming processes.

The Pacific Salmon illustrate why such an approach is essential for preserving threatened and endangered species. This traditional symbol of the Pacific Northwest is in much of the world now under the Endangered Species Act over most of its range in the lower 48 states. The continuing decline of most currently listed species illustrates that we need a more comprehensive approach if we are to reverse the disastrous trends in salmon abundance. The plight of the salmon is not a new problem; it is a problem that the scientific community has been recognizing for many years. In spite of increased understanding of the human influences on aquatic ecosystems, we are well on the way to repeating in the Pacific Northwest the same extirpation of wild salmon that sequentially occurred in England, the eastern seaboard of the United States, and many parts of California. The primary, widely recognized causes for declining salmon populations are overfishing, dam construction, and habitat degradation. Each cause undoubtedly contributes to the plight of the salmon, yet each is fundamental in influencing geologic processes on the structure and dynamics of many ecosystems.

Ecosystem-oriented land management is founded on how geologic processes create, shape, and maintain habitat and how human actions influence these processes. Over geologic time, processes such as uplift, climate change, and volcanism influence regional habitat characteristics, control the frequency and extent of events that extirpate populations, and govern long-term environmental change. Over historic time, spatial and temporal variability of stream discharge and bed scour affect salmon and how they utilize channel habitat. Geologic factors such as topographic and temporal scales, intrusion of sand and silt into spawning gravel, and influences of bedrock type have played important roles in modifying aquatic ecosystems in the Pacific Northwest. This includes the treatment of local and regional factors in habitat-forming processes.

If contemporary human societies are to adopt the approach of ecosystem management, then ecosystem management requires people trained in ecosystems, because of the fundamental interdependence of ecosystem processes. If the current paradigm of ecosystem management is to read and interpret the landscape. If contemporary human societies are to adopt the approach of ecosystem management, then ecosystem management requires people trained in ecosystems, because of the fundamental interdependence of ecosystem processes. If the current paradigm of ecosystem management is to read and interpret the landscape. If contemporary human societies are to adopt the approach of ecosystem management, then ecosystem management requires people trained in ecosystems, because of the fundamental interdependence of ecosystem processes. If the current paradigm of ecosystem management is to read and interpret the landscape. If contemporary human societies are to adopt the approach of ecosystem management, then ecosystem management requires people trained in ecosystems, because of the fundamental interdependence of ecosystem processes. If the current paradigm of ecosystem management is to read and interpret the landscape. If contemporary human societies are to adopt the approach of ecosystem management, then ecosystem management requires people trained in ecosystems, because of the fundamental interdependence of ecosystem processes. If the current paradigm of ecosystem management is to read and interpret the landscape. If contemporary human societies are to adopt the approach of ecosystem management, then ecosystem management requires people trained in ecosystems, because of the fundamental interdependence of ecosystem processes.