Vol. 5, No. 5 May 1995

GSA TODAY

A Publication of the Geological Society of America

INSIDE

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.

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.*

A trench cut into the loess section near Xining, Qinghai Province, China. Xining is currently cooler and drier than Xifeng because Xining lies in the monsoon rain shadow to the west of the Liupan Mountains. However, 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.*

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 grain-producing areas of China and India could become arid and unproductive as a result of such global change.

Oxygen isotope ($\delta^{18}O$) records from the shells of marine foraminifera have yielded relative global ice volume data and, hence, measures of global temperature. We have learned, for example, that the last interglacial (stage 5 in the SPECMAP oxygen isotope stratigraphy; Imbrie et al., 1984) lasted from about 128 to 75 ka, and was much warmer than the present interglacial (stage 1) that began 10 ka ago. If we could obtain reliable, high-resolution (spatial and temporal) records of summer monsoon activities in China for stages 5 and 1, their intercomparison could help teach us what to expect if the world approached stage 5 conditions of climate in the future. Also, the recently discovered sharp instabilities in climate obtained from Greenland ice cores could be compared with continental paleomonsoon records.

The alternating loess and paleosol layers (total thickness ~100 to 300 m) dissected by the Yellow River (Huang He) in central China extend over an area of 500,000 km^2 (see Fig. 1). They constitute a 2.6-m.y.-old archive of high-quality paleoclimatic proxies waiting to be deciphered by modern techniques, even though geologists for more than a century have used conventional approaches such as pollen records and clay/silt ratios to extract a coarse-resolution paleoclimate record. The successful extraction of a magnetic reversal stratigraphy from Chinese loess by Heller and Liu (1984, 1986) has allowed the dating of the numerous peaks in magnetic susceptibility (χ). These peaks had been known to coincide with the warmer interglacials and interstadials when the paleosol layers had formed.

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. Magnetostratigraphic dating by Heller and Liu (1984, 1986) allowed the correlation of loess χ 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 many magnetic parameters that have been measured up to now, we are still waiting to interpret completely the finer scale details of the magnetic signatures.

Kukla et al. (1988) compared the detailed χ-record of two sections at

China *continued on p. 94*

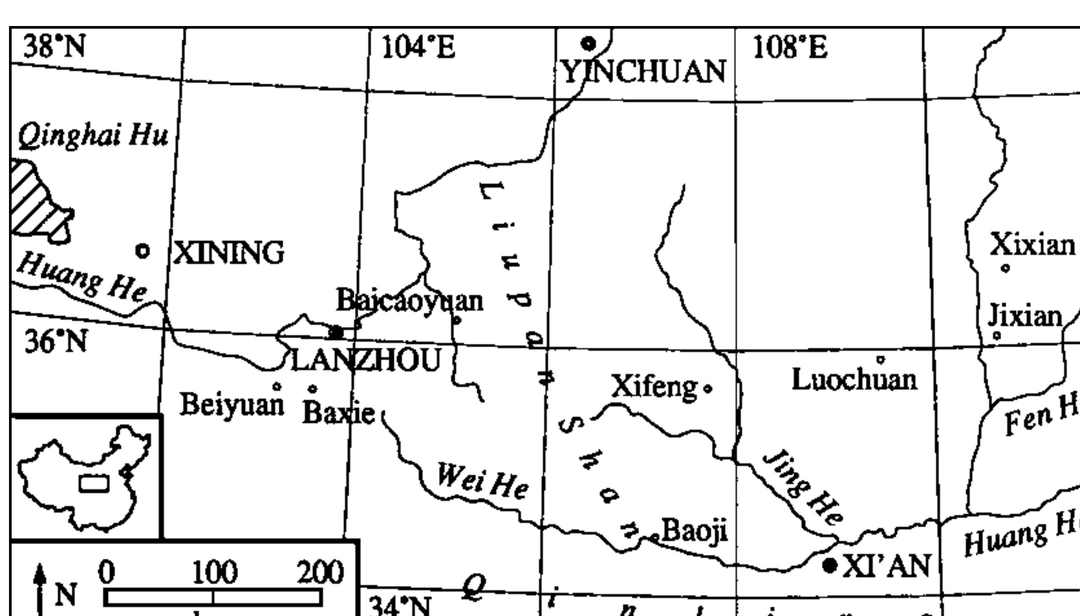

Figure 1. A map of the loess plateau (~500,000 km^2) of China, located north of the Qinling mountains. Open circles mark sampling sites (e.g., Xifeng).

Note: With apologies to Alexander Frater, author of the eminently readable *Chasing the Monsoon* (Holt and Co., 1992).

IN THIS ISSUE

GSA TODAY

Vol. 5, No. 5 — *May 1995*

GSA TODAY (ISSN 1052-5173) is published monthly by The Geological Society of America, Inc., with offices at 3300 Penrose Place, Boulder, Colorado. Mailing address: P.O. Box 9140, Boulder, CO 80301-9140, U.S.A. Second-class postage paid at Boulder, Colorado, and at additional mailing offices. **Postmaster:** Send address changes to *GSA Today,* Membership Services, P.O. Box 9140, Boulder, CO 80301-9140.

Copyright © 1995, The Geological Society of America, Inc. (GSA). All rights reserved. Copyright not claimed on content prepared wholly by U.S. Government employees within the scope of their employment. Permission is granted to individuals to photocopy freely all items other than the science articles to further science and education. Individual scientists are hereby granted permission, without royalties or further requests, to make unlimited photocopies of the science articles for use in classrooms to further education and science, and to make up to five copies for distribution to associates in the furtherance of science; permission is granted to make more than five photocopies for other noncommercial, nonprofit purposes furthering science and education upon payment of the appropriate fee ($0.25 per page) directly to the Copyright Clearance Center, 27 Congress Street, Salem, Massachusetts 01970, phone (508) 744-3350 (include title and ISSN when paying). Written permission is required from GSA for all other forms of capture, reproduction, and/or distribution of any item in this journal by any means. GSA provides this and other forums for the presentation of diverse opinions and positions by scientists worldwide, regardless of their race, citizenship, gender, religion, or political viewpoint. Opinions presented in this publication do not reflect official positions of the Society.

SUBSCRIPTIONS for 1995 calendar year: **Society Members:** *GSA Today* is provided as part of membership dues. Contact Membership Services at (800) 472-1988 or (303) 447-2020 for membership information. **Nonmembers & Institutions:** Free with paid subscription to both *GSA Bulletin* and *Geology,* otherwise $45 for U.S., Canada, and Mexico; $55 elsewhere. Contact Subscription Services. **Single copies** may be requested from Publication Sales. Also available on an annual CD-ROM, (with *GSA Bulletin, Geology, GSA Data Repository,* and an Electronic Retrospective Index from 1972-to-current) for $89 to members, $125 to others; and in an annual, hardbound, library edition for $45. Order from Membership Services. **Claims:** For nonreceipt or for damaged copies, members contact Membership Services; all others contact Subscription Services. Claims are honored for one year; please allow sufficient delivery time for overseas copies.

STAFF

Prepared from contributions from the GSA staff and membership.
Executive Director: Donald M. Davidson, Jr.
Science Editor: Eldridge M. Moores
Department of Geology, University of California, Davis, CA 95616
Forum Editor: Bruce F. Molnia
U.S. Geological Survey, MS 917, National Center, Reston, VA 22092
Managing Editor: Faith Rogers
Production & Marketing Manager: James R. Clark
Production Editor and Coordinator: Joan E. Manly
Graphics Production: Joan E. Manly, Kim Thomas

ADVERTISING

Classifieds and display: contact Ann Crawford (303) 447-2020; fax 303-447-1133

This publication is included on GSA's annual CD-ROM, *GSA Journals on Compact Disc,* and also is available in an annual, hardbound, archival edition. Call GSA Publication Sales for details.

Printed with pure soy inks on recyclable paper in the U.S.A.

China *continued from p. 93*

Xifeng and Luochuan with the $\delta^{18}O$ stratigraphy from SPECMAP, which represents the worldwide average changes in global ice volume measured through the variations in oxygen isotopes ^{18}O and ^{16}O in marine foraminifera. The choice of the sites may have been fortuitous, but even without the benefit of formal statistics it is clear that there is excellent correlation between the χ and $\delta^{18}O$ records (Fig. 2). Many of the details of the peaks in the magnetic parameter can be compared with similar details in the oxygen isotope stratigraphy. Because Xifeng and Luochuan are about 160 km apart, Kukla et al. (1988) concluded that the magnetic variations could not be due to pedogenesis. The preferred model of Kukla et al. called for a relative weakening of χ in the loess layers and a strengthening in the paleosol layers, 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 presenting a relatively large magnetic 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 ka.

Zhou et al. (1990) and Maher and Thompson (1991) showed that when the paleosol and loess samples are studied in detail for their grain-size-dependent rock magnetic parameters, it becomes clear that the paleosol layers are distinguished from loess layers by concentration, mineralogy, and a much different (and much smaller) grain-size of the magnetic carriers. The data presented by Zhou et al. (1990) are shown in Figure 3. Both groups of authors thought that the evidence points, at least partially, to a pedogenic magnetic

China *continued on p. 95*

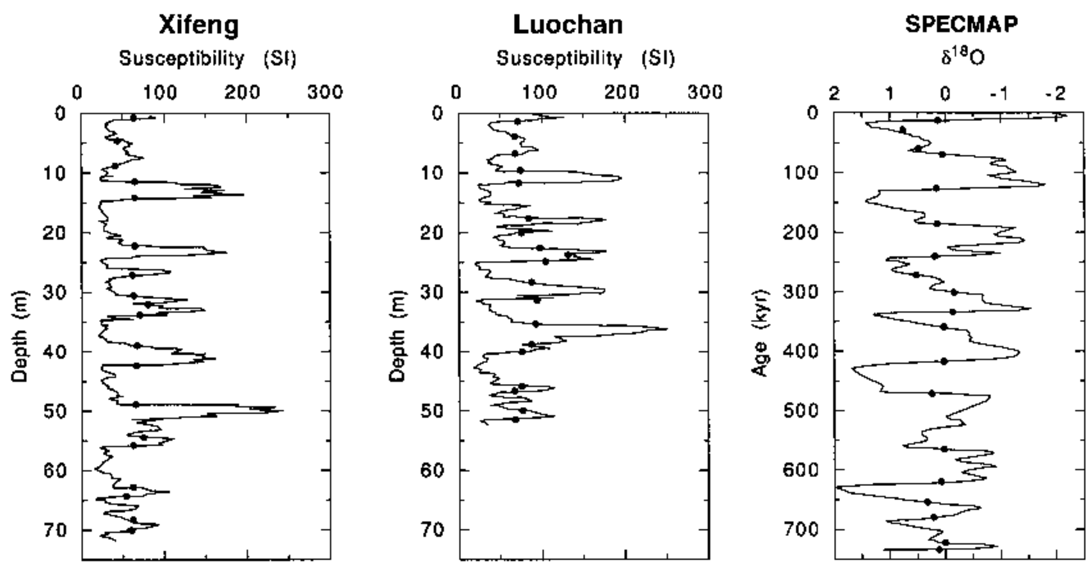

Figure 2. Kukla et al.'s (1988) comparison of the χ depth series from Zifeng and Luochuan with the SPECMAP time series of globally averaged $\delta^{18}O$. Because $\delta^{18}O$ values provide global ice volume data, they indirectly provide data on global temperature fluctuations which coincide in character with the χ depth series, providing the first comparable scale comparison between oceanic and continental climates.

About People

GSA Member **Raymond E. Beiersdorfer,** 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 **Richard Gray,** GAI Consultants, Inc., Monroeville, Pennsylvania, was elected president of the Association of Engineering Geologists.

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 1994 Philip Hauge Abelson Prize to GSA Fellow **Frank Press,** Carnegie Institution of Washington. The award honors sustained exceptional contributions to advancing science or a career distinguished both for achievement and notable services to the scientific community.

The Maryland Geological Survey in Baltimore renamed 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 members: Fellow **Charles W. Naeser,** Reston, Virginia; Fellow **Robert N. Oldale,** Woods Hole, Massachusetts; Member **Charles L. Rice,** Reston, Virginia; member **John F. Slack,** Reston, Virginia; and member **Bruce R. Wardlaw,** Reston, Virginia. ■

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

Marshall Schalk
Northampton, Massachusetts
February 21, 1995

C. Bertrand Schultz
Papillion, Nebraska
March 7, 1995

Reginald C. Sprigg
Port August, South Australia
February 12, 1994

Sherman A. Wengerd
Alburquerque, New Mexico
January 28, 1995

CORRECTION

In *GSA Today,* v. 5, no. 3, p. 46 (March 1995), Francis S. Birch was inadvertently listed among the deceased members. This was an error. We apologize to Francis S. Birch and his family and friends.

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.aescon.com/geosociety/index.html.**

For current information on the 1995 Annual Meeting in New Orleans, go to **Meetings** and choose **1995 Annual Meeting.** This area contains a listing of Symposia and Theme Sessions and has information about Field Trips, Continuing Education, Exhibits, Travel, and Lodging.

If you want to know more about the GSA Employment Service or about becoming a GSA Campus Representative, check the **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.

China *continued from p. 94*

enhancement through the formation of ultrafine (superparamagnetic and single domain, $d \sim 0.1$ μm or smaller) magnetite. Later, Maher and Thompson (1992a) attributed all χ-variation to pedogenesis, as had been done earlier by An et al. (1991), and used a statistical sequence-slotting method to correlate susceptibility features with the SPECMAP $\delta^{18}O$ stratigraphy. Verosub 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 change signal, as indicated by the similarity with $\delta^{18}O$ data from ocean sediments. However, in the absence of an independent high-resolution chronology for the χ stratigraphy, such correlations do not constitute an a priori proof of the pedogenic hypothesis.

To test the model of Kukla et al. (1988), Hovan et al. (1989) and Clemens and Prell (1992) tried to correlate directly the loess stratigraphy with the record of eolian silica flux 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 eolian accumulation rate, which is a rate-dependent parameter. They emphasized that although both were ultimately responsive to climate change, the susceptibility record in the Chinese loess plateau was more a record of pedogenesis and thus indirectly a record of the east Asian monsoon intensity during summer at these sites. Pye and Zhou (1989) also compared the ages of the maxima in wind-blown deposits in the Pacific Ocean and in the Chinese loess plateau and concluded that they are neither coeval nor caused by the same wind system.

In my opinion, both of the proposed models (a pure accumulation model that primarily causes χ minima by dilution and a pure pedogenic model causing χ maxima by pedogenic enhancement) are perhaps two idealized end members. In reality, both the loess and the paleosol layers must have varying amounts of magnetic contribution due partly to detrital input and partly to pedogenesis. Unfortunately, two recent attempts to resolve this problem (Beer et al., 1993; Verosub et al., 1993) have not produced conclusive answers, but they deserve our careful attention.

Beer et al. (1993) measured the depositional input of ^{10}Be in a loess profile (S_0-L_2, or isotopic stages 1–6) from Luochuan and claimed that the ^{10}Be flux in the 0–130 ka interval can be fitted to a constant, and global, atmospheric flux (F_A) and a time-varying contribution due to a dust flux (F_D) from the desert delivered by the winter northwesterlies. By further assuming that part of the magnetic susceptibility flux (the depositional, low-χ part, or F'_D) is linearly proportional to the ^{10}Be dust flux ($F'_D = \alpha F_D$), Beer et al. (1993) and their colleagues Heller et al. (1993) claimed that the rest of the susceptibility signal is pedogenically produced. However, the hypothesis of constant F_A has major weaknesses, as Beer et al. and Heller et al. themselves have pointed out, and it also militates against their own experimental data, sometimes by as much as 50% (see Fig. 4 of Beer et al., 1993). The result is a derived pedogenic χ component that is likely to be inaccurate by up to 50%.

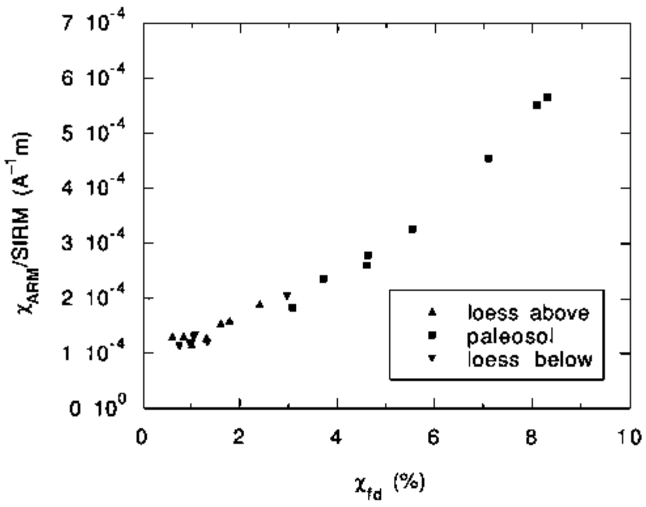

Figure 3. Zhou et al.'s (1990) measurements of susceptibility of anhysteretic remanent magnetization (χ_{ARM}) vs. frequency dependence of low field susceptibility (χ). χ_{ARM} has been normalized by saturation isothermal remanent magnetization to remove any concentration dependence. The ratio χ_{ARM}/SIRM increases with decreasing grain-size of magnetite. χ_{fd} is the percentage change in χ when measured at 400 and 4000 Hz and is very sensitive to the presence of magnetite grains near the superparamagnetic size threshold around 30 nm. The data show that paleosol horizons contain many grains at or below 30 nm size.

The second attempt was made by Verosub et al. (1993), who attributed the pedogenic component of χ to that part of the magnetic signal which is lost when a soil sample or a loess sample is treated with CBD (citrate-bicarbonate-dithionite; Mehra and Jackson, 1960) solution. CBD treatment removes very fine grained iron oxides, e.g., magnetite and maghemite, which make a major contribution to χ and whose origin can be attributed to pedogenesis (Fine and Singer, 1989). But here, too, the situation is murky (Liu et al., 1994a; Hunt et al., 1995), and it may be that CBD reduction of χ can also be due partly to removal of some detrital magnetite-maghemite. Even if the true pedogenic χ enhancement can be isolated and then attributed to summer rainfall variations (for a critical discussion of this hypothesis, see the next section), a question remains as to whether the appropriate cause is regional (~1000 km) or local (~100 km) rainfall variations. In order to answer this question, we took recourse (Banerjee et al., 1993) to low-temperature magnetic measurements of a pair of sites, ~300 km apart, that are on the rainy and arid sides, respectively, of a rain shadow: the roughly northwest-southeast-trending Liupan Mountains in the southwestern part of the loess plateau. Because the summer monsoon at these two sites, Baicaoyuan (arid) and Xifeng (humid), is mostly from the east, the soils at Xifeng are more highly developed and those at Baicaoyuan to the west are less so.

Characteristic thermal decay curves of saturation isothermal remanent magnetization (σ_{rs}) of a soil sample (S_0; glacial stage 1) and a sample from the underlying loess layer (L_1; glacial stage 2) are shown in Figure 4. In both cases the high-field (2.5 tesla) induced magnetization (σ_i) from all grain-size fractions is the same and varies in a similar manner with temperature change, suggesting that the same magnetic phase was present in both loess and paleosol. However, when σ_{rs} is created by a 2.5 T field at 15 K and warmed in zero field, the decay curves are very different for the two layers. In the case of the loess, there is a characteristic transition or "step" at about 100 K which is related to the low-temperature magnetic transition (Verwey transition) of coarser grained ($d > 30$ nm) magnetite. In the case of the soil sample, the Verwey transition is only barely visible, most of the σ_{rs} data showing the decay due to thermal "unblocking" of σ_{rs} of very small or "superparamagnetic" grains of magnetite or maghemite. By extrapolating the nearly linear part of σ_{rs} decay displayed by SP grains (0 nm $< d <$ 30 nm) backward to 0 K, we can graphically separate the SP fraction (SP/total) in the sample. Following Maher and Thompson (1992a), SP grains that are so small are most likely to be produced by pedogenesis. The larger grains, then, could be construed as detrital, having been deposited by the winter northwesterlies from the deserts.

Comparing variation in SP/total grains between Baicaoyuan (300 mm/yr rainfall) and Xifeng (500 mm/yr) (Fig. 4), we see that the more arid site, Baicaoyuan, has an SP/total stratigraphy that is closer to what is expected from the $\delta^{18}O$ record of glacial-interglacial climate change. In Xifeng the fluctuations are much more muted, perhaps because of the higher rainfall producing a much stronger local pedogenic signal. The difference in SP/total signal between the corresponding layers (L, S, etc.) of the two profiles allows extraction of the local monsoon intensity variation between these two sites. In addition, an apparent anomaly emerges whereby the SP/total ratio for both sites during the early Holocene (5–10 ka) seems to be the same. If the magnetic data are correct, there could be at least two interpretations. One, because the Liupan Mountains follow a south-southeast to north-northwest trend, the two sites would have received similar summer monsoon rainfalls if the summer monsoon was more southerly during the early Holocene. Alternatively, we should allow that the rainfall in the western part of the Chinese loess plateau could have been under the influence of a strong southerly Indian monsoon in the early Holocene. Kutzbach et al. (1993) used atmospheric GCMs to predict that the early extremely strong south Asian monsoon of Holocene time could have broken through to the western loess plateau.

CONVERTING MAGNETIC SUSCEPTIBILITY TO PALEORAINFALL

It is now widely accepted that the enhancement in susceptibility of paleosols relative to that of the loess horizons is due to pedogenic formation of very small ($d < 30$ nm) magnetite and/or maghemite grains. An et al. (1991), Liu et al. (1994b), and Maher et al. (1994) have further suggested that such formation is directly related to paleorainfall, especially during the summer. Such a hypothesis requires that the unaltered loess over the region under consideration has uniform mineralogy and grain size. The first proviso is easier to prove than the second. Over an ~1200 km northwest to southeast range in the loess plateau, the grains do tend to decrease in size. We do not, however, know how critical this variation is to loess pedogenesis. An added complication is the lack of precise high-resolution ages beyond ~60 ka. In spite of these difficulties, preliminary attempts have been made based on empirical correlations ("climofunctions") between modern (or slightly older) soils and current rainfall over a very large part of the loess plateau. The first attempt was by Heller et al. (1993), who used ^{10}Be data to separate the strictly pedogenic components of observed χ at Luochuan (see previous section). By using a calibration constant c (where χ = c · current rainfall, with χ from the Holocene layer [S_0]),

China *continued on p. 96*

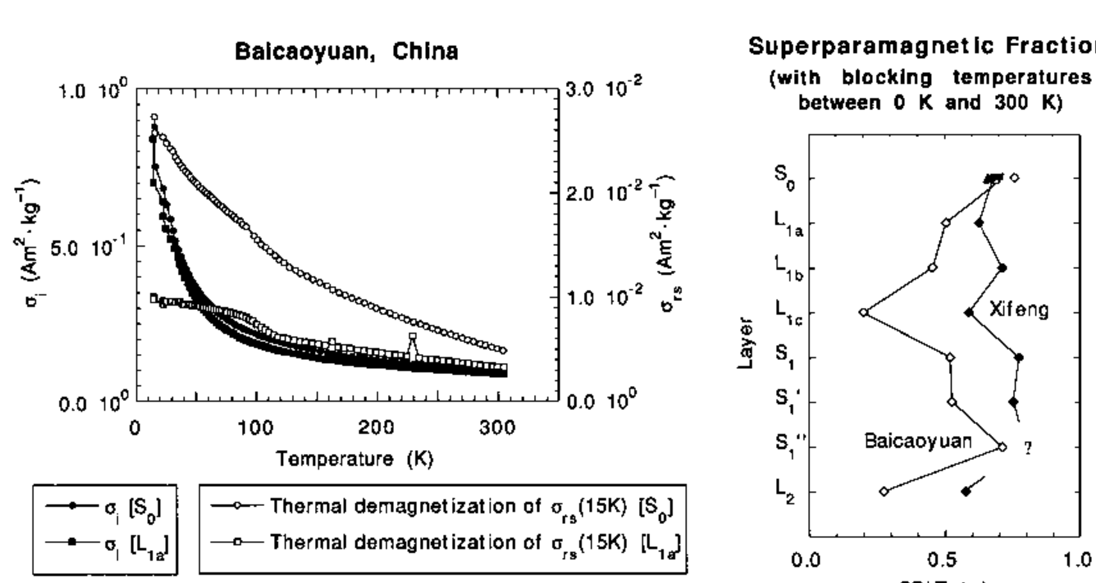

Figure 4. Left: Temperature dependence of induced magnetization (σ_i) and saturation isothermal remanent magnetization (σ_{rs}) of a representative paleosol sample (S_0) and the underlying loess (L_{1a}) from Baicaoyuan. The similarity of $\sigma_i(T)$ curves suggests a similar magnetic mineral composition, and the dissimilarity of $\sigma_{rs}(T)$ curves suggests differences in the grain size distribution. Right: SP/total, the relative fractions of superparamagnetic grains ($d < 30$ nm), plotted against depth for arid Baicaoyuan and the more humid Xifeng sites. The SP fraction causes the nearly linear decay of σ_{rs} between ~100 and 300 K in the plot at the left. Total SP fraction is extracted from the σ_{rs} intercept when the straight line (~100 to 300 K) is extrapolated to 0 K. SP/total represents pedogenically produced very small (i.e., superparamagnetic) magnetite grains. (After Banerjee et al., 1993).

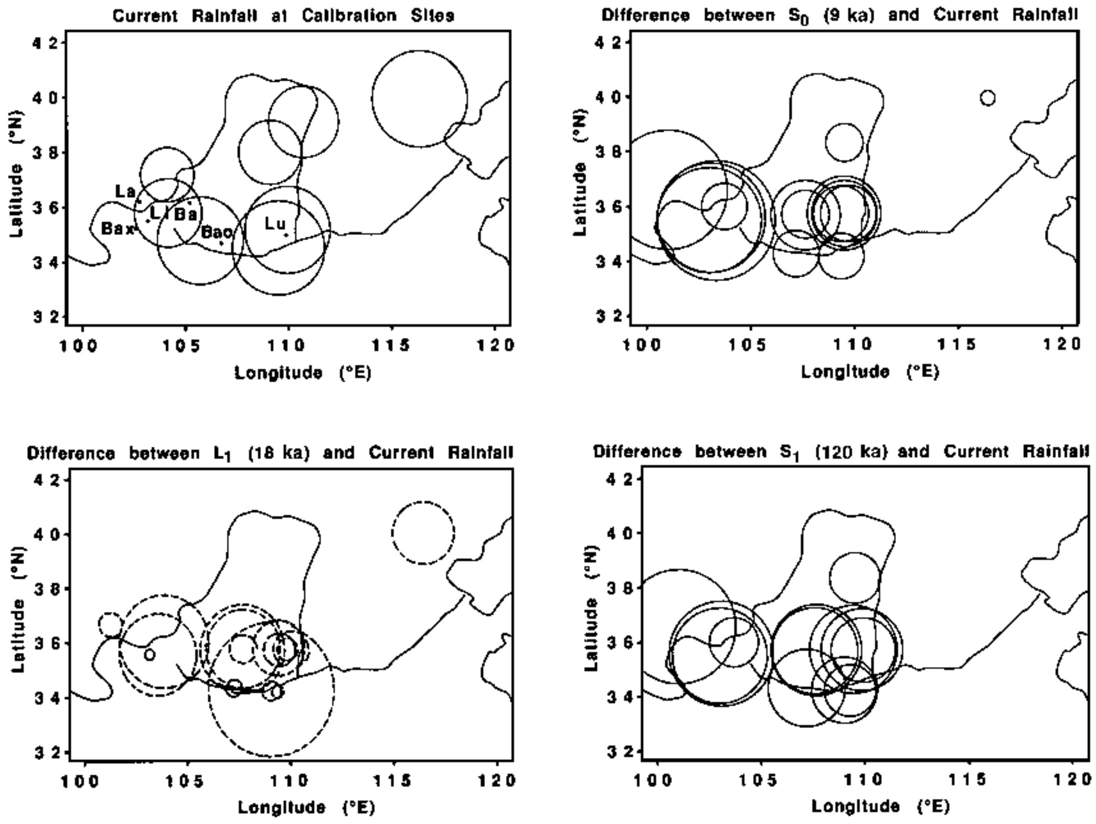

Figure 5. Top left: Calculated rainfall difference between the present and periods when specific soil or loess horizons formed on the loess plateau, China. The diameters of the circles are proportional to current rainfall in mm/yr at different sites of the loess plateau. Bax = Baxie, La = Lanzhou, Li = Linxia, Bai = Baocaiyuan, Bao = Baoji, Lu = Luochuan. In difference representations, solid circles represent excess rainfall, and dashed circles indicate less rainfall than at present. For details of conversion to paleorainfall from magnetic susceptibility enhancement, see text. Data courtesy of Maher et al. (1994).

China *continued from p. 95*

and by utilizing the average χ 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 $\delta^{18}O$ 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_1, 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 TenPas et al. (1994) may shed further light on this problem.

In the second attempt, Liu et al. (1994b), instead of using the χ measurement, used the approach of low-temperature magnetic measurement, σ_{rs} vs. T, 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) then 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 stages 2 (L_{1a}), 4 (L_{1c}), and 6 (L_2), precipitation was about 200 mm/yr—i.e., 350 mm/yr less than today, whereas during the last interglacial, stage 6 (S_1), 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 in stage 5 was higher than in stage 1, as would be expected from the SPECMAP data.

A vertical cut into the deposits near Jixian, Shanxi Province, China. The upper darker soil has formed since the last glaciers retreated about 11 ka. The lighter materal in the lower half is the loess that was deposited during the height of the last glacial period, between about 11 and 23 ka. Magnetic properties vary with degree of soil development, and they can be used as paleoclimate proxies. *Photo by Peter Solheid.*

Maher et al. (1994) gave what I perceive to be an improved approach to calculating paleorainfall. Following Singer et al. (1992), Maher 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 climofunction coefficient. Like Heller et al. (1993) and Liu et al. (1994b), Maher et al. assumed that residence of only a few thousand years is enough for the magnetic susceptibility of the B horizon to have achieved a steady state. Therefore, they converted susceptibility enhancement to paleorainfall using the same coefficient for all the horizons. Base level χ value for the C horizon was approximated by the older, least weathered L_9 horizon.

For the last glacial (L_1) at 18 ka (dashed-line circles in Fig. 5) paleoprecipitation was less than at present at all of the sites, and the maximum decrease was 266 mm/yr. In contrast, both during S_0 (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 compared to today but even compared to the early Holocene on the eastern side of the loess plateau. This compares well with the observations of Banerjee et al. (1993; Fig. 4), that the currently more arid western site, Baicaoyuan, was at least as humid as the eastern site, Xifeng, in the early Holocene. Maher et al. (1994) found that their calibration climofunction appears to compare well with similar functions for modern soils in other warm, temperate regions today such as Morocco, Sudan, and California. However, they also admitted that during glacial times the measured susceptibility values are low and a 25% error in the loess susceptibility measurement could easily produce an error of 47% in the glacial-stage rainfall reconstruction. The reader should remember that for the purpose of this reconstruction, it has been assumed that all of the susceptibility enhancement is due to pedogenesis, which in turn is controlled by the summer monsoon. However, if it proves to be possible in future to separate the influences on magnetic susceptibility due either to the dilution effect mentioned earlier (Kukla et al., 1988) or 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 paleosol horizons (interglacial times) is strictly due to pedogenesis, and therefore strongly reflective of summer monsoon, it has been possible to make a first approximation at calculating paleorainfall and hence paleomonsoon intensity variations from magnetic data alone. Overall, the paleoproxy 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 magnetic proxy method of Maher et al. (1994). However, both the study by Banerjee et al. (1993) and the study by Maher et al. (1994) point to an interesting regional event at 5–10 ka. Rainfall over current values in the western part (now arid) 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 (+900 mm/yr) predicted by the atmospheric GCM approach for this area (Winkler and Wang, 1993). Improvements in spatial resolution and incorporation of additional model parameters (such as aerosol concentration variation) in GCMs and, equally important, parallel advances in extracting true pedogenic components from the magnetic parameters may lead to a proper resolution of this difference. Such improved paleomonsoon time series from magnetic proxies for the Chinese loess plateau may one day provide the only high-quality continental analogs of paleoclimate time series and may lead us to high-resolution spatial and temporal determination of comparative paleorainfall variations on continents to gain an understanding of both global climate change and its regional responses.

ACKNOWLEDGMENTS

I thank my colleague Chris Hunt for help with review of the text and preparation of diagrams. Michelle Elston and Diana Jensen provided valuable help with manuscript preparation. X.-M. Liu and B. 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 Magnetism, which is supported by the W. M. Keck Foundation and the National Science Foundation.

REFERENCES CITED

An, Z., Kukla, G. J., Porter, S.C., and Xiao, J., 1991, Magnetic susceptibility evidence of monsoon variation on the loess plateau of central China during

China *continued on p. 97*

FORUM

Bruce F. Molnia

Forum is a regular feature of *GSA Today* in which many sides of an issue or question of interest to the geological community are explored. Each Forum presentation consists of an informative, neutral introduction to the month's topic followed by two or more opposing views concerning the Forum topic. Selection of future Forum topics and participants is the responsibility of the Forum Editor. Suggestions for future Forum topics are welcome and should be sent to: Bruce F. Molnia, Forum Editor, U.S. Geological Survey, 917 National Center, Reston, VA 22092, (703) 648-4120, fax 703-648-4227.

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, at the Seattle 1994 Annual Meeting, sponsored a forum concerned with disposal sites for low-level radioactive waste, ground-water contamination, reliable earthquake prediction, seismic hazard mitigation, and the causes and rates of species decline. Each is an issue that can lead to an inflamed and fearful public and which creates both problems and opportunities for geological scientists. Forum presentations examined 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 proposed 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 present extinction event occurs in great part because society considers the needs of other species only when they become threatened or endangered. Developing alternative approaches requires geological expertise, because of the fundamental influence of geologic processes on the structure and dynamics of many ecosystems.

An exponential increase in human population together with technological innovations have accelerated landscape alteration to the extent that humans are the dominant geomorphic agent throughout the world today. For millennia 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 neither attention to nor knowledge of 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 historical trends 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 variations 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 poised for listing 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 historical trends in salmon abundance. The plight of the salmon is not a new problem; it is a recurrent story involving processes that have been recognized for many years. In spite of increased understanding of human influences on aquatic ecosystems, we are well on the way to repeating in the Pacific Northwest the historic extirpations 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 the interests responsible for these effects have bickered for decades about assigning culpability for declining salmon runs. Without becoming mired in this unconstructive approach, geologists can contribute crucial expertise on habitat issues.

Ecosystem-oriented land management is founded on how geologic processes create, shape, and eliminate 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 use channel habitat. At the finest spatial and temporal scales, intrusion of sand and silt into spawning gravel influences embryo development during incubation in stream beds. Land management that maintains salmon abundance requires incorporating ecosystem dynamics across the full temporal and spatial range of processes that govern the amount, type, and quality of salmon habitat.

Adapting our actions to reduce negative human impacts on ecological systems requires defining mechanistic links between management activity and ecosystem response. Unfortunately, much of the work on human impacts to aquatic ecosystems has relied on convenient surrogate measures, such as the percentage of a basin area over which timber has been harvested. Geologists need to help rethink and redesign our watershed assessment, research, and monitoring methods to establish underlying cause-and-effect relations. In addition, we need to be able to do this in a spatially explicit context in order to use this information to support decision making for particular places. Furthermore, society must tailor land-use decisions to the capability of the landscape to sustain human activity; this tailoring requires that scientific assessment precede planning and that management involve an adaptive, multi-scale approach based on ecologically relevant planning units. Watershed analysis procedures, such as those adopted by the State of Washington and under development for federal lands, provide a framework for using landscape-specific analyses of geomorphological, hydrological, and biological processes to guide ecosystem management.

Societal pressure to move toward ecosystem management thus holds significant opportunities and challenges for the geological sciences. There is an urgent need for interdisciplinary research with ecologists, engineers, and planners on how geologic processes influence biological communities; on how to design habitat restoration schemes; and on how to incorporate the spatial and temporal variability inherent to geomorphic processes into land-use decisions. Equally important for the future of many university geology departments is that ecosystem management requires people trained to read and interpret the landscape. If the geological community accepts the

Forum *continued on p. 98*

China *continued from p. 96*

the last 130,000 years: Quaternary Research, v. 36, p. 29–36.

Banerjee, S. K., Hunt, C. P., and Liu, X.-M., 1993, Separation of local signals from the regional paleomonsoon record of the Chinese loess plateau: A rock-magnetic approach: Geophysical Research Letters, v. 20, p. 843–846.

Beer, J., and seven others, 1993, ^{10}Be and magnetic susceptibility in Chinese loess: Geophysical Research Letters, v. 20, p. 57–60.

Clemens, S. C., and Prell, W. L., 1992, Comments on "Paleoclimate significance of the mineral magnetic record of the Chinese loess and paleosols": Quaternary Research, v. 38, p. 265–267.

Fine, P., and Singer, M. J., 1989, Pedogenic factors affecting magnetic susceptibility of northern California soils: Soil Science Society of America Journal, v. 53, p. 1119–1127.

Heller, F., and Liu, T.-S., 1984, Magnetism of Chinese loess deposits: Royal Astronomical Society Geophysical Journal, v. 77, p. 125–141.

Heller, F., and Liu, T.-S., 1986, Palaeoclimatic and sedimentary history from magnetic susceptibility of loess in China: Geophysical Research Letters, v. 13, p. 1169–1172.

Heller, F., and seven others, 1993, Quantitative estimates of pedogenic ferromagnetic mineral formation in Chinese loess and palaeoclimatic implications: Earth and Planetary Science Letters, v. 114, p. 385–390.

Hovan, S. A., Rea, D. K., Pisias, N. G., and Shackleton, N. J., 1989, A direct link between the China loess and marine $\delta^{18}O$ records: Aeolian flux to the north Pacific: Nature, v. 340, p. 296–298.

Hunt, C. P., Singer, M. J., Kletetschka, G., TenPas, J., and Verosub, K. L., 1995, Effect of citrate-bicarbonate-dithionite treatment on fine-grained magnetite and maghemite: Earth and Planetary Science Letters (in press).

Imbrie, J., and eight others, 1984, The orbital theory of Pleistocene climate: Support from a revised chronology of the marine $\delta^{18}O$ record, *in* Berger, A., et al., eds., Milankovitch and climate: Understanding the response to orbital forcing: Dordrecht, Netherlands, Reidel, p. 269–305.

Kukla, G. J., Heller, F., Liu, S.-M., Xu, T.-C., Liu, T.-S., and An, Z.-S., 1988, Pleistocene climates dated by magnetic susceptibility: Geology, v. 16, p. 811–814.

Kutzbach, J. E., Guetter, P. J., Behling, P. J., and Selin, R., 1993, Simulated climatic changes: Results of the COHMAP climate-model experiments, *in* Wright, H. E., Jr., et al., eds., Global climates since the last glacial maximum: Minneapolis, University of Minnesota Press, p. 24–93.

Liu, X.-M., Bloemendal, J., and Rolph, T., 1994a, Pedogenesis and paleoclimate: Interpretation of the magnetic susceptibility record of Chinese loess-paleosol sequences: Comment: Geology, v. 22, p. 858–859.

Liu, X.-M., Bloemendal, J., Rolph, T., Shaw, J., Liu, T.-S., and Heller, F., 1994b, Quantitative estimates of palaeoprecipitation in the loess plateau of China: Palaeogeography, Palaeoclimatology, Palaeoecology.

Maher, B. A., and Thompson, R., 1991, Mineral magnetic record of the Chinese loess and paleosols: Geology, v. 19, p. 3–6.

Maher, B. A., and Thompson, R., 1992a, Paleoclimatic significance of the mineral magnetic record of the Chinese loess and paleosols: Quaternary Research, v. 37, p. 155–170.

Maher, B., and Thompson, R., 1992b, Reply to Clemens and Prell: Quaternary Research, v. 38, p. 268.

Maher, B. A., Thompson, R., and Zhou, L.-P., 1994, Spatial and temporal reconstructions of changes in the Asian palaeomonsoon: A new mineral magnetic approach: Earth and Planetary Science Letters, v. 125, p. 462–471.

Mehra, O. P., and Jackson, M. L., 1960, Iron oxide removal from soils and clays by a dithionite-citrate system buffered with sodium bicarbonate: Clays and Clay Minerals, v. 7, p. 317–327.

Pye, K., and Zhou, L. P., 1989, Late Pleistocene and Holocene aeolian dust deposition in north China and the northwest Pacific Ocean: Palaeogeography, Palaeoclimatology, Palaeoecology, v. 73, p. 11–23.

Singer, M. J., Fine, P., Verosub, K. L., and Chadwick, O. A., 1992, Time dependence of magnetic susceptibility of soil chronosequences on the California coast: Quaternary Research, v. 37, p. 323–332.

TenPas, J., Singer, M. J., Verosub, K. L., and Shumway, R. H., 1994, Reinterpretation of the paleoclimate record of the Chinese loess plateau as deduced from magnetic susceptibility data [abs.]: Eos (Transactions, American Geophysical Union), v. 75, p. 187.

Verosub, K. L., Fine, P., Singer, M. J., and TenPas, J., 1993, Pedogenesis and paleoclimate: Interpretation of the magnetic susceptibility record of Chinese loess-paleosol sequences: Geology, v. 21, p. 1011–1014.

Winkler, M. G., and Wang, P. K., 1993, The late Quaternary vegetation and climate of China, *in* Wright, H. E., et al., eds., Global climates since the last glacial maximum: Minneapolis, University of Minnesota Press, p. 221–261.

Zhou, L.-P., Oldfield, F., Wintle, A. G., Robinson, S. G., and Wang, J. T., 1990, Partly pedogenic origin of magnetic variations in Chinese loess: Nature, v. 346, p. 737–739.

Manuscript received September 6, 1994; revision received February 17, 1995; accepted March 2, 1995. ■

Each month, *GSA Today* features a short science article on fast-breaking items or current topics of general interest to the 15,000 members of GSA. What do you think of these articles? Do you have an idea for an article that you would like to see published in *GSA Today*? If so, please contact Eldridge Moores, Science Editor, *GSA Today,* (916) 752-0352, fax 916-752-0951.