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Sediment Reveals Early Holocene Climate Change in China

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A major question regarding paleorecords is whether the easy-to-acquire oceanic record can be validated by continental proxy records that are available only from the Arctic and Antarctic ice cores. The ice core records may not provide a complete record of the changes that have occurred in the temperate and tropical regions of the continents. Thick (100–300 m) deposits of wind-borne dust in China are providing new insight into paleoclimate. These deposits vie with the ice cores in providing a record of continuous accumulation over the last 2.6 m.y., but they are poorer in temporal resolution than the ice cores.

Overall sedimentation rates of the wind-borne dust loess are moderate, ~10 cm/10^3 yr, but during glacial times, it can increase three- to fourfold! During warmer interglacial times, dust input from winter westerlies slows down, and an accretionary soil—now a paleosol—develops. The paleosol reveals weak field-induced magnetization (magnetic susceptibility, χ) 200 times greater than the underlying loess deposited during glacial periods can. The increased χ-values could result from either a higher concentration of ferrimagnetic iron-bearing minerals or when such minerals are formed from pre-existing nonmagnetic or less magnetic precursors.

In either case magnetic measurements provide a new proxy of climate change from glacial to interglacial epoch. Magnetic measurements in the laboratory or in the field can be made in minutes; they are highly accurate; and bulk samples can be measured quickly. In the last decade, more papers have been published on the magnetic properties of Chinese loess/paleosol sequences than on their major element, trace element or isotopic geochemistry. The large number of χ-profiles from different sites of the Chinese loess plateau have confirmed that the broad characteristics and temporal occurrences are the same throughout this large region. Readers are probably aware that in the 1980s χ-time series from several Chinese loess sites 150 km apart were dated with paleomagnetic stratigraphy [*Kukla et al.*, 1988]. The χ-time

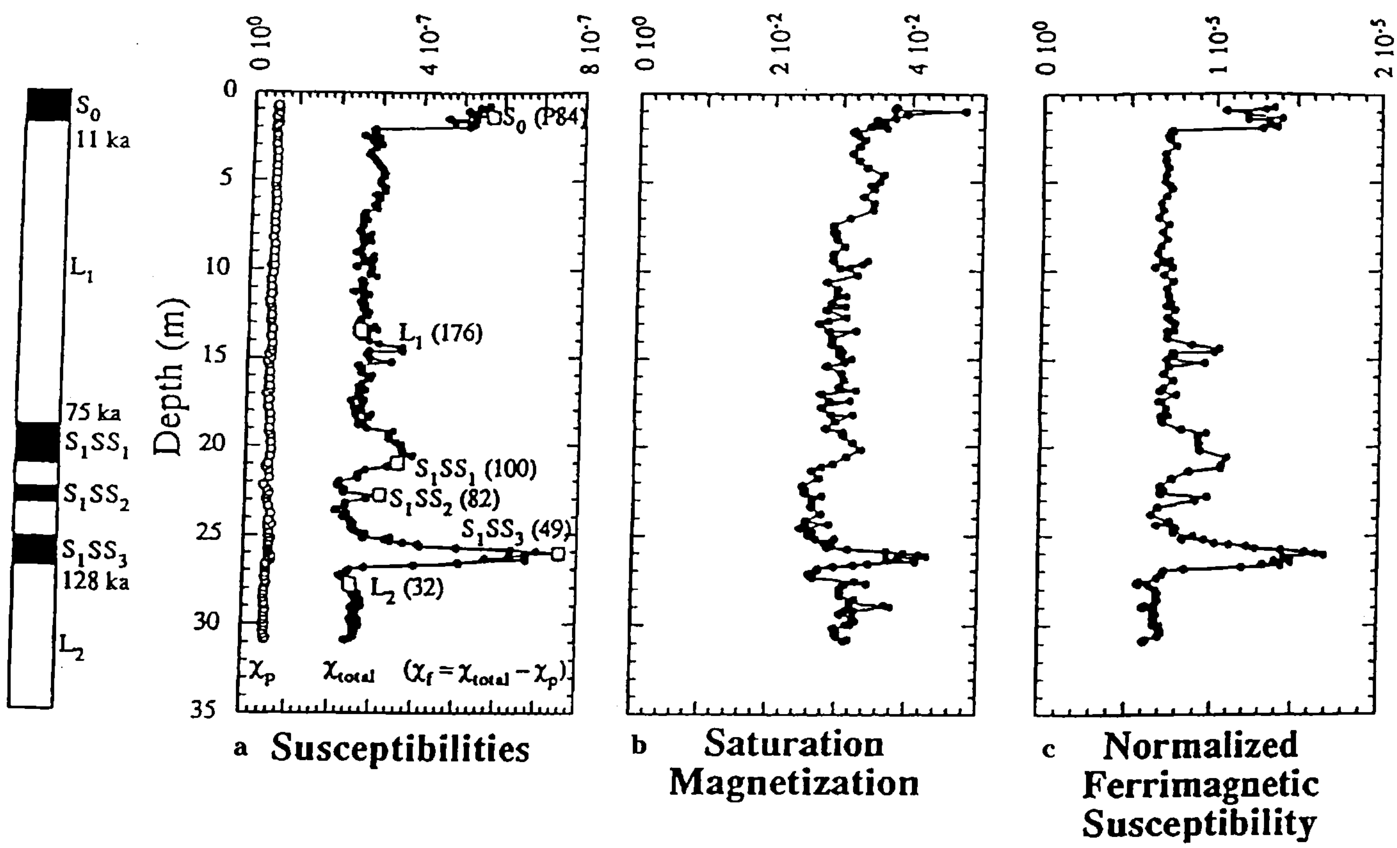

Fig. 1. Loess/palaeosol stratigraphy at Xining, with approximate dates for the boundries between layers. (a) Low-field total magnetic susceptibility. χ_{total}, for all samples and paramagnetic suseptibility, χ_p, for approximately half of the samples. Labeled open squares denote samples that were selected to be representative of their layers and that were subjected to more detailed measurements. (b) Saturation magnetization, σ_s, for approximately half of the samples. This parameter is the best proxy for concentration variation of magnetite. (c) Normalized ferrimagnetic susceptibility, $(\chi_{total}-\chi_p)/\sigma_s$, which represents the concentration-independent variation of (mostly) SP magnetite. This parmeter is the most appropriate proxy for pedogenic intensity variations.

series showed an amazingly high correlation not only with each other but also with the peaks and troughs of worldwide average ("SPECMAP") oxygen isotope stratigraphy, which represent changes in global ice volume at Milankovitch frequencies. Our hope is that the χ-time series provides a continental record of Quaternary climate that is comparable to the ocean sediment record in temporal resolution.

With the loess record at hand, the loess record will be compared with oceanic-isotope record. However, there are three major problems to be solved before one can take a single χ-profile from the Chinese loess plateau and claim that the peaks and troughs, even semiquantitatively, represent any of the climatic parameters—temperature, rainfall, and wind strength. First, a comprehensive sedimentological-mineralogical model is needed to pin down the origin of χ-variations. Second, from this model, the best proxy for a specific climate signal needs to be identified from among the many possible magnetic parameters, not just χ. Third, the local (10^2-10^3 km) climate signal must be separated from the global (10^3-10^4 km) signal; it is the global signal that should be compared with the globally averaged Milankovitch-driven oxygen isotope records from the oceans.

Rapid progress toward solving these problems has been made recently, mostly by our European and Chinese colleagues, although the U.S. scientists are quickly catching up. We now know that both paleosol and the less-altered loess layer contain differing amounts of magnetite (Fe_3O_4) and maghemite (γ-Fe_2O_3), and their grain sizes can vary from ~10 nm to 50 μm. Mineralogy, concentration, and grain size all affect magnetic parameters. But one can separate their effects by using multiple magnetic proxies such as susceptibility, (χ), saturation magnetization (σs), measured in the presence of a large magnetic field, saturation remanence (σrs, the magnetization that remains after the large field is applied and withdrawn) and anhysteretic remanence or σ_{arm}, the remaining magnetization after a combination of a small steady field ~50 μT and a smoothly decreasing alternating field is applied and withdrawn. As a first approximation, χs can be said to measure concentration of magnetite. But subtle grain-sized variations, such as the presence of very small superparamagnetic (SP, grain size <30 nm) grains can lead to relatively high values of χ without an abnormal increase in σs. That is why we recommend σs as the better proxy for concentration variation and χ/σ_s as the appropriate proxy for the presence of SP grains (Figure 1). The SP grains of magnetite can be produced by diagenesis during summer rainfall. Unusually high iron-bearing clay minerals can also lead to large values of χ, but they do not contribute to the ratio σ_{arm}/σ_{rs}, and hence they are distinguishable from SP grains.

For some time it has been thought that high concentration of SP grains causes the high χ seen during interglacials in the paleosols. Low temperature magnetic studies show that this is indeed true [*Banerjee et al.*, 1993]. At 20 K and 2.5 T, almost all the SP grains become thermally stable and contribute to a large value of saturation remanence (σ_{rs}), even when the field is withdrawn. The incremental loss of σ_{rs} on further warming to room temperature leads to a quantitative measure of the amount of SP grains present. A less time-consuming solution is to measure the room temperature ratio, χ/σ_s, which is another measure of SP fraction; we find that these two numbers agree with each other [*Hunt et al.*, 1995a]. The low temperature approach also yields information on magnetic mineral composition. A sharp drop of σ_{rs} near 120 K, the characteristic Verwey transition for spin reorientation in non-SP-sized magnetite, can be used to infer the presence of magnetite larger than SP threshhold (d = 30 nm). Together, the two results tell us how much of the minerals is coarse-grained magnetite and how much is the pedogenically produced fine-grained (SP) magnetite or maghemite.

Verosub et al. [1993] used a chemical approach from soil science, the Citrate-Bicarbonate-Dithionite (CBD) method, to help dissolve the finest iron oxides in a soil. This fraction includes most of the small SP grains. Indeed Verosub et al. find large decreases in X when the CBD method is applied to soils. Joining the forces of our two laboratories, we applied our magnetic methods and their CBD method to small synthetic magnetite and maghemite grains of known sizes [*Hunt et al.*, 1995b]. The results confirm that all three methods, CBD and the two magnetic methods described in the previous paragraph, can be used to estimate the climatically controlled pedogenic SP grains. The enhanced susceptibility in soils (and to a lesser extent in the less-altered loess) is most likely due to variations in rainfall, ambient temperature, and the early loess material—the wind-borne silt and iron-bearing clay. *An et al.* [1991] believe that of the three parameters above, ambient temperature and the early loess material are less likely to affect pedogenic magnetite production than rainfall. On the basis of this hypothesis colleagues in Europe [*Heller et al.*, 1993; *Maher et al.*, 1994; and *Liu et al.*, 1995] came up with with paleorainfall variations for the last 130 ka in the Chinese loess plateau. For input data, Liu et al. used SP/total ratios calculated by our method, Maher et al. used $\Delta\chi$, the difference in susceptibility between unaltered loess and paleosol, while Heller et al. used a combination of χ and ^{10}Be isotope measurements to infer the pedogenic fraction in χ. The pedogenic fraction is converted to paleorainfall by using a calibration function based on modern rainfall and SP-sized magnetic mineral formation in modern soil.

Some unexpected results ensued from this exercise. The western part of the Chinese loess plateau (near Xining and Lanzhou) is arid today, but Maher et al. find that 6000–9000 years ago the western sites had 215 mm/yr more rainfall than today (~300 mm/yr). On the other hand, rainfall at the eastern sites has remained steady since the early Holocene. We did a study of sites on a transect from the west near Xining to the east near Jixian, and we, too, find magnetic proxies indicating a much higher rainfall in the west in early Holocene times [*Hunt et al.*, 1995a]. But the scale of the increase (60–100%) is nowhere near the numerical GCM predictions of 300% [*Winkler and Wang*, 1993] for the loess plateau during early Holocene. Pending confirmation, this difference does indicate that improvements are needed in GCM input parameters.

Furthermore, we tested the local versus global components of climate change by comparing two sites, Baicaoyuan and Xifeng, which are 200 km apart but on either side of a rain shadow, the nearly north-south Liupan mountains in the western loess plateau [*Banerjee et al.*, 1993]. Overall, the intensity of pedogenesis as measured by magnetic proxies shows that throughout most of the last 130 ka, pedogenesis was indeed weaker in arid Baicaoyuan than in humid Xifeng. During early Holocene, however, both sites had the same degree of pedogenesis. The eastern plateau, it seems, has always experienced the same high rainfall during the current and the previous interglacials. While the work of *Kukla et al.* [1988] showed that the magnetic proxies from the eastern Chinese loess plateau agree with the Milankovitch-driven oceanic climate record, the more recent work described above shows that local responses to global change at sites 1000 km apart can indeed vary.

Although more work remains to be done in quantifying the different magnetic proxies to obtain climatic parameters, it is clear that the high sensitivity and rapid measurement time for magnetic parameters are a great boon to obtaining regionally averaged continental paleoclimate proxies through magnetism. The hard work of separating wind-controled, or eolian fraction versus pedogenic fraction in loess is underway in many countries. It is hoped that it will lead to more accurate measurement of paleorainfall intensities as well as of past wind strengths. What is lacking still is a precise method for independent age dating of the loess deposits beyond the temporal limits of ^{14}C method. Modern optically stimulated thermoluminescence methods of dating loess older than 60 ka are being investigated. Without close-spaced high-precision dates for older sediments, we run the risk of a circularity in argument about the coincidence of continental and oceanic climate changes. Using the similarity of χ-peaks to the oxygen isotope peaks as a relative dating tool is too flexible an approach for determining the precise onsets of climate change over large distances. —*Subir K. Banerjee, Institute for Rock Magnetism, University of Minnesota, Twin Cities, Minn.*

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Galileo Brings New Weight to Studies of Jupiter System

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As project scientist Torrence Johnson put it, "The status report on Galileo is both happy and simple. Jupiter now has 17 moons. And Jupiter also put on a little weight... about 350 kilograms."

The new satellite of Jupiter is NASA's Galileo orbiter, which has successfully inserted itself (with some help from the flight team at the Jet Propulsion Laboratory) into orbit around the giant gaseous planet. Jupiter's new heft comes from the Galileo probe, which was incinerated and absorbed into Jupiter's atmosphere after about an hour's worth of work.

On December 7, both spacecraft finally began the missions they were designed to achieve. The probe slammed into the planet at 170,700 km/hr, dropping like a bomb through the top 130 km of Jupiter's cloudy atmosphere and making the first-ever direct measurements of its composition. In a presentation on December 14 at the AGU Fall Meeting in San Francisco, Johnson announced that the probe had radioed data back from the turbulent upper atmosphere to its maternal orbiter for 57 min, only a few minutes short of the expected 60 min of radio contact. All instruments on the probe appear to have operated without a hitch after sitting dormant for the first six years of the mission, Johnson noted.

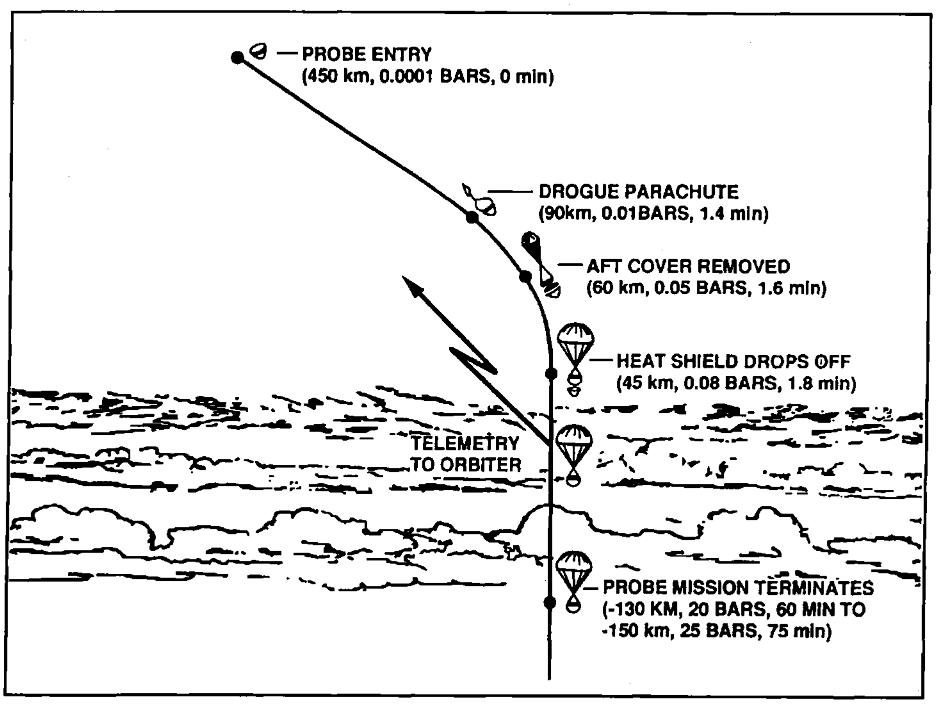

Fig. 1. The Galileo probe's entry into Jupiter's atmosphere was designed to occur at a precise angle of 8.5° to the horizontal. At 7°, or 1.5° less than the necessary angle, the probe would have bounced off of the atmosphere like a billiard ball; at a descent angle of 10°, the probe would have been incinerated almost immediately.

Following a 3.8 billion-km trip from Earth to Jupiter—piggybacking most of the way on the orbiter—the probe sliced a path into the crushing atmosphere of the gas giant at 8.5°to the horizontal. The probe's entry into the planet's atmosphere was confirmed by radio at 3:13 p.m. PST on December 7, but not before causing about 9 minutes of angst at JPL. Engineers had expected the probe to give the OK sign at 3:04 p.m.

What happened after the descent must, of course, remain uncertain, although scientists have some ideas. JPL staff estimated that—facing air pressure 20 times that of Earth's atmosphere and friction-caused temperatures reaching 15,000°C—the probe's Dacron parachute would have burned up within 30 minutes after data collection ended. All aluminum on the craft should have melted within a few hours, and even the titanium components would have melted and evaporated within a half day.

What remains, however, is the first sample of the atmosphere of any of the outer planets. Data from the probe, which was stored on the orbiter's tape recorder, was transmitted back to Earth on December 10–13 and will be retransmitted again, according to Johnson, in early January. A presentation of preliminary findings from the probe was scheduled for December 19, but was postponed due to the shutdown of many