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Loess in China: A Good Archive of Climatic and Environmental Changes during the Quaternary

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Quaternary scientists in China have significantly improved our knowledge of loess deposition as well as our understanding of paleoclimatic and paleoenvironmental changes over the past 2.5 million years. It is recognized that loess is of aeolian origin with loess forming dust continuously deposited. It is also believed that grain-size, magnetic susceptibility, carbon isotopes and fossil assemblages in loess deposits are good proxy indicators of paleomonsoon climate and paleovegetation changes over the past 2. 5 million years. Chinese loess is regarded as one of the best terrestrial archives of climatic and environmental changes during the Quaternary. Further investigation of loess deposits and their records of climatic and environmental change aids understanding of climate change and gives scientific backing for the project of ecological and environmental restoration in northwest China .

Key words Chinese loess, the Quaternary, paleoclimatic archives

On February 20th 2004, Professor Liu Tungsheng was given the "National Scientist of 2003" prize and was awarded five million Chinese yuan (RMB). This news encouraged Quaternary scientists in China, especially the scientists who work on loess research. Since Professor Liu is regarded as "the Father of Loess Research in China", many are interested in what Professor Liu's research work is, why loess research is important and what the current state of loess and environmental research in China is.

One of Professor Liu's most important contributions is that he and his students have ensured that loess is recognized as a versatile recorder of environment changes during the late Cenozoic. From their pioneering investigations, we came to understand how the climate and environment have changed in eastern and central Asia over the past —2.5 million years. He has worked on the loess region since the 1950s and has pushed research on loess and environmental change in China to a new peak. Chinese loess deposits have become one of the most important archives of paleoclimate and paleoenvironment on the Earth over the late Cenozoic era. Loess plays as important a role as the deep-sea sediments in oceans and the ice deposits in the polar regions.

Professor Liu Tungsheng is one of founders of "Xi'an Laboratory of Loess and Quaternary Geology, Chinese Academy of Sciences" (now Institute of Earth Environment, Chinese Academy of Sciences). The reconstructions obtained by him and his students at Luochan, Xifeng and Baojie on the Chinese Loess Plateau have become the standard climate and environment records during the Quaternary of China. Professor Liu Tungsheng was also awarded the "2002 Tyler Prize for Environmental Achievement", one of the most important international prizes won by Chinese scientists in the past half century.

1 Where is loess distributed in China?

Loess covers around 400,000 square kilometers in China, overlaying various landforms of Tertiary sediment and earlier bedrock. The typical loess deposit is found in the middle part of the Huang He (the Yellow River), covering an area of 270,000 square kilometers. The average thickness is **100~200** meters with the thickest being more than **400** meters at Lanzhou and Jingyuan, Ganshu province, west Loess Plateau. On the Chinese Loess Plateau, deposits look like a "blanket" covering the earlier sediments and landforms. Occasionally there are exposures of bedrock, where the land surface was uplifted

and exposed to intense water and wind erosion.

2 Where is the source of the loess?

Loess is primarily constituted of mineral particles with diameters of several to several tens of microns with the major components being quartz, feldspar and some heavy minerals. Sources of these loess forming materials are in northwest and north China where the land surfaces are covered by desert, Gobi, or dry land and wind erosion is very strong. Professor Liu started to investigate these aeolian deposits in the arid and semiarid region of north China in the 1950s. The resurgence of investigations into the aeolian origin of Chinese loess owes much to the findings of these earlier works. In addition, his books and papers published early in the 1960s have become the classical references for this research area.

3 How old is Chinese loess?

The oldest Chinese loess was deposited 2. 5 million years ago. Researchers have used several methods to investigate the age of loess deposits. One of the most accepted and useful methods is paleomagnetic stratigraphy. Professor Liu Tunsheng and his colleague Friedrich Heller established the current age model of Chinese loess in the early 1980s. They investigated the typical loess section at Luochuan, central Chinese Loess Plateau, and concluded that the onset of loess deposition in the area was around 2. 5 million years ago[1]. Since then, further research has confirmed this conclusion[2]. It is well known that the Earth's magnetic field is not stable with reversals of the dipole (north-south, south-north) field periodically recurring over periods of thousands to millions of years. Alterations in the Earth' s magnetic field over the past several tens of millions of years have been recognized and a standard record of magnetic stratigraphy with age has been constructed. Scientists therefore examine the magnetic field changes recorded by sediments and compare them to this standard magnetic stratigraphy. On the basis of this method, the age of certain sediments can be determined. Loess is dominated by silt and clay particles, some of which are magnetic minerals which when deposited, align themselves with the Earth' s magnetic field. In this way the past direction of this dipole field is recorded in loess. By measurement of the magnetic field recorded in loess throughout a sequence and through comparisons with the known standard magnetic stratigraphy, ages can be assigned to loess deposits. Professor Liu and his colleagues have carried on their research through the early 1980s with their findings forcing a major rethink of existing beliefs concerning the age of Chinese loess[1,2].

Underlying the loess, a finer and more reddish sediment, also aeolian, has been deposited. This has been termed the "Red Clay". Recent investigation has shown that it is essentially a "sister deposit" of loess with a maximum age of 22 million years. Thus, the continuous aeolian deposition occurring during the Cenozoic of north China extends back to the early Miocene[3]. Further investigation of loess and the Red Clay deposits enable excellent records of climatic and environmental changes over the late Cenozoic to be reconstructed.

4 How does loess record climatic and environmental changes in the past?

Loess sequences are formed from the deposition of dust with progressively younger sediment from bottom to top. Within the loess are buried soils that indicate the paleoclimate was warmer and wetter at the time of soil formation. Because specific soils are formed under specific climatic conditions, soil type is a good indicator of the paleoclimate. Further observations and investigations have shown an association of particle size in loess with past wind strengths. When the wind was stronger, coarser particles are transported and when the wind is weaker, finer grains transported to the Loess Plateau[4-6]. If we take samples from a loess-paleosol sequence and measure grain-size changes at the micron scale, clear fluctuations in the grain-size of loess can be shown. Thus it can be inferred that the wind strength and the paleoclimate have significantly changed. In addition, the remains of organic matter preserved in loess record changes in the relative proportion of the two stable carbon isotopes contained within the original compound. Scientists extract these alkali molecules and measure their isotopic values to investigate how vegetation has changed on the Loess Plateau and to seek an understanding of the forcing factors that drive environmental change. These investigations have uncovered some interesting results.

5 What information can we obtain from loess deposits?

The loess deposits in China are excellent chronicles in which environmental and climatic changes over the past several million years have been recorded. The alternations of loess and paleosol units in sections have been extensively investigated. It is concluded that when loess was deposited the paleoclimate in north and northwest China was drier and colder, the northwest wind was stronger, major dust storms were more frequent, dust particle size was coarser, the vegetation was sparser and more dust was deposited. However when paleosols developed, the climate was warmer and wetter, the northwest wind was weaker, major dust storms were less frequent, dust particle size was finer, the vegetation was denser and less dust was deposited. The climate zones in north China moved towards the south during these warmer and wetter periods.

These long-term climatic and environmental changes recorded by Chinese loess deposits are synchronous with the major global climate shifts indicated by other archives in deep-sea sediments and ice core records. When the Earth was cold, ice volume in the northern hemisphere expanded, much more water was stored in ice on the continents so that the sea level was lowered, and loess was deposited in China. Shanghai became a "continental city" during these cold periods (glacial period) as sea level was lowered more than 100 meters. The coastal zone moved more than one thousand kilometers, and thus Shanghai was more than one thousand kilometers away from the sea at around 20,000 years before present. When the Earth climate was warmer, the ice sheets on the continents thawed and there was large freshwater input into the oceans, causing the sea level to rise. At 6,000 years before present, the sea level around Shanghai was 1-2 meters higher and part of the Shanghai region was submerged. Intensive investigations of the loess record show that paleoclimatic changes recorded in the loess sequences have approximate periodicities of 40,000 and 100,000 years; these cycles may be driven by Earth orbital perturbations[6].

It is also possible to extract information on neotectonic movement (such as uplift of the Tibetan Plateau etc), volcanic eruptions, cosmic events and landform change from the Chinese loess deposits. This information is important for understanding the Earth's history and in helping to predict potential Earth environments of the future. It is also valuable for gaining an understanding of the current environment in north and northwest China, thus enabling the protection of the region from environmental degradation.

6 What can we learn from the loess record?

There are several tens of millions of people living on the Chinese Loess Plateau. They inhabit a region where much of the environment is extremely vulnerable with soil erosion, desertification, deforestation, and air pollution etc all being major ecological concerns. The Chinese government has more recently paid much more attention to the environment and development of this region, and environmental change researchers must help the policy makers to prevent and reverse environmental deterioration. What has happened in the past can tell us what may happen in the future. The knowledge gained from loess records about past environmental change will be helpful in resolving environmental problems of the present.

Soil eroded form the Loess Plateau is washed into the Huang He (the Yellow River, the second biggest river in China), causing the Huang He to become extremely laden with entrained materials. There is around 1. 6 billion tons of sediment transported into the marginal sea by the Huang He each year, causing much of the fertile land on the Loess Plateau to be seriously eroded. The lower branch of the Huang He has become a "suspended river" because continuously constructed riverbanks over the past two thousand years have raised the riverbed significantly through deposition of water-laden materials. However, it is unknown what the state of the Huang He would be without the influence of humans. What is its natural variability for example? What has been the nature of soil erosion in the past and what is the best way to prevent it in the future? We can get answers from the loess record because past soil erosion has been recorded in the loess sequences. At the same time, the Chinese government has invested large quantities of money in restoring the ecology and environment of northwestern China and has encouraged people to plant more trees and grass. There are a variety of soil types and natural environments along the Loess Plateau; some places are suitable for planting trees whilst oth-

ers are more suitable for grass. Because the loess is very porous, especially in regions of thick loess deposits, it is inadvisable to plant trees on the thick loess Yuan, even where the average annual rainfall would ordinarily be high enough. This has been confirmed by pollen and isotope investigations. There have only been trees in gullies or valleys where water is more available than on the *Yuan*. This has changed the previous view that there was dense forest and grassland on the Loess Plateau before extensive exploitation by humans. Further investigation will help to determine where the better places to plant trees are and where planting grass would be more suitable. This type of information ensures the money allocated to restore the environment in northwestern China is used efficiently and responsibly.

In the context of geological time, humans have occupied the Earth for a very short period of its history. The time since observations and record keeping began is much shorter still. In order to gain an understanding of the Earth's natural environmental variability, we must seek answers from natural archives. Chinese loess, as well as deep-sea sediments and ice deposits of Polar Regions have yielded the most important natural records, enabling us to reconstruct the past environments of the Earth during the Cenozoic. Professor Liu Tunsheng and his students have worked on the loess record and environmental changes in the Loess Plateau for the past half-century and their findings are widely accepted. Their work has been instrumental in recognizing environmental changes of the past, in helping the policy makers protect the regional environment and in testing climate models. Further work in this area will ensure a more complete understanding of climate in the past.

7 Summary

Professor Liu Tungsheng has won "the National Scientist of 2003" award showing that his research has been accepted by society and other scientists. It also shows that his research is extremely important to China. The prize is not only an award for Professor Liu's research but will serve to encourage Chinese Quaternary geologists to contribute more to Quaternary research. Now is a high point for Chinese Quaternary geologists as the government pays more attention to environmental research and allocates more money to support the work. Moreover, Chinese Quaternary geologists have completed a great deal of fundamental research on loess over the last decades. This work has been a catalyst for the advancing of research done by Chinese Quaternary geologists to a new level where more complex and detailed issues can be investigated.

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