# Data Collected in Mongolia Offers Key Clues to Past Climate

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Located in the interior of the Asian continent, Mongolia lies at the northern limit of the Asian monsoon and occupies the zone of highest seasonal climate contrast on Earth. Sediment cores from Mongolian lakes contain crucial information about paleoclimatic variability from a region that is poorly understood relative to continental margins and ocean basins. As the locus of four very large ($M \geq 8$) earthquakes during this century, Mongolia is also a natural laboratory for studies of slip on active, intracontinental faults [see *Molnar and Prentice*, 1996].

Because sedimentation rates, sediment supply, and long-term climate change are all linked to tectonics, it is important that studies of paleoclimate and paleoseismicity proceed simultaneously. During August and September of 1996, an interdisciplinary group of six American and three Mongolian geoscientists conducted field reconnaissance in central and northern Mongolia (Figure 1) to assess the potential for cooperative paleoclimate research and select optimal sites for coring projects and Global Positioning System (GPS) receivers. Preliminary analyses of lacustrine cores, equid teeth, and paleosols confirm that coordinated study of multiple proxies, including palynomorphs, stable isotopes, and rock magnetics, is necessary to determine the relative contributions of temperature, precipitation, and wind to evolution of the terrestrial Asian climatic system.

Changes in regional precipitation and temperature are recorded by variations in rock magnetic parameters and palynomorph assemblages from cores of Lake Hovsgol (see Figure 1). A quantitative paleotemperature proxy is available from oxygen isotopes of freshwater mollusk shells, and initial results suggest that this lacustrine temperature record can be supplemented by estimates of seasonality derived from $\delta^{18}O$ measurements of fossilized horse teeth. Particle size and rock magnetic analyses of soil/loess sequences suggest that Mongolia may be an important source of the thick eolian deposits on the Chinese Loess Plateau. Further studies of soils, loess, and paleosols are needed to determine whether source materials in central Mongolia modulated the magnetic signature of Chinese dust deposits.

Mongolian lakes can be expected to yield high-resolution records of central Asian climate change because they are located in the zone of overlap of two atmospheric systems. The winter climate of Mongolia is dominated by the Siberian high, and summer climate by the Asian low. However, heavy rains brought by the Asian monsoon do not reach Mongolia, and the climate is transitional between the monsoon belt of southern Asia and the subarctic climate of Siberia.

A progressive decrease in precipitation from more than 400 mm/yr in the mountains of northern Mongolia to less than 100 mm/yr in the southern Gobi desert is reflected by the modern distribution of plant communities [*Hilbig*, 1995]. Northern mountain-steppe and forest-steppe complexes give way to steppe, desert steppe, and desert vegetation toward the south. The northern boundary of the forest-steppe vegetation zone lies just north of the Mongolian/Russian border. To the south, the Gobi desert marks the northern limit of modern C4 grasslands. Due to the distribution and proximity of these climatic zones and ecological boundaries, sediments and soils of Mongolia are likely to record temporal variations in vegetation, stable isotopic composition, and pedogenesis associated with changes in the strength and geographic extent of the Asian monsoon.

Mongolia also straddles a tectonic transition zone. Basins in northernmost Mongolia are part of the Baikal Rift Zone, a large, active continental rift. Two of these basins, Darhad and Hovsgol, contain lakes with the potential to produce long paleoclimate records. In contrast to the extensional regime of northern Mongolia, compression in central and southern Mongolia is accommodated by strike-slip and thrust faults, which were the loci of the four recent, very large earthquakes. The microtopography defining these surface ruptures is pronounced, perhaps because the faults cut across domains of frozen ground [*Baljinnyam et al.*, 1993]. Moreover, the dry climate and slow rates of erosion produced unusually well-preserved fault scarps, which have been the subject of recent multinational field studies [*Ritz et al.*, 1995; *Molnar and Prentice*, 1996].

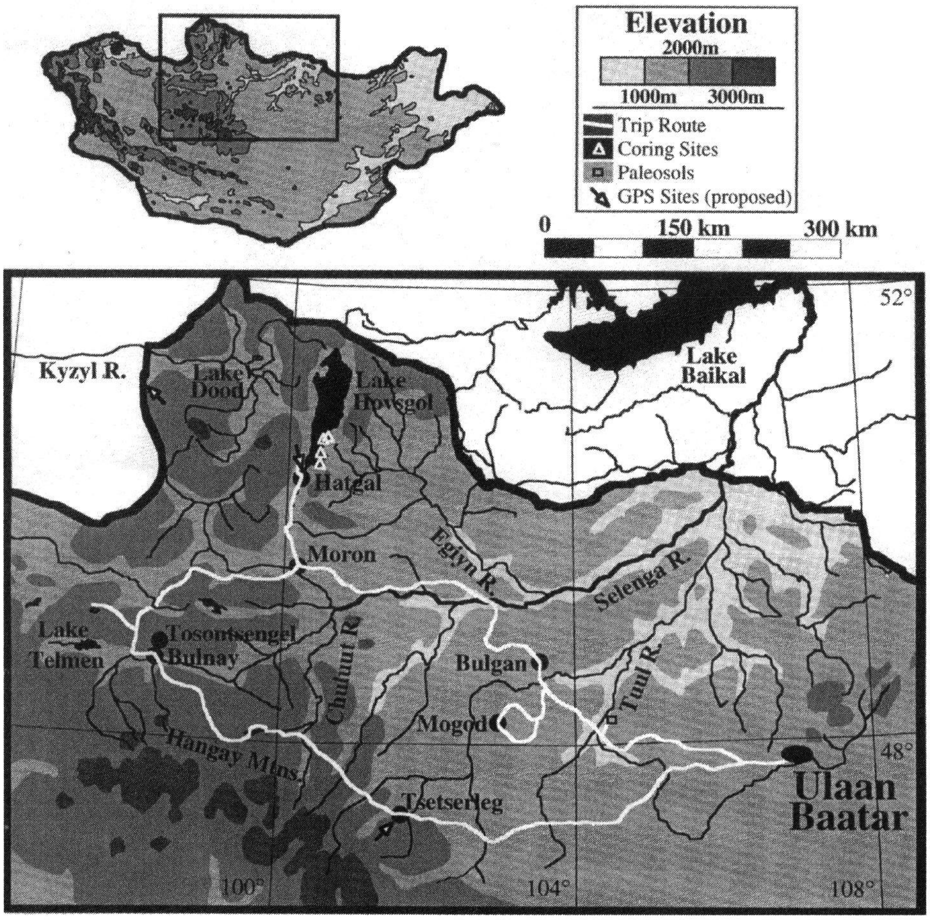


*Fig. 1. Route of the Mongolian field reconnaissance trip, showing topography, selected towns, lakes, and rivers, and locations of coring sites, paleosols, and proposed GPS stations.*

The principal goals of the field reconnaissance in Mongolia were to select sites for proposed GPS receivers and collect an initial suite of paleoclimate records throughout central and northern Mongolia. Priorities included a brief coring cruise on Lake Hovsgol, sampling surface sediments from multiple vegetation zones, and collecting soil samples from the Lake Baikal watershed.

To this end, fieldwork participants traversed approximately 2500 km of north central Mongolia (Figure 1), from the steppe surrounding Ulaan Baatar to the taiga of the northern Hangay Mountains and the forest-steppe south of Lake Hovsgol. A total of nine gravity cores were collected from four stations on Lake Hovsgol. In addition, 24 surface samples were taken for analysis of modern pollen rain, 50 horse teeth were collected for $\delta^{13}C$ and $\delta^{18}O$ measurements, and 13 soil/ loess profiles were sampled from exposed sections along the trip route.

Three of the cores from Lake Hovsgol were left in Ulaan Baatar for study by Mongolian scientists. The remaining six cores were transported to the core repository at the University of Rhode Island, where they were split, described, and sampled for paleomagnetic, palynological, and isotopic analyses. Due to the presence of Cambrian phosphorites and carbonates in the drainage, an initial accelerator mass spectrometry (AMS) date on bulk sediment is clearly too old. AMS dates of terrestrial plant fragments, including wood and pollen, are still pending, but preliminary paleoclimate studies are promising. Laminated deposits of silt and clay, essential for high-resolution analysis of geomagnetic and palynological proxies, were recovered in most cores. Magnetic measurements of all six cores indicate that variations in magnetic concentration and mineralogy closely correlate to descriptions of lithologic composition and texture. Magnetic parameters may thus be used to provide insight on changes in sediment source, transport pathways, and paleoclimate.

Initial counts of pollen and spores reveal assemblages dominated by either *Artemesia* (sage), which is indicative of forest-steppe vegetation, or *Pinus sibirica* (Siberian cedar) from the relatively cool and wet taiga. Migrations of the forest-steppe/taiga boundary in response to changing temperature and precipitation can thus be reconstructed from the Hovsgol palynological record once AMS dating of terrestrial plant matter is completed.

In addition to floral macrofossils, calcareous mollusk, gastropod, and ostracod shells are present throughout the cores, indicating that Hovsgol has the potential to provide a long oxygen isotope record from central Asia. Sediment cores from nearby Lake Baikal (Figure 1) produced excellent records of many paleoclimate proxies, including rock-magnetic properties, diatoms, palynomorphs, biogenic silica, and isotopes of organic carbon [*BDP-93 Members*, 1997]. However, calcium carbonate is not preserved in the Baikal sediments because the lake is undersaturated with respect to carbonate. A long $\delta^{18}O$ record from biogenic carbonate of Lake Hovsgol would enhance understanding of terrestrial Asian climatic change and facilitate comparison of lacustrine data from Hovsgol with marine paleoclimate records.

In addition to the quantitative paleotemperature estimates from lacustrine proxies, fossilized mammal teeth may contain a record of past annual temperature variations. Currently, Mongolia has an extremely continental climate, with annual temperatures ranging from 15°C to -30°C in Tosontsengel (see Figure 1). Temperature is strongly correlated with the stable isotopic composition of meteoric waters.

Although there are no long-term stable isotope records of meteoric waters in Mongolia, International Atomic Energy Agency data for Irkutsk, Siberia, and measurements of river, lake, and spring waters collected during fieldwork indicate that Mongolian precipitation has a $\delta^{18}O$ value of approximately -10 per mil in summer and -25 per mil in winter. A 5 per mil range in $\delta^{18}O$ of modern equid teeth likely reflects attenuation of the estimated 15 per mil seasonal isotopic amplitude of surface waters. Future measurements of $\delta^{18}O$ in the enamel of fossilized mammal teeth are expected to lead to approximations of paleoseasonality.

Present dust-storm tracks suggest that the Mongolian Plateau may have been an important source of eolian deposits on the Chinese Loess Plateau. Analysis of 13 soil profiles from sites along the trip route demonstrate that a vast area of central Mongolia is covered with silt- and clay-rich soils. Soil A horizons (0.5–1.5 m thick) show enhancement of fine-grained magnetic particles and contain 15–35% silt and clay. Bk horizons (1–2 m thick) are carbonate enriched, with lower magnetic concentrations, coarser magnetic grains sizes, and a greater proportion (30–55%) of dust particles.

Bk horizons of Mongolian paleosols are thus a potential source of the carbonaceous Chinese loess deposits. If this proves to be the case, it is possible that the low magnetic concentration of the Chinese loess was inherited from parent material in Mongolia and does not relate directly to paleoclimate conditions on the Loess Plateau.

Furthermore, a sequence of five paleosols exposed along the Tuul River (Figure 1) indicates that the Gobi desert expanded and contracted dramatically during the last glacial/interglacial cycle. Bulk $^{14}C$ dates place the ages of the four lower paleosols at approximately 24.5 kyr, 28.9 kyr, 30.7 kyr, and 34.4 kyr. Units containing 35–60% eolian silt attest to aridification between deposition of the 28.9 kyr and 30.7 kyr paleosols. Vast changes in the areal extent of deserts would have altered the magnetic properties of soils, further modulating the magnetic signature of any loess deposits derived from the Mongolian Plateau.

The success of future paleoclimate studies in Mongolia hinges upon the establishment of a modern baseline for multiple climate proxies. Therefore development of a Geographic Information Systems (GIS) database for modern precipitation, temperature, vegetation, pollen rain, topography, and soil properties is strongly recommended. Mongolian researchers have already compiled data on climate, soils, and vegetation, which should be incorporated into the GIS data set and augmented by additional field collections. The resulting database will provide a foundation for spatially distributed models of the impact of past and future climatic change on the vegetation and soils of Mongolia and facilitate calibration and interpretation of paleoclimate records.

Installation of six GPS receivers at sites throughout Mongolia would improve current estimates of slip on major faults. Three of these proposed sites lie on or near the trip route (Figure 1) in the extensional regime of northern Mongolia. Three additional stations are to lie in zones of compression to the south and west. Criteria for site selection included evidence of bedrock outcrops and proximity to seismic stations or army bases to ensure proper monitoring and upkeep. Placement of GPS receivers at these key locations would benefit multiple disciplines, because GPS technology can be used to acquire relatively precise estimates of current fault motions, assess seismic hazards, and improve field location of climatic and ecological research stations.

A proposed bedrock-mounted GPS receiver with continuous monitoring near the Hatgal seismic station at the southern end of Lake Hovsgol (Figure 1) would advance other science objectives in the area by serving as a base station for transmitting differential GPS measurements to research stations on and around Lake Hovsgol. These measurements would allow submeter scale station locations, a substantial improvement over the hundred-meter level of resolution currently available.

For more information regarding the 1996 Workshop for Interdisciplinary Earth Science Investigations in Mongolia, including photos of coring stations and field sites, visit the web page: http://www.ldeo.columbia.edu/~sjf/mongo.html.

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# BOOK REVIEW

## Experiments to Study Our Atmospheric Environment

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Steven Businger, Prentice Hall, Upper Saddle River, New Jersey, 190 pp., 1996, $30.67.

The teacher of an introductory physics and chemistry course has many choices when it comes to laboratory manuals. Not so with atmospheric science: texts devoted to learning the subject in a lab setting are limited in number and often in scope. A large portion of the available lab texts concentrate solely on exercises in synoptic analysis and forecasting skills, which while important do not convey the full range of the science and its applications. That is why Steven Businger's *Experiments to Study Our Atmospheric Environment* stands out among recent books devoted to teaching atmospheric science in the lab.

Covering subjects ranging from atmospheric optics to air pollution chemistry, this book presents a broad introduction to the atmosphere starting with fundamental physical principles. Not all of the book's lab experiments are equally inspiring, and in places the book may assume too much or too little sophistication on the part of the student. Nevertheless, Businger's new lab text is a well designed introduction to atmospheric science that merits serious consideration by meteorology instructors.

*Experiments to Study Our Atmospheric Environment* sets out, in the author's words, to "...give students of diverse academic backgrounds an opportunity to explore and understand the underlying physical principles of meteorology firsthand." The emphasis throughout is on the use of simple, inexpensive materials and everyday phenomena to explore the physics and chemistry of the atmosphere. Proceeding from fundamental concepts like temperature, pressure, and radiation, the book addresses topics in the thermodynamics of air and water vapor, cloud physics, atmospheric optics, air pollution, and the general circulation. While synoptic analysis is introduced in a series of lab exercises, the primary emphasis of the book is on physical, rather than synoptic or dynamic, meteorology.

The text is divided into nine sections covering atmospheric composition, pressure-temperature relationships, solar radiation, water vapor properties, atmospheric optics, clouds and precipitation, the general circulation, convective storms, and basic atmospheric chemistry. Each section provides four to five pages of introductory material and two to five lab exercises. The exercises were selected to present key physical principles in straightforward ways, and by and large, they work. Most concepts are conveyed nicely in intuitive demonstrations. For example, the composition of the atmosphere is explored quantitatively using little more than a candle, a test tube, and a pan of water. Cloud formation and the role of cloud condensation nuclei is demonstrated neatly and effectively with a beaker of ice and a can of aerosol spray.

Not all experiments are equally engaging and some could be developed better. A case in point is the lab activity on aerosols, which has the student passively collect (by settling) large ambient particles for 48 hours and examine them with a magnifying glass. This exercise would be more valuable if geographic variations were included (sampling in sea shore, urban, and rural environments) and more ambitious apparatus were suggested (say, a vacuum cleaner inlet for sampling and a microscope for viewing the impacted particles). The text could have related the captured particle amounts with ambient particle loadings, and a good instructor could then introduce the current debate about EPA particulate standards. Nonetheless, most of the experiments in the book demonstrate the author's clear sense of which lab experiences will connect with a student in a brief lab session.

The author suggests *Experiments to Study Our Atmospheric Environment* for an introductory atmospheric science course, which is usually encountered at the undergraduate level. This is the level of the introductory material for each section, which will probably require student preparation via lecture or lab instructor. On the other hand, many of the book's experiments strike the reader as rather elementary for a class of undergrads, particularly those entering with a reasonable high school science background. For example, the lab experiments for the sunlight and climate topic involve temperature measurements in front of heat lamps, while the introductory section assumes knowledge of blackbody radiation and the Stefan-Boltzmann law.

This seeming mismatch may work to the book's advantage, allowing it to be used by students at many levels: first-year meteorology undergrads, nonscience majors looking for that science credit, and with appropriate classroom support, high school physics students. Atmospheric science is rarely offered at the secondary level, though it should be. Atmospheric phenomena present direct examples of the physical sciences and could be used to introduce all manner of topics in a traditional high school physics or chemistry course.

*Experiments to Study Our Atmospheric Environment* provides instructors at several levels with a valuable resource for courses in atmospheric, Earth, and/or basic physical science. Its appealing approach and broad applicability make it a welcome addition to the atmospheric science teaching literature.—*James Marti, Aveka Inc., Woodbury, Minn.*