PEP III:
The Pole-Equator-Pole transect through Europe and Africa

with reports from the workshops

"Coordinating paleoenvironmental research along the PEP III transect"

Bierville (France), September 12-15, 1996

Sponsored by:

the Past Global Changes (**PAGES**) Core Project of the International Geosphere-Biosphere Program (**IGBP**), the Global Change System for Analysis, Research and Training (**START**) project, the European Lake Drilling Program (**ELDP**), European Science Foundation (**ESF**), the Centre National de la Recherche Scientififique (**CNRS**), France, the US National Science Foundation (**US NSF**), the INQUA-PAGES Paleomonsoon project and **MEDIAS-FRANCE**

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1. INTRODUCTION AND RATIONALE

One of the main elements in the research strategy of PAGES, the Past Global Changes project within the International Geosphere-Biosphere Program (IGBP) is a series of three Pole-Equator-Pole transects passing, respectively, through the Americas (PEP I), Eastern Asia and Australia (PEP II) and Europe-Africa (PEP III).

The PEP transects focus largely on the terrestrial realm upon which human populations depend for most aspects of life, and are therefore a vital component of PAGES research.

All these transects have common goals, namely to:

• promote a common research agenda for the study of past environmental change, based on the priorities and procedures widely disseminated in PAGES publications;

• unite the paleorecords from the full and diverse range of environmental and documentary archives available within each PEP transect;

• create, from the synthesis of these records, well-dated, high-resolution reconstructions of climate and environmental change spanning the full latitudinal range encompassed by each transect;

• use these records to provide the basis for improving our insight into the causes and consequences of climatic change on both global and regional scales;

• provide, through these reconstructions, a basis both for developing and testing climate models and for assessing the future implications of global change.

Our current knowledge of past environmental change worldwide provides a compelling rationale for the concept of the PEP transects and for striving to overcome the conceptual and logistic challenges they present.

• Abundant paleorecords demonstrate teleconnections between hemispheres. Linkages are observed on both the timescale of the major glacial-interglacial cycles and the shorter timescales of individual events. For example evidence for climatic changes believed to correlate with the Younger Dryas can be found in tropical Africa and in the ice core record from the Central Andes. However, the exact timing of the onset of change from region to region still remains a matter of debate in many cases. Moreover the expression of apparently synchronous changes varies dramatically from region to region. How were these globally parallel changes propagated? What are the phase relationships between their expression from place to place? What will further exploration of these issues tell us about how climate change and the regional impacts of climate change are registered?

• For some time intervals, the degree of coherence between paleorecords from Pole to Equator, even on decadal timescales, is truly astounding, as witnessed by the clear links between the Central Greenland ice core record and the sediment signatures in the Cariaco Basin off the north coast of Venezuela during the late glacial period. Conversely, there are dramatic contrasts in the Holocene between the apparent constancy of stable isotopes values in Central Greenland and the massive switches in hydrological regime indicated by lake level variations at lower latitudes, notably the monsoon domains in Africa. What combination of external forcing and internal system dynamics creates such a global symphony of both unison and dissonance and how will this complex counterpoint play out in the future? For this, as for the previous questions, coordinated research along latitudinal gradients and especially within zones of transition between contrasted responses is one of the most indicative and cost effective ways of resolving the questions posed.

• In the recent period, for which a much more complete range of climate data is available from many parts of the world, short-period oscillations in coupled atmosphere-ocean dynamics, like the North Atlantic Oscillation and ENSO, affect not only the latitudes where they are most strongly expressed, but contribute significantly to variability in relatively remote area of the globe. How have the periodicity, amplitude and effects of such internal oscillations varied in time and space on longer timescales?

• Only models can travel into the future, but the validity of their simulated journeys can be tested against the reality of the past. Evidence for lake level changes in the Sahara, especially the universal and unambiguous demonstrations of high lake levels in the early-mid Holocene, conflicts with all current model simulations and point to the need for their re-evaluation and improvement. Similar model-data comparisons for other parts of the world and across major latitudinal gradients are essential for further model testing. They must be based on the best possible reconstructions of climate conditions in key continental areas. This is one of the major goals of the PEP transects.

• One of the focal tasks for global climate modelers remains the reconstruction of conditions at the Last Glacial Maximum (LGM). The boundary conditions for LGM models have been set by the earlier work of the CLIMAP group; now, there is growing, but still unresolved doubt about the extent to which sea surface temperatures in low latitudes differed from those at the present day. Improvement in the models depends on resolving this question and an important part of the answer lies in the research agenda set for each of the PEP transects.

The PEP transects complement and interact with parallel research programs in the oceans and in polar regions, to yield perspectives on the terrestrial response to climate changes and human impacts. While providing a key part of the framework for global paleoenvironmental research under the larger umbrella of PANASH (Paleoclimates of the Northern and Southern Hemispheres - See PAGES Publication 95-1), they pose daunting challenges of research coordination and synthesis. The present report outlines the current strategy of the PEP III transect which extends from the northernmost part of Europe to the southern tip of Africa. It emphasizes especially the presentations, discussions and conclusions of the Paris-Bierville workshop held in September 1996 and the SIWA workshop held in January 1997.

2. THE PEP III CHALLENGE

2.1 Special characteristics of PEP III

PEP III has some unique scientific challenges, associated with its major bioclimatic features and its pattern of population distribution.

At high and mid-latitudes, the climate of the western part of the PEP III transect is dominated by the influence of the Atlantic Ocean which penetrates inland through the prevailing westerly winds. On long time scales, one of the most dramatic responses to past climate change was the formation of the Fennoscandian ice sheet and expansion of sea ice into the North Atlantic, which in turn induced major changes in atmospheric and oceanic circulation. During glacial periods, the oceanic climate of Western Europe was replaced by a continental climate. On shorter time scales, human activities have deeply modified terrestrial and aquatic ecosystems. Over the past century, industrialized regions have acted as a source of pollutants at regional and global scales.

At Mediterranean latitudes, from the Atlantic Ocean to Eurasian plains, PEP III regions are seriously threatened by desertification. It is crucial to identify the relative importance of, and the synergetic interactions between, natural variations and the intensive deforestation, cultivation, land management and irrigation that these regions have undergone for millennia. The Mediterranean domain is one of the richest regions in the world for historical and archeological archives which can provide valuable new insights into past climate variations and human impacts. The Mediterranean Sea, the Black Sea, the Caspian Sea and the Aral Sea act as large reservoirs, and as evaporative basins which greatly influence regional climate. The sedimental records in these basins can also provide important evidence on climate and hydrological changes.

The PEP III transect includes the largest warm desert of the world, the Sahara-Arabia desert. However, a multitude of lakes developed and Neolithic civilizations flourished in the Sahara 9-5 ka ago. Relicts of a Sahara much less hostile to life are evidenced by groundwater which lies only tens of meters below the land surface. Contraction and expansion phases of the desert are a major concern for populations living at its boundaries, in the Sahel, Maghreb and the Middle-East. During the last two decades, the sensitivity of human society to climatic and hydrologic canges in these arid and semi-arid zones has been dramatically illustrated by drought in the Sahel.

In the tropics, climate is primarily controlled by the monsoon circulation. The African monsoon winds penetrate low-lying areas of West Africa, whereas parts of East

Africa and Southern Arabia are influenced by the Indian monsoon. Rain forests grow in the equatorial zones. A unique feature is the presence of the large rift lakes of East Africa. These lakes comprise a major resource for the dense and rapidly growing population. Especially important is the understanding of short-term environmental variability as induced by El Niño-Southern Oscillation. These large lakes also provide an excellent opportunity for obtaining long-term records of climate and biota in the tropics.
In the South, Africa narrows between two oceans. As a response to the influence of different wind systems and coastal ocean currents, Southern Africa contains a complex mosaic of climate types from desert, to Mediterranean to wet tropical. The region is well-placed to record shifts in the mean position of the circumpolar westerlies, related to the tropical-temperate temperature gradient and the growth and decay of sea-ice in the Southern Ocean.

The PEP III transect thus raises a series of crucial climatic questions with implications for underpinning environmental management decisions.

The PEP III activity was initiated in December 1993 during a small meeting held in Bern, Switzerland, which brought together 13 scientists representative of different geographical regions and scientific disciplines. The fundamental ideas developed during this meeting have provided the basis for the PEP III project (PAGES-PANASH Report). A community workshop held in Sfax, Tunisia (April, 1995) further refined the specific PEP III objectives and established the background for PEP III organization. The Paris-Bierville meeting that forms the main concern of the later parts of this report summarized the main achievements, the organizational structures and the research strategies of PEP III as currently conceived.

A major logistic challenge for PEP III is the need to redress the geographic imbalance in paleoclimatic information between the intensively studied areas of Northern and Western Europe and the much less fully researched areas of Eastern Europe, the Middle East and Africa. The problem of imbalance is compounded by political complexity and, in some cases, extreme poverty and a consequent lack of scientific infrastructure and manpower. The need to mobilize international resources to synthesize existing data, to retrieve new, high quality information from data-poor regions within the transect and to coordinate the whole into a coherent picture of climate change and environmental responses is paramount both for improving climate models and for assessing the human implications of climate change over parts of the planet that include regions of high population density and exceptional vulnerability.

The human dimensions and human implications of environmental change along much of PEP III lend an urgency to the task for PEP III researchers, but at the same time they create some of the most difficult obstacles for reconstructing the history of natural climate variability and its impact on terrestrial and aquatic ecosystems. In regions of long human occupancy, the problem of disentangling the history of climate change from that of human impact becomes most severe. For many of the changes observed in the paleorecord, the question is to document and understand the interaction between the two, their reciprocal influences and their synergies.

Applying the PAGES time streams to PEP III provides a framework for the research proposed.

2.2 Time Stream I

Within PAGES Time Stream I, the last 2000 years, there is some differentiation between the goals, opportunities and temporal resolution appropriate to the last few centuries and those appropriate to the longer time span. For example, the most recent time intervals provide scope for calibration of proxy records against instrumental and documentary records, as well as for intercalibration between seasonally or annually resolved proxies such as tree-rings and laminated sediment records. On the longer timescale, temporal resolution ranging from seasonal to decadal opens up the possibility of reconstructing the spatial and temporal expression of fluctuations of longer periodicity as well as of assessing more fully the interplay between human activity and climatic change. In many parts of the PEP III transect, the span of significant human impact on landscapes and ecosystems extends well beyond the last 2000 years and even beyond the period over which external forcing, sea-level, atmospheric composition and ice extent have been broadly comparable to the base-line values immediately preceding the most recent anthropogenic influences. There is therefore a strong case for extending the Stream I approach to at least the last 6000 years wherever possible.

Within this time frame, some of the intriguing questions posed for PEP III scientists include the following:

• Can we establish to what extent the timing and magnitude of changes in vegetation and hydrology in Europe and Africa since the first human impact on the landscape have been induced by climate change or human activity?

• What was the latitudinal extent of the "Little Ice Age" and the "Medieval Warm Period" phenomena and how does their expression vary along the transect?

• To what extent do variations in insolation find expression in the patterns of temperature and hydrological changes along the transect?

• Can we reconstruct the longer term history of the North Atlantic Oscillation (NAO), and to what extent does the evidence support current views about the nature and operation of the NAO?

• What light can paleoresearch shed on the origin, development, immediate antecedents and future prospects of areas experiencing or currently threatened by desertification and serious land degradation?

• How does the history of the Nile floods compare with other data from Eastern Mediterranean region and elsewhere?

• How does ENSO influence African climates? How do the historical records of African lake level fluctuations from the northern and southern tropics compare with one another?

2.3 Time Stream II

Questions framed within the longer PAGES Time Stream II, the last two glacial cycles, are also of vital importance for they open up the issues of climate variability under very different boundary conditions, both during the periods of glaciation and during the period of late- and post- glacial readjustment. It endows outstanding significance in attempts to validate model simulations of past climate under different, or changing boundary conditions:

- How did Northern Europe respond to climate change? How did changes in ice sheet extent, North Atlantic sea surface temperatures (SST) and thermohaline circulation modify European climate and hydrology?
- What was the magnitude of climate changes from the Atlantic to Eastern Europe in response to changes in the northern ice-sheet extent and during the current interglacial?
- How do inter- and intra-continental seas (Aral, Caspian, Black and Mediterranean seas) and the large East African lakes register global change, and how do they influence on regional climate?
- To what extent do long term changes in the Mediterranean region parallel those to the north forced largely by eccentricity variations or those in lower latitudes, reflecting a stronger influence from precession-linked forcing?
- What is the role of the Sahara-Arabia desert belt on aerosol loading and atmospheric transmissivity? What feedback mechanisms may arise from changes in surface conditions over the present day desert regions?
- How have African and Indian monsoon climates varied in the past? Were the variations synchronous? What was their impact on human populations?
- How did changes in vegetation and wetlands at low latitudes affect trace gas concentrations in the atmosphere?
- How did Southern Africa respond to changes in: (i) the extent of the Antarctica ice sheet and sea-ice in the Southern Ocean, and (ii) the strengh of the oceanic thermohaline circulation?
- What contribution can paleoscience make to a better evaluation of groundwater resources in parts of the transect where they are heavily exploitated?

3. ORGANIZATION AND ACTIVITIES

3.1 Coordination strategy

Project organization depends on two types of coordination, one on a regional/national basis and a cross-cutting one on a thematic/methodological basis. Both are essential to mobilize and integrate scientific effort.

For coordination activities at the national/regional scale, the network includes 25 scientists from 20 countries. National working groups have been established in several countries.

PEP III is developing thematic/methodological working groups in order to encourage the development of standard methodologies, and work towards comparison and integration of data. Important systems that should be considered include:

Climate-human activity interactions (Time Stream I)
• Instrumental, historical and documentary records
• Annual (to decadal) records in all archives and domains (especially tree rings, ice cores, speleothems, lake and nearshore marine sediments and peats)
• Archaeological records.

Time Stream I and II
• Glacial and periglacial archives of climate change
  - The Fennoscandian and Greenland ice sheets;
  - Permafrost, loess, and fluvial records;
  - Mountain glacier systems.
• Hydrological indicators of climate change
  - Speleothem transects (SPEP III);
  - Lake and nearshore marine sediments;
  - Groundwater as an archive of paleoclimate.
• Terrestrial biological indicators of climate change
  - Pollen records;
  - Others (for example macrorests, peats).

Some of these themes, such as the northern ice sheet history and modeling and pollen data, are already developed within other paleoclimatic programs, with which PEP III will work in close collaboration.
The goal of PEP III is to promote the study of "non traditional" but potentially powerful proxy sources, and to develop transects for interhemispheric comparisons.

3.2 Ongoing research

The 'Paleomonsoon' and 'IDEAL' initiatives are key sub-components of PEP III.

The former is the subject of an earlier PAGES publication, "Paleomonsoons in Africa and the surrounding oceans: the last 200 000 years", and of a recent workshop report included within this volume dealing with the proceedings of the SIWA Meeting in January 1997. A special issue of *Global and Planetary Change* will appear as proceedings of this meeting.

IDEAL, the 'International Decade for the East African Lakes' is described in PAGES workshop report 93-1. Both Activities, along with PEP III as a whole are described in the PAGES Implementation Plan published by IGBP in 1998. The IDEAL web site (http://lrc.geo.umn.edu/IDEAL/) provides updates on their progress to date. IDEAL also publishes a newsletter available from (http://lrc.geo.umn.edu/IDEAL/bulletin/). An important step in fulfilling the educational and capacity-building role of IDEAL has been taken with the launching of the Nyanza project, funded by the US NSF (http://www.geo.arizona.edu/nyanza/). This is an African lake study program in which U.S. undergraduate students and young African researchers will study tropical lake science in a summer program based in Tanzania, on the shores of lake Tanganyika, for the next five years. This 'Research experience for undergraduates' program will be based at the Tanzania Fisheries Research Institute facilities in Kigoma, Tanzania. At the same time, the program faculty will run an identical course for young African scientists with funding and research support from the United Nations Global Environmental Facility. The joint Nyanza project fulfills part of the training mission of IDEAL.

Several other tasks related to PEP III are currently being developed within national, European, and international projects. Some of the multi-country projects represented at the Paris-Bierville meeting or recently developed, are listed below. This list is neither exclusive nor exhaustive.

Glacial and periglacial records

- The ESF-EU QUEEN project (Quaternary Environments of Eurasia North), which aims to reconstruct the maximun extent of ice sheets in Northern Russia;
- The UNESCO-IGCP 358 "Circumalpine glacier systems";
- The UNESCO-IGCP 415 "Late Quaternary Glaciation in Asia: its extent and impact on continental hydrology and drainage systems", which aims at integrating data on glacial and periglacial phenomena in Northern Europe and their effect on Eurasian hydrology during the Last Glacial Maximum. This project includes a working group on the Aral-Caspian-Black Sea drainage system.

Hydrological indicators of climate changes

• Lake records

- The ESF-ELDP (European Lake Drilling Program) project, currently centered on laminated lake sediments in Western Europe;

- The EU-INCO "Understanding the Caspian Sea erratic fluctuations" project;
- The INTAS "Climate change and Lake Sediments in South Asia and Southern Kazakhstan" project;
- The KOPAL project (KOnya basin Paleoenvironmental project) which focuses on high resolution lacustrine records in Turkey;
- The EU-INCO CASSARINA (ChAnge, Stress and Sustainability: Aquatic ecosystem Resilience In North Africa) project;
- The EU "Rukwa" project (lake drilling in Tanzania);
- The EU-EDDI (European Diatom Database Initiative) project,

• Groundwater records;
- The EU-ENRICH GASPAL (Groundwater AS continental PALeoindicator) project, which is currently assembling data from the Sahel;
- The groundwater database currently being developed at IAEA (International Atomic Energy Agency, Vienna);
- The EU "PALAEAUX-Management of Coastal Aquifers in Europe" project;

• Past and present isotopic composition of precipitation;
- ISOMAP (Continental Isotope Indicators of Paleoclimate), an international project connected with the IAEA and now incorporated within PAGES;

Terrestrial biological indicators of climate change

- The EU project "Tree-Rings across Northern Eurasia";
- The European Pollen Database (EPD) was developed with EU-funding in relationship with the North American Pollen Database, and can be considered as a model of data organization in a relational database. It has archived an enormous pollen dataset covering the northern section of the PEP III transect. Tertiary pollen data are available for PEP III research in the EPD center (CEREGE-Aix, France), at MEDIAS-France (Toulouse) and at WDC-A (Boulder, USA). All required information (data, and metadata) is stored in appropriate form and is easily retrievable.
- An African Pollen Database (APD) is currently under development. It will include pollen data to the southern most extent of the PEP III transect.

3.3 Meetings

Recent meetings addressing PEP III thematic and/or regional activities include:

• The PAGES-GeoforshungsZentrum Workshop (Potsdam, Germany; June 1995) and the PAGES-Lake Drilling Task Force meeting (Washington, DC; October, 1995) helped to define standard methodologies for drilling and lacustrine core studies, select high priority sites and develop a 5-year plan for lake drilling along the PEP transects. The outcome of these meetings includes PAGES workshop report (No. 96-2 "Continental drilling for paleoclimatic records") and a proposal to the International Continental Drilling Program (ICDP) for drilling lakes along the transect;

• The first steering committee of the European Lake Drilling Program (ESF-ELDP/PEP III), Strasbourg, March 1995;

• The Paleomonsoon project meeting, in conjunction with the INQUA Congress,

Berlin, August 1995;
• A two day PEP III-PEP II Symposium, as part of the International Geographical Union Congress, Moscow, August 1995;
• The Symposium "Middle East Desert. Past, Present, Future" supported by UNESCO, Yarmouk University, Jordan in July 1996;
• The Bergen Symposium "Climate Change: the Karst Records", Bergen, Norway, August 1996, which can be regarded as the first SPEP (Speleothe-mail: Pole-Equator-Pole) meeting;
• A meeting to organize an African Pollen Database, Paris-Bierville, September 1996, preceding the PEP III Bierville meeting;
• The Paleomonsoon project meeting, Siwa, Egypt, January 1997;
• The INQUA Symposium "Late Quaternary paleoclimate in the Eastern Mediterranean", Ankara, April 1997;
• The first two plenary meetings of the European Lake Drilling Program (ESF-ELDP/PEP III), Strasbourg, October 1996; Cracow, November, 1997;
• The first meeting of the IGCP 415 "Late Quaternary Glaciation in Asia: its extent and impact on continental hydrology and drainage systems", Tallinn (Estonia), June 1997;
• The first plenary meeting of the EU-ENRICH GASPAL (Groundwater AS continental PALeoindicator), held in Avignon, France, 16-18 February 1998.

4. RECOMMENDATIONS FOR METHODOLOGIES

4.1 Developing training sets and databases for biological indicators

The goal is to develop transfer functions which can be easily applied by a large number of scientists and at large geographical scales to infer past environmental and climatic variables:
• It is a central task of the European Diatom Database Initiative (EDDI) project to combine reference diatom data sets already available for Europe and Northern Africa. Work is also needed to fill the gaps currently existing for eastern countries, Mediterranean regions, and Southern Africa;
• Chironomids also represent a powerful paleoenvironmental tool; calibration data sets should be developed over the next few years;
• The construction of the African pollen database is an important step within PEP III. It also reflects significant progress towards completing the existing geographical coverage of the Global Pollen Database, available at WDC-A (Boulder, USA).

4.2 Promoting isotope studies

In PEP III, heavy reliance is placed on stable isotope records which can be derived from a wide range of environmental archives, especially groundwaters (which may also provide paleoprecipitation isotopic composition), lake sediments and peat, speleothems, and fossil wood.

• ISOMAP (Continental Isotope Indicators of Paleoclimate) is of special importance in PEP III. It is designed to map and model the isotopic composition of past and present global precipitation. ISOMAP is seen as an opportunity to focus the efforts of the isotope hydrology and paleoclimate community towards a more effective use of oxygen isotope tracers in climate research. It will enhance interaction between researchers especially between the paleodata and climate modeling communities;

• In lake sediments, most isotope records derive from primary inorganic or biogenic carbonates, e.g. ostracods. Diatom-rich lacustrine sediments abound in the volcanic areas along the PEP III transect. Recent studies have demonstrated that the ^{18}O content of lacustrine diatom silica can be used successfully to infer past environmental changes. If both carbonate and silica are available, the combination of the two isotope records can become a powerful tool for inferring past water temperature and lake water isotope composition, which depends on the water source and evaporation rate;

• Heavy carbon content in plant material can provide insight into the ecological impact of past variations in hydrological stress and atmospheric CO_2, provided that the analyzed fraction is identified (e.g. specific molecular biomarkers);

• Whatever the material analyzed, calibration data sets are major requisites for quantitative interpretation of past environments.

4.3 Specific constraints for Time Stream I - lake studies

In many parts of the PEP-III region the recent lake sediment record is strongly influenced by human impact. Proxy methods for climate change, therefore, need to focus on:

• approaches that might be independent of human impact, e.g. stable isotope measurements;

• sites where climate signals can be identified separately from human impact, e.g. diatom plankton variability and cycling;

• sites that are sufficiently remote from human impact for it to be discounted, e.g. mountain and arctic lakes.

4.4 Annually laminated lacustrine sediments

Besides the importance of annually laminated sediments for providing absolute chronology, studies of the varves themselves may provide unique information on climatic variability. The composition of individual laminae may document seasonal changes. Varve thickness may allow the detection of short-term periodicities in the hydrological cycles, such as those induced by ENSO or the NAO. Lakes with annual laminations are common along the PEP III transect, especially in the Northern Hemisphere.

4.5 Dating methods

Dating and chronological control cannot be overemphasized. This is true even for radiocarbon-ages and for their calibration with the sidereal calendar.

As elsewhere, dating sediments beyond the applicability limit of the radiocarbon method is a crucial problem. The PEP III transect is particularly rich in data sources with potential for applying and/or testing other dating methods. Laminated lake sediments, Swedish varve clays, tree rings, speleothems, and corals all provide an actual calendrical chronology. Measurement of the ^{238}U decay series provides long-term reconstruction of speleothem growth history. Radionucleides, such as ^{10}Be can be successfully used for dating moraines. The evolution of the world's largest sand dune fields can now be investigated by thermoluminescence and optically stimulated luminescence dating. The sedimentary chronology in the numerous crater lakes along the transect can be obtained by applying the $^{40}Ar/^{39}Ar$ method to interbedded tephras. Considerable progress has been made recently in tephrochronology in Western Europe. The volcanic regions of West Africa, East Africa and Madagascar are also potentially suitable for developing such a dating approach.

4.6. The multi-proxy, multi-site approach

It is essential that the multi-proxy approach be developed and emphasized.

• any single proxy data source is limited in its ability to represent environmental or climatic variations. The use of mutually constraining results, e.g. comparison of paleoprecipitation values inferred from pollen transfer functions and lake modeling, is thus recommended;

• use of multiple proxies from a single site (or region) may enable estimates of climate parameters that cannot be obtained using individual data sets in isolation. This has been illustrated for instance by constraining the modern pollen data set using lake level status to reconstruct European paleoclimate at 6 ka;

• different records respond to different climate parameters, and different systems or sources respond with different lags to climate change;

• regional comparisons can serve to enhance specific results from particular sites, while at the same time eliminating disturbances induced by local effects.

5. PEP III WORK PLANS

Although they await future funding, plans for fully implementing specific PEP III integrative activities are as follows.

5.1 Thematic activities

We propose to focus our activities around the following four themes over the next few years.

5.1.1 Climate-human activity interactions

The aims are to provide:
1) a specific perspective focusing on the identification of human impacts on paleoclimate systems, and work towards developing methodologies for disentangling human influences from the 'natural' evolution of climate change recorded in various high-resolution proxies;
2) opportunities to explore the interactions between anthropogenic and climate forcings and their joint impacts on terrestrial and aquatic ecosystems;
3) a specialized forum bringing together and comparing high-resolution records derived from different research disciplines with an emphasis on extreme events such as past volcanic eruptions.

Although questions about the links between human modification of the environmental and climate systems are specifically addressed by PAGES-Time Stream I (the last 2 k years), we extend this scope to define the ecosystem variability on annual (seasonal) to decadal timescales throughout the entire Holocene period, as explained above.

Within this timeframe, numerous proxy sources are required for the reconstruction of climate and climate-forcing, and for the rigorous analysis of interactions between climate and anthropogenic effects. Such proxies include instrumental records, historical and documentary records, tree-rings, ice cores, speleothems, lake sediments, marine/large lake/inland sea sediments, peats and archaeological records. Reciprocal collaboration between paleoscientists and archaeologists will be emphasized. Areas of proven archaeological potential for paleoenvironmental reconstruction occur widely in Europe, the Mediterranean and Africa. However, special attention should be paid to Africa (the Nile Valley, East Africa, Madagascar and South Africa) where fewer "conventional" bases for reconstruction are available.

5.1.2 Periglacial processes: permafrost, loess and fluvial records

A large number of paleodata are available for reconstructing variations in natural climate change in Europe over the past glacial/interglacial cycle. Results may help disentangle the respective contributions of the ice sheet, the oceans and the continent on European climate. Short-term, low-amplitude climate changes over the past 30 kyrs, as well as extreme events of varying frequency at several individual sites are well represented in many proxy records. Considerable advances have been made in the qunatitative, climatic interpretation of terrestrial proxy-data.
Assembling this information is a first priority. However, the climatic significance of several proxies remains to be fully analyzed. The climatic thresholds at which specific proxies show a distinct reaction have yet to be defined. This is in particular the case for periglacial records.

The aims of the working group are to:
1) define the contribution of periglacial environments to the quantitative or semi-quantitative reconstruction of climatic parameters (temperatures, precipitation, wind direction). More specifically, the paleoclimatic significance of wind activity (loess, coversands and paleosols), permafrost (including ground ice), cryogenic sedimentary structures and river activity, should be analyzed;
2) make this information suitable for storage in a regional database linked to the Boulder WDC-A, taking into account standards of data quality, degree of quantification, and precision and reliability of dating;
3) define methodological and geographic gaps limiting our ability to answer PEP III climatic questions.
4) bring together Western and Eastern European scientists in a collaborative work program, and develop links between PEP II and PEP III through the Eurasian continent.

5.1.3 Hydrological changes: implications for paleoclimate and water resource research

Groundwater as paleoclimate archive

Under favorable conditions, subsurface waters may record antecedent climate and environmental change in their chemical and isotopic signatures. In particular, groundwater may provide ground temperatures and the isotopic composition of precipitation that recharged the aquifers. Research on groundwater is of special relevance in arid and semi-arid areas of the transect, where there are few potential "classical" indicators for paleoclimate and paleoenvironment. Furthermore, groundwater research acts as a guide for present-day resource assessment.

The compilation of existing information from Northwest Africa is already being undertaken (IGBP-START grant support for PEP III). In collaboration with the International Atomic Energy Agency (IAEA), the EU-ENRICH GASPAL project developed within PEP III is designed to collate and asses the existing information on groundwater systems in the African Sahel region. This will be used to link groundwater records with other "conventional" archives of global change. The combination of groundwater and lake records in the Sahara and the Sahel should help to explain apparent discrepancies between proxies which show high lake water-level, and numerical models which do not simulate significant monsoon rainfall increase in the Sahara at 6 ka. Groundwater chemistry and isotope content should provide relevant information on the source of the water vapor over the Sahara.

The Sahelian data will be complementary to the EU-PALAEAUX project which deals with the investigation of aquifers in Western Europe coastal regions to evaluate the impact of sea level lowering during the Late Pleistocene. PEP III will also ensure close connections with the groundwater database currently maintained by the International Atomic Energy Agency (IAEA, Vienna, Austria).

Speleothem proxy data (SPEP III)

It is now acknowledged that well-dated, precise records from speleothems provide a valuable source of paleoclimate data. This source is geographically widespread throughout the transect, from Norway to South Africa, and from West to East. It complements other, traditional records. Work needs to be done to calibrate the signals employed for inferring climate parameters (i.e. stable isotopes and band thickness), to replicate samples as a check for how strongly the hypothesized forcing factors are represented in each series from a single site, to understand the signal representativeness and to integrate data along the transect.

A crater lake transect from North to South

Crater lakes are especially valuable sources of past environmental change for both time stream I and time stream II.
They have special attributes:
1) they are especially common in Africa and Europe;
2) they have a simple basin morphology that favors rapid, conformable sediment accumulation, and that enables comparisons of environmental records between sites;
3) they have relatively small catchment areas of uniform topography and geology, facilitating the understanding of linkages between allogenic sediments and catchment sources;
4) they have a comparatively simple hydrological budget dominated by the balance between precipitation and evaporation. Inflows and outflows are usually small and water residence times are long, favoring maximum retention of both autogenic and allogenic sediment fractions in the lake;
5) many have annually laminated sediments, allowing accurate dating and enabling rates of change to be calculated;
6) although some lakes are quite young, many are very old, containing records of multiple glacial-interglacial cycles.

Work is required to review existing work, and analyze how crater lakes and crater lake sediments can be used to:
1) generate quantitative, high resolution records of environmental change;
2) compare records of climate variability within and between climate systems along the PEP III transect;
3) bring together European and African expertise in a collaborative work program.

5.2 Coordination and cross-disciplinary linkages

Multi-disciplinary meetings are necessary for:
• maintaining awareness throughout the PEP III community of the results of individual PEP III-related projects,
• bringing together PEP III regional/national efforts,
• assembling proxies from PEP III thematic activities,
• ensuring connections with other scientific programs, especially with other PEP and PAGES foci, multi-proxy mapping (PMAP) and modeling activities (PMIP, PAGES/CLIVAR Intersection), IMAGES, and the IGBP-GCTE transects (Miombo network, the Kalahari Megatransect, and the planned Scandinavian transect SCANTRAN).

5.3 Data integration and management

Relevant data, derived from a diverse range of proxies, form a mosaic of sites along the transect. The data are currently stored in different information systems and formats. Data sets include both calibration data sets (from which transfer functions can be derived by statistical methods), and fossil data sets to which transfer functions are applied for inferring past environmental variables. PEP III datasets should be stored at the World Data Center-A for Paleoclimatology in Boulder, Colorado (WDC-A). But in addition, a PEP III internal data system closely connected with the WDC-A should be made available in order to:
• develop the necessary structure to integrate different proxy records;
• establish a robust chronological framework for inter-site comparisons;
• evaluate and select the most appropriate statistical techniques for transfer functions and core-correlation;
• make information available along the transect easily retrievable to PEP III scientists.

5.3.1 Development of a multi-proxy database structure

The first step consists in laying out the structure of a database able to incorporate a wide range of proxy records in both time and geographic dimensions. Efforts in this direction have already been undertaken, for example by using pollen and lake-level records interactively. However, such efforts need to be extended. Concepts of such a multi-proxy database are already in progress; they will be further developed in close collaboration between European and WDC-A scientists. We will not seek to duplicate existing databases, but incorporate and build on them, by providing a mechanism for linking between existing databases. We will start from the EPD pollen database structure, and then incorporate other sources of data.

The two criteria for the structure of the database are the need to mix different types of data, and to retrieve the data easily. As several scientists often work on the same sites, we are able to develop and test this capability, starting with some sites that are already rich in a diversity of proxy data, e.g.: Tigalmamine, Morroco (diatoms, pollen, geochemical indicators, climatic reconstructions from pollen); Taillefer, French Alps (pollen assemblages, tree-rings, beetles assemblages, charcoal remains).

As the very same parameters, can be derived from many different sources, there are often discrepancies. Thus, estimates of uncertainties for both raw (primary) data and for any transfer functions used are very important.

5.3.2 Development of methods for numerical analysis of multi-proxy and multi-site datasets

Currently accepted methodologies have to be revisited for a sound implementation of PEP III. This type of evaluation has already been undertaken within PALICLAS (EU project "Paleoenvironmental Analysis of Italian Crater Lake and Adriatic Sediments" - see the "PALICLAS, Memorie dell'Istituto Italiano di Idrobiologia, Vol. 55" at http://www.iii.to.cnr.it/mem55.htm) and includes:

• development of a robust chronological framework for inter-site comparisons

Comparison and correlation of different proxy records, and the past paleoenvironmental events inferred from such records depend on an accurate and robust chronological framework. Although errors associated with individual dating techniques are now reasonably well-known, their propagation in the construction of age-depth models, and their effect on the identification of synchronous events is poorly understood.

• techniques for core-correlation

A range of methods exist, but they still need careful evaluation using different types of proxy-data.

• integration of different proxy-records

One major problem in managing and analyzing multi-core data is that samples are inevitably recorded at different "equivalent" depths in different cores. Even when data is derived from the same core, the nature of the various analyses, and their requirements for varying amounts of sediment, mean that few analyses are carried out on the same sediment intervals throughout the core length. A range of interpolation methods exist for the harmonization of such records, which must be done before any subsequent statistical analysis.

PART II: THE PEP III WORKSHOP

Bierville, France, 12-15 September, 1996

Sponsored by:

- the Past Global Changes (PAGES) Core Project of the International Geosphere-Biosphere Program (IGBP),
- the Global Change System for Analysis, Research and Training (START) project,
- the European Lake Drilling Program (ELDP), European Science Foundation (ESF),
- the Centre National de la Recherche Scientififique (CNRS), France,
- the US National Science Foundation,
- the INQUA-PAGES Paleomonsoon project,
- MEDIAS-FRANCE.

Organized by:

- MEDIAS-FRANCE,
- the Groupe de Recherche Paléohydrologie, Paléoclimatologie Continentale, GDR 0970, CNRS, France

1. SYNOPSIS

1.1 Meeting description

The purpose of the meeting was to stimulate, prioritize and coordinate the work of paleoenvironmental researchers in the region of the PEP III transect, in line with the intentions set out in the PANASH project document (PAGES Report, 95-1) and the PAGES Implementation Plan. It aimed to:

• refine the implementation plans for Time Stream I and Time Stream II,
• strengthen the development of thematic working groups,
• stimulate the development of regional PEP III coordinated regional activities,
• lay the ground work for ensuring effective data management and integration,
• ensure linkages with other PAGES activities.

The meeting brought together 78 scientists from 24 countries.

Some thirty oral communications were presented as well as a comparable number of posters. The oral presentations (i) summarized the state-of-the-art in relation to the major scientific questions addressed in PEP III, (ii) focused on the poten-

tial contribution of specific regions and/or archives, (iii) summarized results of PAGES-IDEAL and the PAGES-INQUA Paleomonsoon projects; (iv) highlighted linkages within and outside the PAGES framework.
The posters illustrated scientific results from specific sites and/or methods.

Working group meetings were held to: (i) refine the implementation plans in relation to Time Streams I and II, (ii) develop thematic working groups for specific archives and establish strategies for improving their efficiency along the PEP III transect, (iii) discuss the organization of PEP III activities at regional and national scale.

A series of recommendations emerged which are outlined in the section that follows.

Many valuable reports and individual contributions were presented during the meeting and subsequently forwarded to the editors. Unfortunately, the sum is too large to be published in full in the present volume. Therefor, only reports from three key working groups are reproduced in full in section 2 of this workshop report.
The remaining contributions are listed in section 3 and can be seen in full via the PEP III link on the PAGES Web Site (http://www.pages.unibe.ch/). Anyone wishing to obtain copies of these contributions may also obtain them from the PAGES IPO, Bärenplatz 2, CH 3011, Bern, Switzerland.

1.2. Recommendations

1.2.1 Priorities for Time Stream I studies within PEP III

The working group defined the following priorities:
• A major focus of PEP III Stream I research should be to establish the degree to which 20th century climates are unprecedented. This must involve quantitative reconstruction of past mean climates on multi-decadal and century timescales as well as interannual variability and the frequency of extremes.
• There remains a widespread preconception that the Little Ice Age (LIA) and Medieval Warm Epoch (MWE) were ubiquitous features of the climate history of the last two millennia. There is still a need to further clarify the definition of these concepts in terms of their character, extent and precise timing, even within Europe. More research is required to establish the extent to which the concepts of the Little Ice Age and Medieval Warm Epoch are relevant in other areas of the transect. The relationship between climate variations across the transect and the record of potentially important forcing factors should also be investigated. This should include studies of SST variations in relation to rainfall anomalies, especially in the Tropics. Future research must attempt to clarify whether, the LIA and MWE phenomena represent unique events within the last 2000 years, and, if possible, within the context of the Holocene as a whole.

• Traditionally, high-resolution studies within the Stream I timeframe have been very much concentrated in the mid-to-high latitudes of the northern part of the PEP III transect. In part, this reflects genuine difficulty in locating datable, high-resolution records in low latitudes and in the African part of the transect. The existence of numerous, long tree-ring chronologies in Morocco is an important exception. Some potential for other dendroclimatological studies in North and East Africa has been clearly demonstrated and the future development of this potential should be explored.
• Given the problems of identifying annually resolved paleorecords in Africa, there is a need to explore other less-well-resolved sources of information, particularly where they might be represented across wide areas of the transect. The concept of a specific research initiative aimed at exploring climate proxies in the sediments of a series of African crater lakes along the East African section of the transect is considered worthy of prioritization.
• Even in Europe, there is important potential for identifying and processing historical and early meteorological records. Some paleoseries, produced decades ago, now require updating.
• More research is required in order to identify and gauge the significance of anthropogenic environmental disturbance and the implications for paleoclimate estimates calibrated against modern climate data.
• Collaborative projects, which involve comparison and an integrated approach to the interpretation of different climate proxy sources in areas where these are available, are not common. More projects should be initiated that bring together paleoclimate scientists working with different systems (e.g. with ice core data, tree rings, lake sediments).
• Archaeological data have been under-utilized in a paleoclimate context. Collaboration between archaeologists and paleoclimatologists, especially in areas with a tradition of detailed high-resolution archaeological work and historical and paleoclimate proxies, should be promoted. Several regions, in the Mediterranean and in monsoon areas (particularly in Egypt) and in the South of Africa, are potential foci for such efforts.
• More attention to formal calibration studies and a routine quantitative evaluation of paleoclimate data and reconstruction confidence limits, are encouraged, as is the establishment of standard 'calibration training sets', such as could be used for the interpretation of widespread data, such as chironomids.
• Intense attention to accurate chronology is encouraged in situations where absolute dating is not feasible. This might involve multiple dating proxies.
• Work to establish a detailed network of tephra histories in the circum-North Atlantic region and the possibility of developing a widely applicable tephra chronology to provide fixed dating points for many less-well-resolved data sources is noted.
• Studies within Time Stream I should not be constrained by the 2000-year limit if longer timescales within the Holocene can be embraced with equivalent precision and accuracy.
• The further development of the European paleodata archive in Marseille (linked to the World Data Center-A for Paleoclimatology in Boulder) is seen as fundamental to the feasibility of achieving the aims of PAGES PEPIII Stream 1. Universal submission

of paleodata and the free interchange of these data through the medium of the PEPIII data archive is crucial for the future success of Stream 1 research.

1.2.2 Priorities for Time Stream II studies within PEP III

The following priorities were identified:

- PEP III should focus on assembling and/or reassessing proxy data on the Last Glacial Maximum (ca. 21kyr BP) and the mid-Holocene period ca. 6kyr BP, especially in Africa, for enlarging collaboration with the PAGES PMIP, PMAP and Biome 6k projects.
- More research is required to disentangle the respective contributions of the ice sheet, oceans and continental influences on climate change in Northern Europe. The climatic significance of permafrost, cryogenic sedimentary structures, loess and river activity is not fully analyzed yet. Special attention should be paid to periglacial processes.
- Efforts should continue to compile existing data and to develop a coordinated framework of paleodata sites in Eastern and Central Europe. This has already been undertaken in the framework of the European Pollen Database, the INTAS project "Climate change and Lake Sediments in South Asia and Southern Kazakhstan", the UNESCO-IGCP 415 "Late Quaternary Glaciation in Asia", and the EU-INCO project dealing with the history of the Caspian Sea.
- High resolution study of the penultimate interglacial period is recommended, because it provides a potential analogue for future climate during the current interglacial. Potential sites already recognized are crater lakes from Italy and the French Massif Central, which should also help analyze the continental response to the Heinrich and Dansgaard-Oeschger events.
- The timing of the last deglaciation in Africa has to be reassessed in order to establish whether or not major temperature and hydrological changes were synchronous in the southern and the northern tropics, as recently suggested by some marine records.
- In the tropics and subtropics, studies of the catchment basins of major rivers and their marine deltas (Nile, Senegal, Niger, Congo, Zambezi, Tigris, Euphrates) are encouraged in order to better understand material transfer to the sea through time. This task is to be developed in collaboration with IMAGES.
- The history of the major African biomes (equatorial forest, tropical dry forest, savannas, and wetlands) needs detailed research, in order to understand the role of tropical regions in the carbon cycle and their influence on the chemical composition of the atmosphere and its aerosol content.
- Acquisition of long-term climate records in Africa is an utmost priority. The large rift lakes will be investigated in the framework of IDEAL. In addition, numerous smaller lakes, especially crater lakes, also contain high resolution, long-term archives that can be investigated.

1.2.3 Subsurface waters as archives of paleoclimate

The working group report (see below) and individual papers highlight the importance of subsurface waters as archives over major parts of the PEP III transect. Despite their relatively poor temporal and spatial resolution and inevitable uncertainties in chronological control, noble gas and stable isotope records from the saturated zone, notably from confined aquifers, have been used to provide vital quantitative data for testing GCM reconstructions of past climate, especially for the Last Glacial Maximum. There is also a strong possibility that chlorine profiles from the unsaturated zone may provide important paleohydrological records in cases where the essential criteria are met. These criteria relate to the depth of the unsaturated zone between root layer and capillary fringe, the moisture content of the unsaturated zone, virtual absence of water mixing and a reasonably constant input of chlorine over time. The main overall conclusion of the group was to re-emphasize the special importance of subsurface water studies in large parts of the transect where few other reliable archives exist. The formation of a Subsurface Water Working group will ensure the further development of research in these areas.

1.2.4 Recommendations on other particular archives and proxies

Several presentations were devoted to the role of particular archives in the PEP III transect.

• Peat deposits occur in Northern-western Europe, at high altitude in tropical environments and in lake margin environments, e.g. as papyrus swamps. Rainwater-fed peatlands are currently under investigation as indicators of past variations in surface wetness, hence hydrological balance. They and other types of peat contain a wealth of biological and geochemical indicators of past environmental conditions. Moreover, they often have advantages over lake sediments when it comes to establishing chronologies by either radiocarbon or tephra analysis. Their main role will be on Stream 1 or at most mid- to late-Holocene timescales, though there are exceptions. The importance of replicating results in order to distinguish climatic responses from those reflecting site-specific effects was stressed.

• Several papers illustrated the importance of pollen analytical information across the whole range of timescales and throughout the transect. One of the key developments associated with the meeting was the establishment of an African Pollen Database to complement the well established European Pollen Database. This opens up access to data across the whole range of PEP III and promises to make possible much more widescale development of pollen-based paleoclimate reconstructions.

• One of the most promising concepts for development within PEP III is a transect of high resolution speleothem records (see below for detailed report). Such records are available from the whole of PEP III from 69°N in Arctic Norway to 34°S in South Africa. They provide the basis for both detailed chronologies (Th/U) and strong climate-related signatures from stable isotopes, growth laminae and organic matter. In order to exploit the limited resources of speleothem archives in a way that both maximizes their value within PEP III and respects the need for conservation, the Speleothem PEP (SPEP) has been launched as a special initiative.

• The paleorecord in loess and related aeolianite sediments is also of importance within PEP III. The best known loess deposits within the transect are mostly within Eastern Europe and many of these are currently under intensive study, especially from the point of view of their magnetic properties. Although discontinuities and pedogenic overprinting make these archives less attractive than the classic Chinese loess sections, these are nevertheless of considerable interest, especially where they can be closely linked to other paleoarchives. Moreover, other loess sequences, for example in France and Tunisia, may provide comparable sequences within the Stream II timeframe. There is a need to establish a database of presently known and investigated loess sections so that regional comparisons can be made and key sites and time intervals targeted.

1.2.5 Data storage and management

The meeting also gave preliminary consideration to the issue of data storage and management. Key points that were emphasized included:

• compatibility with the World Data Center A/PAGES database in Boulder, Colorado
• development of a PEP III communication node at MEDIAS-FRANCE
• the need to optimize links with existing databases such as those developed to exploit data within a particular disciplines
• the desirability of creating an open and easily accessible relational database
• the over riding importance of broadly based community discussion and consent in the creation, control and administration of a PEP III database.

The difficulty of compiling a comprehensive database for the PEP III transect is fully realized, but so is the need to progress towards a culture of greater data sharing, timely access and internationally available archives. That this can be achieved on a more modest scale is illustrated by the PALICLAS project summarized in one contribution listed below. Given a sufficient emphasis on chronology, on quality control at the stage of data input and on the mutual compatibility of data derived from different sources and available from different data banks, the key goals can be achieved.

1.3 National and regional groups

Alongside the thematic working groups, PEP III has established national and regional working groups. Reports from these were presented and their importance emphasized, especially in the context of Eastern Europe. One of the most exciting regional developments is the establishment of the PAGES Regional Research Center at the University of Nairobi, Kenya. This center is working with START to implement a modern, efficient data and information system that will more effectively link African paleoscientists with the world wide community through electronic communications. One of the central research tasks of the PAGES RRC is its contribution to the coordination of the East African Lakes (IDEAL) program, though it also has an important research role in relation to the GCTE Miombo transect and study of paleomonsoon phenomena in Africa, crater lakes and the whole wealth of paleoarchives in the region.

1.4 Linkages to other activities

1.4.1 PEP III and PMIP

Presentations at the meeting and subsequent sessions at the recent European Geophysical Society Meeting in Vienna have begun to highlight the importance of parts of the PEP III transect within the Paleoclimate Modeling Intercomparison Project (PMIP). The primary aim of PMIP is to determine the extent to which the simulated results from AGCM's (Atmospheric General Circulation Model) are model dependent. The main focus is on simulations for the Last Glacial Maximum (ca.21kyr BP) and the mid-Holocene period ca.6kyr bp. One of the most dramatic findings so far is that although there is reasonably good comparability between the output from different modeling groups for the 6kyr 'snapshot', there are serious discrepancies between the model reconstructions and the paleodata. This is most clearly apparent for the Sahara/Sahel region where the models fail to reconstruct conditions consistent with the paleorecords of high lake levels at this time. This in turn has provided an improved basis for parameterization of the models, using more realistic terrestrial biospheric and hydrological boundary conditions for the region. The task of reconciling models and data is far from over and this single example shows how crucial data from PEP III are for making the best possible combined use of data and models to improve eventual predictive capability.

1.4.2 PEP III, PMAP, Biome 6k, and the pollen databases

The PMAP Project, the Global Lake Level Database, the European Pollen Database and the African Database were presented during the meeting, as well as major results of the Biome 6k project on climate reconstruction in Europe. The already engaged collaboration with these projects should be pursued, especially through data management and integration efforts.

1.4.3 PEP III and IMAGES

Presentation of the IMAGES project showed how reciprocal benefits could be gained by joint efforts in the study of nearshore environments. IMAGES activities already realized or planned in the Indian Ocean, the tropical Atlantic Ocean and along the Scandinavian shore should provide important insights for analyzing ocean/ continent environmental interactions. Collaboration has already been undertaken along the coasts of Southern Africa, where the cold Benguela Current along the southwest coast and the warm Agulhas Current to the east strongly influence the climate in the interior of the continent.

1.4.4 PEP III and megatransects through Africa

Several presentations showed that a useful exchange of information and ideas can be expected between the PEP III project and large-scale initiatives involving sustainable management of natural resources in Africa; such as the Miombo network and the IGBP-GCTE Kalahari megatransect. Of further relevance is the INQUA-PASH project (Paleoclimates of the Southern Hemisphere). The German initiative ACACIA (Arid Climate, Adaptation and Cultural Innovation in Africa) will also bring important insights on both natural and anthropogenic environmental changes along a transect which runs from the Nile delta to the Namibian desert.

1.4.5 PEP III and IAEA

The IAEA representative provided an overview of the existing global network for isotope values in rainfall, and presented the state-of-the-art in groundwater research along the transect. The IAEA holds a considerable amount of published and unpublished data which can be made available for PEP III purposes.

2. KEY WORKING GROUP REPORTS

2.1 Report of the Stream 1 working group

CONVENORS: K. BRIFFA, R. BATTARBEE, P. SINCLAIR

Introduction

This group was charged with reviewing the potential sources of qualitative, high-resolution evidence of climate variability and climate change on interannual, decadal and century timescales along the PEP III transect within the last 2000 years. The group discussed the specific strengths and limitations of various types of climate proxies and reviewed their temporal and spatial coverage. A principal aim of the group was to re-examine and, where possible, redefine major foci for PEP III Stream 1 activities in the medium term, taking account of ongoing initiatives, identifying new opportunities and highlighting possible geographical imbalances. The following is a brief description of the outcome of the discussions around these topics, including a summary of the major conclusions and recommendations of the group. An expanded review and discussion document, in the form of a revised implementation plan for PEP III Stream 1 activities, is currently being prepared.

Rationale and general objectives

The group recognized that the particular importance of general Stream 1 activities, within all PEP transects, arises from the need to define accurately the history of climate variability on interannual and decadal, as well as longer, timescales. Well-dated, high-resolution climate information from before the period of possible human modification and for sites where human modification over the last 2000 years has been minimal, is essential if we are to understand the mechanisms of natural climate change and rigorously ascribe causes. It follows that there exists a concomitant need to establish quantitatively, and with equal accuracy, the histories of potential climate forcing agents - such as changes in solar output and volcanic activity. The reconstruction of both climate and climate-forcing histories within the Stream 1 timeframe is also highly relevant for attempts at rigorous attribution of recent climate change to anthropogenic causes.

In parallel with the general ambitions of all PEP transects, the group therefore defined the ultimate aims of PEP III Stream 1 activities as follows:
1) To document the full range of climate variability that has taken place across the Western Eurasian and African continents over the last 2000 years.
2) To identify factors responsible for causing climate change.
3) To provide datasets for the parameterization and validation of climate models.
4) To explore the influence of climate change on human activity and the influence of human activity on climate change.

To accomplish these objectives requires sensitive methods because the likely magnitude of change is considerably less in recent millennia than on longer, timescales. It was also agreed that studies within Time Stream 1 should not be constrained by the 2000-year limit if longer timescales within the Holocene could be embraced with equivalent precision and accuracy.

Important 'systems' and proxies

The history, current state and prospects for future development of a number of major sources of paleoclimate and paleoenvironmental information were discussed. The group focused attention on their major strengths and known weaknesses and ex-

plored the immediate prospects for better exploiting these sources and extending the geographical range within the PEP III transect. These sources and the specific proxies that they provide will be discussed in more detail in the forthcoming Stream 1 implementation plan.
They include:
1) Instrumental records
2) Historical and documentary records
3) Tree rings
4) Ice cores
5) Speleothems
6) Lake sediments
7) Marine/large lake/inland sea sediments
8) Peats
9) Archaeological records

A PEP III perspective

Though the primary axis of interest in PEP III activities is defined north to south, the east/west dimension is significant in terms of the large distances across Europe and Africa and because of the existence of large climate gradients.
Localized records that provide well-calibrated climate information are valuable in their own right, the more so where they are of high-resolution (seasonal or annual) and where the dating is good. Even more valuable are similar records or data sources that occur along one or more parts of the PEP III transect, or better still, that have extended spatial or network coverage across large regions.

While recognizing these optimum data attributes, the group felt strongly that the development of data sources that meet only some of these criteria was still to be encouraged. All proxy data sources are limited in different ways in their ability to represent climate variations and a multi-proxy approach to paleoclimate research is most likely to yield maximum results. Different records will respond to different climate parameters. Comparison of different records will identify similarities and differences, providing either mutual support for, or raising questions and suggesting alternative interpretations of, the different data. The multi-proxy approach should highlight individual data limitations; in some cases allowing refinement of the dating control; provide better understanding of the time-averaged or lag responses, and generally lead to a more accurate and complete picture of climate changes than can be achieved using individual data sets in isolation.

Regional foci

To optimize resources, taking account of ongoing research projects and recognizing the current geographical imbalance in traditional regions of high-resolution paleoclimate research, the group recommended a number of areas where future research might be usefully concentrated. Above all, these are regions of major importance within the global climate system. Instrumental records and modeling studies indicate that climate variability in each of these areas is influenced by characteristic large-scale modes of variability of the general atmosphere or the interaction of the atmosphere with the oceans.

The regions identified were:

1) The mid-to-high-latitude section (~north of 60°N) of Fennoscandia and Western and Central Russia
2) Western Europe and the Mediterranean regions under the influence of the North Atlantic Oscillation
3) Monsoon effected areas of West Africa
4) Northeast Africa and the Nile Valley
5) Southern Africa and Madagascar

An archaeological emphasis

Until now, there has been little mention in Stream 1 discussions of the potential for generating past climate information through the use of high-resolution historical and, particularly, archaeological data. Archaeology and PEP III Stream 1 studies in general, will gain reciprocal benefits through a greater emphasis on selected archaeological studies and increased collaboration between archaeologists and paleoclimate scientists. Both require an understanding of how people have impacted on the natural environment, not least in order to interpret proxy climate data. Initiating the development and study of these data in areas of high archaeological potential will be invaluable for understanding human responses to climate and other environmental change. Though such studies are feasible throughout the PEP III transect, they should be especially encouraged in areas where there is known potential to generate high-resolution data in space and time (annual-decadal).

Areas of proven archaeological potential occur widely in all parts of Europe, the Mediterranean and many parts of Africa. However, the group identified the following selected list.

1) The Nile valley
2) East African highlands and coast
3) Madagascar highlands and coast
4) Southern Africa

The background and specific rationale for highlighting these regions will be outlined in detail in the forthcoming PEP III Stream 1 Implementation Plan. These regions coincide with most of the regions already identified as important potential regional research foci.

Important methodological issues

The group reviewed a number of issues of relevance to the interpretational 'value' of paleoclimate sources in general. The group consensus was to encourage explicit recognition among research workers of the importance of six specific topics. It was felt that experimentation with different paleoclimate sources should attempt to address each of these issues explicitly and that direct reference to their particular significance be included in reports or research publications dealing with those sources.

Resolution

The desirability of high resolution paleodata has been stressed already. True annual resolution and, where it can be achieved, subannual resolution offer the prospect of specific seasonal reconstruction of climate and evidence of the range of the annual cycle. Some records may, however, be annually or sub-annually resolved, but may only reflect climate forcing at a specific time of the year. Conversely, annually registered data may still only reflect longer-term climate forcing, integrated over a number of years.

Every effort should be made to establish the true resolving power of the data and the extent to which the resolution varies in time. While recognizing the desirability of annual or subannual resolution, the systems where decadal resolution can be attained, e.g. many lake and mire systems, are also of value, particularly where tephrochronology might provide additional precise links to other time series.

Dating and chronology

The importance of strong dating control, particularly within the context of Stream 1 studies, cannot be overemphasized. The value of statistical techniques for testing the association between different climate reconstructions, or between deduced climate variability and evidence of forcing agents, is highly dependent on accurate chronology. Even where paleorecords are deposited annually or display annual layering, simple counting of the layers does not guarantee absolute dating accuracy. Some individual year boundaries may be ambiguous. In any individual record, depositional discontinuities or hiatuses or post-depositional disruption can occur. Where practical, comparisons of duplicate records at a site, or from adjacent sites, can confirm the dating accuracy or identify anomalies and enable the timescale to be corrected. When annual dating control is not feasible for a particular record, comparison with features of other, better-dated records may improve the chronology. Again, where feasible, multiple approaches to dating should be adopted. Where there is uncertainty in the dating, this must be clearly expressed.

The group laid great stress on the desirability of adapting multiple approaches to dating time series in situations where absolute chronology is not routinely attainable. In this respect it was felt that the continued development of tephrachronologies and studies intended to explore the potential of using specific tephras as absolute dating horizons or time markers in many ice, lake, peat or other paleodata sources should be noted.

Replication

Analyzing multiple or replicate samples of some proxy data record, besides helping to establish good dating control in the timeseries, is highly desirable because it provides a basis for quantifying the underlying signal strength represented in that record. Even perfectly dated, duplicate, records will not agree perfectly. The degree of similarity, however, will give an indication of how strongly the underlying forcing is represented in each series. The degree of difference is an indication of 'noise'. Averaging replicate series (provided they have good dating control) will reduce the noise and produce a record which better expresses the underlying forcing. Because so much more information can be gleaned from duplicated records and higher, quantifiable confidence achieved by producing a mean series, duplicate sampling should be undertaken wherever possible.

Calibration

Climate inferences drawn from paleodata should be supported by rigorous comparisons with observed meteorological data. Statistical regression equations or transfer functions applied to high-resolution paleodata series to estimate past climate variability, should be calibrated in the time domain and not be based only on spatially-derived relationships. Where possible, empirical or statistical approaches to inferring past climate variability should be supported by theoretical modeling studies. Realistic confidence limits on paleoclimate estimates should be provided.

Signal representativeness

Researchers should strive to make explicit the potential weaknesses or limitations in the representativeness or accuracy of their past climate inferences based on their detailed knowledge of the paleodata and systems with which they work. For example, some records may represent high-frequency (interannual) climate forcing with good fidelity, but be limited in their ability to represent the same forcing on longer timescales, perhaps because the systems are able to adapt to gradual changes in forcing. Longer-timescale variations may, of necessity, be removed in the production of a paleorecord perhaps because the primary data are known to be influenced on these timescales by processes other than the climate forcing of interest. Separate calibrations of a paleorecord after spectral decomposition might highlight differences in the fidelity of the climate interpretation on different timescales. However, the short length of many available climate records will limit the extent to which even decadal-to-century timescale fidelity can be demonstrated.

Human impact

It is possible, even probable, that instrumentally recorded climate data are already registering anthropogenic disturbance of the 'natural' climate system. In addition, many other aspects of the natural environment have been modified by humans. In some localized areas this may have occurred over thousands of years. On much larger, even global scales, changes in atmospheric and terrestrial environments have certainly occurred over the last century. These include increasing concentrations of greenhouse gasses, heavy metal pollution, and nitrogen and sulfur deposition. Reductions in stratospheric ozone and ensuing increase in surface ultraviolet radiation levels have been dramatic in recent decades. The potential for these and other factors associated with human activities to complicate the calibration of paleodata against modern instrumental records must be appreciated. The degree to which any or a combination of these might affect the long-term validity of modern paleodata/climate associations will be difficult to establish. The relative importance of different factors will obviously vary greatly according to the data source, and the specifics of the physical or biological systems involved. Still, future work must aim to provide quantitative answers. A combination of statistical, theoretical and experimental approaches will almost certainly be required.

2.2 Report of the working group: "subsurface waters as archives of paleoclimate"

CONVENORS: M. STUTE, K. ROZANSKI, A. DODO, C.B. GAYE, C. MARLIN, J.L. MICHELOT, Y. TRAVI, B. ABOU ZAKHEM, K. ZOUARI AND G.M. ZUPPI

Introduction

During the past decades, the interaction between subsurface waters and climate has been firmly established, mainly in the context of water resources management and development. Numerous studies have shown that subsurface water archives climate information. Most have focused on water in the saturated zone (groundwater). However, under favorable conditions in dry regions, climate signals can also be recovered from the unsaturated zone. Subsurface water archives act as a low-pass filter, and may provide low-resolution, quantitative, reconstructions of temperature, precipitation, and moisture transport patterns.

Climate indicators

A multitude of tracers has been used in the saturated and unsaturated zones to indicate of past climate conditions. Widely accepted indicators are the isotopic ratios of $^{18}O/^{16}O$ and $^{2}H/^{1}H$, dissolved atmospheric gases (neon, argon, krypton, xenon, and nitrogen), radiocarbon (^{14}C), and chloride. Stable isotope data (^{18}O and

^{2}H) from groundwater have been used to reconstruct temperature, precipitation, and atmospheric moisture origin and transport patterns. They may also be used to determine the isotopic composition of paleoprecipitation, which can be treated as an integrating hydrometeorological parameter. Atmospheric noble gases and nitrogen dissolved in groundwater allow the reconstruction of paleotemperatures on the basis of the temperature dependence of the gas solubilities in water. ^{14}C frequency histograms have been used to identify wet and dry periods in the past. Chloride in the unsaturated zone has been studied intensively to reconstruct aridity.

Besides these established tools, the potential of numerous additional indicators are presently being studied. Examples include ^{13}C, Br/Cl ratios and ^{36}Cl.

Subsurface waters as archives of paleoclimate

The use of the groundwater archive is restricted to the past 35,000 years, because of the lack of a dating technique beyond the range of the ^{14}C method. Due to the complicated hydrochemistry of inorganic carbon in subsurface waters, uncertainty in chronology can be as large as several thousand years. In addition, inherent characteristics of subsurface flow, such as diffusion, dispersion, as well as mixing induced by the sampling process, smooth the recorded climate information in time and space. The temporal and spatial resolution of these archives is a function of the scale of the system and certain hydrogeologic characteristics of the particular site and can vary between 5 to several thousand years and 10m to 10km, respectively. In the unsaturated zone, for example, paleoclimatic conditions (drought or high rainfall events) on a decadal time scale may be preserved in a record typically reaching back 50 to 500 years. The characteristic smoothing of climate information has disadvantages and advantages for paleoclimatic reconstructions. While it may not be possible to resolve an event like the Younger Dryas in a groundwater record, it is possible to quantify the average magnitude of the glacial/interglacial climate change, without interference of the signal by local effects or short-term extremes.

Not all unsaturated and saturated flow systems are suitable for paleoclimate reconstructions.
Ideally, the following criteria should be met:
unsaturated zone:
low recharge rates, large thickness of the unsaturated zone, homogeneous lithology, preferably sand or sandstone, non-fractured;
saturated zone:
known flow regime, known recharge area, little mixing, porous aquifers, preferably sandstone, horizontal extension of the order of 50-100 km, and availability of high quality wells.

Scientific issues

One of the key scientific issues that can be addressed by paleoclimate data from subsurface waters is the verification of climate models. Groundwater flow systems, in particular, archive parameters that can be mapped such as temperature, precipitation, as well as ^{18}O and ^{2}H in paleoprecipitation. The fields can be directly compared with climate models. In fact, in arid regions, water in the saturated and unsaturated zone may be the only climate indicators available!

Recommendations

Subsurface water database

Many data on subsurface waters have been obtained for water resources management purposes. As such they are not easily accessible and their interpretation is not uniform. A collection of the available data in a digital database should therefore be undertaken. The format of the database should be compatible with other PAGES databases and should include present-day hydrologic information in addition to paleohydrological data.

The Isotope Hydrology section of the International Atomic Energy Agency (IAEA) is currently setting up a database along similar lines, and efforts may be joined. An advisory panel should be established and organizations involved in past or ongoing studies along the PEPIII transect should be encouraged to contribute data to the database.

New paleoclimatic records

There are large gaps in paleoclimatic data coverage along the PEPIII transect, particularly in Africa and the Middle East. A number of sites should be revisited and newly developed methods applied to derive paleoclimate records. In additions, efforts should be made to identify new sites to fill the existing gaps in the center of the transect (e.g. Syrian desert, Continental Intercalaire, Complexe Terminal, Oligocene-Miocene aquifer, Senegal).

Research

Research aimed at the improvement of current techniques and the development of new tracers and methods should be encouraged.

Working group

A subsurface water working group has been established to coordinate database and field study efforts. An informal meeting of the group was held during the IAEA

International Symposium on Isotope Techniques in the Study of Past and Current Environmental Changes in the Hydrosphere and Atmosphere, April 14-18, 1997 in Vienna. The ongoing EU-ENRICH GASPAL project (Groundwater as continental paleoindicator) is a key component for developing research in Sahelian Africa. A series of specific workshops should be planned for the future. The working group will establish close links to programs such as PMIP, GNIP, ISOMAP, and PAGES' local centers.

2.3 "SPEP: the speleothem record in the Pole-Equator-Pole transects"

CONVENOR: STEIN-ERIK LAURITZEN

Introduction

The purpose of this report is to describe the ideas behind the SPEP ("Speleothem-PEP") project, and to provide some practical advice on speleothem sampling and analysis.

Well-dated, precise multi-proxy records that are now becoming available from speleothems provide a valuable source of paleoclimate data. This source is geographically widespread, represents the non-marine environment and complements other, traditional records.
Speleothems (stalactites and stalagmites) occur mainly in carbonate and evaporate karst caves, but also occasionally in non-karstic (i.e. granite) caves. Research during the last 20 years has demonstrated that speleothem stratigraphy yields various types of data that are potential proxies for paleoclimate analysis: very precise (Th/U) chronology, stable isotope signals ($\delta^{18}O$, $\delta^{13}C$, $\delta^{2}H$), growth laminae, and organic matter, like pollen and humics. Also, speleothems can yield valuable data on sea-level, erosion rates and landscape evolution. Moreover, karst is a globally widespread phenomenon, so that the same type of material (and proxies) can be studied from geographically diverse situations. Along the SPEP-III transect, good quality speleothems are available for relatively dense sampling from Northern Norway (69°N) to Southern Africa (34°S). It is also possible to sample along E-W transects in order to study oceanic-continental sensitivity contrasts in speleothem-derived parameters. The corresponding PEP I and II transects have the same possibilities.

Speleothems as paleoclimatic recorders

Speleothem growth and the hydrological cycle

Precipitation of speleothems occurs when percolation water supersaturated in CO_2 enters a cave gallery. Supersaturation is in most cases accompanied by degassing of CO_2, because (due to ventilation effects) the cave atmosphere in general has a lower pCO_2 than the soil atmosphere above the cave from where the CO_2 is sourced (Ford & Williams 1989).

Speleothem growth is impeded by low temperatures (permafrost and subglacial flooding, e.g. Lauritzen (1995)) and draught. It is stimulated by increased precipitation and increased soil CO_2 production. In this sense, speleothem precipitation is climatically controlled and it is part of the hydrological cycle *(Figure 1)*. This has consequences for time-dependent growth of speleothems and for the stable isotope signal that is preserved in speleothem calcite and associated fluid inclusions.

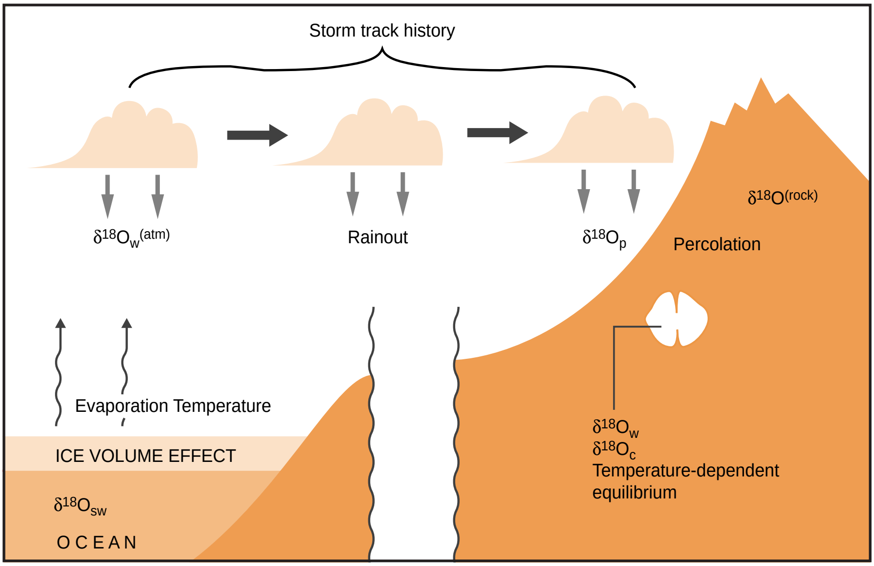

Figure 1
Speleothem precipitation, stable isotopes and the hydrological cycle. Speleothem deposition is dependent on the amount of and the degree of supersaturation in the dripwater. The dripwater itself is derived from meteoric water. Isotopic signals (and other climatic proxies) in speleothems are a function of the local and regional surface climatic conditions, but are filtered through the percolation system.

Fluid inclusions represent samples of paleogroundwater or paleoprecipitation (δ^2H and possibly also $\delta^{18}O$) that are precisely dateable. The $\delta^{18}O$ signal in speleothem calcite reflect cave and surface temperature conditions, e.g. (Schwarcz, 1986). The $\delta^{13}C$ signal contains information on variations in plant cover (i.e. C3 and C4 plants) and the conditions of calcite precipitation, so it is not often possible to present unique interpretations (Schwarcz, 1986). However, in areas where obvious shifts from C3 to C4 plants have occurred, such as in temperate or tropical humid-arid transitions, broad interpretations may be justified (Holmgren et al. 1995; Bar-Matthews et al. 1996).

Dating methods

Provided sufficient uranium content is available (i.e. >1 ppm), the $^{230}Th/^{234}U$ dating technique can yield very precise ages. A-particle spectroscopy may yield 1σ errors of 5 ka at 100 ka old samples, while thermal ionization mass spectrometry (TIMS) may, due to much higher count rate, yield 1σ errors down to 500 years on 100 ka old samples.

TIMS also requires less material so that smaller time intervals become integrated in the dated subsamples. Macrocrystalline, non-porous speleothems that show no signs of recrystallization and insignificant detrital ^{232}Th contamination (which otherwise would violate the assumption made with respect to the initial condition of the radiogenic clock) are best suited for the TIMS method. The $^{230}Th/^{234}U$ dating technique yields calendar years directly.

^{14}C dating may, in some cases, be applicable to speleothems. This is however dependent on the initial dead carbon dilution factor being calibrated against $^{230}Th/^{234}U$ dates, and is therefore hardly worthwhile. For very young deposits, that may be used for correlation with historical records, ^{210}Pb dating is possible. This has been successively done on soda-straw stalactites (Baskaran & Illiffe, 1993).
The best test available for radiometric dates (U-series) is stratigraphic order. TIMS dates sometimes reveal violations on stratigraphic order and age in samples, where the older, rather imprecise a-particle spectroscopic techniques have failed to indicate it. This is not surprising, and almost expected when considering the extremely high precision available with TIMS. The external precision in TIMS needs to be checked against coeval and homogenized subsamples.

The stable oxygen isotope signal in speleothem calcite

Often, but not always, the deep cave temperature is equal to the surface annual mean surface temperature at the site (Wigley & Brown 1976), and hence the stable isotope signal of the calcite may be expressed as (Dorale et al. 1992a; Lauritzen 1995):

$$\delta O^{18} = e(a/T2\text{-}b)\ [F(T,g,t) + 10^3] - 10^3 \qquad (1)$$

where a and b are constants of the O'Neil equation (O'Neil et al., 1969), and the dripwater function, F(T,g,t), is a function of temperature (T), geographic position (g) and time (t). The t- and g- dependencies are intended to describe time- and site- dependent changes in stormtrack patterns (rainout) and changes in the source (seawater) due to the ice-volume effect (Lauritzen 1995). F(T,g,t) also includes any averaging or biasing taking place when rainwater (or snow meltwater) passes down through the vadose zone before it enters the cave. Therefore, the problem of paleotemperature deduction is to find an approximation to F(T,g,t) that is valid for past climates and longer timespans. In its simplest form, the Dansgaard (1964) relationship may serve as an approximation of F(T,g,t):

$$F\ (T,g,t,) \approx c(T - 273{,}15) + d + \Delta\delta^{18}O_{sw}\ (t) \qquad (2)$$

c and d are site-dependent constants. The last term is added to model the time-dependent ice-volume effect. Provided that the constants c and d can be calibrated, equations (1) and (2) can be solved uniquely for T. This has been attempted on a Holocene stalagmite from North Norway (Lauritzen 1996), and results are depicted in *figure 2*. This record, which is only calibrated against the estimated temperature (and stable isotope) shift between the present and the Little Ice Age (LIA) does show a remarkable correlation with botanically and glaciologically derived temperature curves (Nesje & Kvamme 1991), when the much lower time-resolution of the latter records are taken into account (Lauritzen 1996). Also, the more prominent spikes in the speleothem paleotemperature record *(figure 2)* show correspondance with tree-ring and timber-line fluctuation data from Northern Sweden, and with ice-core data (e.g. GISP2).

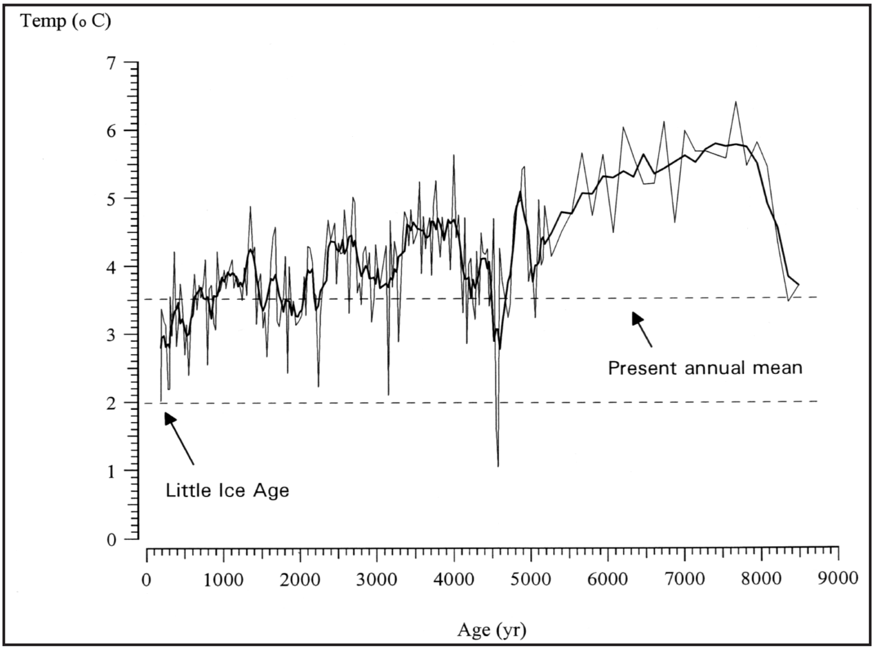

Figure 2
Calibration of the speleothem dripwater function over time for north Norway yield an absolute temperature estimate for the site which on the 100-500 year scale compares quite favorably with other (botanical-glaciological) data (Lauritzen, 1996).

Growth band analysis

It has been known for almost 50 years that speleothems display annual growth layers, in many ways similar to trees (Genty & Quinif, 1996). An example is shown in *figure 3*. From the kinetics of calcite deposition, it may be deduced that speleothem growth rate, and thereby band thickness, is controlled by drip rate and supersaturation (Dreybrodt, 1988, 1996). This theoretically based statement has to be tested in each individual locality using between-sample correlation and absolute dating, as well as testing against historical, instrumental records. Crystallographic fabric and micro-facies analyse have recently revealed further details on the nature and origins of various types of growth bands (Frisia, 1996; Gradzinski et al., 1996a, b; Hercman et al., 1996b).

Growth bands (or stone-rings) may be studied at a variety of scales, either using optical, gray-scale analysis (Quinif et al., 1994), or luminescent micro-band analysis (Shopov et al.,1989, 1994; Baker et al., 1993a), or preferably both methods in combination (Genty et al., 1996).

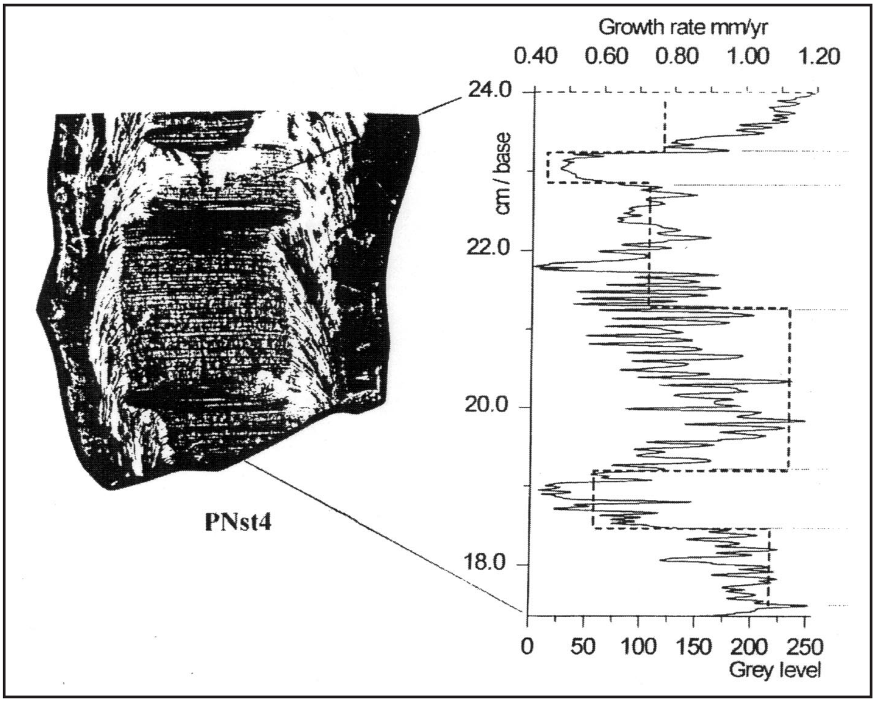

Figure 3
Example of optical growth-band analysis using the grey-scale values of individual pixels (Genty et al., 1996). This makes it possible to measure and count individual growth bands. The same technique can be applied on the microscopic scale, using luminescent bands (Shopov-bands).

Collective properties

The growth of individual speleothems may be affected by local factors, such as variable thresholds in dripwater hydrology (Smart & Friedrich 1987; Baker et al., 1995). On the other hand, the collective properties of speleothem growth through time should cancel out local effects. Given a sufficiently large sample, the distribution of speleothem ages through time approximates the volume of calcite deposited through time. Such distributions (histograms or PDF plots) can indicate that speleothem growth was not continuous through time.

Speleothem ages tend to cluster into time-windows that correlate broadly with warmer periods in the upper Pleistocene (Harmon et al., 1975; Gordon et al., 1989; Baker et al., 1993b; Lauritzen, 1993). The clustering is very distinct at high latitudes (i.e. North Norway (Lauritzen, 1993)), and tends to merge into a more continuous record at lower latitudes (Hercman et al., 1996a; Lauritzen & Onac, 1996; Lauritzen et al., 1996), indicating the paleoclimatic gradients that controlled speleothem growth.

Sea level history

On carbonate islands and coasts, submerged karst caves may contain speleothems that were deposited in periods of lower sea-level. U-series dating and detailed stratigraphic analysis of time sites have yielded very precise chronologies for sea level history for the last 250 ka (Gascoyne et al., 1979; Li et al., 1989; Smart & Richards, 1992; Richards et al., 1994).

Strategy of SPEP

Calibration: Holocene and historical records

As shown in the stable isotope example of *figure 1*, and also with respect to interpretation of growth band analysis, it is essential to calibrate the system against historical records before extrapolation is done. Certain paleoclimatic situations (e.g. glacial/ interglacial transitions) may be so radically different from those of today (violating eqn(2)), that simple extrapolation becomes invalid, and less precise methods must be applied (Schwarcz, 1986, 1996).

Multi-proxy records

A central consensus within PEP III is to select sampling sites where multiple and diverse proxy records are available. Speleothem records should preferably be one such record. The interpretation of certain aspects of speleothem stratigraphy will also benefit by this approach. For example, some types of speleothem micro-banding are interpreted as variation in content of humus-derived organic matter (fulvic acids, or aquatic humus), which should reflect soil development. Peat sequences within the catchment area for the studied speleothems can yield an independent record of the soil development at the site.
Furthermore, there is a vast but unexplored potential of correlating speleothem growth bands with tree-rings.

Data consistency

The growth of individual speleothems is sometimes controlled by local factors. For example temporary blocking of the feeding stalactite, or re-routing of the percolation pathways may cause a growth hiatus. Therefore, speleothem sequences should be tested for reproducibility within-site on parallel samples before correlation between sites are attempted. This demand must to some extent be weighted against conservational aspects of the site.

Practical aspects

Technology

In order to attain a sampling strategy that is as sustainable as possible with respect to the cave environment, some workers have drilled cores from stalagmites and flowstones (Dorale et al., 1992b; Holmgren, 1995). Also, in temperate and tropical sites, speleothems may become so huge that coring is the only alternative. In most cases, there is a logistic limit to the length and size of cores that can be extracted in the field, and 1-inch or even thinner cores have been taken. Testing for isotopic equilibrium growth according to the Hendy criteria (Hendy, 1971) by look-

ing at isotopic systematics along single growth bands is almost impossible on 1-inch cores, unless additional cross-cores are taken along growth bands.
Thicker cores take much more energy and time to extract, but would be preferable on certain flowstone deposits. There is a need for new technology that can provide lightweight, portable drilling or cutting devices for remote cave locations.

Conservation issues

SPEP is a double-edged sword, because too much enthusiasm will erase the limited data bank it is intended to harvest from. The cave environment is a unique and limited resource that is much more vulnerable to various anthropogenic impacts than other, more traditional paleoclimatic archives. Cave conservation is an important issue among all speleologists, whether they are recreational cavers or cave scientists. Less than 10 years ago there were only a handful of seasoned cavers who kept up the faith in speleothems as paleoclimatic proxies, and sampled them with great care. Today, the population of speleothem stratigraphers are at least an order of magnitude larger, and the pressure on vulnerable cave formations proportionally higher.

Local knowledge, quarries and show caves

Fieldwork must be done in close contact with local conservational authorities and speleological clubs. Detailed field information can help to avoid the most vulnerable sites. It is therefore strongly recommended to preferentially sample from quarries, or to take samples that are already broken and/or situated out of common view. During development of show caves, large amounts of speleothem must sometimes be removed or moved, and cooperation with cave owners may yield very good samples. In return, the display value of the show cave will benefit from the results of the paleoclimatic study.
Speleothem database. In order to diminish vandalism and avoid duplicate sampling, it has been suggested to establish a database on existing speleothem samples. In this way, one may find out if a given site or region has been sampled, by who, where these samples are stored, and if any results are published. The first elements of the speleothem database is found at http://www.ex.ac.uk/~abaker/stal.html.

3. TITLES OF ADDITIONAL REPORTS AND INDIVIDUAL CONTRIBUTIONS

The following is a full list of the additional reports and individual contributions presented at the Paris-Bierville meeting and subsequently forwarded to the editors. All are available either via the PAGES web site (http://www.pages.unibe.ch/) or by request from the PAGES IPO, Bärenplatz 2, CH 3011, Bern, Switzerland.

PEP III general tasks

• Report of the working group: "PEP III studies in the African monsoon domain" - summarized by H. Lamb

Specific proxy sources

• "Proxy records from peat deposits" - Fraser Mitchell
• "Loess and paleosols" - John Dearing

Linkages to other activities:

• Paleoclimate Modeling: the Paleoclimate Modeling Intercomparison Project (PMIP) - S. Joussaume, P. Braconnot, V. Masson, N. de Noblet, S. Pinot, G. Ramstein
• The African Pollen Dabase creation - reported by A.-M. Lézine
• IGBP and INQUA projects in Southern Africa - L. Scott
• The German ACACIA project - presented by S. Kröpelin

Regional paleoclimatic changes and multi-proxy approaches

• Variations in Natural climate over the past 130 ka along a N-W European transect as a basis for upgrading GCM's (EPECC) - J. Vandenberghe
• Holocene lacustrine sequences: An example from Baldeggersee, Switzerland - L. Teranes and J. A. McKenzie
• Groundwater as Archive of Paleoclimate: example from Central Europe - M. Stute
• Paleoclimatic data from Eastern Europe: state of the research - Velichko A.A., Tarasov P.E., Borisova O.K., Klimanov V.A., Kremenetski K.V., Nechayev V.P., Zelikson E.M.
• PALICLAS - F. Oldfield
• Cyclic Sedimentation in Lake Albano, Italy: A High Resolution Window Into Latest Pleistocene Climate Change - C. Chondrogianni, D. Ariztegui & J. A. McKenzie
• Pollen in the Mediterranean region - S. Leroy
• A German-Israeli research program on the Dead Sea: Palynological and sedimentological record of lake level and climate changes in the Dead Sea area (Israel) during the last 3,000 yr - S. Leroy
• Archaeology and Paleoclimatic Resarch: Egypt as a Case Study - Fekri A. Hassan
• Past half Millenium climatic and hydrological changes in the Sahel derived from unsaturated zone profiles - C.B. Gaye and W.M. Edmunds

• The paleoclimatology of equatorial Africa: how the rain forest responds to global changes - Jean Maley
• A Late Pleistocene-Holocene climatic record of the southern tropics: Lake Tritrivakely, Madagascar - F. Gasse, E. Van Campo, E. Gibert, F. Laggound-Défarges, D. Williamson.

National-regional nodes
• PAGES Regional Research Center established at the University of Nairobi, Kenya - Eric O. Odada
• The Paleoclimate research in Czech Republic-A review. State of the Scientific society and State of the art - summarized by V. Cilek.
• PAGES and PEP III in Italy - D. Magri
• PEP-related activities of the Laboratory of Limnogeology, ETH Zürich, Switzerland - presented by D. Aritzegui.

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PART III: THE PALEOMONSOON WORKSHOP

"Continental signals of paleomonsoon dynamics in Africa: inter-hemispheric perspectives" Workshop report and recommendations for research

Siwa, Egypt, 11-22 January 1997

The joint workshop of the INQUA-PAGES paleomonsoon project and the cooperative research project 389 (ACACIA) on "Continental signals of paleomonsoon dynamics in Africa: inter-hemispheric perspectives" was held from 11-22 January, 1997 in Cairo and at Siwa oasis, Egypt.

1. BACKGROUND AND RATIONALE

Paleomonsoons are an important sub-system of past global climates and one of the major controlling factors of environmental change in the tropical and sub-tropical zones of Asia, Africa and Australia. Monsoonal variations had and have important socio-economic implications due to the density of population in these regions.

Fluctuations in monsoon circulation have been associated with significant and sometimes abrupt changes in rainfall, temperature and aerosol dynamics. Records of past monsoon variations probably still provide the most reliable basis for predicting future climate trends in the tropics.

Recent marine and terrestrial paleoresearch suggests synchronous variations in Holocene monsoon circulation affecting the lower latitudes of the Northern Hemisphere from the Western Atlantic to Central Asia and beyond. These data have been discussed in a region-by-region approach at previous workshops in Kenya, China, Germany and Venezuela, which focused on the paleomonsoon systems of Africa, Asia, the Americas and their adjacent oceans respectively.

While marine research of the past few decades has provided continuous and high-resolution data for the late Quaternary climatic history of the oceans, it is often not clear to what extent these records have been reflected in the terrestrial paleoenvironments of the continents. Knowledge of continental conditions, especially during the Holocene, is crucial for greater understanding of human responses to climate change, for the development of possible paleoanalogues of future climate change and for improved scenarios of future changes and their impact.

Another research priority is an interhemispheric comparison of continental paleoclimates. Africa provides a good test case because it is the only continent that is more or less symmetrical at lower latitudes on either side of the equator. A wealth of new terrestrial data provides a base for such an approach.

2. OBJECTIVES

The aim of the workshop was to critically assess and interpret the continental signals of paleomonsoon-related phenomena in Africa and Australia since the Last Glacial Maximum, with special emphasis on interhemispheric comparisons.

The 20 participants from nine countries who attended the workshop were welcomed by Théodore Monod who presided at the meeting. Monod's pioneering desert research in the Western and Central Sahara reaches back to the 1920's.

Stefan Kröpelin, coordinator of the Paleomonsoon project, outlined the objectives of the workshop which can be summarized as follows:

- definition of "African monsoons";
- interhemispheric comparison of terrestrial proxy records from the Last Glacial Maximum to the present on the African continent, if possible on a century scale or better;
- indications of abrupt changes in the paleomonsoon system;
- synchronous or asynchronous patterns of climatic variation in Africa;
- comparisons with Australia;
- relationships between climate dynamics, biology, human settlement patterns and cultural evolution.

3. OPENING SESSION

Ulrich Schotterer, from the PAGES CPO in Bern, discussed the background of PAGES and the reasons for its existence. He also addressed the importance of bringing together modelers and field researchers.

Daniel Olago from PAGES Africa indicated that the center in Nairobi is intended to facilitate research exchange between African and non-African scientists and to set-up a database based on the needs of the scientific community. He also mentioned that an increasing number of African Universities are using or realizing the potential of the Internet as a research tool.

Rudolph Kuper, of Köln University, described the topics of research covered by the Cooperative Research project 389 "ACACIA" (Arid Climate, Adaptation and Cultural Innovation in Africa): Holocene environmental and climatic change in Northeastern Africa; history of environment and settlement in Southwestern Africa; crisis management and survival strategies in Southwestern Africa; development of pastoralism in Africa. The project's principal objective is interregional comparisons of the two arid zones in Africa, both of which are influenced by monsoons.

The series of presentations which followed were divided into four general sessions covering: Northern Africa, Eastern Africa, Southern Africa & Australia and Meteorology & Modeling. In the fifth and final session, research perspectives and objectives as well as the outcome of the workshop were discussed.

3.1 Northern Africa

Nicole Petit-Maire's (Marseille) presentation **"Holocene Precipitation over the Present-Day Sahara Desert"** was based on 560 Holocene radiocarbon dates from freshwater lacustrine and wetland deposits in the Sahara. These indicate the changing presence of surface freshwater. Based on her interpretation of the data, during the early Holocene, monsoonal precipitation extended from the South to the Tropic of Cancer and Mediterranean rains extended from the North to at least 29°N. The first humidity maximum occurred at 9,500 yr bp and peaked at 7,500 yr bp, while at ca. 4,000 yr bp, there was a period of severe aridity.

Vance Haynes' (Tucson, Arizona) paper **"Geoarchaeological Manifestations of Younger Dryas and Later Climate Change in the Darb El Arbaíin Desert, Eastern Sahara"** presented radiocarbon dated evidence from archaeological sites, lake sediments and shells of the land snail *Limicolaria kambeul chudeaui*. The results appear to confirm the beginning of the Neolithic pluvial at ca. 9,800 yr BP. The monsoonal Sudano-Sahelian wetting front moved northward through Northern Sudan into Southern Egypt and between 7,000 yr BP and 4,000 yr BP the front retreated.

Rudolph Kuper's paper **"Holocene Climate and Cultural Frontiers in the Libyan Desert"** examined the impact the "Neolithic Wet Phase" had on cultural and economic innovations and specifically the transition from hunting/gathering to farming and livestock-keeping. The shifting of the monsoonal rainfall belt and the ultimate desiccation of the Sahara resulted in the spread of Neolithic elements into the Nile Valley and finally throughout the continent.

Stefan Kröpelin's presentation **"Paleomonsoon Variations in the Eastern Sahara Since the Last Glacial Maximum"** addressed the rather abrupt northward extension of monsoonal rains in Northeastern Africa up to 24°N at 9500 yr bp (c.8800 BC) 700 km further north than today. The Eastern Sahara (24°-16°N) subsequently underwent pronounced humid conditions lasting about 5,500 calendar years in Southwestern Egypt, and about 7,500 calendar years in Northwestern Sudan with annual rainfall between 100 mm and 500 mm respectively. This Holocene humid period—like previous ones, such as the longer and more intense Eemian (isotopic stage 5) wet phases—is mainly attributed to an intensification of the southwest monsoons, which brought large quantities of moisture into the Eastern Sahara. Definite aridification of Southwest Egypt and southward shifting of the desert margin started no later than 4,500 yr bp (c.3300 BC). Southerly rains retreated at an average rate of 30 km per century, leaving the entire Eastern Sahara uninhabitable by about 3,000 yr bp (c.1200 BC). Saharan cultures collapsed and the Pharaonic civilization in the Nile Valley emerged.

Paul Abell's (Kingston, Rhode Island) paper **"Seasonality in the Early Holocene Climate of Northwestern Sudan"** concluded the first session. He used *Etheria elliptica*, a freshwater oyster collected from the lower Wadi Howar (18°N), as a proxy to determine seasonality in mid-Holocene precipitation. Oxygen isotope ratios in the shells' monthly (lunar) accretionary layers revealed a pattern of bi-modal rains at 6,800 bp: heavy monsoonal rains followed by much lighter rain later in the season. The same pattern exists today in Eastern Africa (Lake Victoria) which indicates that bimodality of rainfall moved 800 km or more northward.

3.2 Eastern Africa

Tom Johnson (Duluth, Minnesota) opened the second session with his paper **"A High-Resolution Paleoclimate Record from the Varved Sediments of Lake Malawi: Evidence for ENSO Scale Variability and the Little Ice Age in Tropical Africa"**. His studies reveal that the large lakes of Eastern Africa are highly sensitive to climate change. Sediments collected in box cores from northern Lake Malawi show considerable variability over the past 400 years. Analysis of these cores suggest that when conditions were unusually cold in Europe the biogenic silica accumulation rates in northern Lake Malawi were high. Varve thickness was also subjected to time-series analysis and showed significant spectral peaks on ENSO time scales.Teleconnections between the behavior of Lake Malawi and the global climate system on a time scale of years to centuries therefore seems to exist.

Dan Olago (Nairobi, Kenya) examined in his presentation the **"Long-Term Temporal Characteristics of Paleomonsoon Dynamics in Equatorial Africa"**. Spectral analysis revealed a peak at 11,500 yr bp related to the bi-annual passage of the sun over equatorial regions, which reflects the seasonality (twice yearly) of rainfall in the equatorial region.

Raymonde Bonnefille's (Pondichery, India) presentation was entitled **"Time Series of Mean Annual Rainfall Reconstructed from Pollen Data in East Africa"**. Bonnefille used pollen sequences from peat bogs as a proxy for paleomonsoon variations in East Africa. Mean annual rainfall was reconstructed on eight time series of high resolution pollen data from sites located between 2° to 4° South latitude, in the forest belt, from 1800 to 2240 m above sea level in the East/ Central African highlands. The results, based upon pollen data for more than 600 stratigraphic levels dated by 125 radiocarbon dates, indicate that mean annual rainfall was 30 % lower than at present during the late glacial, and 40% lower during the glacial maximum, but only about 10 % higher during the early Holocene. The Holocene precipitation curve shows no abrupt events such as those recorded in the lake level data in the northern tropical area. There are indications of lower amounts of rainfall post 5 ka BP. The strongest pattern is the great amplitude of variation between low and high values for the period since 4 kyr BP. This appears to reflect strong climate variability at the century scale.

3.3 Southern Africa and Australia

Louis Scott (Bloemfontein, South Africa) began the third session with his paper **"Paleoclimate and Seasonality during the Last 15 000 yr BP in Southern Africa"**. Based on pollen, and geomorphological data, an early Holocene dry phase is indicated in the interior of South Africa. This was followed by moist conditions in the mid-Holocene. They developed in the north (26°S) at around 7,000 to 6,500 yr BP, and spread southwards to 31°S, by about 5,000 yr BP. Compared with the present distribution of plants and pollen assemblages, the Holocene pollen spectra suggest that the shift was accompanied by an increase in the proportion of summer to winter rainfall. The general rainfall pattern of South Africa was established in this way, but stable isotope records which can be related to the distribution of grass types, suggest that summer rains influenced areas furthest to the south quite strongly by ca. 2000 yr BP. In South Africa C3 grass types occur in the southern winter-rain area, where the growing season occurs during winter months. In the summer-rain area, which is usually characterized by C4 grass, they also occur along the high eastern escarpment where winter drought is less marked. Stable carbon isotope records of a stalagmite (Talma & Vogel, 1992) and of fossil hyrax dung deposits suggest that C4 grass may have been more prominent ca. 2000 yr BP, suggesting the relative increase in the proportion summer-rain towards the south.

Paul Abell's presentation **"The Pleistocene/Holocene Transition in South Africa"** examined fragments of shells of the land snail *Achatina sp.* with ^{14}C dates ranging from 9,500 to 12,500 yr BP, which were found in The Bushman Rock Shelter, an archaeological site in the Transvaal region of South Africa. The snails had been used as food by the inhabitants. Oxygen isotope analyses indicate changing ambient temperature and/or rainfall through this time period, with evidence of Older Dryas and Younger Dryas events at 12,500 and 10,000 yr BP respectively, in which the temperature was 4 to 5 degrees colder than early Holocene temperatures, which in turn, were slightly warmer than those which prevail today. Attempted correlations with land snails found in caves in the Leuwin Peninsula of Western Australia were not successful, probably because the latter caves are very close to the coast, where dramatic changes in sea level altered the environment.

Norbert Jürgen's (Köln) paper **"Biogeographical Patterns: a Tool for the Reconstruction of Vegetation History in African Arid Regions"** focused on the combined analysis of the phytogeographical patterns and the phylogenetic history of plant taxa as a means of reconstructing the past. Using the Namib Desert as an example, he indicated that large parts of the Namib were once Savanna or Fynbos and that plants have been forced to migrate extensively in latitudinal and longitudinal directions owing to major shifts in the boundary between and intensity of tropical and temperate climate.

Ernst Brunotte's (Köln) presentation **"Paleosoil Sequences of Southwest Africa: First Results of Investigation in Kaokoland, Namibia"** outlined ACACIA's endeavors to reconstruct environmental conditions in Northwestern Namibia in an attempt to show the impact on past human societies. Pastoral nomadism also had an impact on landscape development as seen in sheet erosion, wind erosion and the development of gullies.

3.4 Meteorology and modeling

Ulrich Schotterer opened the fourth session with his paper **"Past Global Changes and Isotopes in Present-Day Precipitation"**, which described the importance of stable isotope records and their relationship to precipitation controlled by the seasonal shift of ITCZ and monsoonal flow. He also discussed possible continental sources of precipitation in Africa such as the Congo Basin.

Sharon Nicholson's (Tallahassee, Florida) presentation **"The Nature of Rainfall Variability over Africa on Time Scales of Decades to Millennia"** indicated that major climatic fluctuations in Africa tend to be continental in scale and are roughly synchronous in both hemispheres although not necessarily of the same sign. The principle spatial modes of rainfall variability are 1) either most of the African continent becomes relatively dry or wet at the same time, or 2) the equator becomes dry while the sub-tropics become wet or 3) the equator becomes wet and the sub-tropics dry. Africa was mostly dry around 18,000 yr BP and mostly wet around 8,000 yr BP. Around 6,000 yr BP. The second mode prevailed. The Holocene and Pleistocene fluctuations may have been due to the persistence of certain modern modes and do not necessarily require a major change in the general atmospheric circulation. A 20-30% increase in rainfall can increase lake levels by several meters, which could explain Holocene lake levels. Nicholson also addressed the question of the definition of the African "monsoon". Since the circulation features related to rainfall production are complex and include several convergence zones and the African Easterly jet stream, the term monsoon for Africa may be too simplistic. Also, the factors that produce mean climate are not necessarily those controlling long term variability of precipitation. For example, sea surface temperatures and El Niño play a role in Southern and Eastern Africa.

Manfred Geb's (Berlin) paper **"Factors Favoring Precipitation in North Africa from the Viewpoint of Present-Day Climatology"** examined the humid period in North Africa 8,000-5,000 yr BP, taking into consideration global and regional climate factors. Referring to the latter, he pointed out the importance of (1) permanent and seasonal sources of humidity, assuming a scale of at least 100,000 km^2; (2) horizontal advection of water vapor from the south, to be found in lower monsoonal flows as well as in branches of waves in upper easterlies; (3) concentrated vorticity production by organized condensation within the troughs of traveling waves as a feed-back mechanism. In a second part, three analogous present-day (1996) North African weather sequences were shown illustrating (1) the temporary northward expansion of monsoonal rain (Sept.), (2) an interseasonal (Nov.) rain period in the Red Sea area, and (3) the advance of winter rain as far as 20°N (Mar.).

Pascale Braconnot's (Paris) presentation **"Mid-Holocene and Last Glacial Maximum African Monsoon Changes as Simulated Within PMIP"** introduced PMIP and the two time periods currently being studied: the mid-Holocene (6,000 yr BP) and the Last Glacial Maximum (21,000 yr BP). Focusing on the African monsoon, the model indicates an amplification of the seasonal cycle of temperature for the northern continent during the mid-Holocene due to changes in insolation forcing. As a result of summer continental warming, monsoon rains increased and the rain belt migrated northward over Africa.

Sandy Harrison's (Lund, Sweden) presentation **"Land-Ocean-Atmosphere Interactions and the Amplification of the African Monsoon in the mid-Holocene"** focussed on the need to include feedbacks associated with known changes in land- and sea-surface conditions to realistically simulate the African monsoon. Climate model simulations, such as those made by the Paleoclimate Modelling Intercomparison Project (PMIP), show that orbital changes amplify the African monsoon but the simulated changes in summer precipitation north of ca. 20°N are very much less than the 300 mm required to maintain grassland vegetation. The BIOME 6000 project is making global site-based reconstructions of vegetation changes at 6000 and 18,000 yr BP from pollen and plant-macrofossil data. These reconstructions show grassland vegetation in Northern Africa to at least 23°N at 6000 yr BP. New model experiments made by the TEMPO (Testing Earthsystem Models with Paleoenvironmental Observations) project, show a significant enhancement of the orbitally-forced changes in the extent and magnitude of the monsoon when the effects of known changes in vegetation, and in the feedbacks associated with changes in sea-surface temperatures in the adjacent oceans are necessary to explain observed changes in monsoon climates.

Françoise Gasse (Paris) concluded the session with her paper **"Combined Surface and Groundwater Paleohydrology in the Sahara and the Sahel for Understanding Past Climate Change"**, which also addressed the discrepancy of GCM climate simulations at 6,000 yr bp and the existing data. She compared the stable isotope composition of surface and groundwater for sites in Niger, and presented diatom records. She also outlined current and planned activities of the PEP III project.

4. CONCLUDING COMMENTS

Some of the results of the workshop included:
- evidence for the shift of the Inter-Tropical Convergence Zone in the early Holocene;
- indications of winter rains and southerly influence in the Northern Hemisphere;
- westerly winds may have reached further south than previously thought;
- the key factor for environmental change in arid regions is precipitation and not temperature.

Suggestions were made for steps which need to be taken to improve and facilitate research. These included the following:
- data should be compiled in a common database accessible to all;
- modelers and field researchers need to cooperate more closely;
- more (and improved) isotope data is necessary;
- human impact on past environments needs to be more closely examined;
- the link between vegetation and precipitation must be studied, based on modern examples;
- research programs such as ACACIA and the PAGES/PEP III program should collaborate.

It was decided that it would be more productive to focus on a specific question for research. Suggestions for a possible research agenda included:

- determining the origins of the advanced Egyptian civilization, focusing on the history outside of the Nile Valley with regards to archaeology and climatology;
- potential for the existence in the future of a hyperarid Sahara that extends 800 km further south than today;
- fundamental importance of monsoons to African ecology and civilizations;
- extreme climates of Holocene and Pleistocene as possible scenarios for the future;
- the change from hunter/gatherer to pastoral communities, the subsequent spread of pastoralism from Northern to Southern Africa and the resulting impact on the environment.

Based on these suggestions the following "burning question" for research was proposed:

- Was climate change a crucial factor in the development of African civilizations?

Some of the papers presented at the Siwa Workshop will also be published in a special issue of the journal "Global and Planetary Change" devoted to "Paleomonsoon Variations during the Late Quaternary".

Without the assistance of Klaus Kuhlmann of the German Archeological Institute in Cairo (DAI) and logistic support by the ACACIA project (Sfb 389), this workshop would not have come about. It was held at his new research center and included excursions to the Siwa Oasis and the the Great Sand Sea.

The participants also attended the opening of the exhibition "The Water of the Desert" on 21 January, 1997 at the Goethe Institute Cairo. Stefan Kröpelin introduced the exhibition and gave a lecture on the topic. Rudolph Kuper's film: "The Long Road to Wadi Howar" was also shown. The exhibition is sponsored by the Goethe Institute and the Deutsche Forschungsgemeinschaft (DFG) and will tour Africa and the Gulf states this year.

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