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Climatic Changes of the Past

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Thanks to the generous support of the Wissenschaftskolleg during 1989-90, I was able to pursue two avenues of scholarly activity. As an *International Geosphere-Biosphere Research Fellow,* a major activity was aiding in developing a core program on global changes of the past as part of the all-encompassing international initiatives on global change sponsored by the International Council of Scientific Unions. This program is slated to last over ten years with participation of scientists from all over the world. It was recognized early by the scientific community that an understanding of global changes and conditions of the past is a key to predicting future changes and conditions. Therefore, the Scientific Steering Committee was formed with the task of developing and implementing a core project that would aid in meeting the objectives of the *International Geosphere-Biosphere Program.*

Data concerning previous environmental conditions are available from instrumental records and documentary histories as well as from the information preserved in many types of natural archives, including ice cores; marine, lacustrine and terrestrial sediments (loess deposits, in particular); tree rings; corals; and paleosols. Studies of the physical, chemical and biological parameters recorded in such archives have provided a wealth of information on both the "natural" behaviour of the Earth system and on more recent human impacts. Quantitative information on global changes of the past can be used to document forcing factors and to understand the large-scale responses to such forcing mechanisms; to place observed trends in contemporary data into a broader context; to identify unknown and potentially important processes that link biological, physical and chemical components of the Earth system; to test hypotheses regarding these linkages; and to evaluate the validity of analytical Earth system models through sensitivity studies and detailed comparisons of simulated behaviour with changes reconstructed from palaeodata.

Insights from global changes of the past have already enhanced our understanding of changes in atmospheric composition, albedo, landscapes and land-use, global biomass and biogeochemical cycles, the mixing rate of the ocean, solar modulation of cosmic radiation, and the magnitudes and rates of environmental changes associated with glacial-interglacial climatic cycles. Much of the evidence for human-induced change and all the evidence for past changes resulting from natural forcing are drawn from records of the past. Natural archives of past environmental conditions provide important clues about Earth system processes, and help focus research activity on key questions concerning forcing functions and system responses. Parameters such as albedo, atmospheric greenhouse gas and aerosol concentrations, and the distribution of types of vegetation derived from palaeodata are needed to fix the primary boundary conditions used in model simulations of climate and to perform model validation tests.

The recovery and interpretation of historical and proxy data, including the development of tools and techniques, have been traditionally done through individual or single-laboratory efforts, employing an often specialized technique to examine typically regional or continental records that cover an often limited temporal domain. The emergence of an integrated Earth system science calls for a much fuller knowledge of the past, in both space and time, and for data sets that are drawn as composites from different efforts and disparate techniques. Concerns of impending climate change impose a sense of urgency in this endeavour.

It was then necessary to develop a project responding to these needs through a set of coordinated activities that addressed key scientific questions through specific research tasks. In addition, the project had to be broad enough so that scientists worldwide could contribute to the overall objectives.

We decided on a Two-Stream Approach based upon time intervals. Stream I was designed to improve our understanding of the history of the Earth system over the past 2000 years through the documentation of changes in the physical climate system, or in ocean chemistry and conditions in the biosphere. The chosen period is that of man's greatest impact on the planet and the era of significant overlap between written records and the environmental information stored in natural archives. A better understanding of the climatic fluctuations that occurred during this pe-

Hod (such as the Little Ice Age and the preceding, Medieval Warm Interval) can be expected to provide important insights into the rates of regional- to global-scale changes that are expected to occur within the Earth system in the next 50-100 years.

A clearer illumination of the global and regional changes that have occurred in the last 2000 years has many potential pay-offs. The period of most reliable climate history, now limited to at most a few centuries, will be extended at least fivefold; a more extensive global record of land-use changes will allow us to begin to assess the effects of past human impacts on the Earth system; it may be possible to distinguish human-induced changes in this period from natural responses to external forcing mechanisms and internal system dynamics, allowing calibration and estimation of anticipated anthropogenic impacts; and, by focusing on the period of overlap between written history and natural records, Stream I research will provide a Rosetta stone which can be used to validate and interpret data obtained from natural archives of the much more distant past.

Stream II was designed to focus on understanding the dynamics that cause glacial-interglacial variations, as well as the interactive feedbacks among various components of the Earth system that control the response of the system to climatic forcing.

We want to understand both the causes of change and the way the Earth system functions during times of glacial maximum and minimum conditions; to document the onset and nature of the transitions from warm to cold and cold to warm periods; and to define the causes and characteristics of the more abrupt changes that punctuate these periods and the transitions between them. It ist also critical to determine the present phase of the Earth's climate relative to the current glacial cycle. Information will be used, as it becomes available, from the full span of the late Quaternary Period.

Happily, the IGBP Special Committee has approved our core project and so our efforts have paid off. The next step is the implementation. Not an easy task, but an attainable one.

The second major activity carried out during my term at. Wissenschaftskolleg centered around a collaborative project on Quaternary paleoclimates interpreted from the loess-paleosol sequences in north-central China. I was able to spend the necessary time to interpret my field and laboratory data and write two papers for publication.

One of the barriers to a better understanding of past climatic events on a regional or global scale has been the paucity of long terrestrial proxy climatic records that can be correlated to the marine isotopic record. The marine cores reflect worldwide ice-volume and temperature changes forced by variations in the Earth's orbital geometry. The Loess Plateau in north-central China consists of a sequence of fine-grained windblown sediments and paleosols that represent a near-continuous proxy climatic record for the past 2.5 Ma (million years). The soils represent warmer and wetter periods with little loess deposition and the loess colder and drier periods with a relatively high rate of deposition, triggered by the Earth's orbital variations but controlled locally by interaction of a number of factors. Up until now, correlation has been achieved only between terrestrial and marine records for the last one million years or so, or oxygen isotope stage 36. Our work at Baoji, about 200 km west of Xi'an, has revealed a high resolution, loess-paleosol sequence that has enabled correlation to about 1.8 Ma or oxygen isotope stage 61. The section is judged to be the most complete, accessible record of soil and loess deposition in China. The section is 159 m thick and consists of 37 distinct paleosols formed during more than the last 2.5 Ma. It is the first time that paleosols older than about 1.2 million years have been able to be clearly identified in a single section. Geochronological control is based largely on magnetostratigraphy with the Brunhes, Matuyama and Gauss epochs and Jaramillo and Olduvai events clearly recognized. The Baoji pedostratigraphic units can be correlated with equivalent units in many parts of the Loess Plateau by a combination of magnetostratigraphy, and character, position and association of units within the Quaternary succession. The variation in thickness and development of the paleosols and thickness of the loess units suggest climatic cycles of varying intensity and duration.

Before now, only partial success has been achieved in correlating isotope records between marine sediment cores older than about 1.0 Ma. Recently, workers in South Carolina have introduced a more quantitative approach to correlate isotopic records on a global scale. Each isotope record is treated as a time series and common analyses are used to develop criteria concerning the identification of common events in records, and the level of accuracy with which such events can be recognized and interpreted. As a result they have extended the formal definitions of oxygen isotopes stages from stage 22 at 0.8 Ma to stage 63 at approximately 1.88 Ma near the base of the Quaternary. In addition, they have proposed ages for the stage boundaries by integrating time-calibrated biostratigraphic and paleomagnetic datums. This scheme has facilitated us to correlate our long terrestrial record with the marine isotope record. The common factors of both data sets are well established magnetostratigraphic control, the assumption that the sedimentological records are complete or nearly complete, and that climatic variations can be interpreted from the variations of the proxy data.

Correlation of our loess-paleosol sequence or cold-warm sequence with the deep sea isotope curves to stage 61 has been remarkable. Not only can we correlate the number of climatic events between the two data sets, but also can correlate the relative intensity and duration. Of course, there are exceptions but not enough to dampen our enthusiasm. It appears therefore, that we have more than 61 major periods in worldwide climatic variation, during the Quaternary, most likely controlled by orbital and solar variation but disturbed by local or regional influences.

The next step in my work will be to conduct further field investigations to identify variations in the loess-paleosol sequences throughout the Loess Plateau. This will enable us to reconstruct climatic change through time on a regional basis and to better explain the forcing functions causing the changes.

I owe much to the staff and Fellows of Wissenschaftskolleg. The experience was truly outstanding and something that I will recall with fond memories for the rest of my life.