PALEOCLIMATES OF THE NORTHERN AND SOUTHERN HEMISPHERES
The PANASH Project
The Pole-Equator-Pole Transects

Science and Implementation Plans
PEP I: The Americas Transect
PEP II: The Austral-Asian Transect
PEP III: The Afro-European Transect

[Diagram showing world map with arrows indicating PEP I, PEP II, and PEP III transects]
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PAST GLOBAL CHANGES (PAGES) is the International Geosphere-Biosphere Programme (IGBP) Core Project charged with providing a quantitative understanding of the Earth's past environment and defining the envelope of natural environmental variability within which we can assess anthropogenic impact on the Earth's biosphere, geosphere and atmosphere.

In order to evaluate their effectiveness, models intended to predict future environmental changes must be capable of accurately reproducing conditions known to have occurred in the past. Through the organization of coordinated national and international scientific efforts, PAGES seeks to obtain and interpret a variety of paleoclimatic records and to provide the data essential for the evaluation of predictive climatic models. PAGES seeks the integration and intercomparison of ice, ocean and terrestrial palaeorecords and encourages the creation of consistent analytical and data-base methodologies within the paleosciences.

The PAGES Project focuses on specific sets of questions and issues:

- How has global climate and the Earth's natural environment changed in the past? What factors are responsible for these changes and how does this knowledge enable us to understand future climate and environmental change?

- To what extent have the activities of man modified climate and the global environment? How can we disentangle anthropogenic-induced change from natural response to external forcing mechanisms and internal system dynamics? What were the initial conditions of the Earth system prior to human intervention?

- What are the limits of natural greenhouse gas variation and what are the natural feedbacks to the global climate system? In what sequence, in the course of environmental variation, do changes in greenhouse gases, surface climate, and ecological systems occur?

- What are the important forcing factors that produce climate change on societal time scales? What are the causes for abrupt climatic and environmental events and the rapid transitions between quasi-stable climatic states which occur on decadal to century time scales?
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PANASH-PEP SCIENCE AND IMPLEMENTATION

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1. INTRODUCTION

It is the task of PAGES to organize the international paleoscientific community in a concerted effort to produce a coherent quantitative record of the Earth's natural history in order to address critical Global Change questions. To that end, the PAGES Project has developed an international framework within which research initiatives are organized and implemented to accomplish the overall objectives of the IGBP. The PANASH Project (PAleoclimate of the Northern and Southern Hemispheres) is a major observational focus of PAGES. It represents the organizational vehicle to implement research on interhemispheric climatic mechanisms and coupling. PANASH scientific activities are linked in a series of PEP (Pole-Equator-Pole) transects focused on the sequence and phasing of major climatic fluctuations. Each transect provides an opportunity to assess the regional paleo-record in relation to adjacent regions, and thus to expand our understanding of the interhemispheric dynamics of past climate changes.

Late Quaternary paleoenvironmental records contain information on the natural variability of earth's past environments and climate. These data are valuable for assessing the validity of climate-change predictions and for understanding mechanisms of past and present climate changes. Because paleoenvironmental records can be analysed at different levels of temporal and spatial resolution, the derived palaeoclimatic information can provide insight on the character, rate, and spatial extent of climate change. However, there is not one single palaeoclimatic proxy record (terrestrial, marine or ice core) that is representative of global paleoclimates. Therefore, regional and multidisciplinary evidence has to be assembled and integrated to gain a global understanding of the climate change process. Integration of such data must be based on an understanding of both the specific responses of regional environmental systems to climate change, and the climatic linkages between the different regions and systems.

Major uncertainties in global climate change research relate to the mechanisms and causes of climate change. Only when we understand the responses of the environmental system (Figures 1 and 2) to the range of different climate-forcing conditions that occurred in the past, will we have reasonable confidence in predictions of future climate change. A better understanding of inter-hemispheric paleoclimatic correlations and climate change mechanisms is critical to this research. We know very little about how climate change is linked in both hemispheres. To this end, a comprehensive study of paleoclimate records from the northern
and southern hemispheres is being co-ordinated by the PAGES/IGBP Project. The scientific agenda of the PANASH Project is defined by three interhemispheric Pole-Equator-Pole (PEP) transects (Figure 3). These are:

PEP I: The Americas Transect,
PEP II: The Austral-Asian Transect,
PEP III: The Afro-European Transect.

These transects involve both terrestrial and marine-based research projects, as appropriate to each region. A complementary set of studies (IMAGES: International Marine Earth Global Change Study) deals with the deep ocean records of paleoclimate. For seasonal to century-scale climate dynamics, there transects will link with ARTS (Annual Record of Tropical Systems) and CLIVAR (WCRP) which focus on ocean-atmospheric systems. Additional projects focus on paleoenvironments in polar regions: CAPE (Circum-Arctic PaleoEnvironments); EPICA (European Project for Ice Coring in Antarctica); ITASE (International Trans-Antarctic Scientific Expedition) and the WAIS (West Antarctic Ice Sheet) coring project.
Figure 2a
Atmospheric circulation (July)

Figure 2b
Atmospheric circulation (January)
2. GOALS

The primary goals of the PANASH Project are to improve our understanding of global climatic change by:

- documenting how climatic records from the two hemispheres are inter-related (in amplitude, phase and geographic extent);
- determining the record of potentially important forcing factors which may have affected each hemisphere;
- identifying the important feedbacks which operate to amplify, or reduce, the influence of changes occurring in a specific part of the climate system;
- identifying mechanisms of climatic coupling between hemispheres.

These goals require that there be:

- significant new research in data-poor regions to redress the geographic imbalance in paleoclimatic information which currently exists;
- increased collaboration between scientists of the North and the South;
- a new research focus on North-South links, fostered by scientific meetings which address observational projects, logistics and new methodologies (e.g. proxies, geochronology).

Records of climatic changes over the last 250,000 years are needed to document glacial-interglacial variations during two complete climatic cycles which appear to have had very different characteristics (PAGES "Temporal Stream 2"). Records of the last 2000 years are needed for resolving higher frequency changes in climate (PAGES "Temporal Stream 1"). Although it may not be possible to obtain many complete records
with the necessary resolution for these time periods, a well-coordinated international effort, focusing especially on continental records, should greatly improve our understanding of climatic variations on a global scale.

The most detailed paleoclimatic information with annual temporal resolution is available for the last 2000 years and is reconstructed from tree-rings, corals, varved marine and lacustrine sediments, ice cores, and historical records. Records that span the last one or two glacial-interglacial cycles, and can potentially provide a temporal resolution of decades-to-centuries, include loess, peat, lacustrine sediments, lake levels, ice cores, and deep-sea sediments.

In order to compare these different types of records, climatic signals must be quantified (calibrated to modern observations). Quantitative paleoclimate estimates for selected time intervals are essential for two other PAGES projects, PMIP (Paleoclimate Model Inter-comparison Project) and PMAP (Paleoenvironmental Multiproxy Analysis and Mapping Project); results from the PEP transects will be directly relevant to these efforts.

Many paleoclimate data sets are qualitative and will require major efforts to be quantitatively useful for intercomparison. Furthermore, for comparisons to be meaningful at various temporal and spatial scales, stringent age controls are required and the linkages need to be understood between atmospheric, terrestrial, and marine data sets. Only if the linkages are understood, can the hierarchy of climate forcing be determined and the inter-hemispheric connections be identified.

3. CRITICAL RESEARCH TASKS

Here we identify a number of important, but as yet unresolved, general scientific questions on which the PANASH Project will focus attention. This list is not prioritised, and is by no means exhaustive, but illustrates the range of significant questions that will be addressed by PANASH/PEP research activities.

Stream 1 Timescale (the last 2,000 years)

1) How unusual has the 20th century climate been in the context of the last 2000 years in each hemisphere? What role has the Southern Ocean played in limiting anomalous climatic conditions?

2) Was the “Little Ice Age” synchronous and similar in magnitude in both hemispheres?

3) Was there a globally extensive warm period around A.D. 1000±200 years?

4) Are there teleconnections in the Hadley cell circulations of each hemisphere which lead to parallel records of climatic change in both hemispheres, on decadal to century time-scales?

5) What hydrological changes have occurred over the last two millennia and how are these related in phase, magnitude and geographic extent?

6) What is the record of ENSO and its climate teleconnections over the past two millennia?
7) What is the record of explosive volcanic eruptions in the northern and southern hemispheres, including timing, magnitude and chemical composition? How are these records related to climatic variations in each hemisphere?

8) What has been the role of solar irradiance variations in modulating climate variations over the past 2000 years?

9) What is the record of sea-level change over the last two millennia and how does this relate to mass balance changes in the major ice sheets of the two hemispheres?

10) What is the importance of human impact on climate?

Stream 2 Timescale (the last 250,000 years)

1) What were the phase relationships between climate evolution in the northern and southern hemispheres?

2) What is the role of thermohaline circulation and atmospheric trace gases in transferring insolation forcing between the two hemispheres?

3) What was the long-term record of aerosol loading in the two hemispheres and how did this affect climatic variations?

4) Are abrupt changes in oxygen isotopes observed in the Greenland ice core observed in southern hemisphere ice core records? Are there similar abrupt changes in marine sediments and terrestrial records outside the North Atlantic region?

5) Were rapid climatic changes over the last 250,000 years and climate system variability manifested simultaneously in both hemispheres?

6) How were hydrological changes in tropical areas related to changes in ice sheets at higher latitudes? How are changes in large-scale hydrological systems related to orbital forcing?

7) How did biomass change in low and high latitudes affect trace gas concentrations in the atmosphere?

8) How have monsoon climates varied in the past, and were there synchronous changes in monsoon circulation in different parts of the world?

4. PANASH BASIC SCIENTIFIC STRATEGY

All of the research activities within the PANASH Project will follow basic scientific strategies, as outlined below:

- the main PANASH focus will be on continuous, high resolution records, with annual to decadal time resolution for Stream 1 studies, and decadal to century scale resolution for Stream 2 studies;

- PANASH studies using proxy records will pay particular attention to chronology, to obtain the most accurate and detailed dating control possible;

- PANASH proxy records used in paleoclimatic reconstruction will be well-calibrated, providing a clearly understood paleoclimatic signal;
wherever possible, multi-proxy studies will be carried out, to maximise the information retrieved;

- special attention will be paid to comparisons of marine and terrestrial records along each transect;

- wherever possible, study sites will be selected which provide diagnostic evidence for changes in large-scale sub-systems of climate;

- where appropriate, special attention will be given to the influence of human activity on the environment;

- special attention will be paid to the needs of data-model intercomparisons and time-dependent modelling;

- all PANASH data will be archived in the World Data Center-A (WDC-A) for Paleoclimatology to provide open access and free interchange of information to interested scientists.

5. LATE QUATERNARY FORCING AND BOUNDARY CONDITIONS

Among the most important changes in external forcing, and in boundary conditions, that need to be considered in understanding late Quaternary paleoclimates in the two hemispheres are (Kutzbach and Webb, 1993):

- orbitally driven (Milankovitch) solar insolation changes,

- past atmospheric composition (particularly the concentration of radiatively active trace gases such as CO₂, CH₄, etc., and aerosols),

- the extent and volume of terrestrial and marine-based ice, and eustatic sea level changes,

- sea-surface temperature (SST) and salinity changes, which drive the thermohaline circulation.

5.1 Solar Radiation

Solar radiation distribution, which is affected by changes in major astronomical parameters, is of the utmost importance for understanding climate changes at the inter-hemispheric scale. In the frequency band between 1 cycle per 10 kyr and 1 cycle per 100 kyr, the main forcing of the climatic system is related to the changes of insolation due to the changes of the Earth's orbit and of its axis of rotation. Therefore, orbital elements and the subsequent latitudinal and seasonal distributions of insolation constitute an important link between geological proxy records of past climates, and climatic variables simulated by climatic models (Berger, 1992; Berger and Loutre, 1991).

In the context of PANASH, special attention must be paid to the phase relationships between the two hemispheres in order to determine whether synchronism in climatic change is related to synchronism in the forcing or to a global response of the Earth to forcings acting differently on both hemispheres. This is not a trivial problem because the two main astronomical parameters, obliquity and climatic precession act differently on the insolation according to the day, season, and hemisphere considered: obliquity plays the same role in both hemispheres during the same local season but precession has an opposite effect. This means that an increase in obliquity increases the solar radiation received in the

1 We thank A. Berger and M.F. Loutre for their contributions to this section.
Figure 4

Long-term variations of mid-month insolation over the last 130 kyr in Wm$^{-2}$ for 90°N, 60°N, 30°N, equator, 30°S, 60°S, and 90°S at the astronomical summer solstice (i.e. summer solstice of the northern hemisphere and winter solstice of the southern hemisphere) in full lines and at the astronomical winter solstice (i.e. winter solstice of the northern hemisphere and summer solstice of the southern hemisphere) in dashed lines. There is 10 Wm$^{-2}$ between two marks on the left and right scales. Values at $t = 0$ are given for the astronomical summer solstice on the left; values at $t = 130$ kyr B.P. are given for the astronomical winter solstice on the right.

northern and southern hemispheres during, respectively, the northern and southern summer seasons. Going from winter at perihelion to summer at perihelion will increase insolation all over the Earth during northern summer and decrease it during northern winter. Therefore we see an increase in solar radiation in northern latitudes during northern summer and a decrease in southern latitudes during southern summer. The phase relationship between the insolation at a latitude of the northern hemisphere and the same latitude of the southern hemisphere also depends upon the kind of insolation we consider (e.g. insolation received during a specific day or integrated over a whole season).
Moreover, interpretation of climatic data most of the time requires us to consider the same local season in both hemispheres, which implies a time difference of 6 months.

At any given time in the year, the daily irradiation is in phase for all latitudes at which climatic precession is playing a dominant role (i.e. all latitudes except the high latitudes close to the polar night). But there is an exact out-of-phase relationship between the northern and the southern hemispheres when insolation over the same local time is compared (i.e. with a time difference of 6 months between the northern

**Figure 5**

Long-term variations of the seasonal irradiation over the last 130 kyr in $10^6 \text{ Jm}^{-2}$ for $90^\circ \text{N}$, $60^\circ \text{N}$, equator, $30^\circ \text{S}$, $60^\circ \text{S}$, and $90^\circ \text{S}$ for the astronomical summer season (i.e. summer of the northern hemisphere and winter of the southern hemisphere) in full lines and for the astronomical winter season (i.e. winter of the northern hemisphere and summer of the southern hemisphere) in dashed lines. There is $50 \times 10^6 \text{ Jm}^{-2}$ between two marks on the left and right scales. Values at $t = 0$ are given for the astronomical summer season on the left; values at $t = 130$ kyr B.P. are given for the astronomical winter season on the right.
Figure 6
Long-term variations of the seasonal mean irradiation over the last 130 kyr in Wm$^{-2}$ for 90°N, 60°N, 30°N, equator, 30°S, 60°S, and 90°S for the astronomical summer season (i.e. summer of the northern hemisphere and winter of the southern hemisphere) in full lines and for the astronomical winter season (i.e. winter of the northern hemisphere and summer of the southern hemisphere) in dashed lines. There is 5 Wm$^{-2}$ between two marks on the left and right scales. Values at $t = 0$ are given for the astronomical summer season on the left; values at $t = 130$ kyr B.P. are given for the astronomical winter season on the right.

and the southern hemispheres) for the latitudes where precession dominates the insolation signal. For example, insolation at the summer solstice for a given latitude of the northern hemisphere is exactly in phase with the summer solstice insolation for the same latitude of the southern hemisphere and out of phase with the winter solstice insolation for the same latitude of the southern hemisphere (Figure 4). Summer and winter solstices correspond to the same local time when considering the northern and the southern hemispheres respectively.
By contrast, seasonal irradiation (i.e. total insolation received over a given season) for a given latitude in the northern and in the southern hemispheres is exactly out of phase for the same astronomical season, and in phase for the same local season (Figure 5). This is because seasonal insolation is a function of obliquity only. It is exactly the reverse when mean irradiance (seasonal irradiation divided by the length of the season) is concerned; mean irradiance computed for a given latitude in the northern and in the southern hemisphere is exactly in phase for the same astronomical season and out of phase for the same local season (Figure 6) at least for most of the latitudes for which precession largely dominates. This is less evident when obliquity plays a more important role as for 90°N between 60 and 30 kyr B.P.

5.2 Trace gases and aerosols

Concentration of trace gases, such as CO₂ and CH₄, has changed significantly over glacial-interglacial timescales, and at times these changes have been rapid. Changes in past atmospheric CO₂ concentrations have been reconstructed from polar ice cores (Barnola et al., 1987) and more recently from peat bogs (White et al., 1994) and lake cores (Meyers and Horie, 1993). All these records show high-amplitude changes that are approximately synchronous with paleoclimate changes. Possible mechanisms for changes in atmospheric CO₂ are changes in the oceanic thermohaline circulation and ocean chemistry. If this is so, it may explain the apparent inter-hemispheric synchronism of climate change at times when inter-hemispheric differences might be expected as a result of orbitally-induced insolation anomalies. However, many unresolved questions remain regarding the dynamic processes involved in the global carbon cycle. Some of these questions, related to the past role of vegetation for terrestrial carbon storage, characterization of land surface properties, and climate change feedbacks from the land surface, should be addressed in the PEP projects. Changes in the extent of the tropical rainforests (a source and sink of atmospheric CO₂ and terrestrial carbon storage, e.g. Adams et al., 1990; Branchu, 1993) and of tropical wetlands as a source of CH₄ (Thompson, 1992) will be of particular importance. The apparent synchrony between abrupt decreases in CH₄ levels, as deduced from the Greenland ice core record (Chappellaz et al., 1993) and an abrupt post-glacial return to dry conditions over the northern tropics, especially North Africa (e.g. Gasse and Fontes, 1992), raises the question of linkages beween changes in tropical land surface conditions and atmospheric CH₄ levels. This is particularly important during the pre-Holocene period when the northern plains were ice-covered or frozen. Changes in the extent of both tropical and boreal wetlands should be explored within the context of PANASH.

During the late Quaternary period there were enormous changes in the atmospheric aerosol load (e.g. De Angelis et al., 1987) largely as a result of changes in aridity in continental interiors, and the production of extensive outwash plains associated with the development and decay of continental ice sheets. Periods of increased dust flux to the atmosphere during cold glacial periods, are clearly recorded in even very remote polar ice cores. In addition, there have been periods of cataclysmic explosive volcanism which may have played a role in triggering climatic
changes. Such atmospheric changes may not have been the same in each hemisphere, and so both the past record of aeolian dust flux and the consequences of changes in aerosols in each hemisphere needs to be addressed in the PANASH research program. For example, COHMAP Members (1988) find (from NCAR AGCM simulations) that the onset of enhanced monsoon rains after the LGM occurred at 15 kyr, whereas the proxy data show that lake levels did not rise until 12 kyr. They suggest that glacial-age aerosols significantly depleted the incoming solar radiation in the tropics. Other hypotheses could be proposed (e.g. the first wet pulse may have refilled the aquifers before those aquifers outcropped), but further research is needed to fully assess the significance of increased aerosols in the past.

Past variations in the flux and origin of aeolian dust may be reconstructed from loess deposits, aeolian material in lake and marine sediments, and in ice cores, and from the past extent of sand dunes. Offshore marine sediments are probably the best material for reconstructing past wind strength at long-term and large geographical scales, as shown, for instance, by studies off Arabia (Sirocko et al., 1993), northwest Africa (Sarnthein, 1979), west-central Africa (Jansen et al., 1990; Gasse et al., 1989) and in the central Atlantic (Pokras and Mix, 1987). Within all three PEP transects there are long terrestrial records of loess deposition, containing important paleoclimatic information to unravel the past history of aeolian activity in each hemisphere.

5.3 Past ice extent and eustatic sea-level changes

Although ice sheet formation and decay are responses to climate change (as is sea-level fluctuation) the very presence of ice sheets can displace storm tracks and cause associated climate anomalies. This is also true for areas of extensive sea-ice. For example, during the Last Glacial Maximum (LGM) the extent of sea ice in the North Atlantic influenced the location and strength of the westerly jet stream over Europe (Kutzbach et al., 1993). The reinforced westerly jet stream penetrated far eastward over Europe. Both the Fennoscandian and North American ice sheets produced anticyclones that led to surface easterly winds along their southern boundaries, creating colder and drier conditions than today.

When the northern hemisphere continental ice sheets decayed, the flux of meltwater into the North Atlantic may have disrupted thermohaline circulation, with consequences far beyond the North Atlantic region (Broecker and Denton, 1989). Indeed, such changes may have led to additional consequences, e.g. changes in atmospheric greenhouse gas concentrations, as oceanic circulation was disrupted.

Eustatic sea-level changes can be extremely important in areas with shallow marginal seas, such as are found in many parts of the three PEP transects (e.g. Markgraf et al., 1992). At the regional scale, marine transgressions and regressions can dramatically change the availability of moisture as well as influencing the seasonality of temperature. Large-scale oceanic circulation may also be affected by eustatic sea-level changes.

5.4 Sea-surface temperature and oceanic circulation

Sea surface temperatures (SSTs) in the North Atlantic, which depend on the strength of the cross-equatorial heat and salt transport from the South Atlantic, largely control climate in northern and western Europe.
Changes in SSTs in the Atlantic Ocean will have important consequences for climates in both the PEP I and PEP III regions. The efficiency of the thermohaline conveyor belt (Figure 1) is itself largely determined by sea water density, and therefore the temperature and salinity distribution. Salinity is particularly sensitive to freshwater inputs from ice meltwater and river discharge which may act to reduce North Atlantic Deep Water production (Duplessy et al., 1992).

The return flow of the thermohaline conveyor belt in the southern hemisphere is also of great interest. The position of the divergence and surface temperatures in the Algalhas Current (Figure 1) strongly influence climate in the interior of South Africa, Mozambique and Madagascar. Paleodata from these regions and comparison with those from the North Atlantic areas may lead to a better understanding of the relative roles of oceanic circulation and insolation on the regional climate in southeast Africa. There may also be climatic effects in other regions resulting from changes in the thermohaline circulation, through displacement of water masses and changes in the pattern of upwelling. For example, the weakening of the African monsoon during the Younger Dryas chronozone has been tentatively associated with diminished efficiency of the thermohaline circulation, linked to the melting history of the Laurentide ice-sheet (Street-Perrott and Perrott, 1990).

El Niño events (and their connections with the atmospheric Southern Oscillation) play a critical role in high frequency climatic variability in the tropical zone, with important teleconnections to the extra-tropical region (Diaz and Kladis, 1992). Changes in sea-surface conditions in the subtropical oceans partly control monsoon variability. Monsoons are driven by the differential land-ocean heating responsible for the atmospheric pressure gradient (which draws the monsoonal air flow inland in boreal summer) and the subsequent release (by monsoon precipitation over the continents) of latent heat collected from southern subtropical oceans. Currently, both Indian and African weak monsoons coincide with positive SST anomalies over the south subtropical oceans (e.g. Folland et al., 1986; Clements and Prell, 1991) which are partly controlled by the El Niño-Southern Oscillation (ENSO) (Hsiung and Newell, 1983). Modern SST data show that the southern oceans are warm when the North Atlantic and North Pacific are cold (and vice-versa) such situations occurring synchronously with drought periods over the Sahel. Besides changes in seasonal distribution of solar radiation, the relative role of sea surface and tropical land surface temperatures on monsoon variability must be investigated in both the African, Indian and East Asian monsoon domains.

At present there are still controversial discrepancies between various estimates of low latitude sea-surface temperatures in the last full-glacial interval (21 to 18 kyr; CLIMAP, 1981). Full-glacial SSTs estimated from transfer functions were similar to modern values. However, recent geochemical evidence from corals and organic compounds (Edwards et al., 1992; Guilderson et al., 1994; Anderson and Webb, 1994) suggests that tropical SSTs were lower. This is corroborated by research on tropical ice cores (Thompson et al., 1995) and noble gas paleotemperatures derived from ground water archives (Stute and Schlosser, 1993). Furthermore, re-analysis of the original full-glacial CLIMAP data suggests that the CLIMAP SST estimates for the tropical oceans may need to be re-assessed.
(B. Molino, pers. comm). Further work on this question is needed and research within the three PEP transects will help to resolve the problem.

6. RECOMMENDATIONS ON METHODOLOGIES AND TECHNIQUES

International cooperation through PANASH-PEP activities will ensure that the most modern methods are used in analysis of paleo-records. To this end, PAGES is proposing a set of interdisciplinary protocols for continental coring and drilling of paleoclimatic records. Emphasis will be placed on continuous geophysical measurements (such as magnetic susceptibility) prior to sampling followed by detailed geochemical, isotopic, microfossil and macrofossil analyses, as appropriate. Close interval, high precision dating should be an essential part of any project. Multi-parameter micropaleontological studies should be carried out by research teams, using quantitative, statistical reconstruction techniques. Here we outline some important issues, though the following discussion is by no means exhaustive.

6.1 Dating

An understanding of the Earth's past-climatic system depends primarily on a valid and firmly established chronology. The radiocarbon method is limited in its application for several reasons:

- variations in atmospheric $^{14}$C content (the $^{14}$C chronology thus does not correspond to true calendar years),
- reservoir effects in the paleo-oceans and in lakes are not well known, and
- the method does not apply to samples older than 30-40 ($^{14}$C) ka B.P.

An absolute chronological control is needed for establishing:

- the actual duration of climatic events (e.g. the Younger Dryas event),
- the plateau duration ($CO_2$ uptake and release rate of feedback effects),
- true correlations between sites.

An actual calendar-year chronology is established for the past 10,000 years by calibrating the radiocarbon time scale against the dendrochronological record (Stuiver et al., 1993). Further efforts must be placed on extending the calibration curve beyond 10,000 $^{14}$C years B.P., by testing several promising methods against each other (e.g. laminated sediments common in maar lakes from western and central Europe, Swedish varved clays, tree rings, speleothems, corals). Sites or material with potential for an absolute chronology and calibration with the sidereal calendar should be a priority.

Emphasis should be placed on the exact dating of time-synchronous events, e.g. widespread tephra layers or the $^{14}$C plateau. Icelandic, German, French, Italian, Greek tephras have proven to be excellent marker horizons during the last 13,000 yrs, and the eruption of Toba (~80,000 years ago) deposited tephra over a wide area of southeast Asia. Well-defined and well-dated tephras could facilitate correlations between continental, ice, and marine records.

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2 We thank J. Ch Forster and B. Wohlfarth for their contributions to this section.
The $^{14}$C-method applies to the period 0-40 ka. Intercomparison of other methods is needed before being used for dating sediments older than 40 ka, and also to detect possible biases linked to a given method. Methods, such as the $^{238}$U series ($^{210}$Pb, $^{230}$Th/$^{234}$U, $^{234}$U/$^{238}$U, $^{230}$Th/$^{232}$Th), K-Ar, $^{40}$Ar/$^{39}$Ar, $^{10}$Be, $^{36}$Cl, fission track, electron spin resonance (ESR), amino acid racemization, thermoluminescence (TL) or optically stimulated luminescence (on detrital levels in between authigenic levels), could be tested and applied.

Close collaboration between “customers” and “analysts” is highly recommended, especially because technical requirements for sampling and handling of samples for age determination have become increasingly refined (especially for AMS dating). It is also recommended that only well-identified material (e.g. plant macrofossils, pollen, authigenic, non-recrystallized carbonates) be used for $^{14}$C-dating. Scattered data, without stratigraphic context (not self-supported by their in-sequence location), are not recommended for dating.

6.2 Isotope techniques
Among other applications (e.g. Swart et al., 1993, International Atomic Energy Agency, 1993) the isotope composition of paleoprecipitation and paleotemperatures can be obtained from: the isotope composition ($^{2}$H, $^{18}$O) of temperate and tropical alpine ice; $^{18}$O of authigenic lacustrine carbonates in temperate lakes with rapid throughflow (e.g. Siegenthaler and Eicher, 1986; McKenzie and Hollander, 1993); and isotope composition of organic material of both aquatic and terrestrial origin, especially tree rings (e.g. Edwards, 1993). In closed lakes, the $^{18}$O of authigenic carbonate reflects primarily the precipitation-evaporation balance (e.g. Talbot, 1990). However, the correct estimate of this variable requires understanding of the relation between past water and isotope budgets.

Past vegetation types can be obtained from the isotope composition of organic matter of both aquatic and terrestrial origin (e.g. Aucour and Hilaire-Marcel, 1993; White et al., 1994).

The quantitative determination of paleotemperatures during recharge periods is possible from the concentrations of noble gases in radiocarbon-dated groundwaters (e.g. Stute and Schlosser, 1993). This method is especially useful in desert areas (e.g. Fontes et al., 1993 for the Holocene recharge periods in Mali).

6.3 Quantitative paleoclimate reconstruction
The use of transfer functions to infer paleoclimate-paleoenvironmental variables from terrestrial records of biological assemblages is now widely accepted (e.g. in the PEP III area: pollen for Europe [Guitot et al., 1989] or East Africa [Bonnefille et al., 1992], insects [e.g. Coope, 1986] or aquatic materials, e.g. diatoms for Africa [Gasse and Tekia, 1983]). Other approaches rely on geochemical relationships to quantify paleotemperature and paleosalinity conditions in closed basin lakes (e.g. Chivas et al., 1986). Such approaches need to be developed further and applied to other geographical regions. However, great care must be taken to avoid placing total reliance on statistical techniques without understanding the underlying biological and geochemical processes. Intercomparison of paleoclimatic estimates, based on different proxy indicators and different transfer functions, should be made whenever possible.
Quantitative paleoclimatic estimates form the basis for mapping past climates at particular times periods. The results from the three PEP transects will provide an important baseline of information for the PAGES PMAP (Paleoenvironmental Multiproxy Analysis and Mapping) project.

7. MODELING ACTIVITIES

General Circulation Models (GCMs) are important tools for studying past climates. They help to elucidate the mechanisms and interactions that can lead to climate variations and changes, and they are able to simulate climatic conditions which differ from those of the present. Modeled climate simulations also can be evaluated by comparison with paleodata, thus providing a test of the validity of the models. Additionally, when models include transport processes involving climatic tracers, they can help in the interpretation of certain classes of paleodata, such as water isotopes and desert dust.

7.1 Interactions between PANASH and PMIP (Paleoclimate Model-Intercomparison Project)

PMIP will employ a number of GCMs for paleoclimate simulations. About fifteen groups will perform paleoclimate simulations of the Mid-Holocene (6000 yr B.P.) and the last glacial maximum (LGM, 21000 yr B.P.) using identical boundary conditions (i.e. ice sheets, trace gas content, sea surface temperatures and sea ice). This project, endorsed by both PAGES and WGNE/WCRP, will help investigate the sensitivity of model results and simulated mechanisms of climate change to model parameterizations, such as clouds or ground hydrology. PMIP focuses on two snapshot periods corresponding to extreme climatic conditions over the relatively well-documented last 21000 years. The 6000 year B.P. experiment will concentrate on the impact of the change in solar forcing on monsoon circulation and continental warming of the Northern Hemisphere (using the present-day conditions for the ocean and sea ice). The 21000 year B.P. experiment will help diagnose the sensitivity of the tropical and mid-latitude circulation, as well as cloud feedback, to the presence of ice sheets and to CO₂ lowering.

7.2 Model-data comparisons

Model-data comparisons are an important part of PMIP since they help validate model results and evaluate the various parametrizations used. However, this requires global data sets with good spatial coverage and whenever possible seasonal resolution of climate variations for both the 6000 and 21000 years B.P. time-slices. This represents an important challenge for field scientists in the coming years.

Strategies were discussed in a NATO workshop (Aussois; October 1993, Strategies for the use of paleoclimate data sets in climate model intercomparison and evaluation). The recommended time periods for data collection are 6000 ± 250 ¹⁴C years and 18000 ± 1000 ¹⁴C years, in order to capture the warm Mid-Holocene and cold last glacial maximum conditions which are to be studied by AGCMs. As a first step, PMIP requires a synthesis of the available data, with good quality control for both dating and error estimates. Special emphasis will be placed on biome and

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3 We thank S. Joussaume for her contributions to this section.
lake level data bases. For the next step, it is necessary to encourage data collection in order to fill the gaps, particularly for the last glacial maximum.

According to the simulations that have already been performed with various GCMs for both the Mid-Holocene and LMG conditions, we can outline some recommendations for data acquisition within the PEP transects. For 6000 B.P., preliminary model-to-model comparisons emphasise two main features: changes in the African-Asian summer monsoon (the pattern and intensity of which differ from one model to another), and the summer warming of the northern hemisphere continents, which reaches 2 to 3°C (but may differ by 1°C from one model to another). For LGM, important changes are simulated for all seasons, but these may strongly differ from one model to another (e.g. changes in the hydrologic budgets over East Antarctica or Europe). Well-dated and calibrated proxy data will help resolve these uncertainties and provide valuable tests of model simulations.

7.3 Other modeling studies for the interpretation of PEP results

Sensitivity experiments could be performed to address questions such as: the causes of reduced monsoon intensity during the Holocene, the impact of Dansgaard-Oeschger warm events on continental climates, and the impact of tropical land-surface conditions on global climate. Atmospheric general circulation models can be used to test the sensitivity of climate to solar forcing together with changes in the sea surface conditions and/or vegetation changes and/or greenhouse gas concentrations. In the near future, coupled atmosphere-ocean general circulation models will also become available to study abrupt climatic changes. The development of mesoscale models, nested within GCMs, will be of critical importance to explore global and regional climate interactions.

8. PANASH DATA MANAGEMENT

Modern public-domain data management is an integral part of all PAGES activities and tasks. It is essential that this data management be driven by the present and future scientific objectives of the PAGES. Because the future needs of PAGES can not be fully anticipated, the data management plan must be flexible; data being managed must include both derived paleoenvironmental results (e.g. spatial reconstructions) as well as the primary data on which all PAGES results are based. PAGES also requires strong data management for the careful documentation and support of all scientific results. PAGES data management ensures the long-term preservation of all data and results. For all these reasons, every PAGES activity and task includes the management of both primary ("raw") and derived data. PAGES will leave a comprehensive archive of paleoenvironmental data as part of its scientific legacy.

All data used in PEP research will be managed as part of a public-domain database. The responsibility for data management activities will be distributed throughout the PEP regions in a coordinated fashion. All regional data management centers will freely exchange data and data management technology, and will work together to provide paleoenvironmental data and information in a manner that is both easy to use and accessible to all those in the global change community.
Because PAGES data management activities are constantly improving through international interaction, it will be essential for PAGES investigators to contact, and work closely with, PAGES data management centers. At present, the World Data Center-A for Paleoclimatology in Boulder, Colorado, USA, is ready to help with the archiving of data, but it is expected that regional data management efforts will also play crucial roles for the PAGES community. In general, data should be submitted to a recognized PAGES data management center within 3 years of generation, or at the time of publication, which ever comes first. The PAGES data management centers can provide information about how to submit and share data. The following types of data will be archived:

1) Original “raw” or primary paleoclimatic, paleoecologic, and paleoceanographic data, including associated chronological information. These would include data such as raw tree-ring width measurements, information from historical documents, or pollen counts as a function of depth.

2) Secondary data developed from the primary data. For example, these would include tree-ring chronologies developed from multiple tree cores, pollen percentages as a function of inferred age, and radiocarbon dates corrected for secular variations in atmospheric $^{14}C$.

3) Tertiary information inferred from the primary and secondary data, such as paleoclimate estimates or vegetation reconstructions. These data would be managed in both time series and mapped form.

4) Calibration data, primarily the modern environmental datasets needed to convert primary and secondary data into quantitative estimates of past climate, ocean, or biosphere conditions.

5) Time series of hypothesized climate forcing functions (e.g. solar, volcanic, trace gas, or orbital).

6) Climatic boundary conditions through time (e.g. ice extent and height, land surface characteristics).

7) Output from models (e.g. atmospheric GCMs, vegetation models).

9. IMPLEMENTATION AND COORDINATION

By means of a series of scientific planning meetings, a scientific plan for each PEP transect, and for the IMAGES project (International Marine Global Change Study) has been developed. These meetings brought together representatives of the science communities concerned with the reconstruction of inter-hemispheric paleoclimate linkages for the three different parts of the world (Appendix 1). The scientific agenda for each transect is related to the different characteristics of modern-day climates and their forcing. The overall PEP strategies that have emerged from these planning meetings, together with the science and implementation plans, are described in this report. The IMAGES Science plan has been published separately (PAGES, 1994).

The PANASH Steering Committee, consisting of the PEP leaders and selected members of the PAGES Scientific Steering Committee, will act as a catalyst to promote the goals of the PANASH Project. Their
actions will primarily involve two types of activity: the organisation of workshops and symposia to focus the attention of scientists on the objectives of PANASH, and the explicit encouragement of national and international research endeavours which address the goals of PANASH. Both of these actions will be implemented through the PAGES Core Project Office, with guidance from the PAGES Science Steering Committee. Each PEP Transect will establish a Scientific Advisory Committee in order to prioritize and strengthen the development of research along the transects, and to evaluate progress towards the research goals.
10. REFERENCES


Chapter Two

PEP I: THE AMERICAS TRANSECT

Project Leader: Vera Markgraf

1. INTRODUCTION

The PEP I Transect is centered along the western reaches of the North and South American continents. Because of the importance of land-ocean interactions in these regions, the transect also encompasses a broad transequatorial swath including: the eastern regions of the American continents (e.g. the Amazon Basin, the Canadian Maritime), the inter-continental oceanic areas (the Caribbean and Gulf of Mexico) and the Pacific marginal regions.

The Americas Transect is optimal for an inter-hemispheric comparative study of paleoclimate change for three primary reasons: the symmetry of the North and South American land areas, their position at the eastern margin of the Pacific Ocean, and the presence of a continuous series of longitudinal mountain ranges along the western continental margin. Along this transect the land areas have similar poleward extent, similar distribution of mountains and lowlands, and similar relationships to atmospheric and surface oceanic circulation and associated upwellings and major currents along the coasts (Figures 1 and 2). Thus, a PEP transect in the Americas will be particularly well suited to detecting the relationship of paleoclimate events in both Northern and Southern Hemispheres. The transect is also well placed to record the influence of conditions in and over the Pacific at latitudes from 70°N to 55°S. Of an asymmetric character, the North American continent was the location of the largest continental ice sheet during glacial times and its effects on southern hemisphere climates needs to be assessed.

Two meetings, held in Boulder, Colorado (1991) and Panama (1993), were convened to formulate primary questions and design a plan for implementation of an inter-hemispheric paleoclimate agenda. The consensus that emerged was to focus study on the linkages between terrestrial and marine paleoclimate along two intersecting transects, a primary north to south transect (PEP I) centered on the western spine of the American continents from Alaska to Tierra del Fuego/Antarctica complemented by an equatorial trans-Pacific transect. This approach focuses attention on the primary importance of the tropical Pacific Ocean on marine and terrestrial environments of the Americas, especially as influenced by the El Niño-Southern Oscillation (ENSO) and its extratropical effects. It optimizes the retrieval of information on the coupling of the ocean-atmosphere-biosphere-cryosphere at both PAGES time streams.

Inter-hemispheric paleoclimate correlations address the transequatorial extent and dynamics of various climate forcing factors. PEP I research will address: changes in latitudinal and elevational temperature gradients through time; changes in intensity and location of
oceanic upwelling and its relation to shifts in atmospheric circulation; changes in the surface circulation of the Pacific Ocean with respect to North Atlantic ocean dynamics and their teleconnection to tropical and extra-tropical climate in the Americas. A different focus is required for each frequency band to determine the interaction between the climate-system process and environmental response.

At selected frequency bands, the PEP I transect is designed to:

1) develop a longitudinal transect of paleoclimate records for the last 250 ka to analyze climate variability at annual to millennial resolutions;

2) determine the spatial and elevational extent of climate change patterns, including rates, frequency, amplitude, and leads and lags;

3) develop multi-proxy paleoclimate data sets that link marine and terrestrial records. These studies will include the recent evidence of global change, the instrumental record and historical record, and all aspects of the biogeological record;

4) determine the mechanisms and forcings of climate change. Identify processes that transmit changes, and determine phase relationships (spatial and temporal) in regions sensitive to various modes of climate change.

Figure 1
Infrared composite satellite image of November 9, 1994 (source National Oceanographic and Atmospheric Administration) and summer/winter precipitation along the west coast of the Americas from 70°N to 60°S (source Lawford 1993).
2. MODERN CLIMATE AND CLIMATE VARIABILITY IN THE WESTERN HEMISPHERE

Perhaps uniquely amongst the PEP transects, the climate of the Americas can be discussed in an integrated manner as a result of the great influence of Pacific Ocean climatic factors. Satellite images offer a synoptic snap-shot view of climate processes on a global scale. For the climates of the Americas, a satellite image (Figure 1) helps to illustrate the interaction between the tropics and extra-tropics on a day-to-day basis. This figure shows large upper tropospheric cloud flares emanating from the Intertropical Convergence Zone (ITCZ) in the tropical Pacific. From eastern Brazil, upper tropospheric cloud streams are also often directed towards the North Atlantic and Europe. These cloud flares are visual markers for the continuous upper-level export of moisture and
energy from the tropics to mid-latitudes. These locations can shift with time as a result of day-to-day changes in the synoptic weather patterns.

Figure 1 also shows two examples of the temperate-latitudes influencing tropical weather. Two separate outbreaks of surface cold air can be seen moving from the mid-latitudes of both hemispheres toward the tropics. The leading edges of both of these cold air outbreaks are marked by extensive cloudiness. When these cold-air outbreaks interact with mountains (e.g. in eastern Mexico, the Caribbean, and the western slope of the southern Andes) abundant precipitation can result.

Aceituno (1992) has shown that patterns seen on a daily basis (such as illustrated in Figure 1) are often replicated on longer time scales. It is this kind of linkage between time scales that provides a basis for extending knowledge of present-day weather patterns to the analysis of longer time domains in climate and paleoclimate.

Present climate is composed of a “mix” of identifiable weather patterns. How this “mix” varies from month to month and year to year determines both the observed mean climate and climate anomalies. Key elements of these patterns include the strength and position of the ITCZ, subtropical high pressure systems (and the associated trade wind belts), upper circulation features (trough and ridge patterns, polar and subtropical jet streams) and their surface manifestations (mid-latitude storm tracks, frequency of cold air outbreaks, etc.). Because of the steeper pole-equator temperature gradient in the Southern Hemisphere as well as the uneven distribution of land masses between the hemispheres, the resulting circulation patterns of the hemispheres differ significantly. It is therefore not surprising that there are asymmetries in the meridional distribution of climatic elements. Figure 1 shows average precipitation along the west coast of the Americas (Lawford, 1993). Notice the ITCZ-related precipitation maximum is located north of the equator and its strong seasonal variability (both in intensity and latitude), as well as the far stronger seasonal variability of the mid-latitude precipitation maxima in the northern hemisphere.

At present, the most significant modulator of tropical climate and tropical-mid latitude interactions on the inter-decadal time scale is the El Niño-Southern Oscillation (ENSO) phenomenon. ENSO comprises a suite of anomalies in oceanic and atmospheric fields such as sea surface temperature, salinity, upwelling intensity, surface pressure and winds and precipitation (Aceituno, 1988; Aceituno et al., 1993). ENSO-related signals in these fields have been observed throughout the Americas (Figure 3). ENSO is the basic ocean-atmosphere rhythm with (aperiodic) oscillatory variations (2 to 10 years) (Rasmusson et al., 1990). The main feature of ENSO is the remarkably coherent and out-of-phase fluctuations of atmospheric mass between the southeastern Pacific and western Pacific/Indian oceans. The different modes of the ENSO anomaly produce opposing climate signals: El Niño and La Niña. El Niño is characterized by high SSTs in the central and eastern Pacific, negative SOI (Southern Oscillation Index), weak easterly trades, no upwelling along northwestern South America. La Niña is typified in the same locations by low SST, positive SOI, strong easterly trades, strong upwelling, etc.

ENSO-related tropical/extra-tropical climate teleconnection patterns have been the subject of a great deal of study in recent years (e.g. Glantz et al., 1991; Diaz and Kiladis, 1992). Several key areas have been identified...
Figure 3
Precipitation and temperature patterns in the Americas during El Niño and La Niña type conditions (source Kiladis and Diaz, 1989).

as "centers of action" in these teleconnections (Wallace and Gutzler, 1981; Diaz and Kiladis, 1992). Of primary importance to the Americas in the Northern Hemisphere is the Pacific-North America (PNA) anomaly pattern (Hastenrath, 1976; Murphree et al. 1992; Harr et al., 1992), and the Western Atlantic (WA) pattern. The PNA pattern is an alternating out-of-phase oscillation of pressure anomalies (and related weather) between the
central tropical Pacific, the Aleutians, northwestern North America and the Southeastern US. The WA pattern is another out-of-phase oscillation of pressure between Labrador and the western tropical Atlantic. Other teleconnection patterns have been identified linking the tropics to the southern mid-latitudes (Ropelewski and Halpert, 1986; Karoly, 1989; Rutllant and Fuenzalida, 1991; Acetuno and Montecinos, 1992). A recent extensive analysis of global teleconnection patterns between different atmospheric and oceanic fields (Barron, 1993) points to the unique importance of tropical Pacific sea surface temperature anomalies in influencing northern hemisphere surface climate patterns, especially for the winter and spring seasons. No other “predictor field” was found to correlate as strongly with mid-latitude anomalies. It is precisely this area in the tropical Pacific that is most directly influenced by ENSO fluctuations in SST. Accumulating evidence points to the importance of west-east variations in tropical Pacific SSTs to climate anomalies in the Americas generated through teleconnections (such as the PNA, WA and others). Indeed, Wolter and Timlin (1992) have incorporated west-east variations in a variety of oceanic and atmospheric indices in the tropical Pacific to improve our understanding of the relationship of teleconnections to the climate of the Americas. There is, therefore, persuasive evidence to show that a joint analysis of west-east variations in the tropical Pacific with a Pole-Equator-Pole transect of climate along the Americas can be a fruitful approach to the understanding of inter-hemispheric climate linkages.

Quasi-periodic fluctuations of 10 to 30 years are characteristic for the 20th century climates in the Americas, and their temporal and spatial characteristics have been linked to changes in ENSO frequency (see e.g. Trenberth and Hurrell, 1994). Mechanisms for these decadal and multi-decadal periodicities have been suggested, including internal oscillations of the atmosphere-ocean system (Schlesinger and Ramankutty, 1994; Kushnir, 1994), or changes in long-wave patterns alternating between both hemispheres (Allan and Haylock, 1993). Relationships between ENSO and regional extra-tropical precipitation patterns, however, tend to be unstable when ENSO behaves aperiodically (Elliot and Angell, 1988). For example, the negative relation between SOI and rainfall in Bogota (Colombia) and Georgetown (Guiana) breaks down in the middle third of the century, when ENSO is less periodic (Acetuno and Montecinos, 1992). On the other hand it is possible that a more robust ENSO index that combines several ENSO indicators will define a more robust teleconnection as well (Wolter and Timlin, 1992; Dunbar and Cole, 1993). Long-term changes in the distribution of climate modes in South America have also been linked to the ENSO phenomenon (Wells, 1990; Diaz and Markgraf, 1992; McGlone et al., 1992; Martin et al., 1993). Thus far no systematic study has been undertaken to relate ENSO to inter-hemispheric climate teleconnections at all different frequency bands.

Perhaps the most complex region of the PEP 1 transect is Central America, because of a combination of climatic controls, from the Atlantic (e.g. Garcia et al., 1978; Hastenrath, 1984, 1991), as well as from the Pacific (e.g. Rogers, 1987). Of special interest is the analysis of intensity and direction of moisture flux across this region, because models have shown that this could influence the character of thermohaline circulation in the North Atlantic (Stocker and Wright, 1991).
3. EXISTING PALEOClimate RECORDS FROM THE AMERICAS

3.1 Late Quaternary Records

The majority of low-resolution terrestrial paleoclimate proxy records from the Americas are based on changes in pollen assemblages. In some cases, especially in the US Southwest, plant macrofossil analyses help to further define past changes in plant assemblages (Betancourt et al., 1991). Records analyzed for multiple indicators (pollen, diatoms, ostracodes, geochemistry, stable isotopes, etc.), are far less common, although it is evident that the level of paleoclimate interpretation may be greatly enhanced using a multidisciplinary, canonical approach.

Long records on land that extend continuously back 250 ka are rare (Figure 4). There are several long records in North America primarily from the largely unglaciated US Southwest (Adam et al., 1989; Bradbury, 1991). There is only one long record from northern South America, from the High Plain of Bogota (Hooghiemstra et al., 1993; Hooghiemstra and Ran, 1994); but several subsiding basins have the potential for containing the entire Quaternary record.

Continuous records that extend back to about 40 ka are far more frequent and more evenly spaced throughout the Americas; these include records from the lowland tropical forests of eastern South America (Abys et al., 1991; Ledru, 1993; Liu and Colinvaux, 1985). Records for the last late-glacial/postglacial are common throughout, although (especially for South America) concentrated in the cordillera (e.g. Markgraf, 1989). Correlations between records can be reliable for this time interval, because several different dating techniques should be applied to establish the chronological frame. Comparison of paleoclimatic records along the north-south transect show marked differences between the timing, frequency, and amplitude of climate change. These differences suggest the action of several interactive forcing mechanisms whose influences are spatially and temporally delimited. The major findings are:

i) the accumulation of ice over eastern North America and its relatively late disappearance had major consequences for glacial and interglacial climate, extending as far south as northern South America and the adjacent oceans. The regional and global climate implications of this have been studied in considerable depth (e.g. Manabe and Broccoli, 1985; Barnosky et al., 1987; Markgraf, 1993; Webb et al., 1993; Maasch and Oglesby, 1990).

ii) during glacial times, South America experienced shifts in environments comparable to those in North and Central America. Timing of these shifts, however, was not always synchronous in the Americas and were related to the different interplay between Atlantic and Pacific ocean forcings on atmospheric circulation. Whereas northern hemisphere westerly stormtracks were deflected about 20° equatorwards by Laurentide ice (Thompson et al., 1993), the southern hemisphere westerlies moved equatorwards no more than 5 to 10° (Markgraf et al., 1992; Villagran and Armesto, 1993; Heusser, 1984). This suggests different equator-pole temperature gradients in each hemisphere along this transect.
iii) evidence from lowered snowlines in the mountains of central and northern South America and lowered vegetation zones in the highlands and tropical lowlands indicates that the tropics were 5 to 10°C cooler during the last glaciation (e.g. Schubert and Medina, 1982; Heine, 1989; Lozano-Garcia et al., 1993; Bush and Colinvaux, 1990). This temperature depression contrasts with that reconstructed from tropical deep-sea cores (CLIMAP, 1981). A re-assessment of the glacial continental temperature depression and its relation to the SST may resolve the discrepancy between terrestrial and marine data (e.g. Lehman et al., 1992; Edwards et al., 1993; Guilderson et al., 1994; Anderson and Webb, 1993).

iv) terrestrial records from both North and South America reveal repeated high-amplitude, short-term climate oscillations, especially during the glacial and late-glacial periods (Grimm et al., 1993; Allen and Anderson, 1993; White et al., 1994). The
extent to which these are synchronous with rapid oscillations seen in the Greenland ice cores and North Atlantic deep-sea records remains to be determined (Bond et al., 1993).

3.2 Late Holocene High Resolution Records
The Americas are rich in records with annual resolution for all or part of the last 2000 years (e.g. Bradley and Jones, 1992; Diaz and Markgraf, 1992). Apart from the particular wealth of tree-ring series in North America and southern South America (e.g. Fritts, 1991; Briffa et al., 1992; Villalba, 1994), historical documents (e.g. Quinn, 1992), laminated sediments both on the continents and on continental margins (Baumgartner et al., 1989), and corals (Dunbar and Cole, 1993), a notable feature of the Americas is the existence of ice cores from both high and low latitudes (Thompson et al., 1992). Many of these data have already been used to examine aspects of climate variability on Stream 1 time scales, especially in terms of the Southern Oscillation and its influence on teleconnection patterns. The major findings are:

i) variations over recent centuries in the intensity and frequency of the effects of the ENSO, in both its core tropical region and in the extratropics (Diaz and Markgraf, 1992);

ii) the existence of multidecadal modes and step-like shifts in precipitation, temperature, and wind regimes (including variance structure) in a number of regions (e.g. Ebbesmeyer et al., 1991), from the ITCZ (e.g. Linsley et al., 1994; Cole et al., 1993; Dunbar et al., 1994; Thompson et al., 1992) to both northern and southern mid latitudes (e.g. Boninsegna, 1992; Stahle and Cleaveland, 1992; and Meko et al., 1993);

iii) persistence of ENSO teleconnection patterns, e.g. expressed by multi-year subcontinental-scale droughts in North America (e.g. Karl and Koscielny, 1982; Betancourt et al., 1993); the general tri-partite division of climate variability in the 20th century (UNESCO, 1993); periods of flooding in northwestern and eastern subtropical lowlands of South America (Ortlieb and Machare, 1993; Prieto, 1993; Thompson et al., 1992) and of glacier movements in Patagonia (Aniya et al., 1992);

iv) a monotonic warming trend in annual temperatures in northern America since the mid-nineteenth century, seen in borehole temperatures and tree ring widths (D'Arrigo and Jacoby, 1992; Wang et al., 1992);

v) confirmation of LaMarche's (1974) report of a Medieval Warm Period/Little Ice Age pattern in other high elevation records from North and South America but not at lower elevations (Graumlich, 1992; Thompson et al., 1992; Hughes and Diaz, 1994).

4. PRINCIPAL SCIENTIFIC QUESTIONS THAT CAN BE ANSWERED BY PEP I

PEP I is well placed to contribute to the critical research tasks for PANASH. In some cases, many of the necessary data are already available, so that analysis of inter-hemispheric connections can commence immediately. An exploration of the interaction between the
Southern Oscillation and extra-tropical climate on Stream 1 time scales is a particularly good example of this. In other cases, there is a need for major field campaigns to develop new records in regions where they are currently unavailable. Land-based annual resolution records in the tropics, and long (10^4 to 10^5 years) continental cores with century scale or better resolution in many parts of the transect exemplify this need. Here we discuss the critical research tasks that are specific to PEP 1.

4.1 Questions open to analysis by Stream 1 projects.

The primary task is to generate quantitative estimates of past climates with seasonal to annual resolution focusing on decadal modulation of inter-annual variability at all latitudes during recent centuries and millennia. Temporal differences in the amplitude and frequency of climate variations and regional contrasts should provide insights into the mechanisms and teleconnections controlling decadal modulation of inter-annual variability. Such changes are of direct relevance to human societies and natural ecosystems.

4.1.1. What are the major modes of decadal scale climate variability revealed by the instrumental record?

Data availability varies greatly from region to region within the PEP 1 transect, and so efforts must be made to retrieve and subject to quality control hitherto undigitized instrumental records in data-poor regions. It is essential that the degree of intensive analysis that has been applied to relationships between the oceanic and continental climate in the western North America sector be applied to the entire PEP 1 transect. One important component of this will be the mapping of inter-hemispheric correlations between climate anomaly patterns and atmospheric circulation indices, and an examination of the influence of Atlantic and Pacific circulation features. Special attention will be given to improved descriptions and analysis of the effects of ENSO on an inter-hemispheric basis. This will occur in liaison with PEP II, ARTS and the CLIVAR project of the World Climate Research Program. An improved instrumental data base and integrated understanding of the climatology of the Americas should result from these activities. This will provide climate information for the calibration of proxy indicators throughout the transect and provide a baseline for paleoclimate comparisons, and will also give a physically reasonable background for the study of climate dynamics in this region, including an improved knowledge of decadal-scale phenomena.

4.1.2. What were the major modes of sub-decadal, decadal and century scale climate variability during the last 2000 years?

There are several regions in which annual-resolution proxy records of climate are needed, and priority will be given to developing these. The largest gap, to which the highest priority should be assigned, is in the terrestrial tropics and subtropics. Opportunities to close this gap is provided by records such as high elevation ice cores in the Andes, tree rings, historical documents, and laminated sediments. The development of precisely dated coral records will continue in the Pacific, Atlantic and Caribbean. The retrieval of nearshore marine laminated records
throughout the transect, and an increase in the range and density of the tree-ring network in southern South America are important elements of the PEP I Transect. Additional records also would be useful in the Canadian West, the northern Great Basin, much of northern Mexico and the Great Plains. It is certain that tree rings can be used to fill these gaps for some specific climate variables. Other possibilities include: laminated sediments, early historical records (at least for part of the 19th century) and high accumulation rate lake sediments (with perhaps decadal resolution). In all cases accurate chronology, rigorous calibration, and a clear understanding of the mechanisms producing each proxy record will be essential criteria for PEP I objectives.

4.1.3. What have been the roles of the major potential forcing factors on these time scales—ENSO, solar variability, volcanic aerosols, human activity?

Opportunities exist within and adjacent to the region to examine the climatic impact of volcanic eruptions from ice cores (ice core records). Records from the PEP I region have already contributed much to our knowledge of past solar variability (in particular 14C from tree rings) and opportunities will be sought to add to this. Ice cores also have a demonstrated capability to record the aerosol consequences of ancient human activity, as (potentially) do stable isotopic records from tree rings.

Conditions in and over the Pacific are an effective external forcing factor for inter-annual to multi-decadal climate variability in the Americas, and the Atlantic also plays an important role. PEP I will liaise closely with scientists producing suitably high resolution records of these conditions, most notably those from coral annual bands. The primary aim will be to determine the relationship between ENSO and extra-tropical climate. This will use the Southern Oscillation Index, currently being developed from a network of coral records across the Pacific, as a measure of the forcing function. Tree-ring and other annual resolution records from North America and southern South America are records of the extra-tropical response. The primary aim will be to determine the history of major changes in the frequency, amplitude, geographical and seasonal expression of ENSO effects outside the tropics in recent centuries.

In those cases where the forcing factor can be well described in the frequency domain, the coherency of the forcing (which may change through time) and physically relevant components of the paleoclimate response will be explored.

4.1.4. Treeline Project

Within Temporal Stream 1 special emphasis will be given to a 'Treeline project' based on variation of the altitudinal treeline along the entire cordillera. Ecotonal boundaries are optimal recorders of climate change and treelines provide the most extensive global ecotonal boundary from which long high-resolution proxy climate records can be developed using a combination of physical (e.g. glaciers, glacio-lacustrine) and biological systems (tree-ring chronologies, high resolution pollen, macrofossil and paleolimnological data). Comparative studies are possible between selected mountain environments, located ca 20-50° North and South, and it may also be possible to develop comparable records from tropical
environments along this transect. In parallel, these records will outline the longer term changes (with resolution of decades to centuries) that provide a framework for the more detailed (annual) variations in temperature and precipitation patterns. These records will also allow reconstruction of various significant forcing functions such as El Niño and possibly major volcanic events.

4.2 Questions open to analysis by Stream 2 projects.

The major emphasis on Stream 2 time scales will be to determine the influence of SST in the Pacific on terrestrial climates in the Americas and inter-hemispheric linkages. The approach proposed is the analysis of parallel marine and continental records. The analysis will focus on determining the climatic framework in the time, space and frequency domains, and then examining the data set for inter-hemispheric synchronicity, abrupt changes and the effect of insolation changes. Because of its N-S symmetry, the PEP I Transect is ideal for the study of inter-hemispheric correlations in response to external forcing, such as changing solar input determined by orbital parameters. It is also a good transect along which to trace large scale teleconnections to events in and around the North Atlantic.

4.2.1 What were the major modes of century and millennial scale climate variability during the last 250,000 years?

In order to understand inter-hemispheric climate linkages we need long terrestrial records with temporal and spatial resolution at least comparable to the marine records. Multiple proxies will be measured wherever possible to determine the nature and strength of the climate signal. The primary pre-requisite for the marine and terrestrial records is to directly correlate the sites in E-W and N-S transects from the eastern Pacific and the continents. Optimal regions are related to those latitudes with strong seasonal shifts in atmospheric and oceanic circulation. Direct correlation implies measuring the same component in both marine and continental sediment cores. These can include pollen, magnetic intensity, tephra, AMS 14C, among others. Correlation within the marine records include stable isotopes, chemostratigraphy, etc. Only when the marine and terrestrial records are placed in a firm chronostratigraphic framework can orbital forcing, forcing response, lead/lag relationships, etc. be addressed.

4.2.2. How do environments respond to changes in the distribution of solar radiation?

The effects of variations of orbital parameters on daily insolation differ latitudinally (see Section 5.1 in Chapter 1). The obliquity effect is more important in high latitudes; the precession effect dominates in all latitudes in local summer. In local winter, obliquity dominates precession at high latitudes close to the polar night. At equinoxes, daily irradiation does not depend on obliquity. Given geographical and seasonal calculations of solar input, a rich pattern of changing seasonality becomes evident over a long latitudinal transect such as PEP I. The transect forms an ideal laboratory in which to test how natural systems respond to these complex changing orbital parameters. A particularly
rich record of environmental responses will be revealed by combining marine and terrestrial transects.

4.2.3 Are periods of abrupt change synchronous along the transect, and if so, how are they caused?

The PEP I/Stream 2 data base will be used to investigate abrupt changes and climate extremes. Many paleoclimate records appear to contain quasi-2,500 yr events (Dansgaard-Oeschger events). Although the amplitude varies, the signal persists in both glacial and non-glacial climates. Determining whether this represents internal climate system oscillations or external forcing will indicate if one set of climate processes is insensitive to the presence of northern hemisphere ice sheets.

Asymmetrical gradual cooling terminated by abrupt warming events, of length 100-150 yrs, appear in both North Atlantic sediment cores (Heinrich events) and Greenland ice cores. What are the conditions preceding these events, what other elements of the climate system contain this signal and what are the leads and lags of the Laurentide Ice Sheet with the ocean system? Is the glacial climate more susceptible to rapid climate changes? Or are changes not as well-expressed in non-glacial climates? Answering these questions along the full length of the PEP I transect will reveal the sensitivity of the climate system. In addition to establishing the twin transects of marine and continental cores mentioned above, some specific tasks arise from these questions:

- Verify ice marginal positions (of the Laurentide ice sheet) and the timing of advances and retreats. For questions of rapid climate change, a static ice sheet at 18 ka is no longer adequate.
- Understand the mass/energy transfers. What was the timing and source of water transfer from ocean to land? Timing and magnitude of meltwater/iceberg discharge can determine the role of fresh water in modulating the thermohaline ocean circulation.
- Comparison of marine records in the North Atlantic, North Pacific, and Southern Hemisphere (IMAGES), will establish the leads and lags of the climate system during both longer term oscillations (>2,500 yr) or at times of abrupt changes in climate.

5. LINKAGES TO OTHER ACTIVITIES

In order to address effectively the scientific questions discussed in this document, it will be necessary to acknowledge the existence of a very uneven distribution of human resources and scientific facilities between the countries of the Americas. It is essential to establish effective communications between participating scientists and a pattern of exchange of personnel, training and access to facilities if PEP I is to reach its full potential. Collaboration with the Inter-American Institute for Global Change (IAI) offers a potential mechanism for this.

The nations of North and South America established the IAI in recognition of the importance of a regional approach to the study of global change. The IAI is designed to increase our understanding of global change related phenomena and their societal implications, and to augment the overall scientific capacity of the region. The Scientific
Agenda of the IAI is consistent with international global change research programs, such as IGBP/PAGES. The PEP I-Americas transect will provide the regional temporal perspective and a clearer understanding of the transequatorial dynamics of climate forcing mechanisms. Through collaborative research, data exchange and workshop participation, PEP I expects to join with IAI in building the scientific capacity for global change research throughout the Americas.

There are many potential points of interaction between the PEP I transect and the IGBP terrestrial transects in North and South America. Close interaction will be maintained to ensure intellectual and operational linkages. Many of the results of PEP research will provide the long term understanding for the IGBP transects. Similarly, the more focused IGBP transects will provide the proxy-calibration and process information needed to better interpret the paleoenvironment. Research carried out by ecologists, hydrologists, geomorphologists and atmospheric scientists in the IGBP transects will lead to a better appreciation of climatic feedback mechanisms and the role of land surface and biospheric dynamics for all the PEP transects.

PEP I will have important interactions with ARTS and CAPE for the tropical Pacific and the Arctic regions, respectively. These projects will provide valuable input to many of the objectives formulated for PEP I. Additionally, the other PEP transects, under the overall coordination of PANASH, will link with PEP I into a fully-global paleoscience network.
6. REFERENCES


Chapter Three

PEP II: THE AUSTRAL–ASIAN TRANSECT

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1. INTRODUCTION

The PEP II transect covers the Asian land mass from the Indian subcontinent to the Bering Strait, including southeast Asia and the complex of islands from Sakhalin to Japan and Taiwan. It spreads south through the Maritime Continent of Indonesia and the islands of the Philippines and New Guinea, then further south through the Australian continent and the islands of Micronesia, New Caledonia, Fiji and New Zealand, and finally across the Southern Ocean adjacent to Antarctica.

This huge area includes a large variety of environments with their own character, which are linked through regional and global climate systems to those of other regions. These linkages have scarcely been investigated or described and it is essential they be placed more firmly on the international research agenda so that the mechanisms and causes of climate change become better understood. Climate plays a significant role in human health and welfare of many nations of the region, and records of past climates can place more secure limits on the climatic variability to be expected in the future. The human occupation history across the transect includes some of the longest and best documented records anywhere, and includes other places where humans have been present for a millennium or less. Little is known of the influence of human activity on the climate systems, however, records along the transect provide opportunities to test a variety of hypotheses on this topic.

Some research within the region has considered the patterns of change and inter-relationships of synoptic scale processes, however, much has been focussed toward local or regional problems within countries or the surrounding seas. An outcome of this work has been the clear demonstration of the variety and significance of the environmental records in the PEP II region. The purpose of this chapter is to stress the need to define, understand and explain the phenomena which link the large scale features within the transect, and to other regions of the globe. This transect includes a number of unique features, including a large plateau in the north which splits the westerlies, the world's most significant warm pool of ocean water and the largest area affected by monsoons.

The PEP II region contains a considerable body of natural archives of Quaternary environmental history. For example studies of tree line variation on tropical mountains and elsewhere have shown that high amplitude temperature variations have taken place, and pollen and geomorphological evidence has shown that the region's monsoons have operated at greatly different intensities over the period of the last climate cycle. Outside the tropics there are records which have demonstrated
that there have been great changes in the patterns of deserts, ice sheets, aeolian deposits and in the patterns of vegetation and fauna. The scale of these changes needs to be quantified across the region in climatic terms.

In this section of the PANASH science and implementation plan the general biophysical features within the transect are outlined and a review of some of the published environmental records is given. The major part of this chapter deals with the principal questions which should be addressed in the near future, as a set of priorities, and an indication of the data requirements and approaches is given.

2. FEATURES OF THE TRANSECT

The PEP II transect includes areas and features which make its past environmental records unique, providing a great deal of information on the response of systems to a variety of environmental phenomena. Through teleconnections, these link to phenomena in other global-scale systems, including those dealt with in other PEP transects. In this section an overview is given of the special characteristics of PEP II. Figure 1 shows the distribution of selected features along the transect.

2.1 Area of glaciation

A unique attribute of the PEP II transect is the apparently small area of glaciation during the last glacial cycle. In Siberia (e.g. Shilo and Tomirdiaro 1982) and on the Tibetan Plateau it was apparently too dry to support any great ice cap (Thompson et al. 1989) as occurred in the north of the PEP I and PEP III transects. In the tropics a small ice cap formed on the high mountains on the island of New Guinea, and ice formed extensively over South Island, New Zealand (e.g. Hope and Peterson 1975). Elsewhere small areas of ice accumulated on the highest mountains of Siberia, China, Japan, Indonesia, and Australia, but these probably had only local environmental significance.

2.2 Extensive permafrost

The world’s most significant areas of permafrost exist in China, eastern Siberia and northern Sakhalin Island. The influence of these is such that taiga, tundra and bog are the most abundant vegetation types present where permafrost occurs. Many of the large river systems of the region occupy valleys with permafrost exposures, some of these are unstable at present and permafrost retreat is leading to valley widening. Little is known of the history of these regions and how they respond to and/or drive global climates. In some places permafrost is retreating dramatically at the present time (up to 10 m yr⁻¹) and releasing large quantities of entrapped methane. As this may play a major role in greenhouse warming, we need to understand how and at what rates permafrost reacted to past changes in climatic conditions.

2.3 Tibetan Plateau

This, the highest and most significant plateau on earth, has a relatively recent geological history and has undergone significant uplift since the early Tertiary and into the Quaternary. It has had a profound influence on global climates. It acts like a `Third Pole,’ but because of its mid-latitude
Figure 1
The PEP II transect outlining the distribution of important physical features.
position deflects the Westerlies. The Plateau’s ice cover is small because of its continental location and its very position creates a number of deserts, which in turn means any ice cover has a high dust content. Such is the significance of the Plateau and its position that it probably influences the position of the Siberian High, activity and penetration of the Asian Monsoon and any downstream influences these have both within and beyond the Northern Hemisphere. Surface uplift of the Plateau has had a significant impact on global climates from the perspective of the whole Quaternary (e.g. Kutzbach et al. 1993), however, it is unclear what the rate of surface uplift has been over the last 250,000 years. Uplift alone is unlikely to have significantly influenced climate changes on such a time scale.

2.4 Shallow seas
There is an abundance of shallow seas in the region, especially around eastern China, the Sea of Japan and the Sunda and Sahul shelves. During the glacial cycles vast areas would have been variously flooded and dry, and during the period of last glacial maximum not only would the dispersal of plant and animal species (including humans) have been enhanced, but extremely large variations in evaporation, albedo and land cover would have taken place. Much of the vegetation response in Japan, Korea, the maritime continent of Indonesia and Philippines, New Guinea, and in northern Australia around the Pleistocene-Holocene boundary may be a result of these changes.

2.5 The Maritime Continent
The form of the Maritime Continent changed remarkably due to sea-level variations and the northward push of the Australian part of the Indo-Australian Plate. The relative sea and land changes have brought about a shift from a land mass of continental proportions to the myriad of islands seen at the present time. Interpreting the records from this area requires the consideration of regional tectonics, the local implications of relative land and sea level changes and global environmental changes.

2.6 Western Pacific ‘Warm Pool’
The world’s greatest oceanic ‘Warm Pool’, around Indonesia and New Guinea, is currently one of the major global sources of moisture (which is also a greenhouse gas). Sea-surface temperatures (SSTs) in this region generally exceed 29°C. The switching on and off of this moisture source has significant local and global effects, for example through driving ENSO. An intense low pressure system over the ‘Warm Pool’ is responsible for transferring a significant amount of heat from the ocean to the atmosphere, and this rising branch of the Walker Circulation causes high rainfall throughout the Indonesian region (Thunell et al. 1994). Under a lower sea level, as at the last glacial maximum, the role of the ‘Warm Pool’ region would have been greatly changed, perhaps to the point where ENSO was not operative.

2.7 Environmental gradients
Within the PEP II transect there is an abundance of very steep and very broad environmental gradients. These lend themselves to testing the
relative impact and variability of important phenomena like the monsoons, temperature and moisture around the Tibetan Plateau and the high mountains of New Guinea and New Zealand, and the precipitation gradients inland of the coasts of Siberia and northern Australia. The sensitivity of systems to change along these gradients makes accessible questions about the nature of response (whether there is a trend or abrupt change) and whether there are lag effects, including differences between the hemispheres. These questions have very important implications to biota and human activity. Unfortunately, areas with steep environmental gradients usually occur in locations with a shortage of monitoring stations to provide records with which to calibrate proxy data.

2.8 Volcanic activity
There are a large number of very active volcanoes within the PEP II transect. Apart from perhaps Japan and New Zealand the tephra records need a great deal of work to become a valuable resource of time markers across the range of terrestrial and marine records in the region.

3. MODERN CLIMATES OF THE REGION AND THEIR VARIABILITY

In this section we present a brief overview of the major climate controls and of the kinds of questions which are relevant to each region along the transect. More detail on what is known of the climatic variability is given in Section 4.

3.1 Asian climate
The pattern of climate in the Asian mainland section of the transect is dominated by the position of the Siberian High, the jet stream (which is split and deflected by the Tibetan Plateau) and the summer and winter monsoons. In the region of Japan warm currents through the Sea of Japan and to the east of the islands, the passage of air from the jet stream, and easterly airflow from the north Pacific High bring abundant precipitation to Japan and the adjacent coasts of Korea and eastern Siberia. Cyclones track northward and may affect the climate of southern China and adjacent islands from spring to autumn, however, in summer these extend as far as the southern coasts of Japan and Korea and bring intense storms. The annual rain and snowfall patterns are such that there are marked precipitation gradients which run from humid regions in southern China (>2000 mm yr\(^{-1}\)) to the deserts of the Tibetan Plateau and northwest China and Siberia (<50 mm yr\(^{-1}\)) (Ren et al. 1985). The meridional temperature gradient is greatly altered by the position of the Tibetan Plateau.

These patterns are reflected in the natural vegetation, e.g. along the coast of the Asian mainland and adjacent island nations where tropical forest changes to a belt of subtropical forest. This occurs between about 24°N to 34°N in China, and in southermost Japan and Korea. Further north, in China, central and North Korea, Honshu and southern Hokkaido and far southeastern coastal Siberia, temperate conifer forest prevails, while further north again cold conifers dominate and grade through taiga to tundra. Aridity, continentality and the altitudinal gradient control the vegetation patterns inland of the
mainland coast. A broad sweep of boreal forest and grassland dominates
the landscape of China from 120°E and 50°N to 95°E and 28°N, and
inland of this occurs arid grassland and arid steppe, with open and
vegetation-free areas at the highest altitudes.

It is clear that the great glacial cycles are represented in the region
and are expressed in the strength of the monsoons and degree of aridity,
thus these are linked to global processes, but the variability of these
systems on decadal to century time scales is not understood. Warm and
wet periods seem to alternate with arid and cool phases. Knowledge of
these issues is fundamentally important to billions of people in the
region.

3.2 Climate of the Maritime Continent

The tropical location and position of the 'Warm Pool' and associated low
pressure cell dominate the climate of this region. The climate is warm to
hot all year, there is abundant rainfall and the natural vegetation is
tropical rainforest. The high mountains in the region create conditions of
rainshadow, and their great altitude results in local temperature
gadients. Thus the high mountains of New Guinea create local dry
valleys and rainshadow effects in islands to the south of Irian Jaya, and
vegetation ranges from lowland tropical forest through montane forests
and scrubs, to alpine grassland and even permanent snow cover on the
mountains.

The natural variability in the monsoon and of ENSO are of prime
interest in this region, as these affect rainfall delivery and drought which
affects some regions near Australia and in rainshadow areas.

3.3 Climate of Australia

Australia's mid-latitude position ensures a subtropical high centered over
its land-mass. Temperatures are mild to hot and the only significant high
country is in the southeast and in Tasmania where temperatures are
moderated and some local rainshadow areas occur. Much of the
continent is sub-humid to arid, with a weak summer monsoon bringing
much of the precipitation received in the north; southerly fronts,
generated from the Antarctic High, sweep over the Southern Ocean
bringing winter rainfall to the southwestern and southeastern areas of
the mainland. The Australian High migrates latitudinally over the year
and only Tasmania sits squarely within the influence of the Westerlies to
receive rainfall throughout the year. The eastern part of the continent, in
particular comes under the influence of ENSO where periodically the
Australian High has a blocking effect and little rain occurs inland of the
coastal ranges. The precipitation patterns are marked by their great
variability, and mean rainfall is a poor descriptor of the precipitation
patterns. Inland central Australia is poorly served by either the northern
or southern rain-bearing systems. Its mean annual rainfall is low and
uniformly distributed, but in reality most rain falls during high
magnitude events accompanying the occasional incursion of tropical
cyclones or northward penetration of the Westerlies.

Australian vegetation patterns consist of rainforest and tall
eucalypt forest in the best watered parts of the continent, which is
patchily distributed along the north, southwest and east coasts, and this
grades through open forests, woodlands and arid grasslands and shrublands to the interior. Alpine heaths and grasslands occur in the uplands of the southeast.

The major climate questions for this region therefore need to address what controls the moisture content of air masses in the north and south, and how these interact with ENSO, at both Stream 1 and Stream 2 scales.

### 3.4 Climate of the southwestern Pacific

The islands of the southwestern Pacific enjoy maritime climates with low annual temperature ranges, generally reliable rainfall and damped seasonal cycles. High mountains, as for example on New Caledonia and New Zealand, interact with the eastward migrating weather systems and a complex of climate patterns result. Thus western South Island, New Zealand, and the northern-most coast of New Caledonia are wet with mild temperatures and support moist evergreen forests, while the eastern and southern regions of these islands, respectively, contain seasonally dry forests, shrublands and grasslands. The mountains of New Zealand are significant for their alpine vegetation of heath and grassland, as in Australia, but their higher altitude ensures there is permanent ice and snow cover as well.

Many of the smaller island nations of the Pacific are on low lying land in the tropics. The major questions are those which affect sea-level variation and rainfall patterns. The most pressing research questions are those which generate an understanding of what drives ENSO, and of the variability in rainfall and the frequency of cyclones which can be expected.

Figure 2 shows the major precipitation and temperature patterns along the PEP II transect and Figure 3 shows the broad patterns of vegetation cover.

### 4. Overview of Existing Quaternary Records

The terrestrial and marine records from the region include some of the most significant Quaternary data records available and the potential for others is enormous. In a short review here, only a few of the principal records and synthesis works can be mentioned. At the same time there are many spatial and temporal data gaps that need to be filled.

For Asia, on the long time scale of the last glacial cycle, great temperature and precipitation fluctuations have taken place and these have driven great changes in vegetation patterns. These changes have been observed in lake records (e.g. Chen and Bowler 1986, Gasse et al. 1991, Colman 1992), pollen data (e.g. Tsukada 1967, 1982, Sakaguchi 1979, Bryson and Swain 1980, Igarashi et al. 1993, Winkler and Wang 1993), ocean sediments (e.g. Prell et al. 1980, Prell and Kutzbach 1987) and dunefield and desert records from India (e.g. Singh et al. 1972, Wasson et al. 1983). The Loess Plateau record from China, with its sequence of loess and palaeosols (e.g. Liu 1985, Liu et al. 1986, An et al. 1991) and the sediments from Lake Biwa (e.g. Fuji 1987, Horie 1987) in central Japan provide proxy records which cover the full Quaternary. These records have been studied by a number of methods and in many respects form the basis for correlation of the terrestrial climates of the
Figure 2
The major patterns of seasonal temperature and precipitation along the PEP II transect.

region with other parts of the world. There is also a growing body of high resolution data from ice records (e.g. Mayewski et al. 1980, 1984; Watanabe et al. 1984, Cole 1992, Wake et al. 1992) and from tree ring records (e.g. Cheng 1935, Cook and Kairiukstis 1990). In addition China, Japan, Korea and Indonesia have long written archives from a few centuries to several millennia (e.g. Chu 1973, Zhang and Crowley 1989) which contain evidence of short term variability of climate. These also contain records of other environmental phenomena and are valuable sources against which to test proxy records, especially for high magnitude but low frequency phenomena such as floods and other severe weather events. These documentary records need to be translated and organized in a database so that they are more widely available to the palaeo-community. Through these records historians may be encouraged to lend their expertise to the PAGES objectives.

The vast ocean regions of the PEP II transect have a scatter of sediment records as shown in Figure 4. The Solomon Plateau is a key Quaternary site and the records from around Japan and the region of the
Figure 3
The PEP II transect showing the current distribution of major vegetation types.
Maritime Continent provide particularly important data which cover the period from beyond Last Glacial Maximum into the Holocene.

Long pollen and coral sequences from Indonesia and New Guinea provide data on climate variability over part of the last glacial cycle (e.g. Bloom et al. 1974; Hope 1976; Walker and Fenley 1979; Harrison and Dodson 1993; Pirazzoli et al. 1993; Dodson, 1994; van der Kaars and Dam 1994) and on more recent variability in the monsoon (D'Arrigo et al., 1994). Great changes in the strength of the monsoon over the region are now known to have taken place, and at last glacial maximum alpine tree line was lowered by about 1 km, enough to suggest a cooling of at least 5°C. This cooling is not evident in the CLIMAP records (CLIMAP project members 1976, 1981). The region has some of the best untapped climate records in the tropics, including potentially long lake records and tree and coral growth increments which have recorded the recent variability in the monsoon. In this region there is a need to understand what controls the latter, especially how it is related to variability of the ‘Warm Pool’. For reconstructing the long climate record detailed sea-level and tectonic histories are needed, as well as data from the Tibetan Plateau and southeast Asia to reveal how the speed, direction and moisture content of winds have been affected.

Within Australia there are a number of long Quaternary records: sediment facies, palaeomagnetic and pollen records from Lake George, in New South Wales (Singh et al. 1981, Singh and Geissler 1985) and pollen records from Lynch’s Crater in northeast Queensland (Kershaw 1978) and Darwin Crater in western Tasmania (Colhoun 1988). Glaciation in Australia was of limited extent (Galloway 1986), but at Last Glacial Maximum aridity was much more prominent (Bowler 1982). The major climate questions for Australia are those which affect moisture budgets of the region, as cyclones, flooding, drought and bushfires are the major environmental hazards. On the long time scale, the Holocene has been wettest part of the last 100,000 years (e.g. Harrison and Dodson 1993; Dodson et al., 1993; Hope 1994) and is therefore unusual. The moisture budget is controlled by the penetration of the northerly rainbearing systems and monsoon (Gentilli 1972, 1991) and the southerly systems controlled by the Westerlies. These are strongly linked to ENSO in eastern Australia and less so elsewhere.

There are no single site records covering the whole of the last interglacial-glacial-interglacial cycle in New Zealand or the nearby Pacific islands, although several sites include records which extend into the Last Glacial Maximum (e.g. Moar 1980; McGlone et al. 1993). The tectonic component of land and sea-level variation is very significant (McLean 1980). Seasonality and amount of rainfall variation is of great importance to the larger nations such as New Zealand, Fiji and New Caledonia. There are long and high resolution records on the environmental significance of these for New Zealand (e.g. Soons 1979; Notton et al. 1989; Pillans 1994), and Fiji (Southern 1986), but little is known for elsewhere.

An encouraging feature of the southern part of the PEP II transect is that there is now an emerging picture coming from high resolution records in corals (Quinn et al. 1994), other palaeoenvironmental records (e.g. Dodson et al. 1994) and tree rings (Cook et al. 1994), which will be useful for comparison with northern records. However, what is lacking at
Figure 4
Ocean core records in the PEP II transect region.
present is a rigorous comparison of data sets across the major synoptic scale elements along the transect. This may result in part from the perspective of researchers which has been focussed largely on the patterns of local or regional scale environmental changes. The CLIMAP (CLIMAP Project Members 1976, 1981) and COHMAP programmes (COHMAP Members 1988, Wright et al. 1993) and other analyses (Markgraf et al. 1992) are now opening up the regional comparisons, especially through comparisons with general circulation simulations of past climatic conditions. Also lacking is a co-ordinated coring effort organised around a number of key sites along the transect. Some records already exist, but new sites are needed to help make regional syntheses more reliable.

5. PRINCIPLE SCIENTIFIC QUESTIONS THAT CAN BE ANSWERED ON PEP II

The principle scientific questions appropriate within the PEP II framework should concentrate on those records or data which demonstrate the variability of systems; these will include the features which link the northern and southern regions of the transect, and links to other transects. It is clearly important to examine the temporal and spatial patterns of inter-hemisphere exchanges of heat and moisture, in order to determine how the climate system functions. The existing proxy records show that environmental systems have undergone significantly greater change than is evident in the observed instrumental and historical records, and at rates and magnitudes of change which, if repeated, would have significant impact on human societies. Palaeoenvironmental information will provide information on the frequency of important phenomena such as floods, fires and cyclones which is clearly relevant to human society. Under the PAGES project this can be done by attempting to account for the contributions of external and internal forcing of climate variability and the impact of human activity on the environmental systems. The overall strategy described here stresses the importance of research that produces data which allows both a description of past conditions and the testing of simulations by predictive models.

Additional data in both Stream 1 and Stream 2 is required in all regions, but there is considerable scope for concentrating on some data archives in particular regions. The PEP II region is rich in data sources, many of which have not been systematically explored. Each data source has its own functional relationships with climate, and in some cases the data have not been calibrated in climatic or human impact terms. Work in refining and defining the value of proxy data, and in calibration (including an estimate of error terms) is an essential part of the PEP II programme. Importantly, an understanding of the big processes and problems along the transect will most profitably proceed where a multi-proxy approach is undertaken.

Figure 5 gives a diagrammatic representation of the relative positions and major linkages of the principal synoptic scale elements along the transect; in each region the climate is dominated by these elements. Table 1 lists the major proxy data types represented in each element. These are shown in bold where they can reveal both Stream 1 (annual or better resolution) and Stream 2 (lower temporal resolution) data.
Figure 5
Major synoptic features of the PEP II transect and a suggestion of the major interrelationships between them.
### Synoptic Scale Feature

<table>
<thead>
<tr>
<th>Proxy</th>
<th>Siberian High</th>
<th>Tibetan Plateau</th>
<th>Monsoon Winter Summer</th>
<th>Warm Pool</th>
<th>Australian High</th>
<th>Antarctica</th>
<th>West Pacific High</th>
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</tbody>
</table>

**General Coverage:** Volcanism, Orbital forcing, and Solar forcing.

**Table 1**

Proxy data types which may potentially reveal the dynamics of synoptic scale features on the PEP II transect.

A particular data requirement for all palaeoclimate work is chronology building. Some questions will remain unanswerable until technological breakthroughs result in firmer and lower uncertainties in dating. It would seem that a particular strength of the PEP II transect is the volcanic signal which originates throughout the hemisphere from Antarctica to Kamchatka in Siberia. The signal is particularly strong in the New Zealand, Indonesia-New Guinea and Japan regions, yet little systematic work on characterisation, dating and regional extent of tephras has been undertaken.

Selected tree ring records from Tasmania and Asia have shown considerable promise in chronological terms; the next step will be to calibrate these with climate data. The same approach is needed for pollen data from much of the transect. In some cases it may be necessary to establish meteorological stations, especially in areas along steep environmental gradients, in order to generate the data needed for calibration of proxy records.

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The following covers the highest priority, yet broad-based, questions relevant to large scale environmental change in the PEP II region. These questions concentrate on the description, function and dynamic relationships of major synoptic scale elements, and for success will draw together, and rely on, research coming from scientists located in a number of countries. For all questions identified there are a number of common attributes. These include identifying relationships, trends, variability and the likelihood of abrupt changes in systems.

5.1 Questions open to analysis by Stream 1 projects.
Obtaining a good geographic spread of high resolution data is likely to be limited to places where records are available in growth increments of trees, corals and giant clam, and lake basins and ice sheets with continuous and high sedimentation rates. Historical records from China, Japan, Korea and Indonesia also have the potential to provide high resolution records. These may be particularly useful for describing climate variability in relation to the position of the Siberian High, the Asian monsoons, the influence of the 'Warm Pool', and the occurrence of high energy but low frequency events.

5.1.1 What have been the respective roles of climate and humans in late Quaternary environmental changes?
High resolution and well-calibrated proxy records will be required to attempt this kind of enquiry as it is difficult to extract the influence of human impact without a knowledge of the background of natural environmental changes. Many questions fit under this umbrella and they clearly have significance at time scales relevant to human society. The relative significance of a whole range of forcing functions needs to be examined here. More is needed on the fine scale magnitude and variability of solar, volcanic, ENSO and other kinds of forcing. These undoubtedly interact with a variety of physical and biological systems but in which ways are unclear. Our colleagues in other disciplines need to know the answers to these kinds of questions in order to plan and determine levels of environmental risk. There is also considerable scope to analyse this question at a Stream 2 scale, such as analysis of climate response to albedo and hydrological changes resulting from deforestation, agriculture and soil erosion.

5.1.2 How has ENSO varied at low frequencies as higher frequency climate changes have occurred?
ENSO is recognized as a major influence on climate for many parts of the region. Periodic droughts, river flow and economic and social well-being in eastern Australia, New Zealand and many island nations along the transect are particularly sensitive to ENSO variation. It is clear that even large ENSO-related events of the last decade have not been previously observed within the instrumental record which has measured ENSO variability over the last century.
5.1.3 Has the variability and frequency of climatic extremes changed during the last 2000 years, and by what mechanisms?

The variability and frequency of climate systems is much greater than has been directly measured according to a range of proxy data from the Late Quaternary. These are in part controlled by the influence of the Siberian High, monsoon systems in the north from China and India and south across the maritime continent to Australia, and of the Westerlies in both the north and south of the transect. These systems affect precipitation, drought and fire frequency, and it is particularly the extremes which most affect human societies. A fuller understanding of the mechanisms has an important function in planning and preparation to mitigate extreme events.

5.1.4 How has the ‘Warm Pool’ responded to changed boundary conditions, and how have the responses affected ENSO?

The hydrological extremes of a large part of the transect are probably related to this interaction. The interactions are connected in ways that are not very clear, and furthermore, there are teleconnections to other PEP transects. How are these translated, and how long have these translations been operative and in what forms? A critical point here is to understand the relationship between the ‘Warm Pool’ and the monsoon systems. A large part of the long-term trends, the variability and the extremes, are probably related to these kinds of interactions. We know little about any of these kinds of variability. The results will have considerable scientific importance, and social significance for many countries in the region.

5.2 Questions open to analysis by Stream 2 projects

5.2.1 What changes through time have altered the strength of the Asian-Australian monsoon?

The strength of the monsoons will be very much affected by orbital and solar forcing, and the volume of evaporation from the ocean surface. Finely tuned data are needed on the degree of forcing from solar and orbital factors, on the history of the extent and temperature of shallow sea areas in the region of the Maritime Continent, the role of the Tibetan Plateau in deflecting wind flows into the region, and of how these are linked to Northern Hemisphere ice cap growth. These are likely to be particularly sensitive to insolation forcing, and of any feedbacks, and a detailed comparison of low and high latitude climatic variations should enable an evaluation of how this operates. A full analysis of this question will also require records of land and sea surface areas to be determined, as a result of sea level change and significant tectonic activity in the region. The history of the ‘Warm Pool’ is very important for this question; coral and marine data, and a variety of terrestrial data sources will enable analysis of this, and any related influences on ENSO activity to be understood. There is considerable scope for also including this question within the Stream 1 priority list.
5.2.2 Have the Westerlies shifted latitudinally, by how much, and what has caused the changes?

Global environmental gradients affect the vigour of atmospheric circulation and meridional transfer of energy. The interaction of the Westerlies with the high pressure centres of Siberia and Australia have most likely affected the long-term hydrological history, and therefore biogographical patterns and landforms, of significant areas along the PEP II transect. CAPE (CircumArctic Paleo Environments) is an operational task of PAGES designed to focus, in part, on the environmental history of eastern Siberia and Alaska and thus much of the research will be directly relevant to this question.

5.2.3 Have the Siberian and Australian High Pressure systems changed position and intensity through time, and what has caused these changes?

The position of the Siberian High is likely to be linked to climate patterns which are associated with changes in the Asian Monsoons and the Westerlies. Tectonic effects around the Tibetan plateau are not significant on this time scale. To test this interaction there is a need for palaeovegetation, loess and permafrost data from areas to the north, east and south of the present mean position of the Siberian High, and additional marine data to examine the history of the strength of the seasonal monsoons. The HIPP Program (Himalayan Interdisciplinary Paleoclimate Program) focuses on accessing a diverse array of natural archives from the central highland region of Asia. Both Stream 1 and Stream 2 resolution records are being extended to improve understanding of natural climate variability, behaviour of the monsoons and to determine the hierarchy of forces controlling climate of the region. In addition, the Baikal Drilling Project, a PAGES operational task supported by Russia, Japan and the U.S., is recovering long lacustrine records of climate change for central Asia. Lake Baikal is located in a very important region as it occurs in an apparently unglaciated area and is close to the winter centre of the Siberian High. Sedimentation rates are high in some of the sediments and it is already known that the orbital frequencies are evident in the record (Colman, et al. 1992).

The position of the Australian High is influenced by the vigour of monsoon activity in the north, and hence the linkages outlined above, and the strength of the Westerlies in the south. The latter are in part driven by the passage of air flowing from Antarctica across the Southern Ocean. The patterns of desert dune mobility, lake levels and forest cover in Australia are very much influenced by the position of the High and more data from all these realms is needed for tying in with records of sea ice in the Southern Ocean and in the chemistry and physical properties of the Antarctic ice sheet. This should enable the assembly of the larger picture of relationships and causes to be assessed.

5.2.4 How has the climate been affected by sea-level and SST changes in the ‘Maritime Continent’, east Asia and northern Australia?

Vast areas of the shallow seas have been greatly affected by Quaternary sea-level change. Hydrological conditions, including river discharge and the distribution of arid and mesic conditions over many parts of the
regions identified above are influenced by sea-level variations. These changes would certainly have had important biogeographical implications and may even have influenced the migration of humans in the region. The relationship between regional sea-level, SST and the ‘Warm Pool’ is likely to have been important globally through a host of teleconnections. ARTS (Annual Records of Tropical Systems) is a PAGES initiative which aims to facilitate the generation of high resolution records from corals, tree-rings, ice cores and varved sediments. All but the last are well-known or under development along the PEP II transect.

The data available to answer these questions exists in the literature and in the unexamined records indicated in Table 1. Significant progress can be made where scientists are prepared to rigorously test the timing, variability and strength of the climate signal across regions where two or more synoptic scale elements interact.

6. LINKAGES OF PEP II STUDIES TO OTHER TRANSECTS AND INTERNATIONAL PROJECTS

Clearly there are many approaches and problems in common with the other PEP transects. In Chapter 1 there is discussion on dating and some model-data intercomparisons which are highly relevant to answering the questions posed by PEP II. ARTS and CAPE, which are part of the PAGES program, will also provide valuable input to PEP II questions.

There is a strong northern connection between PEP II and PEP III. The Siberian High, which influences the climate of eastern and central Europe and the Indian monsoon, forms an important part of both transects and the INQUA/PAGES Palaecmonsoons Project (Kroeplin 1994) aims to stimulate research on the links between PEP II and PEP III. There is also a major interface between PEP II and PEP I with ENSO. Much of the work concerned with this in either PEP I or II will be relevant to the other. CAPE represents a further strong link between the two transects.

Ocean and Antarctic Ice Sheet studies are being undertaken by many international co-operative ventures, such as IMAGES, and it is important that PEP II keep in close contact with these for exchange of information and joint support where possible.

Many of the outcomes of PEP II research will be needed for other PAGES activities such as PMIP and PMAP, and IGBP's GAIM core project. Likewise research carried out by plant physiologists, hydrologists, coastal geomorphologists and atmospheric scientists in BAHC, GEWEX, LOICZ and others will provide a better appreciation of feedback mechanisms and the role of land and ocean surface dynamics.

Other initiatives, including the recent extensions to the COHMAP programme and those being undertaken by the Commissions of INQUA fall into the category of international co-operation; all PEP transects will provide new data and insights which will be relevant to these efforts.
7. REFERENCES


Chapter Three: PEP II


Chapter Four

PEP III: THE AFRO-EUROPEAN TRANSECT

Project Leader: Françoise Gasse

1. INTRODUCTION

The area covered by PEP III extends from the Atlantic to approximately 60°E, the longitude of the Ural mountain range. PEP III includes Scandinavia, western, central and eastern Europe, the Mediterranean basin and the Middle East, Arabia, and Africa (Figure 1). This area exhibits a large variety of extreme natural environments, ranging from alpine glaciers, Arctic tundra, the greatest warm desert of the world, and equatorial rainforests. A unique feature is the large inter- and intra-continental water masses (the Baltic, Caspian, Black, and Mediterranean Seas, and the great East African lakes) which play a significant role in the regional climate.

Interhemispheric transfers of energy occur through oceanic thermohaline circulation and atmospheric monsoon circulation. The climate of the western part of the PEP III domain is dominated by the influence of the Atlantic Ocean which penetrates inland through the westerlies at high and middle latitudes, and the African monsoon in the tropics. There is no natural boundary between Europe and Asia, creating a marked West-East gradient from oceanic to continental climate. Conversely, Africa south of 10°N forms a land mass narrowing southward between two oceans. The Indian Ocean is landlocked to the north at tropical latitudes, and the Indian monsoon, which is greatly influenced by the Tibetan Plateau, penetrates East Africa and South Arabia.

One of the most dramatic responses to past climate change has been the formation of the Fennoscandian ice sheet and North Atlantic sea ice, 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 and spectacular hydrological changes occurred at low latitudes. Water levels of some East African rift lakes were as much as 300 m above their present-day level during the Early-Mid Holocene. In the Sahara, a multitude of lakes developed and Neolithic civilizations flourished 9-5 ka ago. During the last two decades, the sensitivity of societies to climate and hydrologic changes in arid and semi-arid zones was dramatically illustrated by the drought over the Sahel.

In Section 2 we provide an overview of the main bioclimatic regions and existing Quaternary records. We will consider the sensitivity of individual regions to the main external forcing factors and the potential feedback effects from these regions on the global climate. In this section we will also raise a number of questions that can be addressed in the different regions of the PEP III transect. This does not imply that these issues are not important elsewhere, but only that new
Types of Natural Vegetation

LEGEND

- Mountain vegetation
- Tundra
- Taiga
- Mixed Forest
- Broadleaf Forest
- Mediterranean Scrub
- Prairie
- Steppe
- Savannah
- Tropical Rain Forest
- Dry Tropical Scrub and Thorn
- Desert vegetation

(After White, 1983)

Figure 1
Types of vegetation in the PEP III area.
information from these regions would be particularly valuable and greatly enhance our understanding of paleoclimatic fluctuations. General strategy is presented in Section 3 which proposes a science and implementation plan with questions that should be addressed within PEP III. The specific characteristics of the PEP III transect suggest particular methodological approaches. Section 4 describes the linkages between PEP III and other international activities.

2. REGIONAL FEATURES AND QUESTIONS OF THE PEP III TRANSECT

In this section, we raise a number of paleoclimate questions which can be addressed in different regions of the PEP III transects.

2.1 Southern Africa and Madagascar

How did the region respond to changes in: (i) the extent of the Antarctica ice-sheet and sea-ice in the Southern Ocean, and (ii) the efficiency of the return flow of the oceanic thermohaline conveyor belt? Is there a Younger Dryas signal? Did the Little Ice Age and the Medieval Warm Epoch effect the region?

This region is well-placed to record shifts in the mean position of the circumpolar westerlies, related to the tropical-temperate temperature gradient and growth/decay of sea-ice in the Southern Ocean. The Benguela Current derives cold water from the Circumpolar Current along the southwest coast of Africa affects both air temperature and precipitation over adjacent lands. To the east of southern Africa, the surface temperature in the warm Agulhas Current and the position of the divergence in the Agulhas Current (Chapter 1, Figure 1) influence the climate in the interior of South Africa, Mozambique and Madagascar. The region shows a complex mosaic of climate types ranging from desert (Kalahari and Namib), mediterranean, to wet tropical climate, due to surface winds and coastal oceanic currents.

Late Quaternary and Holocene climatic changes in South Africa have been the subject of several reviews (Tyson, 1986; Deacon and Lancaster, 1988; Partridge et al., 1990; Partridge, 1993). These demonstrate the difficulty of obtaining long "conventional" records on land (e.g. lake, pollen records, and dendroclimatology) and of interpreting palaeodata in terms of past atmospheric and oceanic circulation. They also suggest that longer, more highly resolved, and more easily interpreted records of terrestrial climate may be retrieved from the adjacent coastal oceans. No definitive statement about a terrestrial Younger Dryas climatic change can be made at this stage, although a cooling is suggested by one record from South Africa (Thackray, 1990).

Within Time Stream 1, the identification of the Little Ice Age and Medieval Warm Epoch (Tyson and Lindsay, 1992) has to be confirmed. Corals from the continental margins (e.g. Mozambique Channel) may allow fruitful comparisons with the northern tropics.
2.2 Equatorial rainforests and tropical wetlands

How did these ecosystems respond to glacial-interglacial climatic change?
How did changes in land surface conditions at low latitudes affect trace gas concentrations in the atmosphere?

In equatorial Africa, pollen records document important changes in the extent of the rainforest over the past 30,000 years with a phase of forest degradation during the LGM (Maley, 1991; Servant et al., 1993). These changes, in good agreement with lake level fluctuations in the region (Talbot and Delibrias, 1980), may have induced significant fluctuations in continental carbon storage (e.g. Adams et al., 1990; Branchu et al., 1993). Modern methods of coring and drilling in lakes from this region should be encouraged to obtain information over an entire glacial-interglacial cycle.

Wetlands occur today in the Zaire basin and in other regions, such as the internal Niger delta in Mali. These wetlands were more greatly developed in the past, especially during arid-humid climatic transitions, and may have acted as a source of atmospheric CH\textsubscript{4}. Relationships between African tropical land surface conditions and atmospheric CH\textsubscript{4} levels are suggested by the apparent correlation between short-term dry events in the northern tropics and the decrease in CH\textsubscript{4} levels recorded in Greenland ice cores during the post-glacial period (Chappellaz et al., 1993; Gasse and Van Campo, 1994). Measurements of CH\textsubscript{4} flux from such environments, dating and mapping of past wetlands, and sensitivity experiments in models should help test this relationship.

2.3 The African and Indian monsoon domains

How have monsoon climates varied in the past, and were there synchronous changes in Indian and African monsoon circulation?

The PEP III transect represents a critical area for our understanding of oscillations of the Inter-Tropical Convergence Zone (ITCZ). In the African monsoon region (a highly populated area), the monsoon winds penetrate largely over low-lying land areas into East Africa, whereas southern Arabia and part of East Africa are influenced by the Indian monsoon.

Little is known from southern Arabia (Sanlaville, 1992), except from offshore sediments (e.g. Sirocko et al., 1993) and some data on lake-level changes (Roberts and Wright, 1993). In intertropical Africa, interesting information on continental climate over the last glacial-interglacial cycles is derived from windblown material (Pokras and Mix, 1987; Jansen et al., 1990; Gasse et al., 1989) and pollen in marine sediments off central and west Africa (e.g. Hooghiemstra et al., 1986; Dupont, 1993). On land, much of the available palaeoclimatic data are derived from lake profiles and pollen data. The few records which include periods older than 30 ka are poorly dated. Information on fluctuations in lake level (e.g. Street-Perrott et al., 1989) (Figure 2) and lake chemistry are numerous. However, little has been done so far to infer climatic parameters from lakes (Kutzbach, 1980; Hastenrath and Kutzbach, 1983; Adams and Tetzlaff, 1985). There is an abundant literature on pollen records which allow the reconstruction of the migration of vegetation belts and seasonal wind patterns (e.g. Hooghiemstra et al., 1986; Lézine and Casanova, 1991; Dupont, 1993). Nevertheless, pollen transfer functions, which allow palaeoprecipitation and palaeotemperature to be
Figure 2
Lake level "status" at 18, 12, 6, and 0 ka B.P. (after Street-Perrott et al., 1989).

△ = Low
* = Intermediate
● = High
inferred, have been established and used only in East Africa (Bonnefille et al., 1992). Orbital forcing accounts for the general envelope of changes in monsoonal circulation and in the regional hydrological balance (Kutzbach and Street-Perrott, 1985). However, the abrupt and apparently synchronous changes in monsoon strength documented for the post-glacial period in both the African and Indian monsoon domains cannot be explained by changes in solar radiation. Further research is needed to identify the causes of short-term weakening of monsoon rainfall (Gasse and Van Campo, 1994) and to determine if these episodes coincide with climatic events outside of the monsoon domains.

Efforts are clearly needed to calibrate both pollen and lake data in terms of palaeoclimatic parameters, and to provide long-term, high resolution terrestrial records of palaeomonsoons. In this context, two tasks are being developed as PEP III activities:

- IDEAL Project (An International Decade for the East African Lakes; Johnson, 1993). The deepest East African Rift lakes (e.g. Tanganyika, Malawi, Edwards...) which did not dry during the late Glacial Maximum, are excellent potential sites for long climatic records. Field work for IDEAL has already begun in Lake Victoria.

- Palaeomonsoons. An initiating INQUA/PAGES workshop was held in Mombasa in December 1993, and future research has been proposed (Kröpelin, 1994). This project will form an important link between PEP II and III transects.

2.4 The Sahara–Arabia desert belt

What is the role of the desert in aerosol loading of the atmosphere and how does aeolian dust deplete incoming solar radiation in surrounding areas?

What feedback mechanisms may involve changes in soil moisture, albedo and atmospheric pressure over the desert?

Marine sediments off northwest Africa (Sarnthein, 1979) and Arabia (Stroock et al., 1993) provide information on past variations in the flux of aeolian dust to the oceans, which was considerably enhanced during the glacial/dry periods. The role of these glacial-age aerosols in decreasing net solar radiation in the tropics and thus in decreasing the monsoon rains have been described by COHMAP Members (1988).

Contraction/expansion phases of the desert are documented by a number of continuous records and a large amount of scattered data, mainly from palaeolakes (Figure 2) and playas, pollen, macrofauna, wood charcoal, and archeology (e.g. Street-Perrott and Perrott, 1993). A specific difficulty in desert areas is dating when macrofossils of non-aquatic plants are absent in the sediments. This is because: (i) most palaeolakes were supplied by aquifers and anomalous $^{14}$C ages must be suspected, (ii) diagenetic effects are frequent due to fluctuations of the groundwater table in the sediments after lake regression. The combined study of groundwater and palaeolakes (e.g. Fontes et al., 1993) is strongly recommended, especially for an estimate of the temporal lag between increased rainfall and lake formation. Available data show that changes in the hydrological budget from south to north of the Sahara occurred broadly in phase with those observed in the monsoon regions, including the short-term post-glacial dry spells (Gasse et al., 1990, Lamb
et al., 1995). Increased precipitation-evaporation ratios during interglacial periods may profoundly change land surface conditions. Large salt water bodies occupied topographical depressions about 125,000 yrs ago, as known from Libya (Petit-Maire, 1982) and Tunisia (Causse et al., 1989). During the Early and Mid Holocene period, the Saharan aquifers, lying today at tens to more than 100 m below the land surface, outcropped in a multitude of interdunal depressions, steppic vegetation developed, and Neolithic civilizations flourished.

Several questions arise for periods with a "green" Sahara: (i) what is the time lag between increased rainfall and lake formation due to the refilling of the Saharan aquifers? (ii) what is the origin of precipitation (monsoonal, Mediterranean, or both)? (iii) what feedback mechanisms to atmospheric circulation are generated by changes in land surface conditions over the Sahara? Another crucial problem is the role of human activities on desertification at the Sahel-Sahara boundary.

2.5 Large inter- and intra-continental seas

*How do these systems act on regional climate, and how did they record global change?*

The Baltic Sea, the Caspian “Sea” (the largest inland lake of the world) the Black Sea and the Mediterranean Sea act as large water reservoirs. The three latter also act as evaporative basins and greatly influence the regional climate, as shown by the Caspian Sea modeling experience in studying global and regional climate interaction (Rodionov, 1994).

These sedimentary basins should also provide important records of glacial/interglacial hydrological changes over the European continent as related to the growth/decay of the ice sheet at high latitudes. During glacial periods, the drainage towards the Arctic Ocean was blocked by the ice sheet and large rivers were diverted towards the southern seas (Section 2.8). The catchment of these seas was enlarged, while freshwater discharge to the northern oceans was reduced. Long cores in the Caspian “Sea” are particularly recommended because the Caspian remained a close lake over the past climatic cycle. The eastern Mediterranean has also recorded changes in the precipitation-evaporation balance over East Africa, especially on the Ethiopian Plateau, through the discharge of the Nile River (Strick-Rossignol, 1985).

2.6 The Mediterranean region

*What recent climate information can be retrieved from historical data? How were the west-east/north-south gradients in precipitation modified in response to glacial-interglacial climate change?*

The Mediterranean region is one of the richest regions in the world for historical and archeological archives spanning the past several thousand years (e.g. Hassan, 1986; Weiss et al., 1993; Runnels, 1995). The use of this large source of data can be enhanced for paleoclimatic purposes through a critical inventory and extraction of information on historically dated climatic events. Collaboration between historians, archaeologists and paleoclimatologists should provide valuable new insights into past climate variations.

Climatic changes in the European Mediterranean region are relatively well documented, especially from long pollen series (e.g. Pons et al., 1987; Follieri et al., 1988; Tzedakis, 1991; Watts, 1985). In the
eastern Mediterranean region, and the Maghreb, intensive work with focused goals is still needed, although information is available from different types of proxies (e.g. Amirian, 1991; Begin et al., 1985 Horowitz, 1979; Kaufman and Margaritz, 1980; Roberts and Wright, 1993; Van Zeist and Bottema, 1991). Lakes from Turkey, Israel and Jordan (e.g. Lake Van, Lake Kinnereth or the Dead Sea), some of them showing laminated sediments (e.g. Kempe and Degens, 1978), are good potential sites for PEP III activities. An important question is the characterization of seasonality and rainfall season(s) in glacial and interglacial periods. During the LGM, lakes were high (e.g., Street-Perrott et al., 1989). The paradox between high lake levels and pollen-inferred mean annual precipitation lower than that of today may be due to a southward shift of the westerlies in summer (COHMAP Members, 1988), and/or winter rainfall under a mean temperature lower than present, inducing lower evaporation-evapotranspiration losses. The last hypothesis is suggested by modeling of a lake in Greece (Prentice et al., 1992; Harrison et al., 1993). This scenario needs to be tested by generating new data and modeling other lake/vegetation systems, and also for the Middle East and Maghreb, by the reassessment of the chronology of lake level fluctuations.

2.7 The West-East climatic gradient over Europe

How did Europe respond to ice sheet development, changes in North Atlantic SST and in thermohaline circulation? What was the magnitude and geographical extent of climate changes over the current interglacial?

Northern and Western Europe, the region most sensitive to Atlantic Ocean heat transport (Chapter 1, Section 5.4), lies under the westerlies and is influenced by the strong positive thermal anomalies in winter, the intensity culminating off northern Norway. Eastern and Central Europe is influenced by the winter Siberian High pressure cell. Thermal seasonal contrasts (Figure 3) and aridity increase from west to east across Europe.

**Figure 3**

Palaeoclimates in Western and Northern Europe are well documented from various types of proxies. During the LGM, the extent of the Fennoscandian ice sheet together with decreased North Atlantic SSTs and less efficient thermohaline convection, profoundly modified climate patterns over the region. The surface easterly winds flowing along the southern boundary of the ice sheet generated a dry, cold climate from eastern to western Europe. Over the past few years, the EPOCH program has reconstructed global changes for the last 30,000 years and attempted to reconcile:

- palaeo-ice data with models of the European ice-sheet (e.g. Boulton and Clark, 1990; Boulton and Payne, 1992);
- the Dansgaard-Oeschger warm events (from Greenland ice cores);
- the Heinrich events in the North Atlantic (e.g. Bond et al., 1992);
- North Atlantic sea surface conditions (e.g. Duplessy et al., 1992);
- and terrestrial data (mainly from pollen; e.g. Huntley and Birks, 1983; Frenzel et al., 1992; Guiot et al., 1989, 1993; Huntley and Prentice, 1993).

To advance these studies, the scientific community has organized data bases (e.g. the European Pollen Database) and initiated multi-disciplinary, international programs, such as the European Lake Coring Project (ELCP) and the Terrestrial Initiative in Global Environmental Research (TIGER) sponsored by NERC (UK).

In Eastern and Central Europe, data are available about the palaeohydrology of rivers and lakes (e.g. Starkel, 1983; Kremenetski and Tarasov, 1992; Klige, 1990), changes in vegetation (e.g. Velichko, 1987; Velichko et al., 1983; Peterson, 1993), the environments of the southern seas (e.g. Yanko, 1990) and loess-palaeosol series (e.g. Kulka, 1975). A large amount of information already exists in the former Soviet Union which should be critically compiled and published in the international literature. However, development of a coordinated framework of palaeodata sites remains a first priority.

Within Time Stream 1 and even for long-term records, Western and Northern Europe is rich in thoroughly-analyzed time series with annual or seasonal time control. Dendroclimatology is undoubtedly an extremely powerful approach to high resolution palaeoclimatic reconstruction (e.g. Briffa and Schweingruber, 1992) and tree ring series have been established for the past 13,000 yrs (Kromer and Becker, 1993). Laminated lake series are available from Scandinavia (e.g. Renberg, 1986; Saarnisto, 1986), Poland (e.g. Ralska-Jasiewiczowa et al., 1987), Switzerland, (e.g. Lotter, 1991), Germany (e.g. Zolischka, 1991), Turkey (e.g. Kempe and Degens, 1978) and varved clays occur in Sweden (Wohlfarth et al., 1995a, b). Besides calibration of the radiocarbon time scale, these series establish the precise timing and duration of climatic events at a given site. Studies of laminated speleothems are also promising as speleothem growth rate is dictated by climatic factors (e.g. Hendy, 1971; Baker et al., 1993, Lauritzen, 1993, 1995) and a high-resolution chronology can be established by different techniques (e.g. Baker et al., 1993; Shopov et al., 1994). In laminated lake sediments of northern Europe, the annual flux of carbonaceous particles, regarded as pollutants from fossil fuel combustion,
can be estimated (Renberg and Wik, 1985). This is an interesting approach with regard to changes in trace gas concentration induced by anthropogenic activities. Integration of the many existing series and studies of new series in central and eastern Europe (e.g. the annually laminated sediments of the Black Sea or of Lake Säkki, north of the Black Sea) should considerably enlarge our understanding of natural and anthropogenically-induced environmental and climatic variability.

2.8. The northern latitude ice sheets

How did northern Europe respond to climate change?
What did ice sheets modify European climate and hydrology?

Glaciers, and especially the large ice sheets, represent some of the most dramatic responses to climatic change. The growth and decay of the large ice sheets also involves strong feedback mechanisms through their topographical effect, and by changes of albedo, creating a new locus of atmospheric high pressure.

During some periods of the last glacial cycle, the ice sheet covering the Barents and Kara Seas had important effects on Europe:

(i) The ice sheets dammed the northflowing rivers that now drain the continent towards the Arctic Ocean. The rivers were diverted towards the North Sea or the Caspian and Black seas, and ultimately to the Mediterranean, changing the hydrologic balance of much of the continent;

(ii) The Barents Sea, which now transfers heat from the Atlantic to northern Russia was replaced by a "white mountain";

(iii) The Barents and Kara ice sheets changed atmospheric circulation patterns between the Arctic and northern and central Europe;

(iv) because the Barents Ice Sheet was marine-based, it was sensitive to sea level changes, and presented a strong feedback in sea level, linking the Antarctic and northern hemisphere ice sheets.

The maximum extent of the Scandinavian Ice Sheet during the Late Weichselian (18-25 ka) is reasonably well known (Andersen, 1981). However, the dating precision is poor. Glacial fluctuations through the last two glacial cycles are much less known, due to the removal of the older records within their boundaries. Some two-dimensional glaciation curves are constructed by Mangerud (1991) and correlated with ice-rafted detritus in deep sea cores (Baumann et al., 1995).

The Late Weichselian glacial maximum of the Barents Ice Sheet is reasonably well known on its western flank (Elverhøi et al., 1993; Mangerud et al., 1992; Vorren et al., 1988). On the eastern flank, in northern Russia, the boundary is strongly disputed. Grosswald (1980, 1993) reconstructed a huge ice sheet, whereas Astakhov (1994) reconstructed a small ice sheet, and claimed that the Weichselian glacial maximum pre-dated 40 ka. A reconstruction of the glacial fluctuations through the last glacial cycle on western Svalbard is presented by Mangerud and Svendsen (1992), whereas the fluctuations are unknown for more easterly parts of these ice sheets.
3. GENERAL STRATEGY AND GUIDELINES FOR PEP III ACTIVITIES

PEP III should provide a characterization of climate fluctuations (timing, magnitude, geographical extent...) to increase our understanding of how climatic events from the two hemispheres are dynamically inter-related. The following is a summary of the scientific questions that can be addressed in PEP III and some specific strategies to make further progress and optimize the efficiency of research work.

3.1 Principal scientific questions that can be addressed in PEP III

Coordinated efforts within PEP III may address climatic problems concerning: (i) the history of the northern ice sheets in response to climate change; (ii) latitudinal shifts of westerlies in response to growth/decay of the polar ice sheets; (iii) the response of continental climates to changes in oceanic thermohaline circulation; (iv) monsoon variability; (v) feedbacks from land surface to global climate, especially from the tropics and the Sahara. Here we organize additional questions based on both the critical research tasks addressed in PANASH (Chapter 1) and the problems highlighted for individual regions as a function of time scales. These questions are not prioritized, nor exhaustive.

3.1.1 Time Stream 1. Seasonal to century-scale climatic variability over the last 2,000 years

Networks of paleoclimatic records with annual time control are required to address the following questions: can we reconstruct changes in vegetation and hydrology, in order to determine the timing and magnitude of environmental changes in Europe and Africa which might be climate- or anthropogenically-induced? What were the extent, patterns and causes of climatic change during the “Little Ice Age” and the “Medieval Warm Period”? And how do these events change in time and space?

3.1.2 Time Stream 2. Climate dynamics over the last two glacial/interglacial cycles

PEP III is well-placed to answer the following questions: how does the terrestrial record of long-term change over mid-latitude Europe compare with records from the Scandinavian ice sheet and sea surface conditions in North Atlantic? What was the amplitude of the southward latitudinal shift of the westerlies during the glacial periods? Are terrestrial systems from western and northern Europe and southeast Africa linked to changes in the oceanic thermohaline circulation, and by which mechanisms? What is the impact of changes in land surface conditions in tropical Africa and in the Sahara on global climate. Is there significant climatic feedback induced by changes in albedo, soil moisture and evapotranspiration, trace-gas emission and aerosol loading?

3.1.3 Time Stream 2. The climate system over the post-glacial period

Special attention should be paid to the past 14 ka because of the great amount of available proxy data with high temporal resolution. Work within PEP III should concentrate on the following specific questions: is the dry spell observed between around 11-10 (¹⁴C) ka B.P. in several
African sites actually synchronous with the European Younger Dryas cold event? Are the large decade- to century-scale hydrologic changes in North Africa during the Holocene linked with abrupt changes in Europe, and by which mechanisms? When and where did maximum temperature and maximum precipitation occur during the Holocene period in Europe, in the Sahara, in intertropical Africa and in southern Africa? What is the pattern and intensity of changes in the African monsoon during the current interglacial?

3.2 Improvement of the data pattern and optimal use of available proxies

3.2.1 Geographical gaps

Figures 4 and 5 illustrate the geographical distribution of currently available data for Temporal Streams 1 and 2. Although proxy data are still required in all regions and within both Stream 1 and Stream 2 timeframes, it is evident that PEP III should focus field activities on Africa, Middle East, central and eastern Europe to improve data coverage.

Within Stream 1, many time series are already analyzed in Europe and emphasis should be primarily on their integration and interpretation. Around the Mediterranean Sea, a critical inventory of historically dated climatic events could be attempted. For example, the history of the Nile floods should be compared with data from eastern and northern Mediterranean regions. New continuous series are needed especially from central and east Europe. Other regions are also poor in paleorecords with annual time control, and studies from tree-rings, laminated lakes, laminated speleothems, and coral records from the tropics have to be developed. Further research is needed to confirm the occurrence of the Little Ice Age and the Medieval Warm Epoch in Africa. Tree-ring studies from "mediterranean regions" (Middle East, Maghreb, South Africa) should be undertaken. Although it is certainly difficult to obtain records with annual time control in most regions from Africa, attention should be paid to historical records on lake-level fluctuations (e.g. Lake Chad and East African lakes) or to charcoal analysis as currently conducted in South Africa.

Within Stream 2, long sequences are available for western temperate and mediterranean Europe. Collaborative programs between east, central and western European countries may enable long records to be obtained from the southern European seas. Studies of loess/fossil soil series should be encouraged in central and eastern Europe. Obtaining profiles covering at least one climatic cycle in intertropical Africa is crucial for an understanding of the monsoon variability. Studies of marine margin cores along the Atlantic shores should provide correlation between PEP III and IMAGES results.

3.2.2 Methodological gaps

Available data is highly variable in quality, especially in their chronological control. Unfortunately, the validation of radiometric ages involves geochemical criteria often absent in the literature. The chronology of many sequences, especially in arid and semi-arid zones has to be re-assessed.
Available data may not be calibrated in terms of climatic or environmental variables. In order to expand the information from quantitative proxies, reinterpretation of uncalibrated, well-dated profiles for different environmental variables is required by using available transfer functions. In all regions and for all environmental indicators, transfer functions should be developed and/or improved by enlarging the reference data sets along environmental gradients. For example, efforts should be made to fill the geographical gaps existing in diatom training data sets between the several data bases from northern Europe and Africa, and to merge these ecological data sets to increase their domains of application. Pollen transfer functions are currently available for Western Europe and East Africa but need to be developed and/or extended for other regions.

The study of available records is commonly focused on a given environmental indicator, e.g. pollen, diatoms, or stable isotopes. Multiple proxy, and cross-disciplinary control of palaeoclimatic records should be strongly encouraged, to test the assumptions derived from individual indicators and to reinforce the reliability of reconstructions of past climate.

3.3 Specific approaches recommended within PEP III

On the continents, a difficult challenge is to make the distinction between the effects of local factors and the role of global climate changes. To some extent the interpretation of any environmental signal is site-specific because of the spatial heterogeneity of land systems. The specific characteristics of the PEP III transect suggest some methodological approaches which favor inter-regional and inter-hemispheric paleoclimate comparisons and correlations, and which contribute to PAGES research tasks.

3.3.1 A crater lake transect from North to South

The temporal and spatial sensitivity of a lake system to climate changes depends primarily on the extent and hydrological-hydrogeological behaviour of its catchment, and on the residence time of the water in the system. The simpler the system, the clearer the climate signal.

Over the PEP III area, closed crater lakes are found from the Eifel (northern Germany) to South Africa, including inter-tropical Africa. These systems have several characteristics in common which make comparison suitable for climate reconstruction: (i) generally small catchment area; (ii) similar topography and bedrock; (iii) water budget easy to constrain and generally dominated by the factors of precipitation and evaporation; (iv) no detrital influx from surface runoff except from the crater slopes; (v) no mass loss through outflow; (vi) annual laminations frequent in the sediments; (vii) in many cases, long continuous sedimentary records.

The examination of sequences covering at least one climatic cycle from suitable crater lakes and conducted with standardized methodology and techniques, represents a powerful approach for paleoclimate reconstruction within the PEP III area.

3.3.2 Ecosystems extremely sensitive to minor climatic changes: a mountain transect from North to South

Important paleoclimate information can be derived from the study of selected ecotone gradients along the Pole-Equator-Pole transects and studied with several methods.
Figure 4
PEP III - Temporal Stream 1: seasonally- to annually dated paleoenvironmental records. These include sources such as historical documents, ice cores, tree-rings, corals, glacier movements, and lake sediments. Some areas (e.g. Europe) contain many more records than indicated, whereas others (e.g. Africa) are seriously lacking in available data. Western Atlantic coral records are included because they represent long-monitors of Atlantic climate variability that may have a significant impact on the PEP III region.
Paleoclimatic Records

- Pollen Data
- Lake-level Data
- Midden Data
- Marine Data
- Marine Data (18 ka only)

Figure 5
PEP III - Temporal Stream 2: sites of paleoclimatic records for the last glacial/interglacial cycle, and for the last 18 ka, as reported by COHMAP members (1988). Many additional sites have been added to this coverage in the last decade.
The glacial/tundra boundary is located at high latitudes and in the mountains of Scandinavia, the Alps, etc. During some periods of the last glacial cycle this boundary crossed the entire Russian plain, passed through Poland-Germany-Denmark-British Isles, and was lowered on all mountains in Europe and Africa. The following climate/hydrology-related processes can be detected: the limit of glacial ice, permafrost conditions, changes in drainage pattern. The last glacial maximum can to some extent be morphologically mapped, but development through time must be studied in natural sections (along rivers, coast, etc.), or in excavations or cores. The chronology of mountain glaciers has sometimes been successfully studied in downstream lakes. The Late Weichselian can be dated by radiocarbon; for older glaciation, dating must be established by: luminescence, U-series, amino-acid and other methods.

The tundra/forest ecotone is found at high latitudes and in mountain areas from Scandinavia to South Africa. The following climate-related processes and methodologies can be used to detect the ecotone boundary: treeline change, macrofossil and pollen analysis, tree growth, dendrochronology, faunal change, insect analysis, glacier change, lake sedimentology, erosion. In some regions, dendro-data, and sometimes lake sediments, occur with annual resolution. The climatic gradient is particularly obvious in northwest Europe, reflected in the biotic zonation from arctic to temperate. Past changes are documented in several types of palaeo-records, such as lake sediments for vegetation changes, fossil wood for timberline changes, sediment records for glacier changes (e.g. Huntley and Birks, 1983; Kullman, 1988; Karlen, 1988). The boundary along the Scandinavian mountain range has been particularly sensitive to climatic changes and may be correlated with the northern British Isles and northeast Europe.

The forest/steppe ecotone occurs at lower latitudes, particularly in southeastern Europe, in North Africa and South Africa. The following climate/hydrology-related processes can be detected: treeline change (by pollen analysis, algae change), lake level change (by lake sedimentology and geochemistry). In this environment, it is more difficult to find sediments with annual resolution. Radiocarbon dating should be standard practice on macrofossils or pollen.

The occurrence of the three ecotone boundaries cited above provides important paleoclimate information and clearly demonstrates the need to concentrate effort on mountain transects from North to South. In addition, attention should also be paid to the steppe/desert ecotone. This ecotone is found around the African-Arabian deserts, in the Middle East and in the southern plains of eastern Europe. Migration of the ecotone boundary can be detected from bioclimatic indices, such as the Chenopodiaceae/Artemisia pollen ratio, as done in the Middle East (El-Molismany, 1990), or from terrestrial fauna, such as molluscs (Goodfriend, 1990).

3.3.3 Speleothem studies in PEP III

Speleothems contain pertinent climatic tracers (stable isotope signals, micro-banding, humic matter, pollen) and may represent a wide range of time intervals. Speleothems can be precisely dated with U-series techniques, and may be sampled in almost any karst area. Studies should emphasize two main approaches:
1) growth frequency analysis and detailed hiatuses in speleothem growth. The climatic control on speleothem deposition is well documented by growth-frequency studies, where inter-regional studies may reveal paleoclimatic gradients (e.g., Lauritzen, 1993). Speleothems should be sampled and dated in both glaciated and unglaciated regions. Hiatuses should be identified and dated.

2) long continuous records. High quality, well-dated stalagmites may provide timeseries of stable isotopes that can be related to paleotemperature provided that calibration against current conditions (temperature and stable isotopes) and historical records can be made (e.g., Lauritzen, 1995).

3.4 Interactions between PEP III and Earth system modeling

Interaction with the modeling community is required for: (i) a better understanding of the mechanisms which drive global climate change, (ii) a more complete understanding of the regional responses to global change, and (iii) testing hypotheses on potential feedbacks from specific PEP III regions to global climate.

3.4.1 Interactions with PMIP and PMAP

A key objective of all PEP transects is to provide controlled paleodata for paleoclimate simulations. PEP III will collaborate with PMIP and PMAP scientists to integrate existing data and fill gaps in data coverage with emphasis at 6 and 21 ka (Chapter 1, Section 7). A critical reassessment of paleodata is needed, especially with respect to chronological control. Data which are not integrated in a continuous profile are not recommended.

In Africa, a particular problem arises in the reconstruction of paleomonsoon conditions at 6 ka because a short-term dry episode is documented around 6.2–5.8 ka BP from many lake records. Special attention should be paid to the numerous, but rather scattered and sometimes poorly time-controlled, data in the Sahara and the Sahel to define the pattern (zonal or more local) of monsoon rain increase at 6 ka. Application of hydrological-energy budget models should be attempted for those lakes where lake-level curves are established with a firm chronology, and where the record could not have been biased by tectonics or local hydrological events. Development of pollen transfer functions and/or bioclimatic indices for West Africa is a priority. Studies of groundwater and use of the noble gas paleothermometer in the Sahara-Sahel and Namibia also should be encouraged.

In Europe, the application of pollen transfer functions to well-dated profiles from the European data base is a high priority. Efforts should focus also on the accuracy of paleotemperature estimates at 6 ka by using and comparing multiple techniques. Paleohydrological modeling from lake records also should be encouraged, provided attention is paid to: regional hydrological and hydrogeological features; the density of the vegetation cover in the catchment; and (in semi-arid environments) the relationships between the growing season of herbaceous plants and the rainfall season for a parameterization of past runoff coefficients and moisture efficiency.
3.4.2 Lake system modeling

Especially important in PEP III are the lake-level records and other lake-oriented records. Lake-level fluctuations are among the most commonly used variables for palaeoclimatic purposes (e.g. Street-Perrott et al., 1989; Figure 4). Such an approach allows the analysis of climate-induced hydrological changes at large geographical and temporal scales (Kutzbach and Street-Perrott, 1985). Another approach is to estimate climatic variables from modeling of individual lake systems. As lake-level is the end product of complex interactions between climate, soil and vegetation in the catchment, and groundwater circulation, the entire lake system (lake + catchment area) must be considered to provide faithful climatic interpretation. A combined hydrological-energy budget applied to Lake Chad (Kutzbach, 1980) and to some East African lakes (Hastenrath and Kutzbach, 1983) could be applied to several other river-fed closed lakes at steady states. Development of hydrological models taking into account groundwater supplies (e.g. Almendinger, 1990; Diggerfeldt et al., 1992), seasonal rainfall patterns (Prentice et al., 1992; Harrison et al., 1993), soil water storage, and past water, salt and isotope budgets, is recommended. These approaches require sufficient modern climate and hydrological data for testing models on the modern system. In some PEP III regions, however, this may not always be available.

3.4.3 Global and regional climate interaction

Mesoscale models nested in GCMs have been successfully developed for the analysis of the impact of large hydrologic systems, e.g. the Caspian Sea, on regional climate (Rodionov, 1994). This type of approach should be developed for other systems or regions and applied to the past. Sensitivity experiments using climate-vegetation-geochemical models should help in testing the potential role of land surface conditions on climate. The reconstruction of changes in the extent of tropical wetlands and measurements of CH₄ flux from modern wetlands will lead to a better understanding of the relationships between tropical land surface conditions, short-term changes in atmospheric CH₄ concentration and climate change over the post-glacial period. Similar experiments should be performed for Nordic wetlands. The feedback effects of change in soil moisture in presently arid and semi-arid areas should also be analyzed.

Currently, local sources of water vapor (represented by soil moisture) are very important in West Africa (Druyan and Koster, 1989) and resupply the squall lines along an east-west direction in the Sahel (Rowell and Blondin, 1990). The role of changes in soil moisture on the rainfall pattern should be examined.

4. LINKAGES TO OTHER ACTIVITIES

Given the scope of the PAGES Project and the PANASH organization, it is evident that solid linkages must be established between the different programs developed as PANASH foci. More specifically, there is no clear natural boundary between PEP II and PEP III in the northern hemisphere. The Siberian High Cell is centered on PEP II but influences climate over eastern and central Europe. CAPE (Circum-Arctic Paleo-Environments) will contribute to a number of PEP III questions. It is also
evident that the Atlantic oceanic circulation and the history of the glaciation/deglaciation in the northern hemisphere creates a major linkage between the response of PEP III and North American areas to global forcings. This will be addressed by the IMAGES project. GISP-GRIP activities are also of the utmost importance at both global and regional scales for all PEP transects.

The Indian monsoon dynamics fully concerns PEP II and PEP III. Activities along these two transects have thus to be well coordinated. The INQUA/PAGES Paleomonsoons Project (Kröpelin, 1994) will stimulate paleomonsoon-related links between PEP II and PEP III, and possibly PEP I. The IDEAL Project will also contribute to questions on monsoon variability. ARTS (Annual Records of Tropical Systems) will generate high resolution records from corals, tree-rings, lake sediments and low-latitude ice cores. Together, these will provide valuable information on the global influence of ENSO. Joint efforts must be conducted by PEP, ARTS and IMAGES for, inter alia, a better knowledge of sea surface conditions in the subtropical southern oceans. The growth/decay of the Antarctic Ice Sheet and related changes in the efficiency of the southern westerlies and of the Circumpolar Current influence climate in the southern high latitudes of PEP III, thus making a critical linkage with the Antarctic Programmes.

The PEP transects will need to work with BAHC, GEWEX and GCATE to develop a better understanding of the feedback mechanisms induced by land surface conditions. Special attention could be placed on the dynamics of wetlands, in collaboration with plant physiologists, hydrologists, and specialists in soil-plant-atmosphere exchanges.

Interpretation of stable isotope records from lakes and peat-bogs requires a knowledge of the modern hydrologic systems and of stable isotope values for rainfall, therefore improvements in the IAEA network should be encouraged. The recovery of long and undisturbed sedimentary sequences is central to global change research objectives throughout the PEP III transect. Special emphasis, therefore, should be placed on the development of a widely available continental drilling capability for global change objectives.
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APPENDIX 1

PARTICIPANTS IN THE FIRST PEP I MEETING, PANAMA, SEPTEMBER 1993

M.L. Absy  M. Hughes
P. Aceituno  J. Jackson
T. Baumgartner  J. Kennett
J. Betancourt  J. King
J. Boninsega  T. Lara
J.P. Bradbury  S. Lozano-Garcia
R.S. Bradley  M.F. Loute
M. Brenner  T. Lowell
L. Brubaker  B. Messerli
M. Bush  A. Molina-Cruz
P. Ciais  R. Naruse
C. Clapperton  C. Nobre
P. Colinvaux  L. Ortlieb
R. Dunbar  M.M. Paez
M. Eakin  L. Peterson
R. Fairbanks  M.L. Salgado-Labouriau
V. Ferreira  S. Servant
O. Garcia  D. Soto
J. Gardner  M. Steinitz-Kannan
M.A. Gonzalez  L. Thompson
E. Grimm  C. Villagran
D. Hodel  W. Volkheimer
H. Hooghiemstra  R. Webb
S. Horn  H. Zimmerman

PARTICIPANTS IN THE FIRST PEP III MEETING, BERN, DECEMBER 1993

H. Oeschger, PAGES
S. Leroy, PAGES
B. Berglund, Sweden
B. Wohlfarth, Sweden
J.L. de Beaulieu, France
S. Joussaume, France
A. Berger, Belgium
M.F. Loute, Belgium
T. Johnson, USA
J. Ch. Fontes, IAEA, Vienna
J. Overpeck, USA
A. Velitchko, Russia
F. Gasse, France
PARTICIPANTS AT THE FIRST PEP II MEETING, BEIJING, APRIL 1994

An Zhisheng          Qin Xiaoguang
J. Bowler            Qin Daihe
R.S. Bradley         R. Ramesh
J. Cole              N. Rutter
Chen Minyang         Shen Chengde
Ding Zhongli         Shi Yafeng
J. Dodson            A.K. Singhvi
J-C. Duplessy        Sun Honglie
N. Fedorov           Sun Xiangjun
L. Graumlisch        Tang Maochang
Guo Zhengtang        S. van der Kaars
W. Hantoro           Wang Pingxian
C. Heintz            Wang Hongya
G. Hope              Wang Sumin
Jiang Ailiang        R. Wasson
S. Leroy             Wen Qizhong
Li Wenhua            D.F. Williams
Liu Jiaqi            Wu Naqin
Liu Tungsheng        Yao Tandong
Liu Yanhua           Yuan Baoyin
Liew Pingmei         Yuan Daoxian
A.V. Lozhkin         Zhang De'er
Ma Zongjun           Zhang Xinshi
F. Mayewski          Zhao, Qiguo
Y. Ono               Zhu Zhenda
J. Overpeck          H.B. Zimmerman
J. Filcher

Persons who provided significant inputs to the written report:

A. Berger and M.F. Loutre (solar radiation),
S. Joussaume (PMIP interactions)
J. Ch. Fontes and B. Wohlfarth (dating)
B. Berglund, J. Overpeck, J. Mangerud, F. Lauritzen, S. Leroy and
M. Hughes.
APPENDIX 2

PAGES PUBLICATION LIST

IGBP Reports:

No. 6  Global Changes of the Past. Edited by H. Oeschger and J.A. Eddy

No. 12 The International Geosphere-Biosphere Programme: A Study of Global Change; The Initial Core Projects, Chapter 7, Past Global Changes (PAGES).


Pages Workshop Reports:

93-1 High Resolution Record of Past Climate from Monsoon Asia: The last 2000 Years and Beyond. Edited by Raymond Bradley; September 1993


94-1 Research Protocols for PALE (Paleoclimates of Arctic Lakes and Estuaries). Issued by PALE Steering Committee, June 1993

94-2 INQUA/PAGES Workshop; Paleomonsoons in Africa and surrounding oceans: the last 200,000 years. Edited by Stefan Kroepelin

PAGES-START Workshop, Past Global Changes in Africa. Edited by Eric Onyango Odada

94-3 International Marine Global Change Study (IMAGES): Science and Implementation Plan

Occasional Publications

APPENDIX 3

LIST OF ACRONYMS

AGCM  Atmosphere General Circulation Model
ARTS  Annual Records of Tropical Systems
BAHC  Biospheric Aspects of the Hydrological Cycle (IGBP)
BDP   Baikal Drilling Project
CAPE  CircumArctic Paleo Environments (formerly PALE)
CLIVAR Climate Variability and Predictability (WCRP)
COHMAP Cooperative Holocene Mapping Project
DIS   Data and Information System (IGBP, HDP)
ELCP  European Lake Coring Project
ENSO  El Niño/Southern Oscillation
EPC   European Paleoclimate and Man Project
EPICA European Programme for Ice Coring in Antarctica
EPOCH European Programme for Climatology and Natural Hazards
GAIM  Global Analysis, Interpretation and Modelling (IGBP)
GCTE  Global Change and Terrestrial Ecosystems (IGBP)
GISP 2 Greenland Ice Sheet Project—Two
GRIP  Greenland Icecore Project
HIPP  Himalayan Interdisciplinary Paleoclimate Project
IAEA  International Atomic Energy Agency
IAI   Inter-American Institute for Global Change Research
ICDP  International Continental Drilling Program
ICSU  International Council of Scientific Unions
IDEAL International Decade of East African Lakes
IGBP  International Geosphere - Biosphere Programme
IMAGES International Marine Global Change Study
INQUA International Union for Quaternary Research (ICSU)
ITASE International Trans-Antarctic Scientific Expedition
LGM   Last Glacial Maximum
LOICZ Land-Ocean Interactions in the Coastal Zone (IGBP)
NAD   Nansen Arctic Drilling Project
PAGES Past Global Changes (IGBP)
PALE  Paleoclimates from Arctic Lakes and Estuaries
PANASH Paleoclimates of the Northern and Southern Hemispheres
PEP   Pole–Equator–Pole
PMAP  Paleoenvironmental Multiproxy Analysis and Mapping Project
PMIP  Paleoclimate Modelling Intercomparison Project
SCAR  Scientific Committee on Antarctic Research (ICSU)
SCOR  Scientific Committee on Ocean Research (ICSU)
SST   Sea Surface Temperature
START System for Analysis, Research and Training (WCRP, IGBP, HDP)
TIGER Terrestrial Initiative in Global Environmental Research
WAIS  West Antarctic Ice Sheet Project
WCRP World Climate Research Programme
WDC-A World Data Center-A for Paleoclimatology
WGNE Working Group on Numerical Experimentation