Acknowledgements

“I would like to thank Keith Alverson, Steve Colman, Leila Harris, and Bettina Jenny for their invaluable help in compiling this Plan. Thanks are due also to the PAGES Leaders who have submitted material for inclusion, as well as contributed crucially to the success of PAGES by coordinating the Activities and Tasks for which they are responsible. I am also grateful to the Executive Committee and Scientific Steering Committee members, especially Tom Pedersen, who reviewed parts of the text. The PAGES community as a whole owes a major debt of gratitude to the National Science Foundations of Switzerland and the United States for the financial support provided to run the International Project Office in Bern”.

The International Geosphere-Biosphere Programme (IGBP): A Study of Global Change of the International Council of Scientific Unions (ICSU)
Stockholm, Sweden
The International planning and coordination of the IGBP is supported by National Contributions and the International Council of Scientific Unions (ICSU)

Implementation Plan

This document describes an IGBP Implementation Plan approved by the Scientific Committee for the International Geosphere-Biosphere Programme (SC-IGBP).

The IGBP Report Series is published as an annex to the Global Change Newsletter and distributed free of charge to scientists involved in global change research. Both publications can be requested from the IGBP Secretariat, Royal Swedish Academy of Sciences, Box 50005, S-104 05 Stockholm, Sweden

Cover Illustration: From the PAGES IPO photo archive

Layout and Technical Editing: Lisa Wanrooy-Cronqvist
Copyright © IGBP 1998. ISSN 0284-8015
## Contents

**Executive Summary** .................................................. 7  
**Introduction** ....................................................... 9  
**Project Objectives** .................................................. 13  
**PAGES Priorities** ..................................................... 15  
**Project Organization** ................................................ 17  
**History of PAGES** ..................................................... 19  
**Accomplishments of the Palaeoscience Community in Anticipation of PAGES** ..................................................... 21  
**How has the Climate Varied in the Past – An Overview** ........... 25  
**FOCUS I  Palaeoclimates of the Northern and Southern Hemispheres (PANASH)** ............................................. 31   
  **Activity 1** Palaeoclimates of the Americas Pole-Equator-Pole (PEP I) ............................................................. 35  
  **Activity 2** Palaeoclimates of the Austral-Asian Transect (PEP II) ................................................................. 41  
  **Task 1** Baikal Drilling Project (BDP) .................................. 47  
  **Task 2** The Himalayan/Tibetan Plateau Interdisciplinary Palaeoclimate Project (HIPP) ................................................. 54  
  **Activity 3** The Afro-European Palaeoclimatic Transect Pole-Equator-Pole (PEP III) .................................................. 60  
  **Task 1** The International Decade for the East African Lakes (IDEAL) ................................................................. 69  
  **Task 2** Palaeomonsoons Project (PM II) ................................ 74  
  **Activity 4** The Oceans .................................................... 79  
  **Task 1** International Marine Global Change Study (IMAGES) ............................................................. 79  
  **Activity 5** PAGES/CLIVAR Interactions ................................ 87  
  **Task 1** Annual Records of Tropical Systems (ARTS) ............... 91
FOCUS II  Palaeoclimate and Environmental Variability in Polar Regions 95
Activity 1  Arctic Programmes 95
Task 1  Circum-Arctic PalaeoEnvironments (CAPE) 95
Task 2  Nansen Arctic Drilling Programme (NAD) 107
Task 3a  Greenland Ice-Core Project (GRIP) 112
Task 3b  The Greenland Ice Sheet Project Two (GISP2)
       Ice-Core Record 117
Task 4  Ice Core Circum-Arctic Palaeoclimate Programme (ICAPP) 130
Activity 2  Antarctic Programmes 137
Task 1  International Trans-Antarctic Scientific Expedition
       On 200 Years of Past Antarctic Climate and
       Environmental Change (ITASE) 138
Task 2  Late Quaternary Sedimentary Record of the
       Antarctic Ice Margin Evolution (ANTIME) 144
Activity 3  Bi-Polar Programmes 152
Task 1  Palaeoenvironments from Ice Cores (PICE) 152

FOCUS III  Human Interactions in Past Environmental Changes 159
Activity 1  Human Impacts on Fluvial Systems 159
Activity 2  Human Impacts on Terrestrial Ecosystems 164

FOCUS IV  Climate System Sensitivity and Modelling 165
Activity 1  Climate Forcing and Feedbacks 165
Task 1  Climate Impacts of Explosive Volcanism 165
Task 2  Solar Influences on Climate 170
Task 3  Greenhouse Gases and Aerosol Influences 171
Task 4  Abrupt Climate Change and Internal Climate
       System Dynamics 172
Activity 2  Climate Model-Data Intercomparisons 175
Task 1  Palaeoclimate Modelling Intercomparison Project
       (PMIP) 173
Task 2  Palaeoenvironmental Multiproxy Analysis and
       Mapping Project (PMAP) 179
Task 2a  BIOME 6000 188

FOCUS V  Cross-Project Analytical and Interpretive Activities 193
Activity 1  Chronology 193
Activity 2  Development of New Proxies 196
Task 1  Isotope Calibration Study 196
Task 2  Continental Drilling for Palaeoclimate Records 203
Activity 3  International PalaeoData System 208
Activity 4  Regional Education and Infrastructure Efforts (REDIE) 213
PAGES Management ____________________________________ 215
   PAGES Project Guidance and Administration 215

Interproject Scientific Activities___________________________219
   The BIOME 6000 / PMIP Collaboration with
   GAIM/GCTE/IGBP-DIS 219
   PAGES/CLIVAR 219
   PAGES/IGAC 220
   PAGES/BAHC/LOICZ 220
   PAGES/GAIM/IGAC 150k Year Challenge 220

Appendix I ____________________________________________221
   List of PAGES Workshop Reports and Other Publications 221

Acronyms and Abbreviations ______________________________223

List of IGBP Publications ________________________________229
   IGBP Report Series. List with Short Summary 229
Executive Summary

This document summarizes progress made thus far by the Past Global Changes (PAGES) programme element of the International Geosphere-Biosphere Programme (IGBP). The document also outlines the implementation plans for most of the Foci, Activities and Tasks currently within the PAGES remit. The plan first introduces the scope and rationale of PAGES science and explains how PAGES is organized structurally and scientifically to achieve its goals. For all of the palaeosciences relevant to IGBP goals, PAGES has sought to identify and create the organizational structures needed to support continued work and progress.

The objectives of the PAGES project are set out in the form of key questions related to overall IGBP objectives. These key questions in turn define the priorities described in the following sections. The text then proceeds to outline the way in which PAGES has set about meeting these priorities and objectives. Current activities are set within a historical context. This includes both the sequence of meetings that led to the creation of the PAGES project, as well as the scientific knowledge and understanding that formed the basis upon which PAGES science was established. The text also offers a very brief overview of our current state of knowledge about the way in which climate has varied in the geologically recent past.

From these general considerations emerge the Foci, Activities and Tasks that form the main core of PAGES research. These are summarized in the Table of Contents. The widely distributed PAGES publications that have already emerged and are linked to these are listed in Appendix I. The main body of the text comprises a summary of progress and plans for implementation for each of the current Foci, Activities and Tasks. Each section has been prepared, with relatively few constraints, by one or more of the research leaders responsible for that aspect of PAGES research.

The first sections, on ‘Global Palaeoclimate and Environmental Variability’ fall under the umbrella of the Palaeoclimates of the Northern and Southern Hemisphere (PANASH) and are prefaced by a section devoted to the overarching rationale. Thereafter, each of the Pole-Equator-Pole (PEP) Transects is considered, progress to date reviewed, and plans for the future described. The next section deals with the International Marine Global Change Study (IMAGES), a major initiative co-sponsored by PAGES and the Scientific Committee on Oceanic Research (SCOR). This recently launched activity is the central contribution of PAGES to oceanographic research and emphasizes high resolution palaeorecords from key locations. The de-
scription of plans under Focus I closes with a consideration of high resolution records mostly for the last few hundred years, the time frame of common interest for both PAGES and the World Climate Research Programme (WCRP) through its Climate Variability and Predictability (CLIVAR) initiative. A notable contribution to the CLIVAR programme is the task Annual Records of Tropical Systems (ARTS).

The second Focus, on polar studies, has given rise to a series of reports that range from largely retrospective accounts, in the case of Greenland Ice Core Project (European) (GRIP) and Greenland Ice Sheet Project Two (USA) (GISP 2), to outlines of plans for new initiatives in both polar regions. The Antarctic initiatives are co-sponsored with the Scientific Committee on Antarctic Research (SCAR). Overall, the polar programmes encompass major efforts designed to retrieve long, deep ice core records from both Greenland and Antarctica, as well as coordination exercises to integrate palaeorecords from the many, diverse archives available in polar regions.

Thus far, Focus III within PAGES has received less attention relative to the initiatives described above. Only the first Activity, concerned with “Human Impacts on Fluvial Systems” has resulted in a comprehensive implementation plan.

Focus IV deals with “Climate System Sensitivity and Modelling” with emphasis on climate forcing and feedbacks. Separate Tasks on volcanic, solar, and greenhouse gas/aerosol influences have been identified but only in the case of volcanic influences has a detailed implementation plan been defined. Modelling aspects currently hinge on model intercomparisons, on model-data interaction, data ‘mapping’ and time-slice reconstructions for model validation.

The final section (Focus V) deals with “Cross-Project Analytical and Interpretative Activities”. These include a strong emphasis on chronology, on calibration, especially with respect to stable isotope signatures, and on continental records of palaeoclimate. Thereafter follows a brief description of the educational, capacity building, and infrastructural roles of PAGES.

The concluding part of the text provides an overall perspective on PAGES activities and their future scope.

Frank Oldfield
Executive Officer
PAGES International Project Office
Introduction

PAGES is the IGBP International Project charged with providing a quantitative understanding of the Earth’s past environment and with defining the envelope of natural environmental variability against and alongside which we can assess anthropogenic impact on the Earth’s biosphere, geosphere, hydrosphere and atmosphere.

Models intended to predict future environmental changes must, in order to demonstrate their effectiveness, 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 palaeoclimatic records and to provide the data essential for the validation of predictive climate models. PAGES activities include integration and intercomparison of ice, ocean and terrestrial palaeorecords and encourages the creation of consistent analytical and data-base methodologies across the palaeosciences.

In accordance with the constitution of the IGBP, PAGES embraces the palaeoaspects of the “... interactive physical, chemical and biological processes that regulate the total Earth system.” The overall priorities of the PAGES International Project focus on those global-scale processes and key interactions that may lead to significant environmental change. A more complete understanding of these processes is crucial for improving “… practical, predictive capability.”

PAGES emerged in the context of a palaeoresearch community that had traditionally been divided along continental-terrestrial, marine and polar lines, as well as in other ways reflecting the broad range of specializations and environmental archives employed. In addition, several previous and/or ongoing palaeoinitiatives, such as GRIP and GISP² (see below), evolved together with PAGES. Thus, one of the most important initial activities of PAGES was the development of a coherent scientific plan that incorporated existing activities of global significance and also brought together the marine, terrestrial and polar research communities.

Work of the type that has been incorporated within, and/or promoted by, PAGES is often dependent on the availability of high quality, often unique, palaeoenvironmental archives. The research carried out at many sites is very costly in terms of time, funds, and effort. This means that, while the implications of the research may be wide-ranging or even global, the research activity itself is often highly site-specific and often reflects a considerable and sustained investment over a long period of time, not only in recovery of the palaeoarchive itself, but also in calibration and
analysis of the record. Any programme like PAGES, starting at a given point in time, can develop a range of responses to the ongoing research that reflects its core concerns and scientific remit. The role of PAGES in relation to projects developed during its life span has taken several forms, depending on the part PAGES has played in defining goals, stimulating particular projects, establishing guidelines, protocols, quality control mechanisms, priorities, or developing the infrastructure for the coordination and archiving of results. PAGES works by focusing and fostering the most appropriate contributions possible from a wide range of palaeoscientists, rather than by applying its efforts to more circumscribed research campaigns.

Much of PAGES science is “bottom-up”, driven by the realization among fellow researchers that adoption of an approach, definition of a problem, and acceptance of a set of criteria consistent with PAGES formulations improves possibilities both for funding (since PAGES priorities are so widely recognized and respected at national and international levels) and for full recognition of the significance of the results. This widespread acceptance allows for a broad ranging definition of what constitutes PAGES science when defined by application of PAGES criteria to specific projects or proposals. It also makes it both difficult and inappropriate to claim PAGES “ownership” for much of the ongoing research that satisfies PAGES criteria, has developed in response to PAGES agenda setting, or is actively fulfilling some of what PAGES sets out to promote.

One of the most important roles of PAGES so far has been to set research agendas and thereby shift, sometimes even transform, the perceptions and priorities of the broader scientific community. This process began with the first statements about priorities and time streams (see below) and has continued, reinforced by each successive PAGES publication (listed in Appendix I). In this way, PAGES has taken the lead in achieving the integration of the research agendas of the terrestrial, marine, and polar palaeosciences.

One of the major achievements of PAGES to date is the increasing recognition of the PAGES agenda and of PAGES priorities by national and international funding agencies. PAGES has successfully created, within the wider field of palaeoscience, a series of criteria and foci that define the PAGES mission. Many of these priorities have been explicitly referred to in the mission statements and research priorities generated by both national and international funding agencies. In addition, national programmes have been established in support of PAGES objectives. This widespread and increasing acceptance transcends narrow definitions of specific projects and individual scientists. Its effect has been to sharpen the focus of palaeoscience onto those themes and problems of contemporary and future concern to humankind that can be addressed, in part, through an improved and coordinated palaeopspective.

Notable examples of the impact of PAGES agenda setting are:

- The explicit modification of the science plans and priorities of both China and Australia to support the needs of the PAGES PEP II Transect (see below)
- The establishment of the US NSF Earth System History initiative with a strong PAGES-oriented agenda
• The development of priority programmes both at international (e.g., EU) and national (e.g., Germany) levels that reflect, often explicitly, the goals, criteria and timeframes of PAGES Science

• The specification and implementation of the IMAGES programme, with its focus on high resolution records often in areas where links with continental records are possible, and the emphasis, in the current ODP Science Plan, on themes of direct relevance to the PAGES agenda

• The establishment of the WDC-A for Palaeoclimatology with major involvement of PAGES in defining the standards and goals of the center’s activities.

Some of the major ways in which, during its period of operation, PAGES has actively encouraged the science it supports include the organization and partial funding of workshops and the subsequent distribution of a series of workshop reports, 15 of which have been published so far (see Appendix I).

The roles of these workshops and of the subsequent publications have included:

- Defining the state of the art
- Identifying research gaps and opportunities
- Establishing priorities for future research.

Many of the Workshop Reports, (e.g., PANASH [Introduction], IMAGES [esp. pp. 28–29], Global Palaeoenvironmental Data [pp. 11–27], Palaeoclimates of Arctic Lakes and Estuaries [PALE] and the Continental Drilling Workshop report), emphasize research protocols with a view to improving data quality, maximizing the information retrievable from limited environmental archive material, increasing the degree of compatibility between the results of independently coordinated projects and facilitating eventual data manipulation within major data bases.

In pursuit of its goals, PAGES has often worked in partnership with other international agencies. This cooperation is illustrated by the:

• Strong involvement of PAGES Scientific Steering Committee (SSC) members in major initiatives in polar research and the role they play in linking that research to the broader PAGES global research agenda

• Growing links between PAGES and WCRP centered around the activities of the joint PAGES/CLIVAR Working Group

• Involvement of PAGES in international initiatives like the International Decade for East African Lakes (IDEAL) and the Lake Baikal Drilling Programme (BDP), where the overall scientific goals go beyond the PAGES agenda but where PAGES participation makes possible the achievement of important PAGES science objectives, at minimum additional cost, within the overall goals of the individual programmes
• Lead role PAGES has taken in seeking to strengthen the Global Network for Isotopes in Precipitation (GNIP), administered up to the present by the International Atomic Energy Agency (IAEA) and recognized to be of vital importance for the calibration of stable isotope records of past changes in temperature, atmospheric circulation, and hydrological regimes

• Lead role taken by present and former members of the PAGES SSC in the preparation of Intergovernmental Panel on Climate Change (IPCC) reports on Climate Change.

PAGES has already played a crucial role in the archiving, management and dissemination of palaeodata. This is fully summarized in the recently published Global Palaeoenvironmental Data Workshop Report (95-2). The growing significance of this type of activity is evidenced by the steep increase in consultation and use of the data currently in the public domain and accessible electronically, and by the growing importance of such data for model validation and intercomparison.
Project Objectives

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

- How have global climate and the environmental systems linked to it changed in the past? What factors are responsible for these changes and how can we use our knowledge of them to improve insight into likely future climate and environmental change?

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

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

- What are the important forcing factors that produce climate change on societal time scales? What are the causes of abrupt climatic and environmental events and of the rapid transitions between quasi-stable climatic states that occur on decadal to century time scales?
From its inception, PAGES has established a set of priorities which ensure that important scientific questions relevant to the goals of the IGBP will be addressed in a coherent manner. PAGES focuses on two “Temporal Streams” rather than on the entire record of past environmental change. Stream I concerns the last 2,000 years and Stream II the last few glacial-interglacial cycles. It is within this temporal framework that the information most appropriate to answering issues of fundamental concern to the IGBP will be found. Prioritizing these time streams and recognizing the temporal resolution required in each (see below) implies that a great deal of research at lower resolution, or concerned with earlier time periods, is less likely to contribute significantly to the IGBP research agenda.

PAGES has identified specific criteria for its activities. They are applied for the evaluation and prioritization of research within the two timeframes. They are incorporated specifically into the PANASH scientific strategy (see below and PAGES Report 95-1), but apply to all other observational activities within PAGES.

The main focus of PAGES observational activities will be on continuous, high resolution records, with annual, or even seasonal, to decadal time resolution for Stream I studies, and decadal to century scale resolution for Stream II studies (see below):

- All studies using proxy records will pay particular attention to chronology, to obtain the most accurate and detailed dating control possible
- Proxy records for palaeoclimate reconstruction will be well-calibrated, providing a clearly understood palaeoclimate signal
- Wherever possible, multi-proxy studies will be carried out, to maximize the information retrieved from a site and to provide mutually independent constraints on any palaeoenvironmental reconstructions made
- Wherever possible, study sites will be selected to 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
• All PAGES data will ultimately be archived in the WDC-A for Palaeoclimatology in order to provide interested scientists with free and open access to, and interchange of, palaeoclimate data and information.
Project Organization

The Earth’s environmental and ecological systems operate on a wide spectrum of temporal and spatial scales. Therefore, palaeoenvironmental records are derived from a great variety of natural archives such as: tree-rings; lake and ocean sediments; wind-blown deposits; coral and ice cores; as well as historical accounts. The scientific community has recently developed a set of powerful analytical techniques to recover high resolution records of changes in environment and ecology from these diverse sources. Through detailed analysis of “proxy” records, it is often possible to distinguish annual changes over time spans of many thousands of years. It has become clear that the power of these techniques would be vastly increased by their coordinated application in multi-archive, multi-proxy studies. It is the task of PAGES to organize the international scientific community to target critical scientific questions, regions and time periods in a concerted effort to produce a coherent and quantitative record of the Earth’s natural history.

To that end, the PAGES Project is structured according to five research Foci. Three of these are research-observational Foci, other Foci include Climate Sensitivity and Modelling, and a cross-project Focus to address the broad analytical, data and communication needs of the project. Within this framework, there are evolving research initiatives designed to focus on specific regions and processes and to accomplish the overall PAGES objectives.

The three research/observational Foci address the retrieval of high quality multi-proxy palaeorecords in a global network of field activities. This is an attempt to apply the full complement of operational and analytical methodologies to regions essential for the completion of a coherent global environmental history. Within each of these observational Foci, PAGES has designed two “temporal streams” which address the key scientific questions defined by the overarching needs of the IGBP, as well as associated projects of the WCRP and International Human Dimensions Programme on Global Environmental Change (IHDP).

The objective of Stream 1 is to reconstruct the detailed history of climatic and environmental change for the entire globe for the period since 2,000 BP (Before Present), with temporal resolution that is at least decadal, and ideally annual or seasonal. This constitutes the period of greatest human impact on the planet and the time of significant overlap between written records and the environmental information stored in natural archives.
With at least century-scale resolution, *Stream II* focuses on glacial-interglacial cycles of the last several hundred thousand years and promotes the understanding of dynamics that cause large-scale natural variation. Continued activities of this temporal stream will illuminate the interactive feedbacks among various components of the Earth system and their relation to external climatic forcing.

It should be noted that the goals related to both temporal streams are highly focused when compared with the larger body of research which is at lower resolution or deals with earlier time periods.

Within the sphere of “Human Interactions in Past Environmental Changes” (Focus III), PAGES activities will highlight the impact of human activities on fluvial systems and on terrestrial ecosystems.

A palaeoperspective is required in order to understand rates of change in these systems at both regional and global scales - information which is of importance to present day society.

The fourth PAGES Focus, “Climate System Sensitivity and Palaeoclimate Modelling”, consists of activities designed to better understand the fundamental causes of global climate change and the modelling of the Earth’s changing environmental systems.

In addition, PAGES has established a fifth cross-cutting Focus which is required for the advancement of all other Foci, “Cross-Project Analytical and Interpretative Activities”. This Focus addresses chronological control, measurement protocols, calibration and intercomparison studies, data management activities, fundamental laboratory studies, and regional and educational activities related to the effort of the joint IGBP/IHDP/WCRP project Global Change System for Analysis, Research, and Training (START).
Throughout the last few decades, the scientific community has generated a wealth of information from naturally occurring palaeorecords. These comprise a wide spectrum of environmental parameters which reflect the evolution of earth systems. The discoveries made have been of unique relevance for the initiation of global change research and have crystallized the need to include palaeoresearch within the IGBP.

In 1986, the final report of the International Council of Scientific Unions (ICSU) ad hoc Planning Group recommended the initiation of the IGBP with a focus on interactive Earth system processes and with emphasis on processes that operate on time scales of decades to centuries (IGBP Report No. 1). The establishment of the IGBP was a crucial step in the development of a holistic approach to studies of the Earth system. The IGBP has promoted a scientific culture within which interdisciplinary programmes can flourish. By focusing attention on the importance of understanding physical, chemical and biological processes on a global scale and within a defined temporal framework, the IGBP has greatly enhanced the ability of the palaeoscience community to develop the larger, international, and inter-disciplinary activities needed to achieve maximum impact on global change related sciences.

One response to the ad hoc Planning Group’s recommendations was the establishment of a Working Group on Techniques for Extracting Environmental Data of the Past “... to assist in the interpretation of the history of the geosphere-biosphere” (IGBP Report No. 2). The Working Group met in Bern, Switzerland (July 1988) and prepared a report that outlined the problems and opportunities for cross-disciplinary studies focusing on the potential contribution of palaeoscience to the global change effort (IGBP Report No. 6). Also in 1988, the Science Advisory Council (SAC) for IGBP “... expressed a firm statement of commitment to initiate as soon as possible major new international research projects dealing with ... a coordinated effort to recover information from natural archives that will illuminate connections between atmospheric composition, global temperature, ice extent, solar history, and the distribution of land and oceanic organisms” (IGBP Report No. 7:1). The Council established the Scientific Steering Committee (SSC) to develop the IGBP programme element entitled: “Global Changes of the Past” (PAGES).

Simultaneously, between 1986 and 1990 scientists involved in palaeoscience research met at a variety of Dahlem Conferences, workshops, and NATO conferences. From these meetings, the concept of a coordinated programme of palaeostudies within the
framework of global change research was developed. A detailed plan for such a programme was described in Chapter 7 of IGBP Report No. 12\(^1\) and led to the initiation of PAGES as a programme element of the IGBP.

With the endorsement of the IGBP, the initial PAGES Implementation Plan was formulated at the first meeting of the PAGES SSC (Mainz, Germany, 1991) and published as IGBP Report No. 19.\(^1\) This publication has served as a guide for palaeo studies in the frame of global change research and as a guide for the implementation of the PAGES organization. It also has been used for designing major segments of national IGBP related research programmes.

In 1992, the National Science Foundations (NSF) of Switzerland and the US agreed to the joint support of the PAGES International Project Office (IPO) in Bern, Switzerland, for a initial five-year period. Co-Directors from Switzerland and the US were appointed. At the second meeting of the PAGES SSC (Bern, 1992), an Executive Committee (EXCOMM), composed of the Co-Directors and selected members of the SSC, was formed to administer the day-to-day business of the PAGES IPO and implement the scientific activities of PAGES.

\(^1\)See List of IGBP Publications
Accomplishments of the Palaeoscience Community in Anticipation of PAGES

In the initial phase of the IGBP, strong emphasis was given to Earth system modelling. The general perception was that experiments with ever faster computers would eventually provide the answers to the questions posed. But many key questions discussed within IGBP were raised because of information obtained from reconstructions of past Earth system events. In attempting to understand the complex and interactive Earth system, knowledge of its past behaviour is critical. In addition to the obvious application of providing boundary conditions and validation tests for numerical models, the following results demonstrate that the evolution of the climate system provides the essential context within which to interpret model projections.

Pre-Industrial Conditions

An urgent question posed in the 1970s concerned the pre-industrial concentrations of greenhouse gases and the history of their early increase prior to the beginning of direct atmospheric measurements in the 1950s. Analysis of gases occluded in natural ice of known age demonstrates that the natural variability of gases, such as CO₂, CH₄ and N₂O, during the last millennium was small compared to the increases during the last 200 years. This increase in greenhouse gas concentration, therefore, can be attributed unambiguously to anthropogenic emissions. Atmospheric CO₂ has increased by about 80 ppmv in the last 200 years, and the increase of the anthropogenic greenhouse forcing at present is estimated to be between 2 and 2.5 W/m².

Natural Greenhouse Gas Variations and their Relation to Climate

Analyses of the gas composition in ice cores reveal that the concentrations of the greenhouse gases during the past glacial cycle changed in parallel with climate; during interglacial periods concentrations were high (CO₂ ca. 280 ppmv) and during glaciations they were low (CO₂ ca. 200 ppmv). The change in CO₂ concentration was about 80 ppmv and the difference in the greenhouse forcing was of the order of
2–2.5 W/m², which is similar to the present anthropogenic contribution to the atmosphere. Model experiments suggest that the changes in greenhouse gases were possibly responsible for the amplitude of the climatic (temperature) changes and for the interhemispheric climatic coupling during past glacial cycles.

**Reaction of Terrestrial Vegetation to Past Climate Change**

The effects of both major and minor climate change on vegetation are recorded by the change in pollen composition and other palaeoecological signatures in sediment cores. Many other parameters measured in these cores, such as the oxygen isotopic ratio of biogenically precipitated carbonate and the magnetic properties of the sediments, also reflect changes in environmental conditions. This information demonstrates that terrestrial vegetation tended to change on a global scale with the same rhythm as changes in the oceans and ice sheets. It contributes to the validation of climate models by articulating spatial variability, and it also provides the basis for testing model simulations of vegetation change in response to climate forcing.

Changes in vegetation during major climate changes are also reflected in the variations in atmospheric CO₂ and its $^{13}$C/$^{12}$C ratio, in atmospheric methane and in the isotopic signature of atmospheric CO₂ as recorded in C₄ plants. This information is used to reconstruct the history of atmospheric CO₂ in terms of changes in the partitioning of carbon among the Earth’s reservoirs: atmosphere, biosphere, ocean and sediment.

**Natural Climate Variability**

High-quality natural archives such as tree rings, annually banded corals, ice cores, and varved sediments provide annual or even finer resolution records for environmental parameters over the last few thousand years. Such records provide the only way to disentangle unambiguously the signal of anthropogenic climatic change from natural climate variability. These natural archives contain information on both the history of climatic forcing (solar variations and volcanic eruptions) and the corresponding climatic response superimposed on the internal system variability. The natural variability of system components, such as El Niño-Southern Oscillation (ENSO), North Atlantic oscillations, and monsoonal variations, is becoming increasingly evident through these archives.

**Rapid and Unexpected Events in Past Climates**

Recent observations of rapid transitions of the climate system between well-defined states, as revealed by a broad spectrum of parameters in ocean sediments and ice cores, has had a strong impact on the scientific community’s understanding of climate variability. These changes are attributed to highly non-linear processes leading to dramatic changes in system components, such as the formation of deep water in the North Atlantic Ocean. Rapid changes in deep water formation in the North Atlantic, and the resulting large-scale changes in thermohaline circulation, are well documented for much of the last glacial period. They appear to have given rise to
temporally coherent but spatially differentiated climate changes on decadal to millennial timescales at widely separated locations. Their hypothesized link to Laurentide ice sheet dynamics ties them to the conditions prevailing during cold stages. Both model simulations and somewhat controversial empirical evidence indicate at least the potential for similar instability in thermohaline circulation under warm climate conditions. Possible warm-climate instabilities may be linked to dramatic changes in the hydrological cycle in low latitudes and have the potential for strong impact in large regions of the globe. Such changes and their likely impacts cannot be ignored in any evaluation of future climate change.

**Model-Data Comparisons**

That it is possible to reduce the complex processes of nature to fundamental laws does not imply that it is also possible to completely describe nature by starting from these fundamental laws. The palaeorecord has demonstrated that new approaches with different hierarchies are needed. Model studies of past and present environmental events are especially important for understanding the interactive physical, chemical, and biological control of Earth system processes.
How has the Climate Varied in the Past – An Overview

Although there is considerable uncertainty about the rate and magnitude of any future warming which may occur as a result of human activities, one thing is not in dispute: any human-induced changes in climate will be superimposed on a background of natural climatic variations. Hence, in order to understand future climatic changes, it is necessary to have an understanding of how, why, and to what degree climates have varied in the past. Of particular relevance are: (i) climatic variations of the last few centuries leading up to the recent warming trends observed in instrumental record; and (ii) rapid climatic changes that occurred at societal timescales, e.g., during the last ice age, the last glacial/interglacial (Holocene) transition and possibly during the previous (Eemian) warm period. Two aspects of ocean surface variability are also of particular relevance to understanding long term climatic change: (i) the variability of ENSO events; and (ii) variations in ice age tropical sea surface temperature.

Climate of the Past 2,000,000 Years

The Pleistocene glacial-interglacial cycles characterize recent Earth history. This period, mostly cooler than at present, began about 2,400,000 years BP and was preceded by a generally warmer and more stable climate. Over the last million years, these cycles occurred with a periodicity of about 100,000 years with long glacial periods interrupted by interglacial periods of shorter duration. During the Last Glacial Maximum (LGM) (~20,000 BP), global surface temperatures were approximately 4°C colder than at present. As a consequence of the build-up of continental ice sheets over much of North America and Scandinavia, mean global sea-level was about 120 metres below its present height. The timing of the recurring glaciations is believed to be linked to variations in seasonal radiation receipts in the Northern Hemisphere. This insolation forcing, due to changes in the configuration of the Earth’s orbit, was probably further amplified by changes in the concentrations of greenhouse gases and in the extent of continental ice cover.
Rapid Climate Changes During the Last Glacial Interglacial Cycle

Recent studies have brought new insight on the abruptness of climate changes during the last glacial-interglacial cycle. Large and rapid climatic changes occurred during the last ice age and the transition towards the present Holocene period. In the well-documented North Atlantic region, as noted above, these changes appear to be linked to ice sheet dynamics and to the consequences of ice sheet changes for North Atlantic Deep Water formation and the thermohaline circulation. These changes may have occurred within very few decades. They affected a large variety of climate-related variables, such as: atmospheric temperature and circulation; precipitation patterns; and the temperature and dynamics of the ocean.

Much information on rapid climatic change has been obtained recently either from a refined interpretation of existing records or from new ice, ocean and continental records. Of particular significance are those concerning the North Atlantic and adjacent continents. The GRIP and GISP2 ice cores from central Greenland are more than 3 km deep. They provide detailed climatic information extending back to the penultimate glacial period. More numerous deep-sea records from the North Atlantic and continental records (lake sediments, pollen profiles, etc.) from Western Europe and North America provide further information on the last glacial period and subsequent deglaciation.

Records confirm that the Younger Dryas (YD)/Preboreal transition that took place ~ 11,500 years ago (11.5 ka BP) was very abrupt. Central Greenland temperatures increased by ~ 7°C in a few decades. There are indications of an even more rapid change in precipitation with snow accumulation in central Greenland doubling within as little as one to three years and of rapid reorganization (< 5–20 years) of atmospheric circulation. Changes in Sea Surface Temperature (SST) associated with sudden changes in the flow of warm Atlantic surface waters, also occurred in a few decades. In the Norwegian Sea, changes as great as 5°C occurred in less than 40 years. The warming which marks the end of the LGM resulted in a 10°C temperature increase in the Northeast Atlantic in less than 400 years.

Numerous new deep-sea and continental records show that the YD cooling was felt throughout the Northern Hemisphere. The last deglaciation was probably also a two-step process in the Southern Hemisphere, but as seen from the East Antarctic ice core records, the return to cold conditions was much less pronounced and the subsequent warming was much less abrupt than in the Northern Hemisphere.

The existence of rapid temperature oscillations discovered in Camp Century and Dye-3 Greenland ice cores (now commonly known as “Dansgaard-Oeschger events”) has been confirmed by the central Greenland records. These events are characterized by rapid warmings, often by as much as half of the magnitude of the glacial-interglacial difference and taking place in a few decades. Evidence suggests that Dansgaard-Oeschger events are followed by periods of slower cooling and then a generally rapid return to glacial conditions. Approximately 20 such interstadials, lasting between 500 and 2,000 years, occurred during the last glacial period. They resemble the rapid changes documented in North Atlantic deep-sea core records and have recently been identified in high resolution sediment sequences from the tropical Atlantic and even in records from the Santa Barbara Basin in the Eastern Pacific.
The most prominent of these interstadials may be associated with the sedimentary “Heinrich” layers interpreted as reflecting massive iceberg discharge from Northern Hemisphere ice sheets. These discharges occurred at the end of the cooling cycles and were followed by abrupt shifts to warmer SSTs.

During the last glacial period, continental records also indicate rapid changes. Moreover, a significant increase in atmospheric methane concentration is associated with the warm interstadials. This association may be due to variations in the hydrological cycle at low latitudes. This also suggests that the interstadials were at least hemispheric in their extent. In addition, variability of precipitation has been important at low and mid-latitudes even when temperatures varied little.

The question of climatic instability during the last interglacial (Eemian) has also been raised. For the period predating the last glacial stages (stages 2–4), isotopic records from central Greenland ice cores show a series of very abrupt changes, but they are very different between the GRIP and GISP records, whereas the two cores, separated by only 28 km, are in excellent agreement throughout the glacial period. Furthermore, the comparison between the Antarctic and Greenland records of atmospheric compounds which should be the same (CH$_4$, atmospheric $^{18}$O) indicates important differences. Interpreting the isotopic changes in the early parts of the GRIP and GISP ice cores in terms of climatic changes is therefore problematic. The divergence in the evidence from the two cores shows that ice flow may have altered the chronological sequences of the stratigraphy for the bottom part of one or both of the cores. The possibility that rapid climatic variations occurred during the Eemian requires that the respective contribution of climate and ice flow in the Greenland Eemian signals be fully assessed. The identification of such apparently rapid events in other ice, oceanic or continental records would confirm their occurrence and indicate their spatial extent.

The existence of rapid climatic changes does not fundamentally modify our understanding of glacial-interglacial cycles. However, it appears that the response to the initial insolation forcing is highly non-linear, in particular in the North Atlantic and adjacent continents. These rapid events, which indicate a key climatic role for the ocean, are relevant to understanding future climate because they affect all important climatic variables on a large geographical scale and they do so on timescales relevant to human society. This relevance to future climate will be even more direct if the existence of rapid changes in an interglacial period (the Eemian) is confirmed.

**Tropical Sea Surface Temperatures (SSTs)**

The relationship between modern and past terrestrial and SSTs is still one of the major uncertainties involved in deriving the climate during the last ice age. The relationship is important to general circulation models of the atmosphere, because many models prescribe SST, which then exerts strong control on the spatial pattern of heat flux to the atmosphere.

The project Climate Mapping, Analysis, and Prediction (CLIMAP) demonstrated that oceanic sediment cores contain stratigraphically consistent sequences of microfossils that indirectly record changes in SST. Recent work comparing CLIMAP SST estimates with nearby terrestrial surface temperature estimates show obvious discrepancies. Terrestrial temperature estimates derived from snow line lowerings
and pollen data on the mountains of New Guinea bring into question the earlier CLIMAP SST estimates, suggesting they may have been as much as 5°C too high. Palaeoclimate data from high altitude sites in equatorial East Africa and the Bolivian Andes also point to significant snow line lowerings during the last glacial period and suggest air temperature cooling of between 3° and 8°C. These estimates link snowline depression to temperature change, without taking into account changes in precipitation or humidity.

Although some recent results indicate that the continental cooling might have been somewhat less than suggested earlier, the discrepancy between CLIMAP estimates and terrestrial palaeodata is still significant and the inconsistencies between terrestrial and marine palaeotemperature reconstructions for the LGM remain unresolved.

**Global Temperatures of the Past 1,000 Years**

The period of instrumental records is short, and longer records, extending back 1,000 years or more, are required to determine how the rise in temperature over the last century compares to records from earlier centuries. Historical, ice core, tree-ring, lake level and coral data are used for reconstructing the climate of the last millennium, but this is far from being as fully documented as the 20th century climate. Annually resolved, precisely dated temperature histories from tree rings for the last millennium are still too sparse for hemispheric or global analysis, and must, in general, be interpreted in a regional context. Further, they usually only reflect changes in warm-season temperatures. Coral records occur in regions not represented by tree-rings and usually have annual resolution, but none extends back more than a few hundred years. The interpretation of ice-core records from polar ice-sheets and tropical glaciers may be in some cases limited by the noise inherent in the depositional processes involved. Despite these limitations, a great deal of climatic information is available and records may be combined to produce consistent reconstructions of climate. For this last millennium, there are two periods of special focus, the Little Ice Age (LIA) and the Medieval Warm Period (MWP).

The term “Little Ice Age” is often used to describe a world-wide, 400–500 year long, synchronous cold interval. However, the climate of the last few centuries was more complex than this. It was a period of both warm and cold climatic anomalies which varied in importance geographically. For the Northern Hemisphere as a whole, the coldest intervals of summer temperature were from 1570–1730 (especially 1600–1609) and during most of the 19th century, though individual records show variations in this basic pattern. Although there were warm conditions commonly in the early 16th century and in most of the 18th century for the entire hemisphere, conditions comparable to the decades from 1920 onward have not been experienced for at least several hundred years.

It is important to recognize that the period of instrumental records, from which our limited view of “global warming” has been derived, began at one of the coldest periods of the last few centuries. With a longer perspective on this period, alternative views of the temperature record of the last century emerge. On the one hand, the long-term change of temperature could be interpreted as showing a gradual increase from the late 1500s, interrupted by cooler conditions in the 19th century. This warming might be part of a longer (lower frequency) oscillation, with a period on the or-
der of a millennium. Alternatively, one could argue that temperatures fluctuated around a mean somewhat lower than the 1860–1959 average (punctuated by cooler intervals in the late 1500s, 1600s and 1900s) and then underwent pronounced, and unprecedented (e.g., since 1500) warming in the early 20th century. The development of appropriate strategies for detecting anthropogenic climate change depends on the resolution of such issues.

Recent studies have re-evaluated the climatic interval commonly known as the MWP in an attempt to assess the magnitude and geographical extent of any prolonged warm interval between the 9th and 14th centuries. The available evidence is limited (geographically). A number of records do indeed show evidence of warmer conditions at some time during this interval, especially in the 11th and 12th centuries in parts of Europe. Other records are equivocal, or indicate that warmer conditions prevailed, but at different times. A clearer picture may emerge as an increasing number and better calibrated proxy records are produced. However, at this point, it is not yet possible to say whether, on a hemispheric scale, temperatures declined from the 11–12th to the 16–17th century. There are also indications of changes in precipitation patterns; indeed many records point to drought as the major characteristics of climate in this period. It is therefore not clear if the Medieval period can be a useful analogue for the altered climates expected under enhanced greenhouse gas concentrations.

High Frequency Climate Change – El Niño-Southern Oscillation (ENSO)

The ENSO phenomenon is the primary mode of climate variability in the 2–8 year time band and affects both tropical and extratropical regions. Release of latent heat associated with eastern Pacific warming also affects global temperature, and changes in upwelling influence atmospheric pCO₂ levels.

Climate models suggest that the frequency of El Niño events may vary under higher levels of greenhouse forcing, with a consequent possibility of ENSO perturbations being superimposed on any regional climatic trend predicted by greenhouse models. It is therefore important to understand the temporal variability of El Niño events in order to gauge future changes in terms of natural or forced variability.

As instrumental records for the ENSO extend only to about the beginning of the 20th century, we must utilize various proxy approaches to derive the history of ENSO events over longer periods.

Because instrumental records indicate that ocean-atmosphere changes in the eastern equatorial Pacific have the greatest potential for influencing climate far from that region, it is instructive to assess the coral record for this region. A time series of oxygen isotope measurements from corals in the Galapagos indicates significant decadal-scale variations in this key region. Of particular interest are cool events in the late 17th and early 19th centuries that coincide with decadal-scale cool periods in northern mid-latitudes. These two intervals represent two of the coldest periods in the last 500 years. The abrupt warming at about AD 1700 is of special significance with respect to the possibility of abrupt transitions in the climate system.
Analysis of the Galapagos time series indicates several shifts in dominant modes of variability over the last 400 years. At times, these have ranged from 4.6 to 7 years and at other times averaged 3.5 years. Tree ring records also indicate temporal variations in some of the ENSO periods. Analysis of instrumental records also indicates a significant biennial component to the ENSO periodicities. Coral records from the South Pacific include such a biennial component and, in addition, suggest higher levels of variability in the 19th century.

Recent spatiotemporal analyses of global and regional sets of proxy data at annual resolution indicate that there may be interactions between the interannual, interdecadal and century- scales of variability, with the oceans playing an important role. These findings arise as mechanisms for multi-year and decadal scale variation are being proposed. As more well-understood annual resolution records are developed, better quantitative descriptions of natural variability should emerge. This will facilitate understanding of the underlying processes, and will contribute to establishing a detection strategy for anthropogenically forced greenhouse warming.
FOCUS I

Palaeoclimates of the Northern and Southern Hemispheres (PANASH)

(See PAGES Workshop Report 95-1 for which Spanish, Chinese, and French translations are also available)

Project Leader: Ray S. Bradley

Background and Rationale
The PANASH project is designed to implement research on inter-hemispheric climatic mechanisms and coupling in order to improve understanding of how climate change is linked in both hemispheres. To this end, a comprehensive study of palaeoclimate records from the Northern and Southern Hemispheres is being coordinated by PAGES along three broad PEP transects. These are:

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

These transects involve both terrestrial and marine-based research projects, as appropriate to each region. A complementary set of studies (IMAGES) deals with the deeper ocean records of palaeoclimate, and additional projects link with the transects and focus on palaeoenvironments in polar regions (Focus II).

Scientific Objectives
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 affect 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 climate coupling between hemispheres.

These goals require that there be:

• Significant new research in data-poor regions to redress the geographic imbalance in palaeoclimatic information which currently exists
• Greater degree of collaboration between scientists of the Northern and the Southern Hemispheres
• New research focus on North-South links, fostered by scientific meetings which address observational projects, logistic coordination, and new methodologies (i.e., proxies, geochronology, data access).

Records of climatic change 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 (Stream II). Records of the last 2,000 years are needed for resolving higher frequency changes in climate (Stream I). 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.

Plan of Operations

Activities To Date
An initial series of workshops was held to develop research plans and priorities for each of the PEP transects. For PEP I, meetings were held in Panama City, Panama; Mendoza, Argentina; and La Paz, Mexico (1993–1995). For PEP II, meetings were held in Taipei, Taiwan; Canberra, Australia; and Beijing, China (1993–1994). For PEP III, meetings were held in Bern, Switzerland; and Sfax, Tunisia (1993–1995). Results of these discussions, and recommendations for future research, are summarized in PAGES Publications 93-1 and 95-1. These workshops have had an important impact on scientific planning in many countries by providing a conceptual framework for future palaeoclimatic research as a contribution to the international global change research effort.

Future Plans
Although a great many research projects have been launched within the PANASH framework, we highlight one cross-cutting initiative that is critical for future progress. A common recommendation of all workshops was the urgent need to re-
cover long sedimentary records from terrestrial sites along the PEP transects. This charge has been taken up by the PAGES Lake Drilling Task Force, which is coordinating efforts with the International Continental Drilling Project (ICDP). Initial support for drilling in Lakes Qinghai, China; Poukawa, New Zealand; and Monticchio, Italy is expected. Initial site surveys of several lakes in Africa, Indonesia and South America are also underway.

Specific workshops focused on different aspects of the PEP transects are planned by individual project leaders and others pursuing specialized topics. For example, in the PEP I region, the Inter-American Institute for Global Change Research (IAI) supported several PEP-related workshops in 1995–1996, from which specific research plans will evolve. In Japan, a PEP II meeting on Stream I climate variability was held in November 1995 and a meeting on Stream II records was held in Brisbane, Australia in 1996. A workshop involving regional and national leaders from the PEP III region was held in Paris in late 1996. Finally, there has been consultation with START in April 1996 to discuss how PAGES and START can cooperate to promote research, training and infrastructure development to achieve the objectives of the PANASH project in each of the PEP regions.

These activities will carry forward the research effort through the next few years. However, there is a need to provide a forum for coordination and comparison of research being carried out in the different PEP regions. The PAGES Leaders meeting held in Hilterfingen, Switzerland in November 1997 provided such a forum. Research scientists who are coordinating the PEP transects, as well as those leading other PAGES projects which provide linkages between the transects, met and established much tighter levels of cooperation among the research programmes, including direct ties between marine and terrestrial initiatives. A PANASH Forum to bring together research scientists involved in the PEP transects, as well as those other PAGES projects which provide linkages between the transects (e.g., Circum-Arctic PalaeoEnvironments [CAPE], ARTS, IMAGES, and bi-polar ice-core activities) is also planned. Support will be sought from major institutions and national funding agencies.

**Project Management**

Oversight of the PANASH project is provided by the PAGES SSC. PEP leaders regularly attend PAGES SSC and EXCOMM meetings. Close contact is maintained with PEP leaders through the PAGES IPO.

---

Report prepared by Ray S. Bradley

**Contact:**
Ray S. Bradley
Department of Geosciences, Morill Science Center
University of Massachusetts, Amherst, MA 01003-5820
USA
Tel: (1-413) 545 2120
Fax: (1-413) 545 1200
Email: rbradley@geo.umass.edu
The lines of the Pole-Equator-Pole transects are shown here. The marine research comprises the IMAGES programme. The Arctic and Antarctic programmes are outlined under Focus 2 in the text. From: PAGES PANASH Workshop Report 95-1.
Focus 1  
Activity 1  
Palaeoclimates of the Americas 
Pole-Equator-Pole (PEP I)

Background
The PANASH transect in the Americas (PEP I) is particularly suited to detecting the similarity and degree of synchroneity of changes in both Northern and Southern Hemispheres because of similar poleward extent of land areas, similar distribution of mountains and lowlands, and comparable relationships to atmospheric and surface ocean circulation. The transect is also well placed to record Pacific climatic occurrences in marine and terrestrial records at latitudes from 70°N–55°S. In records from the central portion of the transect, on the other hand, palaeoclimate records will provide evidence for the competing influence of the Atlantic climate forcing. Furthermore, 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.

This PAGES activity was initiated at two meetings (Boulder, USA, 1991 and Panama City, Panama, 1993) both of which included representatives of the palaeoclimate community from throughout the Americas. These meetings formulated the primary questions and designed a plan for the implementation of an interhemispheric palaeoclimate agenda (PAGES Report 95-1). The consensus that emerged from these meetings pointed to the linkages between terrestrial and marine palaeoclimate records placed along two intersecting transects: A north to south transect along the west coast of the Americas from Alaska to Tierra del Fuego, Antarctica, complemented by an equatorial trans-Pacific transect to focus on Pacific climatic phenomena.

Interhemispheric palaeoclimate correlations will be examined with multiproxy climate records in order to address the trans-equatorial extent of climate forcing factors. This will be done by: (i) identifying changes in latitudinal and elevational temperature gradients through time; (ii) changes in intensity and location of upwelling and its relation to shifts in atmospheric circulation; and (iii) changes in the surface circulation of the Pacific ocean versus the North Atlantic ocean dynamics and their respective effects on tropical and extratropical climate teleconnections in the Americas.

Scientific Objectives

- Determine the major modes of decadal scale climate variability revealed by the instrumental record
- Determine the major modes of sub-decadal, decadal, and century-scale climate variability during the last 2,000 years
• Identify the roles of the major potential forcing factors on these time scales – ENSO, solar variability, volcanic aerosols, human activity

• Determine the major modes of century and millennial scale climate variability during the last 250,000 years and their cause(s) – e.g., solar radiation (insolation)

• Establish interhemispheric synchronicity of abrupt changes and their causes.

Project Strategy

Stage 1

Several PEP I regional and international workshops were convened since 1993 to foster scientific communication and collaboration within the palaeoclimate community of the Americas and to develop funding strategies:

- Panama City, Panama, October 1993 (PAGES Report 95-1)
- Springfield, IL USA, November 1994 (Latin American Pollen Database)
- Albuquerque, NM USA, January 1995, Earth Observing System (EOS), v. 76:225-226)
- Potsdam, Germany, June 1995, Earth Observing System (EOS) 12 September 1995, v. 76)

Stage 2

1996–1998: Development of Collaborative Opportunities
The IAI provides an important administrative and financial element for the success of PEP I research. The PAGES-PEP I workshop in Mendoza (Argentina), cosponsored with IAI, and parts of the IAI planning meeting in Belem, Brazil were directed towards the integration of palaeoclimate studies to the IAI core themes. These themes include: Impact of Climate Change on Biodiversity; Comparative Studies of Temperate Terrestrial Ecosystems; High Latitude Processes; ENSO; and Interannual Climate Variability. As a consequence of these joint meetings research proposals have been submitted from the PEP I community in the first round of IAI grants. Several of the PEP I related proposals for workshops and research projects were funded (see below), indicating that IAI will play a central role in the success of the PEP I research effort.

PEP I Related Projects Funded by the IAI in 1996
Vegetation History from Fossil Rodent Middens in the Mid- latitude American Deserts (J.L. Betancourt, V. Markgraf, L. Graumlich).
Fossil rodent middens from the deserts in South America (Argentina, Bolivia, Chile, and Peru) will be collected and analyzed for comparison with packrat middens from North American deserts (USA and Mexico) to resolve questions on: (i) human impacts on semi-arid rangelands; (ii) how climatic extremes and variability affect long-term vegetation dynamics, biogeography and biodiversity in deserts; and (iii) the interhemispheric interrelation between climate change.

Ice-Core Study on the Environment and Climate of the Antarctic Peninsula and the Southern Part of South America (Laboratorio de Estratigrafia Glacial y Geoquimica del Agua y de la Nieve [Argentina]; Laboratório de Pesquisas Antárticas e Glaciológicas [Brazil]; Department of Geography, University of Calgary [Canada]; Laboratoire Glaciologie et Géophysique [France]).

Ice-core samples from the Antarctic Peninsula and the Patagonian Icefield will be recovered and analyzed at annual to decadal resolution to identify atmospheric and climatic variability for the last 1,000 years.

**PEP I Related Workshops Funded by the IAI in 1996**

- Potential Use of Biological Proxy Data as Climatic Change Impact Indicators in South American Ecosystems (C. Villagrán [Chile], M. Paez, A. Prieto, and R. Villalba [Argentina], M.L. Lorscheitter [Brazil])
- The Assessment of Present, Past and Future Climate Variability from Tree-line Environments in the Americas (B. Luckman, Canada)
- Fire and Global Change in Temperate Ecosystems of Western North and South America (T. Veblen, USA)
- Comparative Studies on Oceanic and Coastal Processes in Temperate Zones of the Eastern Pacific (T. Baumgartner, USA)
- Large-Scale Biosphere-Atmosphere Experiment in Amazonia (LBA) (C. Nobre *et al.* Brazil)
- Dendrochronological Studies in Tropical South America with Special Emphasis on Bolivian Forests (J. Boninsegna, R. Villalba, and F.A. Roig [Argentina], J. Argollo and S. Beck [Bolivia]).

The US NSF/National Oceanic and Atmospheric Administration (NOAA) Earth System History (ESH) programme presents another major source of support for PEP I activities. Following a call to help define the major research themes that would provide information on the environment’s natural variability, the coupling of the components of the Earth system, and the biospheric interaction with changing global systems, the PEP I community was called upon to submit white papers to the Terrestrial Earth System History (TESH) steering committee for consideration in the TESH research plan.

One of the products from the La Paz, Mexico, 1995 PEP I workshop was the preparation of several of these “white papers” focusing on specific aspects of the PEP I agenda. The white papers invited for the presentation at the first TESH Workshop (Portland, USA, 1996) included: (i) evidence from intertropical regions for changes
in global water balance; (ii) Earth system sensitivity and variability over interannual to millennial time scales from late Holocene coastal marine sediments along the PAGES PEP transect of the Americas; (iii) assessment of climate variability from alpine tree-line sites in the Americas (Hughes et al.); (iv) late-glacial climate variability in the Americas – interhemispheric patterns and linkages; (v) modes of century to millennial climate variability in the Americas – Lake Drilling Programme; and (vi) inter-American analyses of interannual to interdecadal ENSO variability using multiple palaeoclimatic proxies. The purpose of the TESH workshop was to stimulate collaborative and multi-disciplinary terrestrial palaeoclimate research for global change objectives.

**International Continental Drilling Programme (ICDP)**

One of the major science objectives of the three PEP transects is the development of long records (Stream II) of climate change and forcing. Recovery of such records requires logistic support and technological expertise which exceeds that available through the standard terrestrial palaeoclimate research project and funding programmes. A PAGES Workshop was convened in Potsdam, Germany (June 1995) to develop protocols and logistic approaches for large lake drilling projects. Based on community input, the outcome of the workshop was a five-year lake drilling plan for the three PEP transects submitted to ICDP for consideration. Several site specific proposals were also submitted.

**Stage 3**

**1998: PEP I Science Meeting (see below)**

Planning for the first comprehensive PEP I science meeting is now well under way, including coordination of research presentations, to be published in book form, from members of the PEP I community working on specific topics of the PEP I science agenda. The targeted topics with ongoing collaborative, inter-American research activities include:

- Decadal scale climate variability – instrumental records in the Americas
- The last 2,000 years of climate history, based on correlation of high resolution records from terrestrial and marine settings in the Americas
- Present and past ENSO-related teleconnection modes in the Americas
- Interhemispheric synchronicity of abrupt climatic events, especially during the late-glacial
- Interhemispheric synchronicity of glacial climate patterns in the Americas.

**Products**

1. In compliance with the PAGES objective to ensure preservation of all scientific data compiled in context of past global change research a two year effort began in 1995 to compile a Latin American Pollen Database (LAPD) to complement
the North American and European Pollen Databases. LAPD will be available in the public domain through the NOAA WDC-A for Palaeoclimatology. An inventory listing geographical, bibliographical, and age information of all Latin American pollen records is now available on the NOAA WDC-A World Wide Web as well as in hard copy.

2. The first comprehensive PEP I Science Meeting was held in Merida, Venezuela, 16–20 March 1998. The major objective of this meeting was to provide a first synopsis of interhemispheric palaeoclimate in the Americas, patterns and causes, to be published in book form. This synopsis will address topics, listed above, which have already progressed sufficiently to approach the questions on interhemispheric climate linkages, their mechanisms and forcings. At this stage, discussions will begin on how to link the PEP I information to that from other PEP transects, especially to PEP II in context of the ENSO teleconnection objective.

Project Management

The PEP I project office has been established at the Institute of Arctic and Alpine Research (INSTAAR), University of Colorado, USA; support has been secured for the period 1995–1998. The office will help in promoting inter-American communication and in developing funding strategies. An international steering committee aids with these efforts and meetings are regularly convened, in connection with PEP I workshops. The PAGES Newsletter is considered the most widespread tool for communication with the general science community.

Future Directions

A number of international collaborative projects have resulted from the various meetings convened under the PEP I umbrella. Given the relationships developed with several funding programmes, PEP I planning and research activities have flourished. Several workshops on specific themes related to the PEP I science agenda, as defined by the community, have taken place or been convened for 1996 and 1997. These themes include: Ice-Core Studies in the Americas; Fire History in the Americas; Tree line in the Americas, Present and Past; Oceanic and Coastal Processes in Temperate Latitudes of the Eastern Pacific; and History of the American Deserts; etc.

Close communication will be maintained during the developmental stage of these science activities to ensure interaction among the activities in context of the overall PEP I goals. Communication will also be maintained with the leaders of the complementary PEP transects, with other PAGES and IGBP initiatives, such as ARTS and the PALAEOMONSOONS Project, and with other international global change programmes, including Ecologie et Palaeocologie des Forêts Intertropicales (ECOFIT, France), Institut Français de la Recherche Scientifique pour le Développement et Coopération (ORSTOM, France), Pan American Climate Studies (PACS-NOAA), Palaeoecology of Tropical America (Dutch NSF); and Southern Hemisphere Palaeo- and Neoclimates (IGCP 341).
Report prepared by Vera Markgraf

Contact:
Vera Markgraf
INSTAAR
University of Colorado
Campus Box 450, 1560 30th St.
Boulder, CO 80309-6450
USA
Tel:  
Fax:  
Email: markgraf@spot.colorado.edu
Focus I
Activity 2  Palaeoclimates of the Austral-Asian Transect (PEP II)

(See PAGES Workshop Report 93-1)

Project Leaders:  John Dodson and Tungsheng Liu

Introduction

PEP II is the Pole-Equator-Pole transect which spans from western Asia (east of the Urals) through Australasia (east to the Date Line) and across the Southern Ocean to Antarctica. In April 1994 a meeting in Beijing (China) served to initiate the transect with a series of papers, workshops and discussions. At this meeting participants identified the main features of the region, and the community focused on the important questions which described and identified the main global problems and processes related to environmental change and variability in the region. In short, the process involved a distillation aimed at reducing the complexity of temporal global environmental changes to the regional level, and at a scale which can be used to interface with the work of other PEP transects, in order to describe the features and factors which control global environments.

Major tasks within the PEP II project include the Himalayan/Tibetan Plateau Interdisciplinary Palaeoclimate Project (HIPP), which draws together scientists who work in the Himalaya/Tibetan Plateau region, and the BDP, whose temporal objectives overlap to some extent with those of PEP II.

A second meeting of PEP II scientists was held in November 1995 in Nagoya (Japan) and focused on data and data interpretations of environmental variability and change over the last 2,000 years. More meetings are planned.

PEP II research is important for many reasons, but perhaps the most critical among them is to decipher what impact the rate of environmental change in recent decades has had on many social and economic systems. Within the time frame of the next two generations, environmental change may have extra significance for the PEP II region, where most of the world’s population resides and many economies are growing rapidly.

Scientific Objectives

- Encourage scientists to look beyond local or national scale studies and to consider the wider significance of their work, and to become more involved in the study and understanding of global environmental change
- Establish the role and significance of the important features of the transect in driving climate change
- Increase the level of knowledge of past environments within areas where there are significant gaps
• Understand the relative importance of human impact and natural environmental factors in driving climate change in the region
• Describe the environmental variability of the region over time, in particular to identify the frequency and effects of socially and environmentally significant climate phenomena
• Develop an understanding of how the synoptic scale elements of the climate system interact at the regional and global scales
• Contribute to the understanding of climate changes at a global scale.

Subsequent refinement of these has resulted in the following key themes:

• Identification of signals related to Dansgaard-Oeschger (D-O) cycles and Heinrich events (periods when icebergs deposit glacial sediments far south in the Antarctic) in Asian terrestrial records
• Signatures of the Asian aeolian dust and aerosols in the North Pacific and in ice cores
• Links of aeolian events between the Southern Hemisphere (Australia) and Northern Hemisphere (China and Central Asia)
• Modern relationships of bio-geodata with climates and quantitative estimates of palaeoclimates
• Strength and interplay between the Australian monsoon and the Westerlies in the region of the maritime continent, Australia, and New Zealand
• Role of tropical oceans in climate dynamics in the PEP II region
• The role of climate variability on changes in biodiversity across the region.

In addition, an initiative, High Resolution Reconstruction of East Asian Monsoon (HIREAM), has been launched, open to Chinese, Japanese and Korean scientists. This task will involve the study of palaeoclimates along a transect which runs from the border of the Tibetan Plateau to the western Pacific, traversing across the Sea of Japan to Japan.

Implementation

Australia
Several scientists have already established strong links with overseas organizations and with scientists from New Zealand, New Guinea, the Pacific Islands, Indonesia, and China. Collaborative research projects on lakes through the ICDP (see below), speleothems, dendrochronological research, and studies of corals are planned.

China Mainland
Priority is now being given to establishing state-level research projects. A project entitled “History and mechanisms of environmental changes in Eastern China over the late Quaternary” has recently been proposed to the National Natural Science Foun-
dation of China. The scientific issues to be addressed in the project are relevant for both PAGES temporal streams. The main objectives are to reconstruct the high resolution (decade to century scales) history of palaeoclimates based on various records (varved lake sediments, loess and marine sediments, tree ring, speleothems and historical records), to investigate and map the spatial variability of palaeoclimates for selected timeslices (especially ca. 6 ka BP and ca. 21 ka BP\(^1\)), to study the interactions and potential mechanisms of the different components of atmospheric circulation prevailing in the Asian region; and to further develop the database of palaeoclimates in China. This project is expected to run in parallel with another state-level project in connection with the Global Change and Terrestrial Ecosystems Project (GCTE), which has also designed a transect study in the northeastern part of China. These parallel projects would provide a unique opportunity for the calibration of palaeo-data and quantitative estimates of palaeoclimates.

In addition, a number of international cooperative research projects are under consideration that would address several topics, such as the interhemispheric comparison of aeolian records and aeolian signatures in the oceans and ice cores; the interaction of different atmospheric circulation components (Southwest summer monsoon, Southeast summer monsoon, Northwest winter monsoon and the Westerlies); the Asia-North Atlantic link etc. These international efforts are expected to be developed within the PEP II framework or as links between PEP II and other PAGES projects.

**Taiwan Region**
The PAGES programme in the Taiwan region was initiated in March 1992. At present, funding for the PAGES Programme has been in the range of 10–15% of the geological programmes budget of the entire region.

**Hong Kong Region**
Some significant research activities on palaeoclimates in Hong Kong have been initiated since IGCP 396. These programmes are centered on the history of climate changes, sea level changes, and storm events recorded in the region. Records include those found in sediments on the shelf of the South China Sea off Hong Kong.

**Japan**
The main goals of the proposed HIREAM project are noted above.

**Footnote:**
\(^1\) 21 ka BP = 18 ka radiocarbon years BP
Other Priorities for PEP II

Qinghai Lake (China), Lake Poukawa (New Zealand), and a lake to be selected in Sulawesi are high priority sites for drilling on the PEP II transect.

Increasing the rate of progress for palaeoclimatic research along the transect will depend on securing dedicated support, on the success of PEP II in organizing the community, and on progress towards highlighting critical research issues. Transect meetings are expected to be held every two years to address these issues. Financial support for the analysis of key sites (e.g., ICDP), for training scientists in data poor areas, and for encouraging other scientists to work in these fields must continue to receive high priority. The steering committee has already agreed to focus attention on these issues for the PEP II region in the coming years.

Linkages to the International Union for Quaternary Research (INQUA) must be strengthened. At the 1995 INQUA meeting (Berlin) there was a large symposium devoted to PANASH. The INQUA Holocene Commission has been asked to work on high resolution data sets and on the separation of human impact/natural variability signals. Other activities important for PEP II include possible collaboration with START and Global Analysis, Interpretation, and Modelling (GAIM) as well as discussions between PEP leaders and the scientific community such as those held in conjunction with the International Geological Congress (IGC) Global Change Symposium, Beijing, People’s Republic of China (August 1996).

Output

Objectives achieved to date include:

- Identification of major features of the transect
- Identification of important questions which can be investigated in the medium term (by 2,000 AD)
- Development of a science plan (in the PANASH document)
- Discussions of data within the framework and goals of PEP II held at meetings in Beijing, Kathmandu, and Nagoya.
- Publication in *Quaternary International* of papers presented at recent meeting in Beijing
- Publication of a proceedings volume from the Nagoya meeting
- PEP II is now widely known across the region, and co-leaders are consulted as other meetings are held
- The ICDP has helped identify several key sites in the region that should help to achieve some of the goals of PEP II
- Publication in *Global and Planetary Change* of papers presented at IGC in Beijing
- Enhanced attention is being paid to some of the main data gaps identified along the transect
• Development of pollen and geomorphic databases in Australia, New Zealand, China, Japan and elsewhere to improve data availability to scientists across the region and across the world

• Workshops are planned for Indonesia and Australia to enable scientists to work together to draw hemispheric and trans-hemispheric comparisons

• The modelling community is now more attuned to the value of regional syntheses enabled by palaeodata, and the possibilities for independently testing and calibrating models.

Project Management
This project has a Steering Committee (SC) with the following membership:

Zhisheng An (China)
John Dodson (Australia) (co-leader)
Wayhoe Hantoro (Indonesia)
Ping Mei Liew (ROC)
Tungsheng Liu (PRC) (co-leader)
Yugo Ono (Japan)
One position vacant

The Project Office is located in the Institute of Geology, Beijing-China, and Zhengtang Guo serves as the contact.

Funding support is ill-defined at present and has depended upon external input. A process is underway to establish a “PEP II Foundation” to support research, meetings, and training, especially for scientists in developing countries.

The resources of the project management group are minimal. Scientists involved with PANASH/ PEP II are encouraged to use concepts outlined in the PANASH document to generate support through their respective national funding agencies.

Future Directions
Future scientific meetings and workshops are planned for Perth in Australia (1998) and Bali in Indonesia (1999). These workshops will focus on key issues outlined in the PEP II chapter of the PANASH document. Other activities depend on available resources and the overall funding base, (i.e., the success of the “PEP II Foundation” or similar support). The success of the “Drilling Task Force” group and ICDP are also important elements for the success of the PEP II programme.
Report prepared by John Dodson

Contacts:
John Dodson
Department of Geography
University of Western Australia
Perth, WA 6907
Australia
Tel: (61-8) 9380 2697
Fax: (61-8) 9380 1054
Email: johnd@geog.uwa.edu.au

Tungsheng Liu
Institute of Geology
Chinese Academy of Science
PO Box 9825, Beijing 100029
People’s Republic of China
Tel: (86-10) 620 2766
Fax: (86-10) 255 8066
Email: its%bepc2@scs.bitnet
Focus I
Activity 2
Task 1  Baikal Drilling Project (BDP)

Project Leaders:  Mikhail I. Kuzmin, Takayoshi Kawai, and Douglas F. Williams

Introduction/Background

The BDP is now a multi-national effort (Russia, Japan, Germany, USA) to extract the record of global climate change and tectonic evolution of the Late Neogene from the Lake Baikal sedimentary basin. BDP began in 1989 as a joint Russian/American scientific venture. In numerous meetings over a three year period participants agreed on a scientific programme and leadership structure, including a steering committee. These discussions led to several successful Russian and American coring-seismic expeditions (Lake Baikal Palaeoclimate Project Members, 1992) which laid the framework for actual drilling. This effort also included new multichannel seismic profiling which indicated that sedimentary thickness exceeds 5–8 km in some parts of the Baikal basin.

In January 1993, the BDP team, in cooperation with the Nedra Drilling Enterprise of Yaroslavl, Russia, successfully deployed a light-weight drilling rig from a barge frozen into position over a topographic high in southern Baikal called the Buguldeika saddle. With this system, the first long (>100 m) hydraulic piston cores were successfully recovered from two holes in 354 m water depth.

The climate of the Baikal region is characterized by a high degree of continentality. In addition, Lake Baikal has never been glaciated in its 20–25 million year history. The palaeoclimate research at Lake Baikal is therefore important because it offers unparalleled opportunities to recover a relatively high latitude record of the continental response to atmospheric forcing isolated from marine influences due to its mid-continent position. The sedimentary record of Baikal is also extremely long and continuous with sedimentation rates varying from 1 cm/ka – 1 m/ka. The Baikal record therefore offers exciting opportunities to study palaeoclimate change on a variety of temporal scales and resolutions.

Scientific Objectives

1. Develop and calibrate various proxies of palaeoclimate change in Lake Baikal sediments
2. Develop an accurate geochronology for Lake Baikal sediments
3. Develop models for the response of Lake Baikal to palaeoclimate change over the last 30–200 ka
4. Determine the relationship of this response to orbital forcing on Milankovitch timescales (BDP-93)
5. Recover sediments from the Academician Ridge to determine Baikal’s response to Northern Hemisphere glaciation in the late Pliocene-early Pleistocene (BDP-96)

6. Recover sediments to determine if sub-orbital responses exist in the Baikal record (BDP-97/98)

7. Recover sediments to determine how the Selenga River watershed of Baikal has developed over time (BDP-99)

8. Recover long sedimentary sequences to reveal important new information about the history and seismic stratigraphy of this rift sedimentary basin in response to the geologic history of the Baikal Rift Zone and uplift of the Tibetan Plateau.

**Project Implementation**

**1990–1992**
Russian/American coring and seismic expeditions to calibrate the sediment record of Baikal and to define future drilling targets; development of the Baikal hydraulic piston coring system by the Russian drilling enterprise (Nedra).

**January 1993 BDP-93**
First deployment of the Baikal drilling rig from a barge frozen in southern Baikal (the Buguldeika saddle). Recovery of the first 100 m hydraulic piston cores with an average recovery of 90% and a complete composite hemipelagic section spanning the last 500,000 years admixed with fine-grained materials from the Selenga River drainage basin to the east of Lake Baikal. Magnetic susceptibility logging of holes 1 and 2 reveals excellent core-to-core correlation. Variations in spore-pollen, diatoms, biogenic silica, rock magnetic properties, clay mineralogy and organic carbon reveal a detailed record of how climate change impacted the Baikal limnological system, including the adjacent watershed.

**January 1996 BDP-96**
Drilling was successfully completed on the Academician Ridge using an upgraded drilling system. The objective was to obtain a complete palaeoclimatic record of the last 2.5 to 3 Ma to test models of Tibetan Plateau uplift and development of northern hemisphere glaciation. The final length for the BDP-96 core recovery was 385 m in hole one with a maximum sub-bottom depth attained of 250 m for logging. Core recovery to a depth of 119 m is 95%. Drilling in a second hole has recovered 100 m of cores. BDP-96 cores have been magnetically logged in late April–early May 1996, and core descriptions and sampling were completed in early June.

**January 1997 BDP-97**
The Nedra Drilling Enterprise is currently developing a 1,000 m coring system for a future deep-water (900 m) drill at site 7 in the northern basin. Site 7 contains an expanded section equivalent in time to BDP-93 at Buguldeika. The first season will be devoted to a high-resolution section down to 500 m sub-bottom.
**January 1998 BDP-98**
Drilling will be completed at the northern basin site down to a depth of 500–1,000 m sub-bottom.

**January 1999**
For BDP-99 drilling is planned at site 13 on the Selenga Delta to a subbottom depth of 1 km in order to test models about lake level fluctuations and the development of the Selenga watershed which extends into northern Mongolia.

**Methodologies**
The size and depth of Lake Baikal as a natural field laboratory for global change research, and the logistical challenges of working in remote locations, demand a multi-institutional and multidisciplinary approach. A multidisciplinary approach is necessary to exploit the rich potential of the Baikal sedimentary record as a natural archive of palaeoclimate and palaeoenvironmental changes. The BDP team developed new geochemical proxies (e.g., biogenic silica, organic matter indices), new environmental magnetic proxies and new palynological proxies. Currently the team is testing the level of sensitivity of Asian continental palaeoclimate change to Milankovitch orbital forcing. Studies are underway to resolve new evidence for climatic decoupling between Siberia and North America during the Pleistocene. New evidence for large scale and rapid changes in lake level during the Pleistocene has been found. Dramatic changes in the spore-pollen signals in the Baikal sediments are providing key evidence for the response of the terrestrial biosphere of Siberia to global climate changes. The team is resolving the record of palaeo-pCO₂ signals embedded in the organic carbon of Baikal sediments. The environmental magnetic record contains a readily interpretable proxy signal of late Quaternary climate change and three independent means of dating the sediment (climate proxy, relative geomagnetic intensity, and geomagnetic direction).

**Linkages**
BDP is directly linked to the PANASH project through the PEP II Transect.

**Output**
Objectives 1–4 (listed above) have been accomplished and the results are now appearing in many publications and meeting symposia. For example, the BDP team has developed and calibrated various proxies of palaeoclimate change in Lake Baikal sediments such as biogenic silica, magnetic and rock magnetic properties, etc. The team has also developed an accurate geochronology for Baikal sediments using Accelerator Mass Spectrometry (AMS) radiocarbon dating for the last 30,000 of Earth history and magnetic intensity patterns for the last 80,000 years. In addition, preliminary thermoluminescence dating and uranium series dating are promising in the 0–500 ka window. BDP-96 cores from Academician Ridge should yield the first unequivocal palaeomagnetic chronology. The team has also successfully demonstrated the response of Lake Baikal to palaeoclimate change over the last 30–200 ka on Milankovitch frequencies, and has successfully obtained two hydraulic piston-
cored sections from the Academician Ridge to determine Baikal’s response to northern hemisphere glaciation in the late Pliocene-early Pleistocene (BDP-96).

Plans are well developed to accomplish objective 6 and 7, namely to recover sediments from the northern basin site 7 to determine if sub-orbital responses exist in the Baikal record (BDP-97-98) and to recover sediments from the Selenga Delta site 13 to determine how the Selenga River watershed of Baikal has developed over time (BDP-99).

Objective 8, to recover long sedimentary sequences to reveal important new information about the history and seismic stratigraphy of this rift sedimentary basin in response to the geologic history of the Baikal Rift Zone and uplift of the Tibetan Plateau, is dependent on successful completion of objectives 5–7.

All data from the BDP project will be maintained in a BDP database as well as submitted to the PAGES palaeoclimate database.

**Project Management**

The BDP is managed and coordinated by a SC chaired by Mikhail I. Kuzmin, Director of the Institute of Geochemistry, Siberian Branch of Russian Academy of Sciences, Irkutsk, Russia. Other co-chairman are: Takayoshi Kawai, Japanese Association for Baikal International Research Programme; Douglas F. Williams, University of South Carolina; Martin Melles, Alfred Wegener Institute, Potsdam, Germany (an observer of the committee); A. Goriglad, Kuzmin’s Institute (a financial official) is responsible for BDP financial affairs as well as BDP expenditures and keeping financial records on behalf of the BDP SC. Financial reports are made on a regular basis. The SC meets twice a year, usually in Irkutsk, but in November 1995 the SC meeting coincided with the annual meeting of the Geological Society of America in New Orleans, USA, and in February 1996 the SC met in Tsukuba, Japan at the VIIIth International Drilling Symposium. At such meetings the BDP SC decides financial matters and sets policies with regard to sampling, analytical and publication protocols. These BDP protocols are modelled closely on those of the Ocean Drilling Programme (ODP) and PAGES programme.

BDP coordination and planning meetings are held in Irkutsk twice a year, usually preceding the drilling and after drilling in order to set priorities for sampling distribution and analysis. Typically, summary protocols signed by all parties are produced and available upon request.

Principal support for the 100 m and 300 m drilling in the BDP from 1990–1996 has come from a consortium of institutions in four countries including: the Russian Ministry of Science and Technology; Russian Ministry of Geology; the Science and Technology Agency (STA) of Japan; the Japanese Association for Baikal International Research Programme (JABIRP); the Continental Dynamics Programme of the US NSF; the Global Climate Change Programme of the US Geological Survey; the Samuel Freeman Charitable Trust; and the Alfred Wegener Institute, Potsdam, Germany.

The planning and development for the 1,000 m drilling is currently supported by grants from the STA of Japan to the JABIRP and from Roscom Nedra to the Nedra Drilling Enterprise. A proposal has been submitted to the new ICDP to support the acquisition of a new barge as a drilling platform and to support other drilling operations associated with 1,000 m drilling.
Future Directions

After the 1996–1997 winter drilling (BDP-96) on Academician Ridge, the Baikal hydraulic piston coring system is expected to be available for drilling on other lake systems where a 300–400 ton barge is available and water depths do not exceed 380 m.

A proposal has been submitted to ICDP for support of 1,000 m drilling, which is currently supported by the STA of Japan and Roscom Nedra of Russia. It is also hoped that the results from Lake Baikal will be extended into the carbonate-bearing lacustrine system of Lake Khubsugul in Mongolia.

Report prepared by Douglas F. Williams

Contacts:
Douglas F. Williams
Department of Geological Sciences
University of South Carolina
Columbia, SC 29208
USA
Tel: (1-803) 777 7525
Fax: (1-803) 777 6304
Email: baikal@epoch.geol.sc.edu

Mikhail I. Kuzmin
Institute of Geochemistry
Irkutsk
Russia
Email: tabun@igc.irkutsk.su

Takayoshi Kawai
Japanese Association for Baikal International Research Program (JABIRP)
National Institute for Environmental Studies
16-2 Onogawa Ibaraki
Tsukuba 305
Japan
Tel: (81-298) 516 111 ext 288
Fax: (81-298) 514 732
Participating Nations, Groups or Institutes

**Russia**
Institute of Geochemistry, Siberian Branch, Russian Academy of Sciences, Irkutsk
Limnological Institute, SB-RAS, Irkutsk
United Institute of Geology, Geochemistry and Mineralogy, SB-RAS, Novosibirsk
Institute of the Earth’s Crust, SB-RAS, Irkutsk
Nedra Drilling Enterprise, Ministry of Geology, Yaroslavl

**USA**
University of South Carolina
University of Rhode Island
University of Massachusetts
University of Minnesota
University of Michigan
United States Geological Survey

**Japan**
Japanese Association for Baikal International Research Programme (JABIRP), Tsukuba

**Germany**
Alfred Wegener Polar Institute, Potsdam
GeoForschungs Zantrum, Potsdam.
Figure 2

Biogenic silica, a measure of diatom productivity, from Lake Baikal compared to SPECMAP oxygen isotope record and modelled maximum summer temperature, from Colman et al. 1995. From: Continental Drilling for Palaeoclimate Records Workshop Report 96-4, Ed. Steven Colman.

Footnote:
**Focus I**

**Activity 2**

**Task 2**

The Himalayan/Tibetan Plateau Interdisciplinary Palaeoclimate Project (HIPP)

(See PAGES Workshop Report 96-1)

**Project Leaders:** Cameron Wake and Paul Mayewski

**Introduction**

The highlands of central Asia possess a diversity of natural archives from which detailed palaeoclimatic records can be developed (*e.g.*, forests, glaciers, tree rings, ice cores, lake sediments, loess, speleothems, geomorphologic features, peat deposits, *etc.*) Despite this potential there exists a paucity of terrestrial based records, on both spatial and temporal scales, that can be used to describe palaeoclimate variability in this region over time scales ranging from centuries to hundreds of thousands of years. This is especially significant given the critical role that the highlands of central Asia play in the development and intensity of the Asian monsoon, and the importance of the Asian summer monsoon in providing life sustaining rains to a considerable portion of the world’s population.

The HIPP initiative represents a multidisciplinary programme aimed at improving our understanding of changes in the behaviour of the Indian and Plateau monsoons over the past 2,000 years, 20,000 years, and beyond through the collection and analysis of high resolution, multi-variate palaeoclimatic records from the highlands of central Asia. Due to the large population and the region’s vulnerability to droughts and floods, an improved understanding of the variability associated with the summer monsoon would be immensely beneficial.

The focus of this initiative is to characterize the details of climate change in the highlands of central Asia in order to identify temporal and spatial variations in the linkages between various climate systems in Asia, and determine the hierarchy of forces controlling climate change in the region.

The HIPP initiative was first presented to the PAGES community at the PEP II meeting in Beijing-China in April 1994. Subsequently, the International Himalayan/Tibetan Plateau Palaeoclimate Workshop was convened by Sharad Adhikary, Paul Mayewski, and Cameron Wake in Kathmandu, Nepal, from 2–7 April 1995 in order to synthesize, organize, and stimulate a rigorous palaeoclimatic programme in the mountains of central Asia and to establish and foster linkages between scientists working in the region. Over 70 scientists from a wide range of disciplines representing over 45 research institutions participated in the Kathmandu workshop. Countries represented were: Australia; Bhutan; Canada; China; France; Germany; India; Japan; Nepal; Pakistan; Switzerland; the United Kingdom; and the USA.
Scientific Objectives and Implementation

In order to obtain the most reliable records of past change from the highlands of central Asia, the primary goal of the HIPP initiative is to develop and foster an integrated, multidisciplinary, international approach towards the collection, calibration, and interpretation of high resolution palaeoclimatic records from several natural archives (e.g., lake sediments, loess, speleothems, pest deposits, forests and glaciers, and geomorphologic features) over the broad region defined by the Himalayan and Tibetan Plateau. The main objectives listed below are divided on the basis of three time periods: 0–200 years BP; 0–2,000 years BP; and 0–200,000 years BP.

**0–200 Years BP**

The Objective is:

- To understand current basic environmental processes, as well as develop data for calibrating palaeoclimate records, by establishing a spatially coordinated network of instrumental data collection sites.

The proposed network would “fill in the many gaps” of the existing network. To this end, two north-south and one east-west sub-transects are recommended for the region. Within each transect there should be a number of key “flagship” stations with high quality, standardized data collection procedures. A concerted effort should be made to incorporate existing stations into any expanded network. (For example, an east-west transect of high elevation meteorological and hydrological stations spanning the Nepalese Himalaya has already been established by the German-Nepalese Snow and Glacier Hydrology Project. An aerosol and precipitation chemistry sampling programme has been established at one of these meteorological stations, and an expansion of this sampling network is planned for the near future. The investigation of the isotopic composition of precipitation and its relation to temperature is also underway in the northern and central regions of the Tibetan Plateau).

The main goals are to:

- Advance our understanding of current basic environmental processes and dynamics through process-based field research programmes at “flagship” stations
- Establish national focal points (e.g., Himalayan Climate Centers (HCC) for organizing and disseminating modern observational data. A HCC has already been established in Kathmandu and a center has been proposed for India
- Develop an information catalog of: (i) existing network and research data; and (ii) locations of current network and research observation stations.

**0–2,000 Years BP**

The objectives are:

- To describe how the Asian monsoon climate system has varied on annual to century time scales over the past 2,000 years through the collection and interpretation of high-resolution (e.g., annual to decadal) palaeoclimate records (e.g., tree rings, ice cores, speleothems, lake sediments, etc.) and historical records.
Variability on this time-scale is likely to cover a wide range of climatic conditions including those associated with the so-called LIA and MWP, as described in other regions of the world. This time-scale is also likely to be the most relevant to natural resources planning and utilization. In order to accomplish this, it is critical to directly calibrate the palaeoclimatic records with instrumental climate records in order to empirically define the palaeoclimatic signal. Doing so will require well-dated, high-resolution palaeoclimatic records because of the short time span of instrumental records.

- To describe the spatial variability of the Asian monsoon (by area and altitude) over the Indian sub-continent and the Tibetan Plateau.

Climate variability is a joint space-time process, the dynamics of which can only be understood within this context. Therefore, it is important that the spatial dimension of climate be emphasized as part of these objectives. In this regard, we need to expand the geographic coverage of Himalayan/Tibetan Plateau high-resolution palaeoclimate records extending back ca. 2,000 years.

- To develop multi-proxy records for cross-calibration and comparison.

The Himalaya and the Tibetan Plateau have often been described as the “third pole”. The logistical difficulties and high cost of field work have limited the amount of palaeoclimatic research expeditions in the region. As a result, there are only a few records that describe climate change over this vast region. In order to develop representative and reliable climate reconstructions, it is critical that we utilize records developed from as many different sources as possible.

- To determine the relationship between Asian monsoon variability and various forcing factors such as the quasi-biennial oscillation, the ENSO, solar cycles (i.e., sunspot activity), Tibetan Plateau snow cover, explosive volcanic eruptions, and atmospheric dust loading.

Modern instrumental records have been used to identify a clear relationship between ENSO and the Indian monsoon. However, it is not known how this relationship has behaved in the past when climate was distinctly different. The same uncertainty applies to other possible forcing factors on monsoonal variability. Therefore, it is presently not possible to say how the monsoon system reacts to changes in forcing. In order to answer these questions we need to investigate periods of increased volcanic activity and increased snow cover over the Tibetan Plateau. These investigations require longer climatic time series than are presently available. Long palaeoclimatic time series will also allow for a more detailed study of putative links between solar variability and the monsoon.

- To determine the climatic and anthropogenic impacts on key natural resources of water, forests, and air.

Global climate is thought to be increasingly influenced by greenhouse gases and sulfate aerosols as a result of anthropogenic emissions. Therefore, it is possible that the Asian monsoon is currently responding to greenhouse gas/sulfate aerosol forc-
Instrumental records extend back only to the beginning of the industrial period. Hence, we need to use high resolution palaeoclimatic records to extend our understanding of monsoon climate variability back into the pre-industrial period. In so doing, it will be possible to determine if any change in the variability of the Asian monsoon has occurred during the 20th century with respect to recent global climatic changes.

- To contribute to the development of predictive models of Asian monsoon variability through an improved understanding of the monsoon climate system.

Predicting the monsoon would have great socio-economic importance. By understanding the past monsoon variability and its relationship to various forcing factors, it should be possible to improve our fundamental understanding of this dynamic system. This improved understanding will hopefully lead to the development of improved physically-based dynamic models having robust predictive capability.

**0–200,000 Years BP**

The objective is:

- To reconcile current widely-divergent views on the uplift history of the Tibetan/Himalayan region through an independent measure of uplift, yielding absolute uplift values and discrimination of differentially uplifted zones.

Northeastern Tibet, southern Tibet and the Himalayas, and northwestern Tibet are critical regions. Key data will be basin sedimentation, dated terrace and lake shoreline series, speleothem isotopes, heat flow and geodetic measurements, and loess-palaeosol series to the east of the region. By means of a dating database, the quality and representativeness of all dates for the region should be evaluated as a first step to an improved chronological base. As part of current PAGES time-scale mapping programmes, time slice maps for the region should be compiled for the periods 21–18 ka BP and 6 ka BP.

In addition, maps should be compiled for the LGM and the last interglacial, including examination of environment and complexity of the climate record in the loess-palaeosol series of the north-east margin of the Tibetan Plateau. Time series (continuous records and dated sets) should be used to consider forcing mechanisms (Milankovitch, solar cycles, atmospheric chemistry, volcanic activity, ENSO), with special attention to leads, lags and feedbacks. High quality data should be used, particularly from the loess, lacustrine and fluvial sedimentary records. Liaison with the marine coring community is essential (especially Bay of Bengal, Arabian Sea, China Sea) and groups researching foreland basin stratigraphies (e.g., Indo-Gangetic Plain).

**Data Sharing**

The objective is:

- To encourage data sharing among HIPP researchers and institutions.
In order to maximize the potential of the limited modern and palaeoclimatic data sets from the highlands of central Asia, both current and future, there is a critical need to develop a workable data-sharing framework. It is proposed that a distributed HIPP data and information management network be established which builds on the existing capability of the International Center for Integrated Mountain Development (ICIMOD), Kathmandu, the HCCs, and the WDC-A for Palaeoclimatology / PAGES Data Coordination Center. The HCCs, which should be established in each participating country (one of which has already been established in Nepal), could also serve as national focal points for PAGES data and information management.

Palaeoclimate Research in Nepal – An Example of HIPP Implementation
As an example of the potential organization of HIPP, a group of researchers representing several institutions within the US (i.e., University of New Hampshire, Lamont-Doherty Earth Observatory, University of Arizona, and the US NOAA) have established a cooperative palaeoclimate research project in Nepal. A Memorandum of Understanding (MOU) developed through the Department of Hydrology and Meteorology, Ministry of Water Resources, His Majesty’s Government of Nepal provides interested researchers with the opportunity to develop palaeoclimate and/or related studies in Nepal. Under the auspices of this MOU, palaeoclimate investigations in Nepal have been undertaken in 1993, 1994, and 1995 via field investigations of tree rings, glacier fluctuations and glacial geology, atmospheric chemistry, lake sediments, and snow and ice chemistry. Researchers from the Nepalese Department of Hydrology and Meteorology have participated in all of these field programmes. In addition, a collaborative study of hydrological and meteorological records from Nepal is being undertaken by personnel from the University of New Hampshire (UNH), USA, and the Nepalese Department of Hydrology and Meteorology (DHM), Nepal. Furthermore, several institutions have developed exchange programmes in order to help scientists from the DHM study abroad. DHM also has a long-standing collaborative programme with the Japanese-sponsored Glaciological Expedition to Nepal. Recently, the HCC in Kathmandu has developed a cooperative research programme with scientists from the University of Iowa, USA, studying speleothems in Nepal. Among other activities, the Kathmandu HCC aims to facilitate studies and research in the fields of climatology, glaciology, hydrology, atmospheric chemistry, biogeochemical cycling, palaeoclimatology. In addition, the HCC plans to provide administrative support for field research in Nepal, as well as to promote the exchange of ideas and data between scientists working in the region. The Nepal programme provides an example of a multinational, cooperative, palaeoclimate research project which has been a focal point for the initial development of HIPP (PAGES Workshop report 96-1).

Products
The main product to date is the report written as part of the Kathmandu Workshop (see IGBP Report 43). This report includes a review of palaeoclimatic research with an extensive reference list, a Science and Implementation Plan, and sections on data sharing and modelling of the monsoon. This report is available from the PAGES IPO and on the Internet at the following address:

http://www.grg.sr.unh.edu/hipp/hipphp.html
In addition, abstracts from the workshop presentations and an extensive bibliography are available at the same Internet address. In conjunction with the PAGES IPO, HIPP leaders are also planning to publish an annual newsletter which would report on HIPP activities and events.

Project Management

HIPP has been organized and is run by an *ad-hoc* SC consisting of Paul Mayewski and Cameron Wake of the Climate Change Research Center, EOS, UNH, USA; Ed Cook and Paul Krusic of the Lamont-Doherty Earth Observatory, Columbia University, USA; and Sharad Adhikary of the Himalayan Climate Center, Kathmandu. Information on the programme is available on the HIPP home page or from Cameron Wake. Primary communication with the HIPP community occurs via the web page, workshops, and our proposed annual newsletter.

Future Directions

A second HIPP workshop is planned. In addition, the HIPP planning committee is considering sponsoring a special HIPP/PEP II session at the 1998 American Geophysical Union (AGU) Western Pacific Geophysics Meeting. In the near future, emphasis will be placed on developing closer links with the Palaeomonsoons Project, INQUA, and GAIM activities.

---

Report prepared by Cameron Wake and Paul Mayewski

*Contact:*
Cameron Wake  
Climate Change Research Center  
EOS, University of New Hampshire  
Morse Hall, 39 College Road  
Durham, NH 03824  
USA  
Tel: (1-603) 862 2124  
Fax: (1-603) 862 2329  
Email: cameron.wake@unh.edu  
URL: [http://www.grg.sr.unh.edu/hipp/hipphp.html](http://www.grg.sr.unh.edu/hipp/hipphp.html)
Focus I
Activity 3

The Afro-European Palaeoclimatic Transect Pole-Equator-Pole (PEP III)

Project Leader: François Gasse

Introduction
The PEP III Activity was initiated in December 1993 at a meeting held in Bern, Switzerland, which brought together 13 scientists representative of different geographical regions and scientific disciplines. The fundamental ideas developed during this meeting have provided the basis for the PEP III project (PANASH Report). A community workshop held in Sfax, Tunisia (April 1995) further refined the specific PEP III objectives and established the background for PEP III organization. A third meeting, held in Bierville, France (September 1996) allowed for continued discussion on PEP III coordination with special attention to data requirements for the transect.

The primary PEP III goals are to document how climatic records from the major climatic regions are inter-related, and to provide the palaeoclimatic proxy data required for evaluating the performance of climate models under changing boundary conditions.

These goals require cooperation at an international level to:

- Redress the geographic imbalance in palaeoclimatic information which is particularly crucial along the PEP III transect. It is evident that PEP III should focus activities on central and eastern Europe, the Middle East and Africa to improve data coverage. The development of an international framework may help to advance research initiatives in these regions which are politically complex and where many countries suffer from weaknesses in their scientific infrastructure.

- Encourage data acquisition on those types of records and methods that favour comparisons and data integration between sites, hemispheres, oceans and continents, palaeodata and models.

- Assess and synthesize existing data.

- Organize data management, and multivariate data assimilation, for a true interdisciplinary, quantitative interpretation of palaeoclimatic records.

Scientific Objectives
The project aims to use the specific regional characteristics of the PEP III transect to provide timely answers to many important global change questions, examples of which are given below.
1. Is it possible to determine the timing and magnitude of changes in vegetation and hydrology in Europe and Africa, and can the extent to which they have been induced by climate change or human activity be established?

2. What is the actual significance of the largely accepted, ubiquitous concepts of the LIA and the MWP?

3. How does the history of the Nile floods compare with data from Eastern Mediterranean regions?

4. What are the consistencies/discrepancies between historical records on lake-level fluctuations of African lakes from the northern and southern tropics?

5. How did variations in solar radiation contribute to temperature changes? Are the effects observed in Europe recognizable in records from Africa?

1. How did northern Europe respond to climate change? How did the northern latitude ice sheet modify the European climate and hydrology, the north Atlantic SST and the thermohaline circulation?

2. What was the magnitude of changes in precipitation and temperature from the Atlantic to eastern Europe in response to changes in the northern ice-sheet extent and what is the range of these changes during the current interglacial?

3. How do inter- and intracontinental seas (Aral, Caspian, Black, and Mediterranean Seas) and the large East African lakes act on regional climate, and how did they register global change?

4. How were the west-east/north-south gradients in precipitation over the Mediterranean climatic domain modified in response to global boundary conditions?

5. What is the role of the Sahara-Arabia desert belt on aerosol loading, and how did 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?

6. How have African and Indian monsoon climates varied in the past, and were the variations synchronous? How did changes in land surface conditions at low latitudes affect trace gas concentrations in the atmosphere?

7. How did Southern Africa respond to changes in: (i) the extent of the Antarctica ice sheet and sea-ice in the Southern Ocean; and (ii) the efficiency of the return flow of the oceanic thermohaline conveyor belt?
Implementation Plan – Project Strategy

The PEP III Transect is implemented through:

- Coordination activities at the national/regional scale. A network of contact persons has been established and includes 25 scientists from 20 countries. National working groups are also being developed in several countries.

- Thematic working groups act within the transect to encourage comparison and data integration between all elements of the transect (sites, regions, oceans and continents, palaeodata and models). Within these groups, scientists work on the most pertinent archives and issues for the PEP III transect.

A PEP III Workshop took place in Paris, France (September 1996). The purpose of this meeting was to: (i) strengthen the development of disciplinary working groups and establish a strategy to make working groups efficient in data acquisition; (ii) establish protocols for interdisciplinary data management and integration; and (iii) stimulate the further development of regional PEP III coordination committees.

Meetings have already occurred within some PEP III thematic activities:

- Lake Sediment Records: The PAGES–GeoforschungZentrum Workshop (Potsdam, Germany, June 1995) and the PAGES–Lake Drilling Task Force meeting (Washington, USA, October 1995) helped to define standard methodologies for drilling and lacustrine core studies, to select high priority sites and develop a 5-year plan for lake drilling along the PEP transects.

- A special session on Quaternary palaeoclimate of Africa was held at the American Geophysical Meeting (San Francisco, USA, December 1995).

- The first steering committee of the European Lake Drilling Program (ELDP)–European Space Foundation (ESF)/PEP III (Strasbourg, France, March 1996)

- Palaeomonsoons: A workshop was held in conjunction with the INQUA Congress (Berlin, Germany, August 1995). A special issue of Climate Dynamics will result from this workshop.

- An initial meeting was held to discuss the opportunity for and feasibility of developing an European-African diatom database (London, UK, February 1996).

- A meeting was held to organize an African pollen database (Bierville, France, September 1996).
Methodologies

Special attention will be paid within PEP III to the following tasks:

Developing Training Sets and Databases for Individual Biological Indicators

The goal is to develop transfer functions which can be easily applied by a large number of scientists and at large geographical scales for inferring past environmental/climatic variables, for example:

- Special effort is needed to combine the reference diatom data sets already available for Europe and northern Africa, and to fill the gaps currently existing for temperate and Mediterranean regions
- Chironomids also represent a powerful palaeoenvironmental tool
- Calibration data sets should be developed over the next few years
- An African pollen database should be constructed to complete geographical coverage of the Global Pollen Database, available at WDC-A.

Promoting Isotope Studies

Several initiatives are underway to promote the use of isotopic techniques:

- The isotopic composition ($^{18}$O) of lacustrine diatom silica can be used to infer past isotope composition of lake waters and possible evaporative rates (arid zones) and/or lake water temperature (temperate zones), and to complement studies based on carbonate and organic matter stable isotopes
- Continental Isotope Indicators of Palaeoclimate (ISOMAP) is an international project designed to map and model the isotopic composition of past and present global precipitation. ISOMAP is seen as an opportunity to focus the efforts of the isotope hydrology and palaeoclimate community in order to make more effective use of water isotope tracers in climate research, enhance interaction between researchers, and promote stronger interaction with the climate modelling community. This focus represents an important contribution to PEP III. (Please refer to isotopes section, pages 196–202).

Specific Constraints for Stream I – Lake Studies

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

- Approaches that might be independent of human impact, e.g., stable isotope measurements)
- Sites where climate signals can be identified separately from human impact, e.g., diatom plankton variability and cycling
- Sites that are sufficiently remote that human impacts can be discounted, e.g., mountain and arctic lakes.
Annually Laminated Lacustrine Sediments
Besides the importance of annually laminated sediments for providing absolute chronology (see PAGES Workshop Report 95-1), studies of varve thickness may provide unique information for studying climatic variability. Lakes with annual laminations are common along the PEP III transect, at least in the Northern Hemisphere.

The Multiproxy Approach
It is essential that the multiproxy approach be developed and emphasized for several topics, for example:

- Integrating archaeological data on deforestation and pollen records, migration of civilisations and palaeohydrological archives in arid zones
- Interpreting lake-level data in terms of palaeoclimatic variables, through lake system modelling combined with water, salt and isotope budgets
- Constraining the modern pollen data set by lake level status, as has already done for reconstructing European palaeoclimate at 6 ka BP
- Cross-checking of results, e.g., comparison of palaeoprecipitation values inferred from pollen transfer functions and lake modelling.

Stream I Priorities
Arising from discussions at the September 1996 Bierville Meeting, the following priorities were identified:

- A major focus of PEP III Stream I research should be on establishing the degree to which 20th century climates are unprecedented. This must involve quantitative reconstruction of past mean climates on multi-decadal and century timescales as well as inter-annual variability and the frequency of extremes
- There remains a widespread preconception that the LIA and MWP were ubiquitous features of the climate history of the last two millennia. There is still a need to further clarify the definition of these concepts in terms of their character, extent and precise timing, even within Europe. More research is required to establish the extent to which the concepts of the LIA and MWP are valid or relevant in other areas of the transect. The relationship between climate variations across the transect and the record of potentially important forcing factors should also be investigated. This should include studies of SST variations in relation to rainfall anomalies, especially in the tropics. Future research must attempt to clarify whether the LIA and MWP phenomena represent unique events within the last 2,000 years, and, if possible, within the context of the Holocene as a whole
- Traditionally, high-resolution studies within the Stream I timeframe have been concentrated in the mid-to-high latitudes of the northern part of the PEP III transect. In part, this reflects genuine difficulty in locating datable, high-resolution records in low latitudes and in the African part of the transect. The existence of numerous, long tree-ring chronologies in Morocco is an important exception. Some potential for other dendroclimatological studies in north and east Africa has been clearly demonstrated and the future development of this potential should be explored
• Given the problems of identifying annually resolved palaeosources in Africa, there is a need to explore other less-well-resolved sources, particularly where they might be represented across wide areas of the transect. The concept of a specific research initiative aimed at exploring climate proxies in the sediments of a series of African crater lakes along the East African section of the transect is considered worthy of prioritization and a future workshop is planned.

• Even in Europe, there is important potential for identifying and processing historical and early meteorological records. Some palaeoseries, produced decades ago, now require updating.

• More research is required in order to identify and gauge the significance of anthropogenic environmental disturbance and the implications for palaeoclimate estimates calibrated against modern climate data.

• Archaeological data have been underutilized in a palaeoclimatic context. Collaboration between archaeologists and palaeoclimatologists, especially in areas with a tradition of detailed high-resolution archaeological work and historical and palaeoclimate proxies, should be promoted. Several regions, such as in the Mediterranean, in monsoon areas (particularly in Egypt) and in the south of Africa, are potential focal areas for such efforts.

• Intense attention to accurate chronology is encouraged in situations where absolute dating is not feasible. This might involve multiple dating proxies.

• Work to establish a detailed network of tephra histories in the circum North Atlantic region and the possibility of developing a widely applicable tephra chronology to provide fixed dating points for many less-well-resolved data sources is underway.

• It has been agreed that studies within time Stream I should not be constrained by the 2,000 year limit if longer timescales within the Holocene can be embraced with equivalent precision and accuracy.

### Linkages

The PEP III transect will benefit from close linkages with other international programmes. Within IGBP, START has already provided substantial help. PEP III has established close relationships with PMIP-PMAP. Collaborative projects are currently underway with the International Atomic Energy Agency (IAEA, section of Isotope Hydrology, Vienna). Relationships with INQUA are strong, for example, through the INQUA Holocene Commission and the Palaeoclimates of the Southern Hemisphere (PASH) project.

### Outputs

Continued attention will be paid to geographical gaps to redress the spatial imbalance in palaeoclimatic data. Progress towards this goal is planned for the next few years, especially through the GLDP.

• Assembly of a database for the PEP III transect:
(i) The pollen and lake status databases are already complete within other programmes, but will be enlarged and refined in conjunction with PEP III. Integration of diatom, lake sediment and groundwater data will be undertaken in the near future.

(ii) Reconstruction of interannual- to multidecadal time-scale climate variability over Northern Eurasia through tree-ring work is planned for 1998.

• A better understanding of:

(i) The relative role of the competing effects of the three main variables that have affected Europe’s climate:

- Variations in the amount and position of glacier ice (the dominant influence in the north); The northern ice-sheet growth and decay; and impacts of the northern ice-sheet fluctuations on global climate, through field and modelling investigations
- Oceanic influences (mainly from the West and Southwest)
- The continental influence.

Model-data intercomparisons are essential to understand the relative importance of these influences.

(ii) The Indian and African monsoonal variability; publication of available proxies and model-data intercomparisons.

(iii) The timing and geographical extent of short term climatic events during the glacial and the post glacial period; synchronism / diachronism of such events at high and low latitudes.

Syntheses and regional reconstructions, especially:

- Synthesis of quantified climatic variations over the past 130,000 years along the west to east European transect in order to develop a basis for testing and refining GCMs / European PalaeoEnvironment, Climate and Circulation Programme (EPECC)
- Holocene palaeoclimate reconstructions along a transect from the Barents to the Caspian Sea (M. Antipov and collaborators)
- The southern part of the African continent (PASH-PEP III activities, J. Hamilton, T. Partridge et al.).

Time-series of environmental changes over the past 2 ka derived from different indicators (tree rings, lakes, etc.) at least for some regions (e.g., northern Europe, South Africa)

For a few key sites (especially the priority sites targeted for lake drilling within the PAGES Lake Drilling Task Force), continuous, well-dated, quantified, multi-proxy palaeoclimatic data for the last climatic cycle in currently data-poor regions (Eastern Europe, Middle East, East and West Africa)

Vegetation and climatic maps (key periods 6, 21, and 126 ka BP) to evaluate the GCM palaeosimulations (PMIP)

Times series and time-slice maps of hydrological changes and palaeoclimatic variations over the last climatic cycle.
There is no secured funding support at the moment for PEP III. PEP III workshops (Sfax and Bierville, France) and related secretarial costs have been supported by PAGES, ENRICH/European Union (EU), START, ESF (ELDP), US NSF, Centre National de la Recherche Scientifique (CNRS) (France), and MEDITerranée et Afrique Subtropicale (MEDIAS) (France). START has provided a six month fellowship grant for work on surface and groundwater palaeohydrology in the Sahel. Other activities are supported by National or EU funding.

Secure funding is needed and is being sought to bring together (at least once a year) the SSC, and (at least every two years) the leading scientists in the working groups. Secure funding is also needed for a wide range of regional and thematic meetings and for data integration and management.

It is also crucial that scientists from many countries of Africa and Eastern-Central Europe are given Internet access to involve them more fully in PEP III activities and data integration. Obtaining and maintaining efficient analytical equipment also represents a difficulty for many scientists in less developed countries. Fellowship grants and opportunities to work with other scientists in European laboratories are also potentially beneficial options for scientists from developing countries. These and other options will continue to be explored.

Drilling equipment is available from several countries. However, long drilling below several tens or hundreds of metres cannot be supported by any single nation. The shared contribution to ICDP and to the Global Lake Drilling Project is considered to be critical for achieving PEP III goals.

**Future Directions**

From 1998 onwards, leadership of PEP will be shared between Françoise Gasse and Rick Batterbee, the latter concentrating mainly on promoting and coordinating research within the Stream I time-frame. Further initiatives will be to:

- Encourage specific actions along transects, *e.g.*, the speleothem, crater lake, mountain glacier transects, in connection with GCTE transects where they exist
- Encourage specific actions in surface and groundwater palaeohydrology in arid and semi-arid regions, especially the Sahara and the Sahel. These studies will be important for understanding the timing and mechanisms of groundwater recharge and monsoon variability. START and the IAEA also expect to participate in this focused study
- Reinforce interactions with IAEA to enlarge the network of stations recording precipitation and isotopic composition along the PEP III transect
- Reinforce interactions with climate modelling scientists
- Develop linkages with IGBP Projects: Global Change and Terrestrial Ecosystems (GCTE), Biospheric Aspects of the Hydrological Cycle (BAHC), Land Use/Cover Change (LUCC [IGBP/IHDP]), and Land-Ocean Interactions in the Coastal Zone (LOICZ).
Report prepared by Françoise Gasse, with contributions from Rick Battarbee, Björn Berglund, Keith Briffa, Joel Guiot, Suzanne Leroy, Jan Mangerud, and Jörg Negendank.

Contacts:
Françoise Gasse
Laboratoire d’Hydrologie et Géochimie Isotopique
URA CNRS 723 Bat 504
Université PARIS XI
91405 ORSAY
France
Tel: (33-1) 69 41 67 56
Fax: (33-1) 64 46 59 38
Email: gasse@geol.u-psud.fr

Rick Battarbee
Environmental Change
University College London
26 Bedford Way
London WC1H 0AP
United Kingdom
Tel: (44-171) 380 7582
Fax: (44-171) 380 7565
Email: rbattarb@geog.ucl.ac.uk
Focus I
Activity 3
Task 1 The International Decade for the East African Lakes (IDEAL)

(See PAGES Workshop Report 93-2)

Project Leaders: Thomas C. Johnson and Eric Odada

Background
The large lakes of the East African Rift Valley are among the oldest on Earth, and are vital resources for the indigenous people populating their basins. They are unique among the large lakes of the world in terms of their sensitivity to climatic change, their rich and diverse populations of endemic species, their circulation dynamics and water-column chemistry, and their long, continuous, high-resolution records of past climatic change in the tropics.

More than 4 km of sediment underlie Lakes Tanganyika and Malawi, whose ages are estimated to be on the order of 10–15 million years, based on models of sedimentation and compaction in rift basins. Some of the lakes of the rift valley are closed basins (i.e., without outlets) and their surface levels fluctuate dramatically both seasonally and interannually in response to rainfall variability. Even the open-basin lakes such as Tanganyika, Victoria and Malawi lose 80–90% of their water by evaporation. These lakes have fluctuated between closed- and open-basin status frequently in response to varying rainfall and evaporation, causing their levels, water chemistry and biota to shift significantly with climatic change.

IDEAL was first conceived at a workshop supported by the US NSF and the Swiss National Climate Programme in Bern, Switzerland (March 1990). Although the scientific focus of IDEAL originally was on the palaeoclimatic record archived in the bottom sediments of the rift-valley lakes, it has evolved into an investigation of biogeochemical processes in the large lakes of East Africa as well. IDEAL also carries a major commitment to training for African scientists, students and technicians in the aquatic sciences. The intention is to combine the talents and expertise of a multidisciplinary group of limnologists and oceanographers to establish an infrastructure that can support a sustained and comprehensive study of the large African lakes over the span of a decade.

The scientific issues to be addressed by IDEAL were conceived and discussed at the IDEAL Symposium on the Limnology, Climatology and Palaeoclimatology of the East African Lakes, held in Jinja, Uganda (February 1993). More than 100 aquatic scientists from North America, Europe, Africa, Asia, and New Zealand attended the symposium. The issues were restricted to five topical areas: climatology, physical limnology, geochemistry, biological sciences, and palaeoclimatology. Papers resulting from this symposium are published in The Limnology, Climatology and Palaeoclimatology of the East African Lakes, Gordon and Breach, Amsterdam (July 1996). The IDEAL Science and Implementation Plan, also resulting from the Jinjia symposium, was published as PAGES Workshop report 93-2.
For the purposes of this PAGES document, we are confining this particular description of IDEAL to the palaeoclimatic programme. The general goals of the palaeoclimatic programme of IDEAL closely parallel those of PAGES (IGBP 1990). A primary focus of IDEAL is the high-resolution climate change that has occurred within the past thousand years (comparable to PAGES Stream I) and on the lower-resolution examination of climate change over the past two cycles of glacial-interglacial conditions (PAGES Stream II). IDEAL researchers would like to extend the palaeoclimatic record back even further, i.e., into the Tertiary, on a time scale that coincides with the evolution of Homo spp. Whether this will be achievable within the budgetary constraints of IDEAL remains to be seen.

**Research Questions**

- What is the tropical record of past climate change?
- How is this record linked to global climate on various time scales?
- What is the response and sensitivity of the African great lakes to climatic change?
- Given the importance of the tropics to the global heat budget, do changes in East African climate lead or lag behind other elements of the global climate system?

**Time Intervals of Focus**

**A. The Last Millennium**

- In what ways does the sediment record of the last century reflect historical records of lake levels (e.g., the 1961 highstand event), ENSO variation, drought recurrence and intensity, rhythmic rainfall intensity and patterns, and seasonal variation?
- Were the lakes affected by the climatic excursions responsible for the LIA or the MWP?
- Are there climatic links to the known human migrations?
- Do the lakes record the spread of exotic foods in Africa, the history of land use and burning, and the history of human changes in the catchment regions?

**B. The LGM through Holocene**

- What was the nature of the climatic transition from the LGM? The fine scale climatic structure of the African tropics appears complex – is there a coherent YD signal?
- Does tropical African climate show evidence of centennial-scale oscillations such as those that occur in ice cores? What is the direction and magnitude of change over the tropical belt?
• Do the lake sediments show coherent records of rapid change events (thresholds)? Do they indicate multi-modal states of climate? What are the rates of change across transitions? Can precursor signals be identified that are useful in forecasting events?

• What is the evidence for climate stress as a factor in the development/collapse of prehistoric societies?

C. Multiple Glacial/Interglacial Cycles

• Is the fine structure of the last termination of a glacial cycle repeated in earlier terminations?

• What are the interactions of tectonic forcing and mesoclimates in tropical Africa?

• What is the record of volcanic eruptions linked with environmental dynamics and, perhaps, human evolution?

• What are the leads and lags in the behaviour of lake systems in terms of their relationship to Milankovitch cycles?

• What are the origin and coherence of seismic sequence boundaries in the great lakes, and what is their relationship to high latitude glacial/interglacial cycles?

The IDEAL project also includes a longer term perspective beyond the scope of PAGES:

D. The Tertiary

• What is the coincidence of hominid evolution, culture, and environmental history?

• Are the origins of the East African great lakes coupled with the onset or intensification of the monsoon system?

• Do we see evidence of relative shifts in the importance of the different orbital cycles?

Implementation

Investigation of the East African great lakes presents special challenges in logistics and technical support because the basins are of the scale of marginal seas but cannot be accessed by the oceanographic research fleet. Some of the field requirements of IDEAL can be served by regional facilities and local personnel trained at various levels. However, IDEAL supplements these efforts substantially by provision of shoreside facilities, shared instrumentation, shipboard equipment, and technical expertise that travels with the programme. Economies of both scale and efficiency can be obtained by identifying equipment and facilities that will be needed to conduct the field work, and by planning for their general use in East Africa. IDEAL has a Northern Hemisphere SC and an African SC, each consisting of 10–12 scientists who provide guidance to the programmes.
The IDEAL SC decided, for several reasons, that the first major focus in IDEAL would be Lake Victoria. A major expedition to the lake in March and April 1995 resulted in extensive coverage of the lake floor with an intermediate frequency (small airgun) seismic reflection profiling system and recovery of seven piston cores from the central basin. These are being analyzed at the present time and the first manuscript has been submitted for publication. This expedition was a collaborative effort by American, Norwegian, Ugandan and Tanzanian scientists. Analysis of the piston cores will provide answers for Lake Victoria to the questions provided in Time Interval of Focus B, above. A second expedition to Lake Victoria was completed in May 1996. The focus on this expedition was on recovering high-quality short cores that have an intact sediment-water interface to address questions in Time Interval of Focus A, above. The Lake Victoria cores are archived at the Limnological Research Center of the University of Minnesota in Minneapolis. Sediments are available for further analysis by researchers funded by federal palaeoclimate research programmes, and can be accessed by contacting the Limnological Research Center.

With prospects of drilling operations evolving for palaeoclimatic studies of lakes worldwide, the IDEAL SC has ranked Lakes Edward, Malawi and Tanganyika as its top priority targets in East Africa. Lake Edward is the highest priority because it is logistically the most feasible of the three lakes (relatively small, shallow and accessible) and, at the same time, shows great promise for strong signals of past climatic variability. A first reconnaissance survey of the Lake Edward basin was undertaken in May 1996. This will be followed by a more extensive seismic and coring programme in 1997, in preparation for drilling in 1998. Recovery of 100–200 m of sediment from the lake floor will, for the first time, provide opportunities for addressing the Time Interval of Focus C, above, in tropical Africa.

IDEAL Project Offices are located in the Department of Geology of the University of Nairobi, Kenya, and at the Large Lakes Observatory, University of Minnesota, USA. Management and coordination of IDEAL is served by an Administrative Assistant in Madison, Wisconsin, USA. A modest level of support is provided for IDEAL management by the US NSF through 1998.

IDEAL is developing a shared pool of instrumentation in East Africa. It currently consists of an oceanographic winch, 12 kw generator, piston coring system and associated hardware. A four-wheel drive vehicle is also available for IDEAL researchers. Suitable research vessels are available on Lake Tanganyika and Lake Malawi, but not on Lake Victoria. (IDEAL used the R/V Ibis of the Ugandan Fisheries Research Institute for its current operations, but the vessel lacks suitable space, power and navigational equipment to be an acceptable vessel for most operations.) The other large lakes in East Africa (e.g., Edward, Turkana, Kivu) do not have vessels suitable for palaeoclimatological research. Drilling operations will probably be accomplished under contract to commercial drilling companies in East Africa, with technical guidance from engineers with experience in scientific drilling.

Funding support for Lake Victoria is secured, at least for the field work and initial analyses of the sediment cores. No funding has yet been generated for the reconnaissance survey or drilling on Lake Edward. IDEAL investigators are proposing palaeoclimate studies on the other large lakes in East Africa at present, most notably Tanganyika and Malawi, with proposals under review.
IDEAL is an element of the PEP III Transect and, as a result of PEP III Workshops, is communicating with other programmes on the African continent (e.g., ORSTOM projects in West Africa and the Sahel). Other European palaeoclimate initiatives in East Africa, including the French Recherche sur l’environnement et le climat intertropical en Afrique (ERICA) Project in Ethiopia and the European Commission (EC) project on Lake Rukwa, are in communication with IDEAL (Marseille Meeting, 1994), but this could be improved. The PEP III Workshops are probably the best mechanism for this.

Report prepared by Thomas C. Johnson

Contact:
Thomas C. Johnson
Large Lakes Observatory
University of Minnesota
Duluth, MN 55812
USA
Tel: (1-218) 726 8128
Fax: (1-218) 726 6979
Email: tcj@d.umn.edu
Focus I
Activity 3
Task 2  Palaeomonsoons Project (PM II)

(See PAGES/START Workshop Report 94-2)

Project Leader: Stefan Kroepelin

Background
Changing monsoon precipitation has a tremendous impact on the tropical environment, and monsoons are of critical importance to human populations. Roughly half of the Earth’s population lives in the monsoon zone, including sub-Saharan Africa and the world’s two most populated countries, China and India. The economies of these regions are largely dependent on agriculture; therefore, monsoon rains are crucial for both their present and future means of existence.

The records of earlier climatic and environmental changes, stored in biogeological archives, still provide the most reliable scenarios of possible future climatic development in the tropics and subtropics. A better understanding of past monsoon variation is imperative. PM II was initiated as a joint project of PAGES and INQUA to coordinate and contribute to palaeomonsoon research.

Scientific Objectives

• To promote the retrieval, interpretation and critical assessment of high-resolution climate-proxy records of palaeomonsoon phenomena and provide palaeoanalogues for predictive efforts for the densely populated tropical belt

• To promote international and interdisciplinary cooperation through a better exchange of relevant data from terrestrial, marine and atmospheric palaeoclimatic research; to enhance the communications of scientists through the organization of and participation in workshops and the coordination of publications.

Implementation
PM II held its initial planning meeting in Mombasa, Kenya (December 1993) as a joint workshop with the START Africa programme. Approximately 40 representatives of leading research groups from Africa, Asia, Australia, Europe, and the USA met to discuss the means to facilitate the retrieval and interpretation of high-resolution climate-proxy records of palaeomonsoon phenomena on a 200,000 year timescale (PAGES Temporal Stream II). The resulting recommendations for research on “Palaeomonsoons in Africa and surrounding oceans: The last 200,000 years” were published as a PAGES Workshop Report (Series 94-2).
Linkages

Taking into account the limits in accuracy of current means of dating, recent marine and terrestrial palaeoresearch suggests synchronous variations in Holocene monsoon circulation that affected the lower latitudes of the northern hemisphere from the Atlantic to central Asia and beyond. Palaeomonsoon dynamics therefore provide a link between the PANASH Pole-Equator-Pole transects PEP II (Australia-Asia) and PEP III (Afro-European), and also to PEP I (The Americas).

There is close interaction with PEP III on monsoon variations in Africa north and south of the equator, and with the Palaeoclimate Modelling Intercomparison Project (PMIP) on a palaeodata/model comparison for the monsoon domain.

Other PAGES and IGBP projects in Africa, IDEAL and the Northern Africa Regional Committee for START (NAFCOM), also contribute to the objectives of PM II.

From its initiation, this project has worked closely with IGCP “Desert margins and palaeomonsoons of the northern hemisphere old world: 135,000 years BP to the present (IGCP 349)” on both national and international levels.

Scientific Meetings

The project has been presented and discussed at international conferences and meetings in: Niamey (Niger); Canberra (Australia); Taipei (Republic of China); Marseille, Dourdan, Gif-sur-Yvette, and Paris (France); Hamburg, Berlin, Cologne, Giessen, Ludwigshafen, Potsdam, Überlingen, and Garmisch-Partenkirchen (Germany); Xian (People’s Republic of China); Kemer (Turkey); Venice (Italy); Sfax (Tunisia); Cairo and Khartoum (Egypt); Boulder and Flagstaff (USA), among other places.

The complexity of the monsoonal history of each continent and its surrounding oceans necessitates a region-by-region approach. Previous workshops in Kenya, China, and Germany focused geographically on the palaeomonsoon systems of Africa and Asia and their adjacent oceans.

August 14–23, 1994

A symposium on desert margins and palaeomonsoons of the old worlds of the Northern Hemisphere 135,000 years BP to the present was held in Xian, People’s Republic of China, and organised by the Chinese, IGCP 349 “Palaeomonsoon variations in the Old World desert margins”.

The papers presented provided insights into the substantial progress achieved by scientists from China and elsewhere in the study of past variations of the East Asian winter and summer monsoon circulation. Other contributions were devoted to past monsoon dynamics in the South China Sea and to India, Africa and Australia.

August 1–2, 1995

Joint Writers’ Workshop with PEP III and IGCP 349, Berlin, Germany.

Twenty participants from Europe, Asia, and the USA were invited to the workshop to discuss their palaeomonsoon research. The workshop’s aim was a critical assessment of the current knowledge concerning palaeomonsoon variations in Africa and Asia and their surrounding oceans, particularly with respect to the extent and inten-
sity of monsoonal rainfall. The workshop sought to contribute to PAGES’ goal of establish-
ing a concise and time-controlled basis for climate model improvement through palaeodata/model comparison. This meeting was part of cross-project activities and intensified interaction with PEP III and PMIP. A compilation of papers will be published in a forthcoming special issue of Global and Planetary Change.

August 9, 1995
Symposium #10 “Palaeomonsoon Variations and Global Change during the Late Quaternary” as part of the XIV INQUA Congress, Berlin, Germany.

The symposium was held and sponsored by the Palaeomonsoons Project. In addition to the papers presented and discussed at the writers’ workshop some of the contributions included: Late Holocene monsoon variation in the Sahel and Sahara; abrupt palaeomonsoon decline in China; and monsoon modelling for Africa and Asia.

August 10, 1995
Business Meeting for the German members of PAGES and the Palaeomonsoons Project, Berlin, Germany.

The meeting was intended to increase awareness of the need to include studies of monsoon variations in current and future research activities in the lower latitudes.

August 11–14, 1995
Archaeoclimatology Workshop, Berlin, Germany.

The goal of this workshop, headed by Reid Bryson, Center for Climatic Research at the University of Wisconsin, Madison (USA), was to provide field scientists with hands-on experience with high-resolution, site-specific monsoon modelling for the last 15,000 years.

January 11–22, 1997
Continental Signals of Palaeomonsoon Dynamics in Africa: Inter-Hemispheric Perspectives, Siwa, Egypt.

Output

1. Improved exchange of palaeomonsoon research through workshops, meetings, newsletters, Internet-correspondence, *etc.*
2. Successful implementation of new research programmes
3. Special issue of *Global and Planetary Change*
4. Compilation of a global directory of scientists engaged in palaeomonsoon research with a comprehensive bibliography, under preparation in cooperation with IGCP 349
Project Management/Guidance/Resources

The German Ministry for Education and Research (BMBF) allocated funds for an IPO for an initial three-year period: 1994–1997. The secretariat was set up at the Department of Geosciences, Free University of Berlin, and allows for a translator/secretary, a scientific assistant, annual workshops, publications, etc. The office is actively engaged in various coordination activities. The office is currently moving to the University of Cologne, where it will be more closely linked to the ACACIA initiative described below.

Future Directions

Numerous new important palaeomonsoon-related projects have been developed in China, India, tropical Africa and Australia and surrounding oceans.

In Germany, for example, a new large scale cooperative research project – Arid Climate, Adaptation and Cultural Innovation in Africa (ACACIA) has been established at the University of Cologne (Sonderforschungsbereich [SFB] 389). The research programme is funded by the Deutsche Forschungsgemeinschaft (DFG). It offers a 12–15 year perspective for multidisciplinary fieldwork in Northeast and Southwest Africa. The project also provides the opportunity to compare the climatic, environmental and cultural evolution on both hemispheres of the continent during the last 10,000 years.

Research will include the socio-economic implications of climatic and environmental change, such as the human response to deteriorating living conditions through the development of survival strategies and changes in land use. Geoscientific work will contribute to focus topics of the PAGES, such as the metachronicity of past monsoon variations.

Marine research related to palaeomonsoons is also underway in the South China Sea. Another new programme focuses on monsoonal influences at the southern fringe of the Central Sahara.

Recent and Future Meetings

July 1–8, 1996
Joint Meeting with the UNESCO project Climate of the Past (CLIP), Punta Cardon, Paraguana, Venezuela.

Focus was on past monsoon variations in the Americas during the last glacial-interglacial cycle. The joint workshop will evaluate proxy records from Central America, a region often neglected in the context of palaeomonsoons.

November 19–22, 1996
Centennial of the Geological Survey of Egypt in Cairo, Session on “Present-day deserts and palaeomonsoons: Records from the Eastern Sahara”.
January 1997
Joint workshop with MEDIAS and other organizations on “Continental signals of palaeomonsoons in Africa: an interhemispheric comparison” Siwa Oasis, Egypt.

Report prepared by Stefan Kroepelin and Leigh Love

Contact:
Stefan Kroepelin
SFB 389
Heinrich-Barth Institut
Universität zu Köln
Jennerstrasse 8
Köln 50823
Germany
Tel: (49-22) 155 6680
Fax: (49-22) 155 2303
Email: S.Kroe@uni_koeln.de
Focus I
Activity 4  The Oceans
Task 1  International Marine Global Change Study (IMAGES)
(Co-sponsored by SCOR)

(See PAGES Workshop Report 94-3)

Project Leader: Laurent Labeyrie

Introduction

There is now abundant evidence that significant natural variations in the ocean and climate system have occurred on time scales of oceanic and cryospheric processes. Over of tens to hundreds of thousands of years (glacial to interglacial time scales) changes in the distribution of solar radiation due to the Earth’s orbital parameters (the Milankovitch hypothesis) have provided an important external forcing to the climate system. While the response to this forcing can be documented in a wide variety of oceanic and climatic records, the processes which control the sensitivity of the climate system to such forcing are still largely unknown. The ice-core records document major changes (100 ppm) in atmospheric CO₂ concentration on the 10,000 year time scale. The ocean is the only natural reservoir capable of absorbing and releasing large amounts of CO₂ over such short intervals. Evidence is now emerging that significant climatic changes can occur within a few hundred years. Sea surface temperatures have varied over a range up to 15°C on the 10,000 year time scale, but recent evidence indicates that at least in some parts of the oceans major temperature changes occurred much faster, within a few centuries. It is clear that internal feedback mechanisms, including natural variations in atmospheric greenhouse gases, play a critical role in controlling the sensitivity of the climate system to external forcing. The international scientific community is poised to take the next major step in improving our understanding of the global climate system, and especially, the role that the ocean plays in controlling long-term climate variability. A worldwide campaign is necessary to understand natural mechanisms for transferring CO₂ and heat into and out of the oceans.
For this study, palaeoceanographical records must be examined with a time resolution compatible with the time scales characteristic of oceanic processes (up to $10^3$ year) and ice sheet dynamics (up to $10^4$ year), taking into account that those rapid changes are superimposed on climate variability at Milankovitch periodicities (20, 40, and 100 ka). Long records (several hundred thousand years) are necessary to document changes related to well-known astronomically-driven changes in insolation. The complexity of the climatic system and the limited capabilities of available sedimentary proxies to monitor most of the climatic processes require that a major effort be devoted to multiproxy development and analyses. This research requires significant improvements in:

- The capability to map the sea floor and, using high-resolution acoustic techniques, to image the sediment cover of the ocean floor
- The capability to document very high resolution variability in marine sediment records by using continuous, non-destructive analysis techniques
- High-resolution dating techniques and advanced analytic instrumentation that allow rapid, high precision analysis of geo-chemical parameters which provide new methods to extract quantitative estimates of past ocean properties.

**Scientific Objectives**

During the past few years several international workshops have been held by the palaeoceanographic community to define major global change questions that can only be answered through the study of the marine geologic record of past climate. The over-riding IMAGES science issue is to quantify climate and chemical variability of the ocean on time scales of oceanic and cryospheric processes; to determine the oceans’ sensitivity to internal and external forcings; and to determine its role in controlling atmospheric CO$_2$.

Under these major scientific objectives, IMAGES proposes to coordinate a global programme to collect and study marine sediment records to address three fundamental questions:

- How have changes in surface ocean properties controlled the evolution of global heat transfer through the deep and surface ocean and thereby modified climate?
- How have changes in ocean circulation, ocean chemistry, and biological activity interacted to generate the observed record of atmospheric pCO$_2$ over the past 300 ka?
- How closely has continental climate been linked to ocean surface and deep water properties?
Project Strategy

The programme consists of four major tasks:

Sediment Coring Cruises
The designation of the essential geographic areas and the retrieval of the appropriate samples and data needed to reconstruct the natural variability of the oceanic system over the last several hundred thousand years with the necessary spatial resolution.

Palaeoceanographic Data Acquisition
The acquisition, analysis and sharing of the large amount of quantitative palaeoceanographic data needed to characterize past oceanographic conditions.

Sample and Data Management
Management and protocols for sample recovery and data management to optimize the investigative efforts and promote collaboration among researchers.

Modelling
Treatment of the palaeoclimatic data in order to make them accessible to climate modellers as well as definition of the physical and geochemical processes which may be significant for long term climatic changes.

The major scientific issues presented above can only be achieved through the examination of the records preserved in ocean sediments. At least thirty dedicated oceanographic expeditions will be necessary over the next decade to collect appropriate sediment samples and supporting data. To obtain the necessary temporal resolution for IMAGES objectives requires sampling regions of the ocean where sedimentation rates range from 5–10 cm/ka and higher. This, combined with the necessity for 300,000 year records, requires core sample lengths of no less than 15 m. For many areas, core lengths of at least 30 m and as great as 50–75 m will be necessary.

Current and Longer Term Plans

1. Scientific Operations
The Namibia/Angola Upwelling System and the Indian Connection to Austral Atlantic (NAUSICAA) cruise (September–October 1996) took place around the southern tip of Africa. Its two main objectives were: (i) to study the variability of the western boundary currents (Agulhas Current) and eastern boundary currents (Benguela Current) around South Africa; and (ii) to study the variability of the high productivity zones (Walvis upwelling). Scientists from seven countries participated in this cruise (France, Germany, The Netherlands, Portugal, South Africa, Taiwan, and the UK). During this cruise, 30 giant piston cores were retrieved. Several research proposals were submitted at the European programme “Environment and Climate” Délégation Général XII (DGXII) in January 1997.
An IMAGES cruise (R/V Marion Dufresne) in the eastern Indian Ocean and Western Pacific area (Autumn 1997), initiated by France, Australia, and New Zealand has also been undertaken.

2. Information and Data Management
An IMAGES home page has been set up on the World Wide Web (Address: http://www.images.cnrs-gif.fr). This page provides a general presentation of IMAGES (scientific objectives, organization, contacts, etc.) for scientists interested in participating in the programme, and gives monthly up-dated information concerning specific IMAGES palaeoceanographic cruises (proposals, schedule, significant results).

An IMAGES database will be organized and made available through FTP. This database will contain:

- Measurements and observations obtained during the IMAGES cruises (access to these data will be limited to shipboard and shore-based cruise participants for two years after the cruise and will be made available to the entire community thereafter)
- Published data obtained on IMAGES projects.

A post-doctoral position will be created to develop this database with links to the National Geophysical Data Center (NGDC) WDC in Boulder, USA.

3. Planning Meetings
Meetings (1992–1995) were held as part of SCOR Working Group 100 (WG 100). The Scientific Committee for IMAGES (SCICOM) will meet at least once a year. Scientific meetings will be organized on an ad hoc basis for each of the IMAGES activities. The International Conference on Palaeoceanography (ICP), which meets each three years, will serve as general forum. The next ICP is planned for Lisbon, Portugal (1998) to be hosted by the Portuguese Geological Service.

Methodology

1. Site Survey and Coring
The major requirement of the project is the availability of sufficiently long sediment cores (no less than 15 m) to allow the study of the last several hundred thousand years in areas of high sedimentation rates in which high temporal resolution can be obtained. For many areas, core lengths of at least 30 m and as great 50–75 m will be necessary. At the present time, only the R/V Marion Dufresne is able to retrieve large diameter, piston cores that exceed 50 m in length.

Recent high resolution seismic and sea floor mapping techniques are required to efficiently locate good quality coring sites. Additional data should include a hydrographic profile, including measurement of conductivity, temperature, and depth (CTD) and near-bottom water samples.
2. **Palaeoenvironmental Proxies**

In order to address the IMAGES objectives it is essential to extract quantitative estimates of past ocean and climate properties from the preserved sedimentological record. Proxies are available to estimate most of the major oceanic properties, but all require continued development. Several of these tracers are especially important for the reconstruction of palaeohydrology and the carbon cycle in the oceans:

- Micropalaeontological transfer functions and biomarkers provide estimates of past sea surface temperature. It appears possible to reconstruct sea surface salinity from the planktic foraminifera $^{18}O/^{16}O$ ratio by correcting the temperature dependency of the isotopic fractionation, with sea surface temperature estimated at the same locations. This should allow the construction of past surface density fields.

- $^{13}C/^{12}C$ and Cd/Ca ratio in foraminifera shells, flux of biogenic skeletons and organic carbon, $\delta^{13}C$ and $\delta^{15}N$ of organic matter, and the distribution of carbonate in the sediments are all important proxies for the reconstruction of the carbon cycle.

3. **Chronology and Stratigraphy**

Stratigraphy and chronology will require that important efforts should be devoted to the acquisition of high-resolution $\delta^{18}O$ records. Furthermore, recent developments in the acquisition of near-continuous records of sediment physical properties (e.g., density, magnetic remnant intensity, colour reflectance) hold great promise in the development of high resolution chronostratigraphy (at least century-scale).

Absolute dating of key periods is mandatory. More AMS $^{14}C$ analyses of foraminifera are necessary for precise dating of the oceanic history over the last 40 ka. Other material may be dated and correlated within palaeoceanographic records: U/Th of corals (sea level); and K/Ar of volcanic material (tephro-chronology). This should allow progressive extension of the absolute time scale over the last several thousand years.

Development of improved methods for correlation between ocean, continent, and ice palaeorecords is also essential.

**Facilities and Drilling Requirements**

Although some essential analytical facilities are widely available (e.g., stable isotope mass spectrometry), other analytical techniques are often available only in a few centers. It will be necessary in some cases to set up new facilities, and in others to support a facility at such a level that it can provide sufficient data for international demand.

There is a limited number of coring platforms that are able to perform giant coring (>15 m) routinely. At present, only one ship (the R/V Marion Dufresne) has the capability to take cores longer than 50 m. Improvement of the coring capabilities on additional platforms will be necessary to fulfil the objectives of IMAGES.
Linkages

IMAGES is cosponsored by IGBP and SCOR through PAGES. Linkages with national or multi-national projects: Earth System History (ESH/Marine Earth System History (MESH) in the US; Environment and Climate (DGXII at the EU); as well as international programmes (Ocean Drilling Program [ODP] for example) will be essential to provide the funding and/or access to the sediment and laboratory analyses necessary to attain the IMAGES objectives.

Output/Results

IMAGES First Test Cruise: Marion Dufresne MD 101 May–July 1995
A cruise of the French R/V Marion Dufresne has been completed from Brest (France) to Marseille (France) to test the feasibility of IMAGES goals and policies. Its main scientific objective was the collection of giant piston cores on rapidly sedimenting drifts and continental margins of the North Atlantic ocean and Norwegian Sea, along the track of the main thermohaline circulation. The cruise crossed the North-East Atlantic margins, the Feni drift, the Scottish, North Faroe and Norwegian margins (to 72°N), the Iceland South-East margins, the Gardar Drift, the North Atlantic Mid Ocean (NAMOC) Channel, the Newfoundland margin, the Bermuda rise, the mid Atlantic ridge, and the Azores and Iberian margins. Seventy scientists from 22 institutes (nine countries) participated in at least one of the three legs. Funding for the programme came from agencies in France, Canada, Germany, and the US, with Norway, the UK, and Spain as additional participants. The cruise collected 43 long, large diameter (11 cm) piston cores at 41 locations with sedimentation rates between 5–50 cm/ka. Twenty-eight of the cores were over 30 m in length. The longest core, MD 95-2036 (52.64 m), was retrieved at 4461 m water depth on the Bermuda Rise. It covers about 150 ka with a sedimentation rate over 30 cm/ka. The cores were analyzed on board for physical properties, and partly sampled at 1 cm intervals. This cruise proved that the IMAGES model for international cooperation is workable and has great potential in achieving its goals. Six presentations of preliminary results from cruise IMAGES MD101 were made to the ICP V (Halifax, Canada, October 1995). Nineteen presentations were also made at the AGU Autumn Meeting (San Francisco, USA, December 1996).

Images Management

1. Administration and Management of IMAGES
The IMAGES programme was initiated in 1995 by IGBP-PAGES and SCOR WG 100. After the success of the first test cruise in the summer of 1995 (under the control of SCOR WG 100), the IMAGES programme started in 1996. Both the Executive Director and the Chairman of the SCICOM have been appointed. The Secretariat is being organized by the Centre des Faibles Radioactivités, Laboratoire Mixte du Centre National de la Recherche Scientifique et du Centre de l’Energie Atomique (CFR-Gif), France. The initial SCICOM, derived from SCOR WG 100, will be modified with the arrival of new partners.
2. Participation
IMAGES research relies on the principle that samples and data be made readily available to the international community. Acceptance of this principle is a requirement for participation in IMAGES. IMAGES partners include scientific institutes, or national/multi-national programmes which participate in the activity and funding of the programme. Partners have a key role in the IMAGES structure, and serve as fundamental links between management and scientists. Each partner is entitled to appoint one member to the SC.

Developing countries or countries with very limited involvement in palaeoceanography are welcome to participate in IMAGES as “invited” partners. These partnerships are granted by the IMAGES SCICOM.

An independent role is given, on an ad hoc basis, to the Principal Investigators who co-finance specific international oceanographic cruises in accordance with IMAGES principles. Principal Investigators have a leading role in the planning, participation, coordination and exploitation of these specific cruises.

The IMAGES SCICOM, EXCOMM and Secretariat have the responsibility to coordinate the various tasks necessary to reach the goals of the programme. Sample and data management are essential parts of the Secretariat activity, as is optimization of research efforts and promotion of collaboration. The Secretariat will provide a central information database of field programmes being conducted by IMAGES participants. The IMAGES EXCOMM and Secretariat will directly organize, support and coordinate a small number (about 10) international coring expeditions in the different oceans, on platforms which allow collection of giant cores (over 35 m). They will help to organize about 20 other expeditions, mostly supported at the national level. Such nationally supported cruises are entitled to become “associated with IMAGES” on the condition that they have international participation and follow IMAGES objectives and policies (especially concerning coring and analytical strategies as well as sample and data sharing), as outlined in the IMAGES report (IGBP-PAGES document 94-3).

3. IMAGES Science Planning
Overall science planning and prioritization is done through a science planning committee, which meets at least once a year. The SCICOM took its final form in 1997, with partnership representatives and delegates nominated by the parent programmes SCOR and PAGES.

4. IMAGES Executive Committee
Major functions:
Advice to the Executive Director; implement decisions of the SCICOM.

Coordination:
Ensure genuine international collaboration and promote international funding for IMAGES; interact with national funding agencies and scientific community (liaison); help coordinate proposals between funding agencies at the international level.

Appointed:
From and by the SCICOM for terms of three years. The final EXCOMM was established in 1997 when all partners and their representative members to the SCICOM have been determined.
5. **Secretariat Activities**

**Operations:**
Organize IMAGES operations and daily tasks, including funding for SCICOM and EXCOMM activities; oversee, accumulate, collate and distribute data; monitor proper deposition of data in archives; administer and coordinate requests for samples; maintain IMAGES world wide web information page (including research ship schedules); coordinate IMAGES cruise plans and cruises.

**Reporting/Publicity:**
Report, through SCICOM, to SCOR-PAGES; organize IMAGES publicity; informing scientific community of IMAGES activities (e.g., newsletter).

**Appointed:**
By EXCOMM on recommendation of SCICOM, for a term of three years.

**Leadership:**
Secretariat is headed by the Executive Director. Laurent Labeyrie has been designated as the first Executive Director. The Secretariat is located in CFR-Gif-Yvette, France. Franck Bassinot (CEA-France) serves as Deputy Director, and Nicholas Pisias is the initial Chair of the Scientific Committee.

---

Report prepared by Laurent Labeyrie and Frank Bassinot

**Contact:**
Laurent Labeyrie
CFR-Laboratoire mixte
CNRS-CEA Domaine du CNRS
91198 Gif-Yvette cedex
France
Tel: (33-1) 69 82 35 68
Fax: (33-1) 69 82 35 68
Email: Laurent.Labeyrie@cfr.cnrs-gif.fr
URL: http://www.images.cnrs-gif.fr
Focus I
Activity 5  PAGES/CLIVAR Interactions

(See PAGES/CLIVAR Workshop Report “The PAGES/CLIVAR Intersection” 1996. Edited by Jean-Claude Duplessy and Jonathan Overpeck. Available from the PAGES IPO)

Project Leader: Jean-Claude Duplessy

Introduction

PAGES and CLIVAR share many common objectives. In particular, CLIVAR requires a reconstitution of global climate and environmental changes over the last several centuries. This is one of the central objectives of the PAGES project. Both projects also aim to improve our understanding of the natural processes that invoke global climatic changes at interannual and decadal to centennial time scales. Diagnostic studies of natural climate variability rely upon palaeoclimatic proxy-data derived from biogeological archives. To achieve these goals, CLIVAR and PAGES are cooperating to assemble the detailed palaeoclimatic information needed to study the variations of the Earth’s climate over the last 100–1,000 years. In addition, palaeoclimatologists have identified a variety of striking climatological events on decadal to century time-scales. These insights highlight the need for further interpretative studies based on existing palaeoclimatic evidence and model simulations of past climatic states.

Scientific Objectives

Dynamics of Low-Latitude Climate Change

Over interannual-decadal time scales, tropical ocean-atmosphere systems orchestrate global climate variability, and the tropical ocean is the primary source of energy and water vapour to the global atmosphere. To gain insight on the intrinsic variability of tropical systems, palaeoclimatic records from all pertinent archives will be generated to:

• Extend the observational baseline of tropical variability and document the sensitivity of these systems to past changes in forcings
• Determine the intrinsic variability of the spatial and temporal signatures that characterize modern tropical climate variability
• Provide the database required to reconstruct the long-term variability in ENSO and its teleconnections, and the interannual-decadal monsoonal variability
• Determine the role of tropical variability in extratropical climate.
Global Ocean Thermohaline Variability

The Gulf Stream circulation and surficial gyre systems transport warm water into the North Atlantic. This water is cooled almost to the freezing point before sinking to great depths. The heat flux released to the atmosphere by this process enhances the solar radiation received by the troposphere over the northern Atlantic and helps to maintain mild climatic conditions over western Europe. However, this heat transport varied significantly in the past. To document these variations, more detailed palaeoclimatic records will be needed, such as:

- Long high-resolution geochemical profiles (e.g., $\delta^{18}$O, $\delta^{14}$C, trace elements) of large coral heads and molluscs to obtain seasonal reconstructions of SST, salinity, ventilation and nutrient content of North Atlantic waters
- Geochemical tracers in ice cores from Greenland and Arctic Canada and tree-ring records to establish information on atmospheric parameters influenced directly by the North Atlantic variability
- High-resolution geochemical and micropalaeontological records from North Atlantic sediment cores to reconstruct past variations of SST and salinity and changes in deep water fluxes.

This information will be used to help fix the causes of thermohaline circulation variability (e.g., changes in the water cycle budget, the advection of low latitude saline water and mixing with high latitude water, the flux of fresh North Pacific water through the Bering Strait into the northern North Atlantic, and massive iceberg discharge from melting of large continental ice sheets and release into subpolar waters).

Regional- to Global-Scale Hydrologic Variability

The objective is to document the range of climate and hydrological variability over the continents at the regional- to sub-continental-scale, and to exploit any predictability associated with this variability. The research includes:

- Compilation and integration of seasonally- to annually-resolved palaeoclimatic time series into broad-scale networks suitable for synoptic analysis
- Investigation of hypothesized climate system interactions and forcing
- Evaluation of predictive climate and hydrologic models.

Abrupt Climatic Change

The instrumental record contains only a subset of possible climate system behaviours. Palaeoclimatic evidence show that the climate system repeatedly switched, in a matter of years to decades, between significantly different climatic modes during the last glacial period, and perhaps also during interglacial conditions. Careful work is needed to map out the spatial-temporal patterns of change associated with such past abrupt events, to determine their causes, and to determine if they are predictable. Related research foci include:

- Past abrupt climatic events with hypothesized oceanic causes
- Past abrupt climatic events without known forcing
- The possible abrupt events of the last interglacial.
Model Evaluation and Improvement
A major intersection of PAGES and CLIVAR objectives falls in the area of climate modelling. The research area includes:

- Simulation of extreme climate conditions (6 ka, 21 ka BP) in collaboration with the PMIP model evaluation framework and using ocean and coupled ocean-atmosphere models
- Simulation of natural variability
- Simulation of abrupt change.

Climate Change Detection
Generate centuries-long reconstructions of hypothesized natural climate forcing (e.g., solar, volcanic, trace gas, and ENSO). This can be combined with the model simulations to recognize the climatic “finger prints” of natural climate variability. A global network of centuries-long palaeoclimatic time series can then be calibrated and integrated with available instrumental data, and with appropriate statistical methods, to isolate the roles of natural and anthropogenic climate change.

Implementation
The CLIVAR and PAGES projects sponsored a joint workshop to bring together palaeoclimatologists involved in the quantitative reconstruction of past climates and physicists studying climate dynamics. The aim of this workshop was to: (i) inform palaeoclimatologists of the data/analyses that are required to reach the objectives of CLIVAR; (ii) inform climate physicists of the relevant palaeodata which may be obtained by palaeoclimatologists; and (iii) establish a research programme which would strengthen the interactions between palaeoclimatologists and the modelling community. This workshop was held in Venice, Italy, 16–20 November 1994.

A Formal PAGES/CLIVAR Programme and Working Group
Coordination between PAGES and CLIVAR will be enhanced with the establishment of a formal PAGES/CLIVAR Working Group (P/C WG), with the following terms of reference:

- To formulate and promote a programme of palaeoclimatic reconstructions providing long-term records of palaeodata with seasonal to interannual resolution in areas which are of direct relevance to CLIVAR
- To formulate and promote a programme for collecting, analyzing, and integrating palaeodata to provide patterns of variability within the climate system over seasonal to century time scales
- To formulate and promote the use of palaeodata in evaluating predictive climate models as well as the use of inverse models to understand the variability present in the palaeoclimatic and palaeoceanographic record.
Joint Workshops, Short Courses, and Research
PAGES/CLIVAR interactions include both a planning mode and meetings where both communities can interact on a routine basis. In addition to encouraging cross-disciplinary joint research proposals, the PAGES/CLIVAR WG encourages workshops, such as annual investigators meetings, that are specifically focused on PAGES/CLIVAR goals. In the early years of the PAGES/CLIVAR programme the PAGES/CLIVAR WG also sponsored short courses designed to educate the PAGES and CLIVAR communities in the methods, data requirements and formats, models and strategies used by the other community.

Data Management and Access
Instrumental and palaeoenvironmental observations provide the foundation for both the PAGES and CLIVAR programmes. All data generated by, or used in, PAGES activities will eventually be shared freely via the WDC-A for Palaeoclimatology in Boulder, USA. Non-palaeoenvironmental data used and generated by the CLIVAR programme will also all be safely archived and shared via electronic means in a distributed fashion. A key to the success of joint PAGES/CLIVAR interaction is the existence of well tested data sharing mechanisms.

Timetable
The report of the PAGES/CLIVAR Workshop (Venice) is available from the PAGES IPO. The PAGES/CLIVAR Working Group met for the first time in October 1996.

Report prepared by Jean-Claude Duplessy

Contact:
Jean-Claude Duplessy
Centre des Faibles Radioactivites
Laboratoire mixte CNRS-CEA
F-91198 Gif sur Yvette, Cedex
France
Tel: (33-1) 69 82 35 26
Fax: (33-1) 69 82 35 68
Email: Jean-Claude.Duplessy@cfr.cnrs-gif.fr
Focus I
Activity 5
Task 1 Annual Records of Tropical Systems (ARTS)

Project Leaders: Julia E. Cole and Robert B. Dunbar

Introduction

Tropical ocean-atmosphere systems orchestrate climate variability worldwide over interannual-decadal time scales. In addition, the tropical ocean is an important source of energy and water vapour to the global atmosphere. Intensive observational programmes such as The Tropical Ocean and Global Atmosphere Project – Coupled Ocean Atmosphere Response Experiment (TOGA-COARE) and The Tropical Ocean and Global Atmosphere Project – Tropical Atmosphere and Ocean (TOGA-TAO) have focused on improving our empirical basis for understanding and modelling the tropical ocean-atmosphere. However, most instrumental observations of tropical climate span only the past few decades, and only a handful of instrumental records from the tropics predate the turn of the century. Thus, most state-of-the-art predictive models are based only on the information available from the past several decades. The new PAGES ARTS activity is fundamentally motivated by the need to understand the natural spatio-temporal dynamics of tropical climate systems over interannual-century time scales in order to improve long-term climate predictability.

Large-scale ocean-atmosphere systems play a key role in the variability of all major tropical ocean basins and their adjacent continents. Of particular interest within ARTS are the ENSO system, tropical moisture convergence zones, the monsoons of Africa, Asia, and Australia, and regions of large-scale, coherent SST anomalies. These systems evolve between extreme states over periods of months to seasons, and anomalies usually persist for one year or less. Thus our records must have at least annual resolution. Continuous records of these systems from the past millennium will extend our observational baseline of climate information in the tropical oceans, providing a solid foundation for the analysis and modelling of decade-century scale variability and the response of the tropics to specified forcings.

In the tropical oceans, where long climate records are scarce, the development of multi-century, subseasonally resolved climate records from corals are providing new information about the functioning of the tropical ocean-atmosphere systems on the interannual-century time scales relevant to society. For example, recent results from long-lived Pacific corals indicate the persistence of decadal patterns of variability in the ENSO that are unrecognizable from the instrumental data in hand and are not simulated by the current generation of numerical models. Records from varved sediments, tree rings, and ice cores have the potential to provide similar information. To be most useful, these records must be annually dated and quantitatively calibrated to instrumental climatic data. Long-term changes in the variability of tropical ocean-atmosphere systems would have profound effects on extratropical climate variability and may influence boundary conditions such as the atmospheric water vapour content.
Developing these records from the best sites requires a combination of climatological insight, local expertise, and logistical and analytical facilities. ARTS is a new PAGES activity designed to facilitate these interactions and expand our knowledge of the behaviour of the tropical ocean-atmosphere, with seasonal-annual resolution, over periods of years to centuries. This initiative will comprise the first detailed examination of the PAGES Stream I time interval (the past 2,000 years) in the tropics and will link the three north-south PEP I (Pole-Equator-Pole) palaeo-climate transects through the reconstruction and analysis of common processes and dynamics. ARTS also provides a strong link to the CLIVAR programme of the WCRP.

**Scientific Objectives**

- To define the range of natural variability the tropical ocean-atmosphere systems over the past millennium, and the relationship between this variability and extratropical changes, external climate forcings, and internal system feedbacks
- To evaluate the response of tropical ocean-atmosphere systems to large changes in global climate boundary conditions over the past 30,000 years
- To analyze the interactions between key tropical climate systems (e.g., ENSO, the Asian monsoon, tropical Atlantic moisture convergence) over interannual and longer time scales.
- To document the stability of observed teleconnection patterns between the tropics and extratropics through time, especially in the face of long-term tropical variations
- To define the role of the tropical oceans in establishing past climate boundary conditions (e.g., water vapour concentrations) and past extratropical climate variability
- To utilize quantitative reconstructions of tropical variability to evaluate the skill of numerical climate simulations and constrain mechanisms by which tropical systems respond to or enhance extratropical changes.

**Implementation Plan**

ARTS received approval as a PAGES activity in early 1995, and in late 1995, the US NSF granted the coorganizers US participant support for an ARTS planning workshop. PAGES contributed to international participation in this workshop which took place in Autumn 1996, organized by: J. Cole, R. Dunbar, and M. Gagan (Australia); and J. Recy (France). Planning this workshop served as a catalyst for developing international collaborative research projects focused on tropical climate variability. Workshop participants have produced a consensus science and implementation plan for ARTS research. This document includes specific projects that: (i) address ARTS science priorities; (ii) involve collaboration among climate researchers whose perspectives include instrumental data, models, and paleoclimatic resource; and (iii) are based on international collaboration. Projects described are sufficiently specific to provide a focus for future proposals to national funding agencies. Participation in these projects is not limited to workshop invitees. This planning meeting was in-
tended to initiate research programmes focused on ARTS priorities. All research ef-
forts described can be expanded to include other interested parties as desired. The
ARTS Science and Implementation Plan will be published and will be distributed

Project Strategy

ARTS was conceived as an interdisciplinary, international programme to facilitate
interaction among those with climatological, oceanographic, palaeoclimatic, and
logistical expertise, and to focus this diverse expertise on specific questions related
to tropical climate variability. We expect to include palaeoclimatologists working
with a variety of proxy climate records, as well as oceanographers, climatologists,
and numerical modellers, in the development of the ARTS science and implementa-
tion plan. Members of CLIVAR are involved in all aspects of programme coordina-
tion to maximize the likelihood of programme success.

ARTS will address the history of tropical variability associated with the boundary
condition changes of the past 30,000 years, using isolated but well-dated sequences
that allow annual or better resolution. Large coral colonies, spanning several de-
cades to centuries, are commonly penetrated by cores drilled through fossil reefs;
other sources of information might include varved sediment sequences, ice cores,
and subfossil wood chronologies. These studies will provide the best way to test the
sensitivity of tropical systems to known large changes in climate boundary condi-
tions, with implications for future predictability. This approach has a strong prec-
edent in earlier successful workshops convened on coral records of climate variabil-
ity (Puerto Rico, 1992) and on PAGES/CLIVAR interactions (Venice, Italy, 1994).
From the palaeoclimatic side, coral records will form a primary basis for this initia-
tive, but records from other sources, such as varved sediments, tree rings, and ice
cores, will be incorporated to the extent that they address ARTS priorities. These
records will be particularly important in linking oceanic variability with its impacts
on adjacent continents. The ARTS planning workshop convened in 1996 drew from a
broad international scientific community with interests in tropical variability. Such
international participation is vital for the combination of expertise required to
achieve ARTS’ goals.

Expected Output

We envision that ARTS will provide the focus for international collaboration needed
for fresh insight into long-term (interannual-century scale) tropical climate sensiti-
ity and dynamics. We expect to develop, through priority ARTS projects, climate re-
constructions valuable to a range of projects. ARTS will facilitate development of
calibrated climate reconstructions from networks of sites that will provide important
tests and constraints for numerical simulations. For example, one such effort already
under discussion involves a coral ENSO index that would extend the instrumental
ENSO indices back by several centuries. Similar indices could be developed for
many regions and systems. These reconstructions, once published by the primary
investigators, will be shared through the WDC-A for Palaeoclimatology. In addition
to the development of tropical climate reconstructions, we expect ARTS to facilitate
the use of these records in evaluating linkages among different regions and different
systems, and to promote the synergistic interplay between the researchers developing the records and those exploring these climate systems from the perspective of instrumental observations and numerical models.

**Project Management**

As a new activity within PAGES, ARTS is currently under the informal guidance of its two initial proponents, Julia Cole and Robert Dunbar. At the ARTS planning workshop, in addition to defining scientific priorities, further options for ARTS management were discussed. It is envisioned that the projects defined as priorities at this workshop will define their own working groups and that, in the near term, future ARTS activities will coalesce around these specific projects. As ARTS science progresses, broader activities will again become necessary to integrate and synthesize results from specific regions.

The published outcomes from the planning meeting will determine the need for scientific resources for ARTS. Facilities that would benefit ARTS research include oceanographic ship time for drilling projects and access to remote locations, support for long-term monitoring designed to improve palaeoclimate record calibrations, analytical instrumentation support, and the development of funding avenues for medium scale projects.

Report prepared by Julia Cole

*Contact:*
Julia Cole
Geological Sciences – INSTAAR
University of Colorado
Campus Box 450
Boulder, CO 80309
USA
Tel: (1-303) 492 0595
Fax: (1-303) 492 6388
Email: coleje@spot.colorado.edu
FOCUS II

Palaeoclimate and Environmental Variability in Polar Regions

Activity 1  Arctic Programmes
Task 1  Circum-Arctic PalaeoEnvironments (CAPE)

(See Workshop Report 94-1 “Research Protocols for PALE – Palaeoclimates of Arctic Lakes and Estuaries”)

Project Leaders:  Gifford Miller and Anders Elverhøi

Mandate for CAPE

CAPE is proposed as a Task within PAGES through which international and national Arctic palaeoclimate research programmes are coordinated to address global change issues. “Arctic” includes present and past northern limits of the boreal forest, the tundra-boreal forest ecotone, all vegetation/climatic zones north of tree line, and the adjacent shallow marine environment. The primary emphasis of CAPE is to facilitate scientific integration of palaeoenvironmental research on terrestrial environments and adjacent continental margins covering the last 250,000 years of Earth history, particularly those tasks that cannot be easily achieved by individual investigators or even regionally-focused research teams. CAPE would serve primarily to promote hemispheric syntheses, enhance data compilation and exchange, coordinate modelling efforts, and to facilitate linkages and integration with ongoing related
programmes. Through focused international meetings and workshops, key members of the data and modelling communities will be brought together to synthesize available evidence, integrate modelling efforts, and identify key geographic regions of climate variables requiring additional primary data acquisition. Particular emphasis will be given to the synthesis of circum-polar environmental reconstructions over PAGES Streams I and II: the last 250 ka (particularly century-scale changes during the last 20 ka), and annual records for the last 2 ka.

**Scientific Objectives**

1. What are the timing, rates, magnitudes, spatial patterns and controls of Arctic climate variability?
   - What is the basic record of environmental change in the Arctic over the past 2,000, 20,000 and 250,000 years?
   - How have large-scale processes governed climatic variations in the Arctic on these time scales?

2. What are the climatic controls over continental ice sheet inception, mass balance variation, and recession?

3. What is the linkage and impact of the Arctic climate system on the global system?
   - What are the amplifying or stabilizing feedbacks to the global system that originate in the Arctic?
   - What are the unique features of the temporal variability of the Arctic climate system that would influence global systems?

**Long-Term Goals**

To address these scientific questions requires a circumpolar network of well dated sites for which the palaeoclimate proxies (*i.e.*, pollen, foraminifera, diatoms, stable isotopes, tree rings, etc.) are either quantitatively calibrated with modern climate datasets or qualitatively assessed through an understanding of key ecological and/or process relationships. The pattern of change for key boundary conditions for atmospheric general circulation models (AGCMs), particularly ice sheet margins and elevations, seasonal distribution of sea ice, position of tree line, distribution of permafrost, continental shorelines, and river patterns through time are required. Palaeoclimate patterns derived from the proxy data may then be compared to AGCM predictions or conceptual models of climate change to elucidate possible mechanisms and feedbacks responsible for the observed changes. This coupled approach of documenting “what happened” based on fossil data, and deriving explanations utilizing data-model comparisons (*i.e.*, “why the observed patterns occurred”), is the core of the CAPE objectives. Such an undertaking necessitates international collaboration between those researchers who acquire the primary proxy data, and the palaeoclimate, glaciological, and vegetational modelling communities. These interactions are intended to address the following issues:
Short-Term Goals

CAPE proposes to take advantage of several ongoing and proposed research thrusts in the Arctic. The group will attain its goals of integration and synthesis by holding highly focused international meetings approximately every other year with identified objectives clearly spelled out in advance. It is anticipated that these meetings will require significant advance planning so that state-of-the-art compilation of specific datasets can be accomplished, and integrated with the modelling communities. The first meeting took place in Lammi, Finland, April 1997. A primary goal of the meeting was to define the spatial variability of Holocene environmental change across the Arctic in thousand year time slices.
Project Implementation

Palaeoenvironmental Reconstructions
Local to regional-scale palaeoenvironmental reconstructions for the Arctic are the focus of several ongoing and proposed research programmes. Because they contain a variety of proxy indicators and are characterized by rapid sedimentation rates, Arctic lake sediments and sediments from the adjacent shelf/slope are valuable repositories from which past environments may be reconstructed. Several programmes are designed to retrieve, analyze, and interpret sediment cores from Arctic lakes and adjacent continental margins.

Advances in radiocarbon dating allow more precise ages to be determined using dramatically smaller increments of core. Efforts to calibrate biotic and abiotic proxies to specific climate variables have improved the reliability of palaeoclimate interpretations. These advances allow the community to make significant advances in the systematic reconstruction of site-specific time-series of climate change. As this network of high-quality data expand, it will be possible to develop circum-Arctic syntheses of palaeoenvironmental reconstructions through PAGES Streams I and II. Although the primary acquisition and interpretation of high-quality records is generally under the purview of focused research teams, it is the aim of CAPE to facilitate these efforts by serving as a conduit for communication between research groups.

Modelling Activities
Numerical modelling is an important methodology being used to make predictions in global change research. Palaeoenvironmental research is important to climate modelling and related modelling research because it provides a means for testing models against climatic conditions substantially different from today. CAPE will contribute to the understanding of global climate change by providing enhanced understanding of, and access to, palaeoenvironmental Arctic data. The Arctic emphasis of CAPE is particularly relevant to the modelling community because the Arctic is sensitive to climate forcing and, through strong feedback mechanisms, has a substantial influence on the climate of lower latitudes.

Numerical modelling will make use of palaeoenvironmental data supplied by CAPE researchers in two ways: (i) as input data to the models such as boundary conditions on ice extent, topography, vegetation types and coverage, or surface meteorology; or (ii) as validation datasets to test the model’s performance. For category (i), datasets will need to be gridded or otherwise processed to be used as input in the models. The validation data, which is potentially the larger category, need not be as constrained. It is sufficient for many validation purposes that the data be geo-referenced and calibrated for a given site rather than gridded. If enough sites are available, and they are calibrated so as to be comparable, then a pointwise model-data intercomparison can be performed. Similarly, it is not necessary in many cases that palaeodata have high precision to be useful. For example, the presence or absence of land ice in a model grid cell, or a simple “warmer” or “colder” quantification for a palaeoclimate reconstruction may suffice.
CAPE should facilitate the work of small, multidisciplinary associations of observational researchers and numerical modellers. The interaction of climate modellers at the National Center for Atmospheric Research (NCAR) USA, with other researchers within the PALE programme is an example of the type of integrative work that should be encouraged. An advantage of such group efforts is that each involved discipline receives the benefits of iterative interactions on problems of mutual interest. Examples include the ability of palaeoenvironmental researchers to test hypotheses by having direct access to modelling teams and the development of more realistic modelling scenarios through access to up-to-date observational information.

Numerical Models: Of the wide range of numerical models applied in global change research, three types are of particular interest to CAPE:

- General Circulation Models (GCMs), which simulate the circulation of the atmosphere and, in some cases, the ocean. They form the basis of most climate prediction research
- Ice Sheet Models, which calculate the dynamic behavior of large ice masses
- Hydro-Geological Models, which calculate the sediment loads and runoff of rivers and the effects of sediment depositional patterns in lakes, estuaries and on continental margins.

When applied in palaeoclimatic research, these models require palaeoenvironmental data for boundary or initial conditions. Examples include ice sheet configuration and vegetation cover for climate models, sea level for ice sheet models, and sediment properties and patterns for hydro-geological models. Moreover, it is anticipated that these types of models will be linked in the future in such a way that climate models provide data to ice sheet models which together provide the necessary input to hydro-geological models.

Interactions Among Observational Researchers and Modellers
A key to the success of CAPE will be the productive interaction among numerical modellers and researchers who collect and analyze palaeoenvironmental data. The CLIMAP and the Cooperative Holocene Mapping Project (COHMAP) projects provide evidence that the climate modelling community will make use of palaeoclimatic reconstructions to help validate models. Indeed, PMIP is designed to use palaeoclimatic reconstructions to evaluate the performance of state-of-the-art climate models.

PMIP was established to provide a framework for evaluating state-of-the-art atmospheric climate models by comparing the performance of 17 models in simulating palaeoclimate conditions significantly different from today. The next stage of PMIP calls for model comparisons with palaeoclimatic reconstructions. CAPE will interact with PMIP in two important ways:

- The circum-Arctic synthesis of palaeoclimatic data to be used in model validation. CAPE will coordinate the creation of truly circum-Arctic palaeoclimatic reconstructions for the PMIP standard times of 21 ka and 6 ka BP
• Advising on the design of future PMIP modelling protocols. CAPE will contribute to the design of PMIP modelling protocols whenever possible (e.g., by generating improved boundary conditions). Through its component organizations, CAPE will also be in a position to suggest alternative model experiments for enhanced realism or to better test hypotheses.

Palaeoenvironmental Multiproxy Analysis and Mapping Project (PMAP) is focused on the use of multiproxy data to document past change, to understand changes in terrestrial environments, to examine global climate processes and variability, and to validate Earth system models. PMAP has been designed to work within the PAGES framework to maximize coordination among ongoing data compilation efforts and eliminate unnecessary duplication among various research groups, including CAPE. Within CAPE, palaeoenvironmental data have two major inputs to the modelling of past climates:

• Establishing boundary conditions for simulations of specific times
• Reconstructing past climates in a form that can be used to validate (evaluate) palaeoclimate and palaeoceanographic simulations.

Geochronology
A common concern throughout palaeoenvironmental research is the development of a secure independent geochronology for each time-series of proxy climate indicators. There is broad agreement that many past studies of lake and estuarine records suffer from inadequate temporal control, both in terms of the number and quality of dates. This is particularly true in the Arctic, where low levels of organic carbon require large sections of core for conventional radiocarbon dating. To rectify this situation CAPE recommends protocols be established that define the appropriate number and type of dates per core for primary datasets, and encourages basic research in radiocarbon, luminescence, and cosmogenic dating methods.

0–250 ka Stream
Advances in thermal ionization mass spectrometry for uranium-series dating, cosmogenic exposure dating and refinement of the luminescence methods offer additional means to better date past environmental change. The luminescence family of dating methods and cosmogenic surface exposure dating (particularly $^{10}$Be, $^{26}$Al, and $^{36}$Cl) currently offer the greatest promise. CAPE endorses the need for support of basic research in these technologies.

0–20 ka Stream
Accurately dating time series of Arctic environmental change by radiocarbon has been difficult, due to the low rates of primary productivity, which, combined with low rates of organic matter decomposition, often result in the incorporation of significant levels of “old” carbon in lacustrine and marine sediments. The refinement of carbon extraction procedures, coupled with the dramatic reduction in sample size requirements accompanying the development of AMS, has fundamentally improved the accuracy and potential resolution of environmental reconstructions by radiocarbon dating. In most instances AMS $^{14}$C dating is capable of providing dating accuracy within 500 years throughout the last 20 ka.
For most deposits AMS $^{14}$C dating will provide the primary dating control; however, there may be lakes for which radiocarbon is inappropriate. In these instances, luminescence methods may be capable of providing a low-resolution chronology (ca. 1 ka resolution), although uncertainties in the “zeroing” of waterlain sediment compromise the accuracy of the technique. Additional basic research may resolve the uncertainties.

0–2 ka Stream

Over much of this interval, especially the last 500 yr, variations in $^{14}$C production rates preclude reasonable time control from radiocarbon dating. Verification of annual laminations can often be accomplished by $^{210}$Pb and $^{137}$Cs dating.

Multiproxy Indicators

Not only has temporal control improved, but the tools by which environmental change may be quantified have been refined in recent years. Rather than rely on a single proxy of past environments, most studies now integrate several different parameters. These multiproxy studies often include variables that have been largely ignored in the past, including diatoms, *Chironomidae*, *Chrysophyta*, and light stable isotopes from such diverse media as plant macrofossils, dissolved organic matter, and inorganic carbonates. Advances in the preparation and analyses of many of these parameters now allow more rapid and more precise measurements than were previously possible. For some environmental proxies, there have been substantial advances in the calibration of the proxy data in the modern environment to the modern climatology, allowing a more precise estimate of past climate conditions.

Calibration of Proxy Data

There is need to improve the calibration of proxy data used in the Arctic with additional modern observations and process studies, particularly in remote areas. CAPE proposes to facilitate this effort by providing opportunities for sharing of modern materials (e.g., surface water and sediment samples, plant and invertebrate specimens), establishing lines of communication to assist in shared logistics, and compilation of databases on relevant environmental parameters (e.g., gridded modern climate data, species distribution ranges).

The calibration effort requires a variety of modern studies in order to convert the diverse proxy data of CAPE into qualitative or quantitative forms usable by modelling groups. A further requirement is provision of a standardized means of display of spatial and temporal data to enable the comparison of various proxy and environmental data. The community would benefit from access to GIS and similar spatial display systems (e.g., PMAP).

Palaeoenvironmental proxies can be divided into biological and physical groups. These may be further subdivided into:
**Biological**
- Limnic e.g., diatoms, Chironomidae, Chrysophyta
- Marine e.g., forams, Mollusca, Ostracoda, vertebrates
- Terrestrial e.g., pollen, plant macrofossils, tree rings, Insecta.

**Physical**
- Geochemistry e.g., stable isotopes, trace elements, organic carbon, gas inclusions
- Morphological indicators e.g., shorelines (marine and freshwater), moraines, permafrost
- Sedimentological e.g., facies, provenance indicators, varves, sequence stratigraphic boundaries.

The basic contribution of the calibrated proxy data is to provide a network of sites in grid format that provide information on meteorology, topography, and albedo effects, which can be used for either model specification or evaluation. Potential palaeoenvironmental variables that can be addressed are listed in Table 1 pages 126–127.

**Data Management Issues**
CAPE data storage and compilation needs will vary depending on the nature of the tasks undertaken by the project members. For this reason, CAPE must develop a flexible data plan that allows a wide range of resource tasks. The primary CAPE data management will be done by the CAPE members and the projects in which they participate. Furthermore, CAPE-member projects should stipulate data management plans and allocate resources for data management at their inception. This policy eliminates the need for a multinational data effort sponsored under CAPE, and leaves the critical data management issues up to the individual researchers and/or projects. Some of these issues are data policy, exclusive use periods, and which data are important to archive. Perhaps the largest benefit of leaving the data management up to the individual researcher/project is that it provides the expertise needed for data handling, thereby allowing the specific problems related to certain proxies to be handled within the disciplines. Many proxy data used by the CAPE participants are being collected in independent database efforts. Where possible, CAPE should utilize these existing database tools. However, if no such databases exist, CAPE strongly encourages the development of a new database.

**Data Protocols**
It is important to ensure that CAPE proxy data are internally consistent. To accomplish this, CAPE will need to identify specific research and data protocols for each type of proxy record it generates. Where possible, CAPE members will use existing data and research protocols. However, if no such protocols exist, CAPE strongly encourages the establishment of new protocols wherever they are needed.
Data Requirements
To accomplish its goals, CAPE must make its data available in a form that is easily accessible and easy to use. The data must be in their primary form (e.g., raw counts), and must be accompanied by the necessary metadata (data about the data) to make them generally useful. The metadata should include: location data (latitude, longitude, elevation, etc.), contact person, relevant publications, spatial resolution of the proxy, and temporal resolution and coverage (accuracy and length of record). Secondary and tertiary data will be stored for CAPE purposes, but only if the primary data are also archived. However, for some data (e.g., spatially defined geomorphic features) it may not be practical to store the primary data used to generate the records. In these cases, the documentation of the process used to generate the data must be sufficient to allow the reproduction of the original interpretation, or the reinterpretation of the data.

Data Storage
The CAPE data archive will be held at the WDC-A for Palaeoclimatology in Boulder, CO, USA. The WDC-A can help individual researchers and projects and provide a long-term archive for CAPE data. It will also provide data management for CAPE once the data are established at the WDC-A. Through on site data coordination efforts, it will also provide an efficient means for executing multi-proxy data searches. It should be noted that once the CAPE data are contributed to the permanent archive at the WDC-A for Palaeoclimatology, they are freely accessible to the general research community. There may be a need within CAPE for a data coordinator, but a specific CAPE data manager is not required.

Project Management
At the initial organizing meeting in 1995, a 10-person SC was elected to guide the organization. The SC was intended to reflect a balance of national and disciplinary interests from which a smaller four-person ExComm was chosen to attend to practical aspects of the organization. The SC is charged with identifying important topics, appointing an Organizing Committee for biannual CAPE meetings, establishing short-term objectives, and bringing longer-term objectives before the community at the biannual meetings.

Future Directions
The following topics were identified at the September 1995 CAPE meeting in Copenhagen, Denmark, to be the focus of meetings in coming years. Further consideration is currently being given to the closer incorporation of the dendroclimatology research community into CAPE and to the relationship between CAPE and the Ice-Coring Circum-Arctic Palaeoclimate Program (ICAPP).
Holocene Spatial and Temporal Patterns of Environmental Change

The Holocene period offers possibilities for palaeoenvironmental reconstruction levels of precision unavailable for earlier periods. It includes the interval of instrumental and written records, thus allowing a firmly-based calibration of proxy data in terms of climate variables. It also overlaps with the period of increased CO₂ content in the atmosphere, a significant feature when predicting future climate change.

The range of proxy data available for the Holocene is both rich (e.g., pollen, diatoms, Chironomids, Coleoptera, areal plankton, tree rings and physical and chemical variables) and exists as a continuous long series with a potential for high resolution reconstructions. It also has good chronological control which, in the case of tree rings and varves, can be dated annually, and for radiocarbon, is frequently dated with century-scale resolution.

Because the spatial coverage of these high-resolution records are increasingly comprehensive, availability of multi-proxy data in the circum-Arctic is increasing and a “critical mass” of researchers is now available, making regional and global syntheses increasingly feasible.

Such syntheses for a selection of time slices, including the 6 ka BP window which is central to PAGES programmes, could focus on:

- Location of the tree line
- Temperature (summer, winter)
- Precipitation
- Glacier margins and elevations
- Sea ice cover
- Coastline changes.

This collection of high-resolution data would permit a close examination of rates of change during the Holocene. The improved coverage allows an assessment of the spatial variations of environmental response to climate change. The available palaeoenvironmental data suggest dramatic differences in the timing, rates and magnitude of environmental change across the Arctic. A synthesis of these data will provide a more substantive basis from which to evaluate the heterogeneity of environmental change across the Arctic.

Timing and Extent of Maximum Ice Sheet Post Isotope Stage 5e

Both the timing and extent of the LGM are debated over significant areas of the Arctic (e.g., western Siberia, high Canadian Arctic). This uncertainty extends to whether the maximum occurred during the Early or Late Weichselian/Wisconsinan/Valdaian. Reconstructions of ice sheet dimensions at the maximum also vary by an order of magnitude or more in some regions.
CAPE proposes to re-examine existing stratigraphical, sedimentological and chronological data on ice distributions across the Arctic. From this, a status report will be produced containing the following:

- A reconstruction of the geometry of Arctic ice masses for 21 ka BP, which will be used as a boundary condition in GCM modelling under the PMIP programme. This reconstruction will also include physical and biological parameters from beyond the ice sheet margins (e.g., tree line, permafrost limits, shorelines)
- An assessment of the spatial variability in timing of the LGM
- Glacier reconstruction for the earlier Wisconsinan/Weichselian/Valdaian, especially for areas where this represents the maximum extent of post Stage 5e ice.

**Holocene vs. Eemian: Interglacial Contrasts**

The present (Holocene) and the last (Eemian; ca. 130–120 ka ago) interglacials are pronounced warm intervals following rapid terminations from a time of extensive continental glaciation. For the well-being of the densely populated and highly industrialized subarctic countries, it is appropriate to ask whether these two latest interglacials are comparable and typical. Do we live at the end of an interglacial? Are we already experiencing the onset of a new ice age? Can we learn to predict future climates, especially with respect to the impact of any anthropogenic “greenhouse” effect and interactions with natural climate variability?

The two interglacials resemble each other in that they are both relatively short (ca. 10 ka). They were both heralded by an oscillative, although still rather abrupt termination of the preceding glacials, with YD-type temporal glacial recoveries during the transition interval. The climate development during the interglacials culminated with a thermal optimum, after which came a gradual/stepwise deterioration towards the next glacial. In the current interglacial, the thermal maximum occurred in the early to middle Holocene. Beginning at least 5,000 years ago, and accelerating about 2,500 years ago, the high latitudes cooled. The significance of the modest warming in the current century remains uncertain. During both the current and previous interglacials much heat was advected northwards, via oceanic currents and air masses, allowing the limits of sub-Arctic marine and terrestrial biota to advance far into what are today distinctively Arctic areas. These marine and terrestrial sediments with extralimital boreal molluscs, plant remnants, etc. bear witness to these warm pulses. Similarly, Eemian (5e) beds often serve as marker horizons.

Among the differences between the Eemian and Holocene, one of the most important is that temperatures during the Eemian optimum were 2–3°C higher than the warmest period of the present interglacial. As a result of this, ice sheets were smaller and sea levels higher. Meridional and latitudinal gradients were apparently different during the Holocene, and this points to significant qualitative and quantitative differences in the global pattern of atmospheric and oceanic circulation. Thus, while northern Eurasia was more than 5°C warmer, there were areas in the northeastern Atlantic region, notably Fram Strait, which were considerably colder. Major differences in surface boundary conditions include, besides the smaller ice sheets, the existence during the Eemian of large epicontinental seas along the Russian and Siberian coasts and a sea connection from the Baltic to the White Sea, which may also have influenced the northwards transport of warm Atlantic water into the Arctic.
Ocean. Although the general succession of ecosystems through the two interglacials were principally the same, there were marked differences in the species compositions of both terrestrial and marine biotas.

In recent years, ice-core data have suggested that the Eemian climatic development was very different from that of the Holocene and was interrupted by several periods of drastic cooling. The true nature of these climatic oscillations is still not clearly understood, but the circumpolar Arctic rims (lowlands and shelves) are superbly suited to investigate the characteristics these interglacials.

**Report Preparation**

Most of this document was written by the CAPE community at the first organizing meeting held in Copenhagen, Denmark, 1–3 September 1995. Gifford H. Miller combined and integrated the text, with written comments from Anders Elverhøi, Svante Bjoerck, and Jörn Thiede. Robin Webb provided the PMAP section.

---

**Contacts:**
Gifford H. Miller  
INSTAAR  
University of Colorado  
Boulder, CO 80309-0450  
USA  
Tel: (1-303) 492 2330  
Fax: (1-303) 492 6388  
Email: gmiller@colorado.edu

Anders Elverhøi  
Department of Geology  
University of Oslo  
Oslo  
Norway  
Tel: (47) 316 0510  
Fax: (47) 2285 4015  
Email: anders.elverhøi@geologi.uio.no
Introduction

The Arctic system is a sensitive indicator of environmental changes. Understanding the evolution of Arctic climate as well as its feedbacks to the global system is necessary to decipher processes controlling climatic changes. Before simulating the future development of the Earth’s climate, with appropriate consideration of the greenhouse effect, it is necessary to reconstruct the Arctic environment through recent geologic time. The Arctic Ocean may therefore offer good opportunities for real-time monitoring of global change. A quantitative analysis of past Arctic climate variability will also contribute to an assessment of short to mid-long term environmental changes and the impacts of such changes on ecosystems of the Arctic Ocean as well as surrounding shelves and continents.

NAD was initiated to deeply probe the marine sedimentary record of the Arctic Ocean. NAD was established during the IGC in Washington, USA, in 1989. A science plan has been published in NAD Science Committee “The Arctic Ocean Record: Key to Global Change”, Polarforschung 61:1-102 (1992).

Scientific Objectives

The long term goals of NAD are to understand the climatic and palaeoceanographic evolution of the Arctic region and its effects on global climate, the biosphere and the dynamics of the world ocean and atmosphere with an emphasis on the last two glacial-interglacial cycles, and to include understanding of relevant forcing functions. Specific objectives are to study:

- The evolution of the Arctic sea ice cover and water masses
- The history of circum-Arctic ice sheets
- The evolution and adaptation of the biota to extreme shifts in environment
- The forcing processes which cause the rapid shifts in climate as seen in the ice cores
- The relationship between the marine, terrestrial, and ice-core palaeo-environmental records of the region.
Implementation Plans

After careful analysis of technology to determine the feasibility of Arctic drilling, NAD then undertook site surveys and long sediment cores from the POLARSTERN. Eventually the Laptev Sea was chosen as the initial site. For further definition, a first Laptev Sea drilling workshop (November 1994), hosted by the Arctic and Antarctic Research Institute (AARI), was held in St. Petersburg, Russia. At this meeting, Russian scientists and institutions agreed enthusiastically to participate in the programme. Scientists at the meeting also affirmed the technical feasibility of the programme. Cores from onshore suggest that dating of the sequences will be possible due to the presence of calcareous fossils.

The initial drilling programme will focus on sampling the uppermost 200–300 m of sedimentary cover with continuous coring and recovery of undisturbed core samples. Candidate drill platforms at present are the drill vessel Bavenit (AMIGE, Murmansk, Russia), Skate 11 a jackup for marine geotechnical investigations (ARKTIKMORNEFTEGAZRAZVEDKA-AMNGR, Murmansk, Russia), and a Baikal “mobile unit” (Nedra, Yaroslavl, Russia) which has been used in the Baikal Lake Drilling Project. The first two would drill in the summer ice free time; the latter from land fast ice in the spring.

During the summer of 1996, the Swedish Icebreaker ODEN attempted wire-line drilling on the flank of Lomonosov Ridge. The plan was to drill to a depth of 50 m in a step fashion up the flank of the ridge to sample the outcropping seismic reflectors which should reflect the Cenozoic history of the Arctic Basin. Drilling was aborted when an obstruction in the riser was encountered, and time available expired. Ultimately drilling in the deep Arctic will require an ice reinforced drill platform like SHASHIN with icebreaker support. The workshop held October 1996 in St. Petersburg, resulted in a scientific implementation plan, now available from the NAD Secretariat.

Accomplishments

Ocean Drilling Programme (ODP) Leg 151 co-chief scientist, Joern Thiede, is a NAD representative on the science committee and obtained the first samples in the North Atlantic Gateway to the Arctic: the Fram Strait. POLARSTERN cruises starting in 1991 and continuing through 1995 have obtained long cores in the Arctic, as well as sedimentologic data from the Laptev Sea as part of the joint German/Russian Programme “Laptev Sea”. The latter is essential prior to any drilling programme.

Linkages

As a longer-term objective Quaternary and older palaeostratigraphy of the deep Arctic must be obtained to tie the Arctic to the global system. NAD would provide the northern link to the IMAGES programme. NAD is currently an ODP Liaison Group, allowing for ODP to communicate with national and international geoscience programmes with interest in ocean drilling. A proposal was submitted to ODP to provide NAD with an infrastructure of management, science advice and coordination, and a potential working system of repositories through access to those components of ODP. Both the Policy Committee (PCOM)/ODP and EXCOMM/ODP gave favourable responses.
NAD is a coordinated programme with the Russian Arctic Land-Shelf Interactions (RASE), a proposed new initiative initially supported by the US NSF. The marine geology working group of the International Arctic Science Committee (IASC) has scientific drilling as one of its methodologies for solving questions related to the Arctic palaeoenvironment.

Project Management

NAD has a contributing membership of seven nations: Canada, France, Germany, Japan, Norway, Russia, the UK, and the USA. Observer Nations are: Denmark, Iceland, Sweden, and The Netherlands. Annual dues are used to maintain a formal secretariat with the Joint Oceanographic Institution (JOI) Inc., Washington, USA and publication of a biannual newsletter *The Nansen Icebreaker*.

A proposal for the field programme of scientific drilling, as an integral component of the Arctic Grand Challenges Programme, was submitted to the European Committee on Ocean and Polar Science (ECCOP). Due to the cost of the programme it was decided to delay funding for one year. A proposal for support of the Laptev Sea Drill Sites as well as for site surveys was submitted in spring 1997 for field work in 1998 and drilling in 1999.

Future Directions

After shallow drilling on the continental margin, plans are to shift the programme to deeper water initially by use of land sediment cores.

Report prepared by Leonard Johnson and Heidi Kassens

Contacts:
Garrett Brass
Arctic Research Commission
4350 N. Fairfax Drive, Suite 630
Arlington, VA 22203
USA
Tel: (1-703) 525 0111
Fax: (1-703) 525 0114
Email: g.brass@arctic.gov

Yngve Kristoffersen
Chair, Science Committee
Institute of Solid Earth Physics
Seismological Observation
University of Bergen
Bergen, N-5014
Norway
Tel: (47-55) 23407
Fax: (47-55) 32009
Email: yngve@ibg-uit.no
Alister Skinner  
Chair, Technology Committee  
Marine Geology and Operation  
British Geological Survey  
Murchison House, West Mains Road  
Edinburgh EH3LA  
UK  
Tel: (44-131) 667 1000  
Fax: (44-131) 668 4140

Andrea Johnson  
NAD Secretariat  
JOI Suite 800  
1755 Massachusetts Ave. NW  
Washington, DC, 20036-2102  
USA  
Tel: (1-202) 232 3900  
Fax: (1-202) 232 8203  
Email: ajohnson@brook.edu
Inspiration for the Nansen Arctic Drilling programme came from the F. Nansen, the great Norwegian polar explorer, who prepared, organized and executed the well known expedition to the Arctic Ocean. The illustration by Nansen shows the FRAM drifting in the sea ice. Courtesy of NAD (project leader, Leonard Johnson).
Focus II  
Activity 1  
Task 3a  
Greenland Ice-Core Project (GRIP)

Project Leader: Bernhard Stauffer

Goals, Structure of the Project, and Field Work

The analysis of polar ice cores, consisting of well stratified layers of precipitation from the last several hundred thousand years, allows very detailed reconstruction of climatic as well as of some very important environmental parameters. Interesting results have been available from previous ice cores drilled in Antarctica and Greenland. However, very important questions relating to the nature, rates, amplitude and spatial expression of climatic change remained unanswered by these cores. The available Greenland ice cores had the disadvantage that evidence for fast and drastic climatic variations during the last glacial period was found in the deepest parts of the cores where stratigraphic disturbances could not be excluded. Therefore, a new drilling programme in the central part of the Greenland ice sheet was needed.

Europe has a number of influential glaciological laboratories which are leaders in important aspects of ice-core analyses, as well as agencies which have the logistic infrastructure and expertise for polar operations. These laboratories, distributed throughout the continent, asked the ESF to provide an umbrella for a better collaboration. The general assembly of the ESF accepted in Autumn 1988 the “European Glaciological Programme” as an “European Science Foundation Associate Programme”. The first project defined within this programme was GRIP with the goal to investigate the climatic and environmental changes of the past 250,000 years by drilling and analysis of an ice core from the central part of the Greenland ice sheet.

Laboratories from eight European nations decided to participate in the project: Denmark, Switzerland, France, Germany, the UK, Italy, Iceland, and Belgium. An international SC provided guidance for the project with advice from a management group. Funding was provided by national funding agencies of the participating nations and by the EC.

The task for the logistics (transport, camp construction and maintenance) and for the drilling operation was contracted to the GRIP Operation Center (GOC), established for this purpose at the Geophysical Institute of the University of Copenhagen, Denmark.

Fieldwork started at Summit (72°37′33″N, 37°37′37″W) in summer of 1989 with the construction of the camp infrastructure. The ice cover at Summit is approximately 3,000 m thick, the mean annual air temperature -32°C and the present mean annual accumulation rate 0.21 m water equivalent. Summit was selected because:

- The location is on a summit at present and has not been far from a summit in earlier climatic epochs. This makes ice flow modelling easier
• The bedrock topography is relatively flat according to radar measurements, which simplifies ice flow modelling and age calculations and reduces the risk of stratigraphic disturbances

• Ice deposited during the transition from the last glaciation to the Holocene was expected to be found at about half the depth of the core, allowing investigation of this key period with a very good resolution

• The bedrock temperature never reached the ice melting point

• Extensive surface melting can be excluded based on the present low mean annual air temperature.

Drilling started in summer 1990 and was continued during the summer field seasons 1991 and 1992. A version of the drill ISTUK, constructed in Denmark and used already by the Danish/Swiss/US GISP at Dye 3, was used. ISTUK is an electromechanical drill, 11 m long. During drilling it hangs on a thin steel cable. The drill hole has to be filled with a thin oil of the same density as the ice to counteract the hydrostatic pressure, which would otherwise quickly close the hole. The functions of the drill are controlled by electrical signals transmitted through thin wires in the cable to a microprocessor in the drill itself.

During hoisting and lowering the drill (which at great depth takes 50 minutes each way) a charging current is sent through the same wires to the batteries in the drill. These batteries carry the power needed for the actual drilling. This arrangement allows use of a cable of only 7.2 mm diameter. Once the drill has been brought up again, it is tilted into horizontal position for easy maintenance and core removal.

The average progress was 150 m a week, and the core came up in sections of 2.4 m at a time. In the 1990 field season ISTUK reached a depth of 710 m, where the ice is 3840 years old. In 1991 it reached 2320 m depth, where the ice is approximately 40,000 years old, and on 12 July 1992, drilling was stopped at a depth of 3028.8 m, because the cutting knives were destroyed by hitting gravel and stones close to the bottom. The last core sections were yellow with bedrock material.

One of the characteristic features of GRIP was that a whole sequence of analyses on the ice cores was performed immediately in the field. Measurements in the field were done to select samples for special and very urgent analyses and to minimize the risk of contamination, such as from formaldehyde, ammonium and organic acids. Continuous measurements along the core included dielectric properties and electrical conductivity (related to the concentration of hydrogen ions and total neutral salt) and the concentration of micro particles, ammonium, nitrate, hydrogen peroxide, formaldehyde and calcium. Many of these parameters show seasonal variations and allow identification of annual layers well down into the last glaciation. The analyses in the field had the additional advantage that the scientists from the various laboratories had the opportunity to work closely together. The collaboration between the scientists was also stimulated by annual workshops, during which scientists had the opportunity to compare their results and to prepare common publications.
The US partner project, GISP 2, was underway 30 km west of Summit. The partner project was carried out with similar objectives to those of GRIP. The collaboration between the two projects in the field was strong and helped to maximize economies for both projects. To ensure collaboration between the scientists for the ice-core analyses and the interpretation of results, the steering bodies of the two projects decided to organize two common workshops. The first was held in April 1993 in Annecy, France, the second in September 1995 in Wolfeboro, New Hampshire, USA.

The scientific results have been published primarily as individual articles in international scientific journals. Several of the articles have received great attention by the larger scientific community. References and abstracts are available from the world wide web address:

www.nerc-bas.ac.uk/public/icd/grip/griplist.html

The results of the common GISP 2/GRIP workshops will be published in a special issue of the *Journal of Geophysical Research*. This special issue will give a very comprehensive overview of the results of both ice-core projects. In addition, collaboration between GRIP and GISP 2 scientists is planned in order to publish a monograph-style book to reach a wider audience.

The workshop in Wolfeboro brought the main phase of the GRIP project to an end. The remaining ice cores are stored in a cold room at the Geophysical Institute of the University of Copenhagen, Denmark. The ice-core curator and an advisory committee will ensure that they are used according to the GRIP guidelines.

**Selected Results**

The $\delta^{18}O$ records confirm large and rapid temperature oscillations through most of the last 110,000 years. They are of a scale which has not been experienced during the past 10,000 years, since the development of modern human society. A few of these stadial/interstadial oscillations, such as the YD cold period, have already been evidenced from pollen and other records. Similar evidence was also found in previous Greenland ice cores (Camp Century, Dye 3). However, for these earlier cores, most of the oscillations were found in ice close to bedrock where stratigraphic disturbances could not be excluded. In the Summit ice core the past 110,000 years are represented in ice far enough above bedrock to rule out such disturbances. The perfect agreement of the records of the GRIP and the GISP 2 ice cores down to this depth is further evidence for the climatic character of the $\delta^{18}O$ records. One of the more astonishing results is the very short time necessary for major warmings. For example, the ice-core data indicates that a temperature increase of 5°C can occur in as little as a few decades.

The $\delta^{18}O$ and $\delta^2H$ values of water vapour and water in air masses are depleted when moving to colder regions. In Greenland and in Antarctica, a linear relationship between the delta values of an annual snow layer and the local mean annual surface temperature is observed. This empirical linear relationship observed at present for locations with different surface temperature is the basis for reconstructing past temperature. The linear relationship can be explained qualitatively through simple Rayleigh type isotopic models, but there is no guarantee that exactly the same empirical relationship was valid in earlier climatic epochs. With the two ice cores from
Summit it is now possible to make a kind of calibration of the stable isotope based temperature records. Although it is influenced by heat conduction and heat produced by friction, the temperature at a certain depth in the borehole still reflects the surface temperature at the time the layer was deposited as snow. Borehole temperatures lack the high time resolution of isotopic records, but they are relatively insensitive to factors other than surface temperature at the time of snow deposition. The idea of this calibration is not new, but it can only be applied with accuracy when the ice providing evidence for the transition from the last glaciation to the Holocene occurs far above bedrock. Two independent calibrations, using separate data sets and different techniques, agree closely in yielding much larger glacial-interglacial temperature changes than assumed based on the delta records and the present relationship between delta values and temperature. The temperature increase from the coldest part of the last glaciation to the Holocene is about 21°C, roughly double the value assumed based on a constant relationship between $\delta^{18}$O values and temperature. The question of whether only the long term variations follow a changed relation or whether the fast climatic variations are also larger than hitherto assumed remains open.

The fast climatic variations observed in the $\delta^{18}$O record of the Greenland ice cores would attract limited attention if they were of only local character. But, there is ample evidence that these fast climatic fluctuations are events which also affected regions far away from Greenland. There is a good correlation between some of the fast climatic variations observed in the Greenland ice cores and variations observed in deep sea sediment cores from the North Atlantic. Therefore, it is assumed that the deep water formation in the North Atlantic plays a key role in the fast climatic variations. However, the climatic signal is not only seen in the North Atlantic region. The fact that methane shows a good correlation with the variations, with high methane concentrations in mild periods, shows that low latitude regions (the main source for methane at this time) were also influenced by these fast variations. After the $\delta^{18}$O analyses performed on $O_2$ extracted from air bubbles demonstrated synchronicity between the time scales of Greenland ice cores and Antarctic ice cores, it became also evident that the major events also are recorded in the isotopic temperature record from the Vostok core, although with apparently smaller amplitude and more ramped appearance than in Greenland.

The CO$_2$ concentrations measured along the core also confirmed earlier findings: an increase of the atmospheric CO$_2$ concentration from about 200 ppmv at the end of the last glaciation to about 280 ppmv at the beginning of the Holocene and a drastic increase coinciding with the beginning of industrialization approximately 200 years ago. The section representing the last glacial period is similar to that from Dye 3 with elevated CO$_2$ concentrations during mild climatic phases (Dansgaard-Oeschger events). No CO$_2$ variations of the same magnitude are found in Antarctic ice cores and the differences are too large to be explained by interhemispheric atmospheric gradients. A possible explanation for the differences is a production of small amounts of CO$_2$ in the ice by acid-carbonate reactions (mainly in Greenland ice with its higher carbonate concentrations). This hypothesis requires further investigation.

Methane is an indicator of bioactivity with its main source in low latitude wetlands during the last glacial period and the early Holocene. Other parameters which are also bioindicators have been measured on the GRIP ice core, such as ammonium and
organic acids. The comparison of the records of these parameters is puzzling at present. The records deviate considerably from each other, indicating that each parameter is sensitive to other characteristics of bioactivity or influenced by variations in different regions. While methane shows a distinct concentration minimum during the YD period, NH₄⁺ shows a maximum. The source for methane is assumed to be all wetlands in low latitudes, the source for NH₄⁺ the soil bioactivity of parts of North America. The interpretation of these parameters is not well developed, but the investigations on the GRIP ice core show clearly that ice cores have the potential to provide information on past biospheric activity.

The GRIP ice-core data suggests that rapid climatic oscillations similar to those during the ice age persisted during the previous warm period (the Eemian period). The GISP 2 core also shows rapid oscillations during that period, but with different timing and character. Therefore, the question was raised if one or both cores are affected by stratigraphic disturbances. Careful physical examinations of both cores showed that significant structural disturbances occurred in both cores even above the depth where differences between the two cores were clearly evidenced (ca. 2,800 m below snow surface corresponding to an age of about 110,000 years). The results from methane and δ¹⁸O measurements on O₂ from bubbles and their comparison with results from Antarctic ice cores show that the ice is at least partly representing the Eemian period but they give also indications for stratigraphic disturbances affecting at least some of the rapid variations. However, an explanation in terms of stratigraphic disturbances is insufficient as long as ice flow modellers are not able to explain the mechanisms for such disturbances. This will be a difficult task, especially for the very short cold periods where the ice layer, with completely different characteristics, is only about 0.2 m thick. Scientists remain hopeful that much can be learned about the Eemian climate from the existing two cores through additional analyses. Ultimately, just as these cores were needed to validate the rapid oscillations observed already in the Camp Century and Dye 3 cores, a new core, where the Eemian period is farther above bedrock, will be needed to provide insights into some of these important questions.

Report prepared by Bernhard Stauffer

Contact:
Bernhard Stauffer
Institute of Physics
University of Bern
Sidlerstrasse 5
CH-3012 Bern
Switzerland
Tel: (41-31) 631 44 67
Fax: (41-31) 631 44 05
Email: stauffer@climate.unibe.ch
URL: www.nerc-bas.ac.uk/public/icd/grip//griplist.html
Focus II  
Activity 1  
Task 3b  
The Greenland Ice Sheet Project  
Two (GISP2) Ice-Core Record

(The GISP2 “Near Final” Report)

Project Leader: Paul Mayewski

Introduction

On 1 July 1993 the GISP2 project successfully completed drilling through the base of the Greenland Ice Sheet and another 1.55 m into bedrock at a site in the Summit region of central Greenland (72.6°N; 38.5°W; 3200 masl). In so doing GISP2 recovered the deepest ice-core record in the Northern Hemisphere (3053.44 m). GISP2 and its European companion project GRIP (the Greenland Ice-Core Project, sited 30 km to the east of GISP2), which penetrated the ice sheet to a depth of 3028.8 m one year earlier, have now developed the longest palaeoenvironmental record, >100,000 years, available from the Northern Hemisphere.

The Summit region has proven to be an ideal site from which to recover deep ice cores. The ~ -31°C mean annual air temperature at Summit and minimal occurrence of melt layers throughout the record assure the in situ preservation of a broad range of gaseous, soluble and insoluble measures of the palaeoenvironment. The ~ -9°C ice temperature measured at the base of the two cores assures that the ice sheet in this region is frozen to its bed. This in combination with only gently sloping local bedrock topography and surface siting close to the current ice divide minimize (but do not eliminate) the possibility of any ice flow deformation (other than vertical thinning), that would disrupt the original depositional order of the record. These conditions hold true for most of the thickness of the ice sheet in this region.

The δ¹⁸O of ice has classically provided the basic stratigraphy and palaeoclimatology of ice cores. Independent calibrations of the oxygen isotope-temperature relationship have been developed through the analysis of GISP2 borehole temperature, allowing conversion of isotope-derived surface-temperature histories to temperature-depth profiles. Grootes et al. (1993) measured the δ¹⁸O of ice in the GISP2 core and compared their record with the previously published record for GRIP. Down to a depth of 2790 m in GISP2 (corresponding to an age of about 110 ka BP) the GISP2 and GRIP records are nearly identical in general shape and in most of the details. The same interpretation was developed by Taylor et al. (1993a) based on a comparison of the electrical conductivity records from the two sites. The electrical conductivity of ice has been widely measured in ice-coring programmes because it allows the rapid characterization of certain chemical properties of the core.

The similarity of the GISP2 and GRIP records is compelling evidence that the stratigraphy of the ice is reliable and unaffected by extensive folding, intrusion, or hiatuses from the surface to 2790 m. This agreement (between the two cores separated by 30 km, or ~ 10 times the depth of each of the cores) provides strong support
for the climatic origin of even the minor features of the records and implies that investigations of subtle environmental signals (e.g., rapid climate change events with 1–2 year onset and termination) can be rigorously pursued.

**Dating GISP2**
The depth/age relationship for the GISP2 core has been developed from a variety of core parameters including: annual layer counting of visual stratigraphy; electrical conductivity; laser light scattering of dust; stable isotopes; major anions and cations; insoluble particles; $^{210}$Pb; total beta activity; $\delta^{14}$C from occluded CO$_2$; and ice dynamics modelling. The current, conservative, estimated age error is 2% for 0–11.64 ka BP, 5% for 11.64–17.38 ka BP years ago and 10% for 17.38–40.5 ka BP years ago. While the age scale back to 40.5 ka BP comes from a variety of techniques, below 40 ka BP the chronology comes from correlating GISP2 into the Vostok chronology of Sowers et al. (1993) derived using the $\delta^{18}$O of O$_2$. This approach to correlation invokes the fact that the $\delta^{18}$O of atmospheric O$_2$ varies with time but, at one time, is constant throughout the atmosphere. Recently, annual layer counts based on visual stratigraphy and solid laser light scattering have been extended back to ~110 ka.

**GISP2 Measurements**
As evident in Table 1 (pages 126–127) a variety of projects and a total of 42 types of measurements comprised the GISP2 deep drilling effort as of the completion of drilling, and a total of nine additional projects provided direct information necessary for the interpretation of the resultant record (e.g., atmospheric sampling, automatic weather stations, surface glaciology, modelling). A general description of these activities has already been presented. For purposes of this report we will focus only on highlights of the environmental record thus far deduced.

**The Anthropogenic Era**
Previously identified increases in sulfate and nitrate seen in south Greenland ice cores and attributed to anthropogenic activity have been identified in the GISP2 core and contrasted to the pre-anthropogenic atmosphere. An observed increase in excess chloride at GISP2 as of the 1940s, is believed to be a by-product of the increased levels of anthropogenically-derived HNO$_3$ and H$_2$SO$_4$, since the latter are believed to aid in the volatilization of HCl from seasalt aerosol. Additional confirmation of the role that anthropogenic pollutants may have on perturbing the chemistry of the atmosphere comes from the coincidence of increased sulfate levels and depression of North Atlantic temperatures between ~1940–1970, which has been demonstrated by a comparison of GISP2, south Greenland and Yukon Territory ice cores with temperature change records.

Examination of a 217 m temperature profile developed from a site near the GISP2 borehole reveals a recent warming in near-surface firn which is within the range of natural variability, providing no definitive evidence of anthropogenically-induced greenhouse gas warming.

**The LIA and MWP**
The Little Ice Age (LIA) and Medieval Warm Period (MWP) environments (the most recent analogs for conditions cooler and warmer, respectively, than the present century) can be characterized by interpreting the multi-parameter GISP2 series (e.g.,
CO₂, stable isotopes, major ions, accumulation rate, particles). The LIA appears to span the period ~AD 1350 or 1450 to ~AD 1900 depending upon measurement type (since each may respond to climate change differently).

GISP2 temperature records modelled from oxygen isotopes reveals a relatively subdued temperature effect at this site for the LIA period. However, year-to-year correlations between the GISP2 isotopic record and sea surface and land temperatures over the North Atlantic, covering the period AD 1840–1970, have revealed changes in atmospheric circulation patterns, such as the seesaw pattern of the North Atlantic Oscillation, demonstrating the sensitivity of the isotopic record. Accumulation rate, which is indicative of transport distance from the open ocean plus temperature en route, is generally lower during the LIA than the MWP.

Levels of continental source dusts and marine seasalts increased during the LIA in response to increased meridional circulation. The LIA is one of several glacio-chemically identifiable climate events in the Holocene record that correlate with other palaeoclimate records and interestingly the LIA is characterized by the most rapid onset of any of these Holocene cold periods.

Initial measurements of CO₂ in air bubbles of the GISP2 core indicate that between AD 1530–1810 atmospheric CO₂ levels remained relatively constant at 280+/- ppmv. After this period concentrations rise rather abruptly and smoothly connect to the atmospheric observations at Mauna Loa.

Non-seasalt (nss) sulfate (reflecting primarily volcanic source SO₂) does not appear to be a major forcing agent on multi-decadal scale climate. Individual volcanic event signatures have been studied in the GISP2 core by the measurement of electrical conductivity and the presence of both volcanic source sulfate and particles. Examples of specific events that have been described include: local eruptions (e.g., the AD 1362 Oraefajokull (Iceland) eruption, Palais et al. 1991), intrahemispherically distributed eruptions (e.g., the AD 1479 Mt. St. Helen’s (Washington) eruption, Fiacco et al. 1993) and interhemispherically distributed eruptions (e.g., the AD 1259 eruption possibly produced by El Chichon (Mexico), Palais et al. 1992). Zielinski et al. (1994) provide a complete description of the Holocene volcanic event history developed from continuous, high resolution sampling of sulfate in the GISP2 record, which is now available for the entire 110 ka record (JGR Special Issue 1997).

The YD and Other Rapid Climate Change Events Over the Last 110 ka

The YD was the most significant rapid climate change event that occurred during the last deglaciation of the North Atlantic region. Previous ice-core studies have focused on the abrupt termination of this event because this transition marks the end of the last major climate reorganization during the deglaciation. Most recently the YD has been redated using precision, sub-annually resolved multivariate measurements from the GISP2 core as a 1300+/-70 year duration event that terminated abruptly, as evidenced by an ~7°C rise in temperature and a twofold increase in accumulation rate, at ~11.64 ka BP. The transition into the Preboreal (PB), the PB/YD transition, and the YD/Holocene transition were all remarkably fast, each occurring over a period of a decade or so.
The isotopic temperature records show 23 interstadial (or Dansgaard/Oeschger) events first recognized in the GRIP record and verified in the GISP2 record, between 110–15 ka BP. These millennial-scale events represent quite large climate deviations: probably many degrees C in temperature; twofold changes in snow accumulation; order-of-magnitude changes in wind-blown dust and sea-salt loading; roughly 100 ppbv in methane concentration, etc.; and with cold, dry, dusty, and low-methane conditions correlated.

These events are regional to global since they are observed in local climatic indicators such as snow accumulation rate and the isotopic composition of snow linked to temperature; in regional climatic indicators such as wind-blown sea salt and continental dust; and in regional-to-global indicators such as atmospheric concentrations of methane, nitrate and ammonium. Some events are readily identified in the ocean-sediment record in regions critical to global ocean circulation. Furthermore, new correlation techniques involving the gaseous composition of the atmosphere demonstrate that the major events also are recorded in the isotopic temperature record of the Vostok core from central East Antarctica, although with apparently smaller amplitude and a more ramped appearance than in Greenland.

**GISP2 and GRIP Records Prior to 110 ka BP**

The climatic significance of the deeper part of the GISP2 ice core, below 2790 m depth and 110 ka BP age, is a matter of considerable investigation and controversy. The isotopic temperature records and electrical conductivity records of GISP2 and GRIP, so similar for younger ice, are very different in the lower part. Ice in GISP2 below 2790 m depth is folded and tilted, and shows evidence of unconformities. The \( \delta^{18}O \) of O\(_{2}\) in GISP2 above 2790 m matches almost perfectly with the Vostok record; below it is far noisier and the smoothed Vostok signal cannot be aligned with GISP2. These features all suggest that ice age changes discontinuously in the deepest part of GISP2 as a result of folding, extensive boudinage (squeezing out of layers of ice), and/or intrusion. Bender *et al.* (1994) concluded that the bottom ~ 200 m of ice at GISP2 may be correctly ordered but discontinuous and extremely condensed, perhaps extending back to several hundred ka BP. Alternatively, the core may contain a disordered sequence of much younger ice, perhaps largely from marine stages 5c–5e (about 115–130 ka BP).

Initially the climate proxy records from the deepest part of the GRIP ice core were interpreted as being properly ordered and continuous. They observed large and rapid changes in isotopic temperature with depth and concluded that these features represented rapid changes in climate during marine isotopic stage 5e, the warmest part of the previous interglacial period. Such a conclusion has extremely important implications for climate because, together with the Dansgaard-Oeschger events, it suggests that rapid cooling events are possible during the current interglacial period. Evidence for rapid climate change during Stage 5e rests on the assumption that the deep part of the GRIP ice core is continuous, in contrast to GISP2. GRIP is located over the present ice divide, while GISP2 is 30 km to the west. Therefore GRIP may in fact be more likely to be continuous, although a recent modelling study has shown that the divide itself has probably migrated. Continuity of the deep part of the GRIP core has not yet been definitively demonstrated. Until this is done by demonstrating that gas composition records at GRIP are identical with those at Vostok or by some other approach, the evidence for rapid climate change in Greenland during the last interglacial remains equivocal.
What Next?

With the completion of the two ice-coring programmes (GISP2 and GRIP) in Summit Greenland, a new era in palaeoenvironmental investigation has been opened. These records are of extreme significance to our understanding of environmental change because they not only provide the highest resolution, continuous, multi-parameter view produced thus far but, as importantly, the two records can be used to validate each other (e.g., dating, presence of events, length of the environmental record, presence or lack of discontinuities), the only such experiment of this magnitude in ice-core research.

Now that the longest ice-core record from the Northern Hemisphere is a reality, it is time to develop new ice-core records for the Southern Hemisphere and fill in regional details across the Earth. Future deep drilling in the Antarctic promises new approaches to our understanding of environmental change. For example, the recovery of ice cores from Antarctic sites with accumulation rates similar to those at GISP2 (e.g., interior West Antarctica) will provide equivalent (continuous, high resolution and multi-parameter) and comparable records from which bipolar studies of climate change (response and forcing) can be investigated. In addition, the recovery of ice cores from Antarctic sites with lower accumulation rates and thicker ice than that at GISP2 (e.g., interior East Antarctica) will eventually provide the longest ice-core records (spanning several glacial/interglacial cycles) available on Earth. In addition to planning future GISP2/GRIP scale deep drilling efforts in Antarctica it is imperative that ice-coring activities also continue throughout the Arctic (e.g., north Greenland, the Arctic Islands) and low to middle latitude/high elevation sites (e.g., Asia and South America). These efforts will be essential to our understanding of regional scale climate change events and to the eventual linkage to existing ice-core records.

Acknowledgements

We thank the Office of Polar Programmes, US NSF for their support and encouragement, the Polar Ice Coring Office of the University of Alaska, Fairbanks for drilling and logistic support, the 109th Air National Guard (Scotia, New York, USA) for many years of close cooperation, support and enthusiasm, the GISP2 Science Management Office of the University of New Hampshire, USA, for their scientific and logistic coordination and our GRIP colleagues for the seasons we shared as neighbours in central Greenland. The Greenlandic and Danish Governments kindly granted permission for GISP2 to work in Greenland. Finally we would like to thank all of our GISP2 colleagues (scientists, drillers, support crews) for their unflinching dedication, efforts and camaraderie over the duration of the GISP2 field reconnaissance (1987–1988) and drilling seasons (1989–1993).
Appendix A

Surface Investigations Related to the Summit Ice Cores

The GISP2 and GRIP deep drilling programmes at Summit, Greenland, included support (both logistical and scientific) of extensive investigation of atmospheric transport and air-snow exchange processes of gases and particles relevant to the interpretation of the ice-core records (Table 2, page 128–129). Much of the sampling for these investigations was conducted at a unique solar-powered camp and was characterized by a high degree of international cooperation.

During the early phases the focus was primarily on aerosol-associated species and their incorporation into the snow plus studies related to the spatial distribution of chemical species and understanding stable isotope, chemical and physical signals in aerosols and snow. Since 1993 increasing effort has also been devoted to the bi-directional exchange of several reactive gases between air and snow. Parallel study of the exchange of mass and energy driving early metamorphism of the snowpack has allowed development of models (ranging from simple empirical estimation up to full 3-dimensional representation of the top few metres of the firn) to simulate the coupled exchange of energy and mass (of water and reactive chemical species) between the atmosphere and snow. At present, we can predict seasonal concentrations of several species in the snowpack, given prescribed atmospheric concentrations and conditions, to well within a factor of two. The more important (and difficult) inverse problem is the next step.

Results of these investigations have been presented in more than 40 papers to date. Recent review papers summarize and provide access to this growing body of literature (Mayewski et al. 1994, Jaffrezo et al. 1995, Dibb 1996, Dibb and Jaffrezo 1996). Field data and modelling results are archived on an ftp server maintained at the University of Arizona, USA. Access is presently limited to the group of active investigators. We are transferring data to the National Snow and Ice Data Center (NSIDC) as the data sets are published and expect that all of the data will eventually reside at this public archive.

The investigators of air-snow exchange were active participants in the annual GISP2 and GRIP workshops and in the joint workshops in Annecy (France) and Wolfeboro (USA). We have continued to hold annual workshops since the successful completion of the drilling projects, meeting in Tucson, USA, in 1994 and Cambridge, UK, in 1995. We were also well represented at the NATO ARW on “Processes of Chemical Exchange between the Atmosphere and Polar Snow” at Il Ciocco in March, 1995.

Key References

Dibb, J.E. 1996. Overview of field data on the deposition of aerosol-associated species to the surface snow of polar glaciers, particularly recent work in Greenland. Chemical Exchange Between the Atmosphere and Polar Snow. E. Wolff and Roger C. Bales (eds), NATO ASI Series 43:249-274.


---

Report prepared by Paul Mayewski

**Contact:**
Paul Mayewski
Climate Change Research Center
Institute for the Study of Earth, Oceans, and Space
University of New Hampshire
Durham, NH 03824
USA
Tel: (1-603) 862 3146
Fax: (1-603) 862 2124
Email: paul_mayewski@grg.sr.unh.edu
Figure 4

Inside the GISP2 drill dome, logging the ice core. Courtesy of GISP2 (project leader; Paul Mayewski).
Figure 5

GISP2 drill dome at Summit, Greenland. Courtesy of GISP2 (project leader; Paul Mayewski).
## Table 1

### GISP2 Activities.

<table>
<thead>
<tr>
<th>Investigators</th>
<th>US Institutions</th>
<th>Properties</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alley, Richard</td>
<td>Penn State Univ.</td>
<td>Physical properties of core. Continuous visual logging of core, density, texture, and fabric</td>
</tr>
<tr>
<td>Bales, Roger</td>
<td>Univ. of Arizona</td>
<td>Snow-atmosphere transfer function for hydrogen peroxide</td>
</tr>
<tr>
<td>Barry, Roger</td>
<td>Univ. of Colorado</td>
<td>Data storage and public distribution</td>
</tr>
<tr>
<td>Armstrong, Richard</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bender, Michael</td>
<td>Univ. of Rhode Island</td>
<td>Occluded gas analyses. $\delta^{18}O$ of $O_2$, $\delta^{15}N$ of $N_2$, $O_2/Ar$ ratio, $N_2/Ar$ ratio</td>
</tr>
<tr>
<td>Bolzan, John</td>
<td>Ohio State Univ.</td>
<td>Regional surface strain net, velocity, accumulation, ice flow modelling</td>
</tr>
<tr>
<td>Borys, Randy</td>
<td>Desert Research Institute</td>
<td>Crystal habits and rime chemistry</td>
</tr>
<tr>
<td>Boyle, Ed</td>
<td>MIT</td>
<td>Trace metal chemistry</td>
</tr>
<tr>
<td>Craig, Harmon</td>
<td>Scripps Inst. of Oceanog.</td>
<td>Helium isotopes</td>
</tr>
<tr>
<td>Davidson, Cliff</td>
<td>Carnegie Mellon Univ.</td>
<td>Major ions and trace metals of aerosols and snow</td>
</tr>
<tr>
<td>Dibb, Jack</td>
<td>Univ. of New Hampshire</td>
<td>Radionuclides in aerosol and snow</td>
</tr>
<tr>
<td>Gow, Tony</td>
<td>Cold Regions Research and Engineering Laboratory</td>
<td>Physical properties of core, Annual layering, core relaxation mechanisms, precision density measurements, crystal fabrics and basal debris</td>
</tr>
<tr>
<td>Meese, Debra</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Groote, Pieter</td>
<td>Univ. of Washington</td>
<td>$\delta^{18}O$ record of ice</td>
</tr>
<tr>
<td>Stuiver, Minze</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hodge, Steve</td>
<td>US. Geological Survey</td>
<td>Airborne ice radar determination of the surface and bed topography</td>
</tr>
<tr>
<td></td>
<td>St. Olaf College</td>
<td></td>
</tr>
</tbody>
</table>

Cont ...
<table>
<thead>
<tr>
<th>Name</th>
<th>Institution</th>
<th>Contributions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mayewski, Paul *</td>
<td>Univ. of New Hampshire</td>
<td>GISP2 Science Management Office</td>
</tr>
<tr>
<td>Mayewski, Paul *</td>
<td>Univ. of New Hampshire</td>
<td>Major anions and cations, total acidity, and ionic balance</td>
</tr>
<tr>
<td>Mosher, Byard</td>
<td>Univ. of New Hampshire</td>
<td>INAA analysis of aerosols and snow</td>
</tr>
<tr>
<td>Nishiizumi, Kunihiko*</td>
<td>Univ. of California -Berkeley</td>
<td>Cosmogenic Radionuclides, $^{10}\text{Be}$, $^{26}\text{Al},^{36}\text{Cl}$</td>
</tr>
<tr>
<td>Arnold, James *</td>
<td>Lawrence Livermore Lab.</td>
<td></td>
</tr>
<tr>
<td>Finkel, Robert *</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ram, Michael *</td>
<td>State Univ. of NY-Buffalo</td>
<td>Continuous particulate concentrations</td>
</tr>
<tr>
<td>Saltzman, Eric *</td>
<td>Univ. of Miami</td>
<td>Methanesulfonate (MSA) and iodine (iodide and iodate) in ice</td>
</tr>
<tr>
<td>Stearns, Charles</td>
<td>Univ. of Wisconsin</td>
<td>Automatic Weather Stations</td>
</tr>
<tr>
<td>Taylor, Kendrick *</td>
<td>Desert Research Institute</td>
<td>Continuous electroconductivity of core</td>
</tr>
<tr>
<td>Waddington, Edwin</td>
<td>Univ. of Washington</td>
<td>Temperature history inference from bore-hole temperature measurements, ice flow modelling, local strain net, ice flow velocity</td>
</tr>
<tr>
<td>Wahlen, Martin *</td>
<td>Scripps Inst. of Oceanography, Lamont-Doherty Earth Observatory</td>
<td>$\text{CO}_2$/Air ratios, $\delta^{13}\text{CO}_2$ in occluded gas, total gas content, CH$_4$ and N$_2$O concentrations, bubble volume</td>
</tr>
<tr>
<td>Broecker, Wallace *</td>
<td></td>
<td></td>
</tr>
<tr>
<td>White, James *</td>
<td>Univ. of Colorado</td>
<td>$\delta D$ ($^2\text{H}/^1\text{H}$ ratio) of ice</td>
</tr>
<tr>
<td>Wilson, Alex *</td>
<td>Univ. of Arizona</td>
<td>$^{14}\text{C}$ dating of core from occluded $\text{CO}_2$</td>
</tr>
<tr>
<td>Donahue, D. J. *</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wilson, Alex *</td>
<td>Univ. of Arizona</td>
<td>Concentration and $\delta^{13}\text{C}$ of $\text{CO}_2$ in occluded gas</td>
</tr>
<tr>
<td>Zielinski, Greg *</td>
<td>Univ. of New Hampshire</td>
<td>Insoluble particles. Mass concentration, size distribution, chemical composition, and morphology</td>
</tr>
</tbody>
</table>

* Denotes GISP2 deep drilling investigators
### Table 2


<table>
<thead>
<tr>
<th>Atmospheric Measurements</th>
<th>Principal Investigators</th>
</tr>
</thead>
<tbody>
<tr>
<td>Radionuclides ($^{210}$Pb, $^7$Be)</td>
<td>Dibb</td>
</tr>
<tr>
<td>Major anions / cations</td>
<td>Davidson/Jaffrezo</td>
</tr>
<tr>
<td>Organic acids</td>
<td>Legrand/Jaffrezo/Dibb/Davidson</td>
</tr>
<tr>
<td>Trace metals</td>
<td>Davidson/Jaffrezo/Boutron</td>
</tr>
<tr>
<td>Trace elements</td>
<td>Mosher/Colin/Winchester</td>
</tr>
<tr>
<td>MSA</td>
<td>Saltzman/Jaffrezo/Kuhns</td>
</tr>
<tr>
<td>Size fractionated aerosol chemistry</td>
<td>Saltzman/Maenhaut/Hillamo</td>
</tr>
<tr>
<td>Gas phase soluble acids</td>
<td>Legrand/Dibb/Talbot</td>
</tr>
<tr>
<td>PAH and heavy organics (aerosol and gas phase)</td>
<td>Masclet</td>
</tr>
<tr>
<td>Aerosol number</td>
<td>Baltsenperger/Bergin</td>
</tr>
<tr>
<td>Aerosol black carbon</td>
<td>Cachier/Hansen</td>
</tr>
<tr>
<td>Cloud condensation nuclei</td>
<td>Bodhaine/Bergin</td>
</tr>
<tr>
<td>Trace gases (O$_3$, CO, CO$_2$, CH$_4$, NMHC)</td>
<td>Rasmussen/Blake/Munger/Jacob</td>
</tr>
<tr>
<td>Reactive N (NO$_3^-$)</td>
<td>Munger/Jacob</td>
</tr>
<tr>
<td>H$_2$O$_2$, HCHO</td>
<td>Bales/Stauffer/Neftel</td>
</tr>
<tr>
<td>Hg (aerosol and gas phase)</td>
<td>Vandal/Boutron</td>
</tr>
<tr>
<td>Streaker sampling (year-round aerosol)</td>
<td>Heidam/Wahlin</td>
</tr>
<tr>
<td>Year-round Rn monitor</td>
<td>Wagenbach</td>
</tr>
<tr>
<td>Stable isotopes of Pb in aerosol</td>
<td>Rosmann</td>
</tr>
</tbody>
</table>

**Background Studies**

(Spatial, input timing, interrelationships) | Alley/Shuman |
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Grootes</td>
</tr>
<tr>
<td></td>
<td>Mayewski/Yang</td>
</tr>
</tbody>
</table>

**Fresh and Aing Snow Analyses**

Radionuclides | Dibb |
| Major anions / cations | Davidson/Jaffrezo/Dibb/Bergin |
| Trace metals | Boyle/Boutron |
| Trace elements | Mosher/Colin |
| Organic acids | Legrand/Jaffrezo/Dibb/Davidson |
| Microparticles | Zielinski |
| Carbon (total, soot, soluble) | Cachier |
| Stable isotopes (of water) | Grootes/White |
| PAH, heavy organics | Masclet |
| H$_2$O$_2$, HCHO | Bales/Stauffer/Neftel |
### Snow Related Studies

- **Snowflake habit**
  - Borys / Albert / Davis
- **Fog droplet size distribution**
  - Borys
- **Chemistry of occult deposition**
  - Borys / Davidson / Jaffrezo
- **Isotopic composition of vapor / fog / rime**
  - Grootes / White
- **Accumulation network**
  - Dibb / Jaffrezo / Gow / Meese
- **Snowpack microphysics**
  - Albert / Davis
  (permeability, energy budget)

### Meteorology

- **AWS network and echo sounder**
  - Stearns
- **Tether sonde profiling**
  - Kahl
- **Back trajectory calculations**
  - Harris / Kahl
- **Micrometeorology**
  - Albert / Davis / Munger / Jacob
  (energy balance, eddy correlation)
Introduction

Many climate models have suggested that the Arctic is one of the most sensitive regions of the globe to any anthropogenically-induced climate change. Continued modelling to further test this hypothesis and checks on the validity of past model runs should rely on boundary conditions established by the palaeoclimatic records available from throughout the Arctic region.

The ICAPP initiative is an international project that will use existing and newly obtained palaeoclimatic records from the circum-Arctic region, with particular reference to ice-core records, to evaluate the variability in past climate change on time scales ranging from hundreds to tens of thousands of years. In addition, more recent snow and ice sampling will allow for the evaluation of the magnitude and spatial variability of natural and anthropogenic pollutants reaching the Arctic. This will be useful in discerning transport paths to and circulation systems within the Arctic. In addition, detailed records of past climate change from the circum-Arctic may be readily linked to the PEP initiatives within PAGES. One of the basic concepts of ICAPP is that circumpolar climatic change will not be understood from the Greenland record alone. Smaller ice caps give lower resolution records but are essential to a broad-based understanding of the linkages between the polar and temperate regions.

History of the Programme

Over much of the last two decades, the collection of ice cores from the Arctic region outside of Greenland has been uncoordinated. The former Soviet Union has drilled cores from ice caps in Severnaya Zemlya and from Spitsbergen. Most of this work has been published in Russian and not in the international network of journals. These data need to be re-examined and some sites re-drilled. The Japanese National Institute of Polar Research (NIPR) has drilled cores from the Norwegian Arctic, Spitsbergen, and Greenland. The Glaciology group now with the Geological Survey of Canada has been responsible for the palaeoclimatic records derived from cores they drilled on Meighen, Devon and Agassiz (Northern Ellesmere Island) ice caps, providing the basis for much of our present understanding of climate change in the Canadian Arctic. The Glacier Research Group at UNH, USA, has been involved with the analysis and drilling of short ice cores from Mt. Logan, Yukon Territory and southern Greenland prior to their lead in GISP2.
The development of an international programme to evaluate the ice core based record of climate change across the Arctic resulted from meetings on a cooperative ice-coring project on the Penny Ice Cap, Baffin Island, among individuals in the Ter- rain Sciences Division of the Geological Survey of Canada (R. Koerner and D. Fisher), NRC of Canada (A. Kudo), and the Glacier Research Group of the UNH, USA (G. Zielinski, C. Wake, and P. Mayewski). An initial meeting to introduce the concept to interested members of the glaciological and palaeoclimatic communities was organized by R. Koerner and D. Fisher at the International Glaciological Society Symposium in Columbus, Ohio, USA, August 1994. The interest in ICAPP generated at this organizational meeting indicates the need and desire to formally develop composite palaeoclimatic record across the Arctic through the compilation and re-evaluation of all existing ice-core records and the collection of new ice cores. The concept was further discussed and presented initially by R. Koerner and O. Watanabe (NIPR, Japan) at a meeting of the working group on Glaciology of the IASC in Poland, October 1994, and again at the IASC/ICAPP meetings in Germany, December 1995. ICAPP was then included as a linked part of the IASC “Mass balance of Arctic Glaciers and Ice sheets in relation to Climate and Sea level change” (MAGICS) programme.

**Scientific Objectives**

The primary objective of ICAPP is to integrate all ice-core records (new and old) across the entire Arctic region into composite records that will define the spatial and temporal variability of climate change. These records will provide important information addressing climate variability within Temporal Stream I (last two millennia) and II (glacial/interglacial transition) of the PAGES programme. The driving force for the development of this programme is based on the premise that no single ice core from the Northern Hemisphere provides a complete picture of past climate change, especially on time scales through the Holocene. Individual objectives are as follows:

- To develop fundamental connections among the ice-core records from smaller ice caps throughout the Arctic and link them with those recently developed from the Summit region of Greenland (i.e., GISP2 and GRIP cores). Existing ice-core records will be re-examined and new ones obtained. The existing cores plus the new ones from Penny Ice Cap on Baffin Island, Academy of Sciences Ice Cap in Severnaya Zemlya, one from the Franz Josef Land and cores from Hans Tausen and NE Greenland will provide the information needed to more completely understand the spatial variability of changes across the entire region.

- To provide guidance to individuals working in the Arctic that will lead to the development of compatible data sets for comparisons between the eastern and western Arctic and along north-south gradients. Ice-core records may then be compared to other proxy data in the circum-Arctic region; for example to tree-ring chronologies and Arctic lake records. Detailed correlations drawn between continuous records derived from the Palaeoclimates of Arctic Lakes and Estuaries (PALE) initiative and ICAPP further typifies the cooperative research opportunities available through ICAPP.
• To construct detailed records of episodic events that may have a short, but intense, influence on the climate and other aspects of the Arctic atmosphere, for example explosive volcanic eruptions and large biomass burning events. Compiling spatially and temporally extensive records of such events as available from ice cores and surface snow studies will be critical to establishing their widespread effects on the Arctic environment.

• To establish the existence of discernible climatic events (like the Little Ice Age) and possibly establish the changes in the intensity of their signals across the region. Newly-developed statistical methods applied to all ice-core time-series, including existing data sets, will greatly enhance the ability to identify time periods with consistent signals.

• To determine the present distribution of parameters to be studied in the ice cores and fully utilize the ice-core records in our palaeoclimate reconstructions. A survey of pollen, chemistry, microparticle, stable isotope, and trace metal fluxes in the surface snow pack on five Russian Arctic island ice caps, four sites on the Arctic Ocean sea ice between Russia and Canada and on six Canadian ice caps is presently under way. This survey has been extended in 1996 and in 1997.

• To determine the effect of Laurentide ice sheet surges (Heinrich events). The only part of this ice sheet remaining today is towards the base of the Barnes Ice Cap. A core from this ice cap could provide vital information (along with that from Penny Ice Cap) of the nature of these events.

• To determine ice-cap topography and thickness for ice-core interpretation and drill site selection. NASA (R. Thomas) extended its Greenland airborne, laser altimeter/radar ice-depth sounding to the Canadian ice caps in spring 1995. NASA plans to extend the flights to the Russian ice caps covered under ICAPP.

Implementation

Methodology — Ice-Core Parameters

• Ice caps in the circum-polar area withstand a varying degree of surface summer melting. Study of ice layering in the cores provides a detailed picture of summer climate changes to complement the traditional stable isotope (annual temperature) approach.

• Major ion suites measured in ice cores are representative of the majority of the chemical compounds found in the atmosphere. The development of robust statistical techniques to deconvolute the various sources of individual ion species in a single sample as well as identify the relationships among all ions measured within these multiparameter data sets has greatly improved the environmental records available from the chemical time series. Discrete events, such as volcanic eruptions and biomass burning events, are recorded by anomalous peaks in specific ions or groups of ions.

• Insoluble microparticles provide extremely detailed information on palaeo-environmental conditions that affect continental dust transport to the polar ice caps.
• Quick scanning of major parameters in ice cores is now available using modern technology. Changes in the acidity, conductivity (both liquid and solid), and microparticle concentrations in the cores can be determined ‘on site’. These measurements provide pointers to events or periods of interest that require measurements of the complete ion suite.

• Studies of the temporal and spatial variability of pollen found in ice cores has not been readily undertaken in the past. The results of the proposed analysis of pollen by the GSC will be used to postulate changes in latitudinal tree line relative to the particular coring site and provide details on the presence of tracer-species that may be used to discern changes in circulation patterns.

• Dating of cores from small ice caps is more problematic than those from the dry snow zone elevations of Greenland and Antarctica. Radiometric methods will be used; Canadian National Research Council (NRC) has developed a new approach in the previously undatable basal layers based on a combination of the $^{36}\text{Cl} / ^{129}\text{I}$ ratio and $^{36}\text{Cl}$ using the Atomic Energy of Canada Accelerated Mass Spectrometer. Bedrock will be cored (University of Arizona, USA) to date the time of ice-cap inception, again using $^{36}\text{Cl}$.

• Stable Isotopes (Oxygen-18) will be analyzed at the Geophysical Isotope Laboratory of the University of Copenhagen, Denmark. The $^{18}\text{O}$ series is the primary time series against which other parameters are interpreted. Co-isotopes ($^{18}\text{O}$ and deuterium) will be done by the Geology Department of the University of Ottawa, Canada.

**Principal Organizations that have Expressed Interest in ICAPP**

**Canada**
- Geological Survey of Canada (GSC): Koerner; Fisher; Bourgeois
- National Research Council (NRC): Kudo; Zheng

**USA**
- Climate Change Research Center, Institute for the Study of Earth, Oceans, and Space, University of New Hampshire (UNH): Mayewski; Wake; Zielinski
- Byrd Polar Research Center, (Ohio State University): Thompson; Mosely-Thompson
- National Aeronautics and Space Association (NASA): Thomas (PARCA)

**Japan**
- National Institute of Polar Research (NIPR): Watanabe
- Nagaoka Institute of Snow and Ice Studies (NISIS): Goto-Azuma

**Russia**
- Arctic and Antarctic Institute, St Petersburg (AARI): Savatyugin; Potapenko
- Institute of Geography, Russian Academy of Sciences (IG): Glazovski

**Germany**
- Alfred Wegener Institute (AWI): Miller; Hubberton
Denmark
Geophysical Isotope Laboratory, University of Copenhagen (GIL): Hammer

UK
British Antarctic Survey (BAS): Pasteur

Proposed and Completed Ice-Cap Sites

Canada
- Penny Ice Cap: Surface-to-bed core April/May 1995. The GSC drilled 334 m to the bed on Penny Ice Cap. UNH, NIPR, NISIS, AARI participated in the field. A second borehole to 180 m was drilled from a separate top-of-the-flow-line site in April 1996 by the GSC with NISIS and NIPR from Japan. Both cores are being analysed by the cooperating agencies
- Barnes Ice Cap: A prospective site to examine Heinrich event effects in the remnants of the Laurentide ice sheet near its base. To be drilled by the GSC.

Spitsbergen
- Vestfonna; May 1995: NIPR, Japan, drilled a borehole in this ice cap in May 1995. They are completing the core analysis in house.

Russia
- Franz Josef Land: An ice core was drilled from Graham Bell Ice Cap, July/August 1996 in a cooperative project between the Byrd Polar Research Center, (USA) and the Institute of Geography (Moscow). The project has already taken and analysed shallow cores from some of these ice caps for multi-parameter analysis
- The Academy of Sciences Ice Cap (Severnaya Zemlya) was drilled in 1987, but the various agencies will undertake to drill a new core using an AARI drill. This drill will be built specifically for this project using funding from some of the ICAPP agencies. The GSC has already completed surface studies at a prospective site where an automatic weather station was established in 1993.

Greenland
- Part of the European Science Programme plans. The GIL (Denmark) have requested inclusion of their proposed Hans Tavsen and NE Greenland cores under the ICAPP umbrella.

Project Management and Resources
ICAPP was included in the plans of the IASC at a general IASC meeting in Hannover, Germany, in 1995. Presently the funding of joint projects like the Penny drilling are made by independent application of the groups to their domestic funding agencies. The Penny operation was well funded by the participating groups at levels proportional to their scientific/logistical input. This approach to funding will continue to be used.
The logistics, drilling and analyses of samples for this project cost a total of $950k (USD), including salaries. About 70% of the analysis work has been completed by March 1996. An ICAPP workshop was held in Ottawa, Canada, in June 1996 to discuss and plan the publication of the results from the 1995 Penny Ice Cap drilling.

Report prepared by R.M. (Fritz) Koerner and David A. Fisher

Contacts:
R.M. (Fritz) Koerner and David A. Fisher
Terrain Sciences Division
Geological Survey of Canada
601 Booth St, Ottawa Ontario K1A 0E8
Canada
Tel: (1-613) 996 7623
Fax: (1-613) 996 5448
Email: koerner@gsc.emr.ca, fisher@emr.ca
Figure 6

Drilling for the ICAPP in Northern Canada. Courtesy of ICAPP (project leader; R.M. Koerner).
SCAR Global Change Programme Office
Antarctic CRC, University of Tasmania, Hobart, Tasmania, Australia

Focus II
Activity 2  Antarctic Programmes

Introduction
Antarctic programmes are jointly sponsored by PAGES and SCAR’s Global Change in Antarctica (GLOCHANT). Hence their scientific agendas are determined from the objectives of both organisations. However, SCAR has the responsibility under ICSU for the organisation of scientific programmes in the Antarctic, and through its close relationship with the Council of Managers of National Antarctic Programmes (COMNAP) determines strategies for the implementation and logistic support of these scientific programmes, largely through the resources of SCAR national and multi-national projects. Thus individual projects must first obtain national approval and eligibility for logistic support to work in the Antarctic. Projects that are proposed for remote locations in the ice sheet interior, or in coastal locations far from established bases, require long planning times and often multi-national support before they can be implemented.
Focus II
Activity 2
Task 1 International Trans-Antarctic Scientific Expedition
On 200 Years of Past Antarctic Climate and Environmental Change (ITASE)

Project Leader: Paul Mayewski
Project Coordinator: Ian Goodwin

Introduction
The broad aim of ITASE is to establish how the modern atmospheric environment (climate and atmospheric composition) is represented in the upper layers of the Antarctic ice sheet. Primary emphasis is placed on the last ~200 years of the record. This time period was chosen for study because it is relatively simple to recover many ice cores covering this period on oversnow traverses, and to develop a spatially significant study. Even more importantly, this time period covers the onset of major anthropogenic involvement in the atmosphere, and the end of the LIA.

History of the Programme
The ITASE programme was endorsed by the SCAR Working Group on Glaciology and approved by the XXII SCAR Delegates at Bariloche (Argentina) in 1992, and was subsequently endorsed by SCAR Delegates as a core programme of SCAR-GLOCHANT in August 1996. ITASE was formally approved and adopted by PAGES within Focus II on Antarctic Palaeoenvironments. It is also forms a contribution to IGAC under their focus on Polar Atmospheric Snow and Chemistry (PASC), and it links to Southern Ocean Joint Global Ocean Flux Study (SO-JGOFS) and potentially to WCRP-CLIVAR. Some ITASE oversnow traverses have been completed by national programmes, including those of the Chinese, British and the Swedish/Norwegian programmes, since 1992.

An international ITASE workshop was held in Cambridge, UK, 2–3 August 1996, prior to XXIV SCAR. The workshop was cosponsored by PAGES, GLOCHANT, and the US NSF. The purpose of the workshop was to develop a science and implementation plan. This plan (PAGES Workshop Report 97-1) is now available from the PAGES IPO.
Rationale and Scientific Objectives

Antarctica plays a critical role in the dynamic linkages that couple the spatially and temporally complex components of the Earth system (atmosphere, biosphere, anthroposphere, hydrosphere, cryosphere, lithosphere and cosmogenic input). However, our knowledge of the functioning of Antarctica within the global system and of the spatial and temporal complexity of Antarctic climate is poor. This is largely due to the limited quantity and the short period of observational and instrumental data on Antarctic climatic variables, collected over the last 30–40 years. Fundamental questions unresolved by the instrumental record include: How typical of Antarctic climatic history are the last 30–40 years? Has Antarctica experienced a typical spatial climate pattern over the last few centuries to thousands of years, as suggested for other regions of the globe (e.g., the LIA and MWP).

To complicate matters, Antarctica exhibits significant regional contrasts in present day climate. As an example, evidence from instrumental records suggest some decoupling of climate change on decadal scales between different parts of the continent. Large areas of the interior of the ice sheet are influenced by the continental temperature inversion while other portions of the interior and the coastal regions are influenced by the incursion of cyclonic systems that circle the continent. As a consequence, these coastal regions are mainly connected with lower tropospheric transport whereas high altitude regions in the interior are more likely influenced by vertical transport from the upper troposphere and stratosphere. As a result the coastal regions experience higher climatic variability than those regions in the interior.

Ice-coring studies have shown that Antarctica has experienced millennial to decadal scale climatic variability associated with changes in temperature, snow accumulation, wind-blown dust, sea-salt loading and methane composition. Such studies have highlighted the possibility that dramatic shifts in the patterns of atmospheric circulation may explain the rapidity and magnitude of the change in the above parameters. High frequency climatic changes also occur on interannual timescales, and have been attributed to the ENSO and other regional to global scale factors that are associated with atmospheric blocking, sea-ice variations and volcanic event induced shielding.

ITASE is focused on fundamental issues of spatial and temporal climatic variability, through the key scientific objectives:

- To determine the spatial variability of Antarctic climate (e.g., snow accumulation, air temperature, atmospheric circulation) over the last 200 years and where possible 1000+ years. These variations include: extreme events such as volcanic eruptions, dust storms, drought; major atmospheric phenomena (e.g., ENSO); and snow accumulation variations. This comprehensive programme for the continent of Antarctica will provide an unrivalled, extended climatic depiction for the world’s major atmospheric heat sink, a land mass comprising 10% of the Earth’s land surface.

- To determine the environmental variability in Antarctica over the last 200 years and where possible 1000+ years. Environmental proxies could include: sea ice variation, ocean productivity, anthropogenic impacts, and other extra-Antarctic continental influences. Because of the remoteness of the continent, Antarctica is an ideal location to monitor biogeochemical cycles and global scale changes.
In fulfilling these objectives ITASE will: (i) produce continental scale “environmental maps”; (ii) elucidate transfer functions between components of the atmosphere and snow/ice; (iii) verify atmospheric models; and (iv) interpolate spatial time-series determined from satellite remote sensing.

Implementation

ITASE intends, over a period of several years, to sample an extensive geographic area of the Antarctic ice sheet, including many of the proposed drilling sites and a sampling of much of the topography and climate of the Antarctic ice sheet. The field planning of ITASE has been designed to build upon existing national programmes and their plans for oversnow traverses for the period 1996–2002. The majority of proposed traverse routes are already planned to establish and resupply the deep drilling programmes. In this manner ITASE plans to build upon traverses of ‘opportunity’ for the collection of shallow ice cores at intervals of 100 km along these routes. A major product of ITASE will be a continental-scale map of several environmental parameters. This surface coverage will be extended over the time domain (~200 years) by a series of cores collected every ~100 km along selected traverse routes. Several segments of the overall traverse plan may be conducted during a single season. The preliminary oversnow traverse plan is shown in Figure 8.

Several key properties have already been identified as part of the sampling programme: chemistry (major anions and cations, H$_2$O$_2$, trace metals); isotopes; 10 m temperatures; stratigraphy; and high resolution radar and gravity. Additionally, traverses could include the installation of automatic weather stations (AWS), and the measurement of properties (e.g., dielectric, reflectivity) and deployment of experiments valuable for providing ground truth in remote sensing missions.

Participants at the 1996 international workshop in Cambridge, UK, determined that ITASE should comprise four research phases, as follows:

Phase 1: Remote sensing, meteorology, geophysics.
Phase 2: Ground-based sampling (e.g., ice cores, snowpits, ground truth, high resolution snow radar).
Phase 3: Associated studies (e.g., surface glaciology, AWS deployment, aerosol monitoring).
Phase 4: Modelling and interpretation.

Proposed Ice Core Measurements

It was agreed that a standardized suite of measurements would be collected from surface snow samples and shallow ice cores on oversnow traverses.
Table 3

Standardized ITASE ice core properties.

Accumulation rate
Gamma-ray and beta detection
Electrical conductivity measurements (ECM)
Physical properties (size, shape, arrangement of grains, c-axis fabrics, depth-density analyses, melt layers, visible strata)
Stable isotopes (δD, δ18O and deuterium excess)
Major chemistry (Ca, Mg, Na, NH₄, K, Cl, SO₄, NO₃)
Microparticles
Other chemistry (F, I, Br, MSA, H₂O₂, HCHO)
Temperature

Table 4

ITASE opportunities for research.

Cosmogenic isotopes (¹⁰Be, ³⁶Cl, ²⁶Al)
Radionuclides
Tephra
Trace metals (Se, Pb, Hg, V, Mn)
Trace elements (Cs, Rb, Ba, Sr)
Isotopes (Nd, Sr, Pb)
Gases (CO₂, CH₄, N₂O, CFCs, CO, methyl-halides)
Biological particles (pollen, diatoms)
Biogenic compounds (DMSO, DMSO₂)
Organic acids
Figure 7

Figure 8

Traverse in Western Antarctica. Courtesy of ITASE (project leader; Paul Mayewski).
Focus II
Activity 2
Task 2 Late Quaternary Sedimentary
Record of the Antarctic Ice Margin
Evolution (ANTIME)

Project Coordinator: Ian Goodwin

Introduction

The physical and dynamical processes controlling the nature of the Antarctic ice sheet and the surrounding oceans have been found to be highly variable, both geographically and temporally, on interannual to inter-decadal timescales. Because of this large background variability and because instrumental records span such a short time span, it is difficult to predict the responses of the ice sheet to future forcings such as global warming. Attempts to determine this variability on century-to-millennial time scales by medium depth ice-core drilling and analysis have been only partially successful. Ice cores have provided detailed historical information on climatic variability, with respect to changes in temperature, relative humidity, moisture source, and atmospheric circulation. They cover periods from the last few hundred years to the last 10,000 years, at Law Dome and Taylor Dome, East Antarctica, and Dyer Plateau, Antarctic Peninsula, and over the past ~250,000 years at Vostok and Dome C, in the East Antarctic interior. The new Law Dome summit core may provide a detailed climatic record over the Holocene and perhaps the Late Pleistocene transition, while the proposed Siple Dome and Byrd Basin cores may also provide a detailed Holocene climatic and late glacial history of the West Antarctic ice sheet. In addition, the present and proposed deep drilling activities that form the Palaeoenvironments from Ice Cores (PICE) programme will result in new ice-core records covering multiple glacial-interglacial cycles. However, the ice-coring projects to date have experienced significant difficulties in absolute dating and in providing temporal data on changes in ice-sheet elevation and fluctuations in ice dynamics during the Holocene and Late Pleistocene. This information is vital if we are to understand the response of the ice sheet to climatic variability as well as other forcing mechanisms (i.e., rising sea-level and deformation of the bed on which the ice sheet rests).

This difficulty might be overcome by utilizing the geological record. The Antarctic sedimentary record in the marine, coastal, lacustrine, and glacial environments has already yielded high-resolution information on palaeoenvironmental and palaeoclimatic changes, particularly on ice marginal and outlet glacier fluctuations, climatic variability, and lacustrine and marine ecological and biogeochemical changes. The coordinated SCAR-GLOCHANT and PAGES initiative on the Late Quaternary Antarctic sedimentary record of the ANTIME will provide a circum-polar palaeoenvironmental perspective on the Late Quaternary (last 250,000 years) record. ANTIME will include a detailed component on the last 20,000 years and the
very high-resolution Holocene records. This will provide a solid basis for the understanding of present and future variability in the Antarctic, when combined with the ice-core records (PICE). It will also provide the foundation for a PAGES sponsored bipolar examination of palaeoenvironmental changes when combined with the ICAPP programme on the Arctic. ANTIME together with PICE will also complement the PAGES/SCOR IMAGES transects in the circum-Antarctic regions.

History of the Programme

GLOCHANT has developed a joint initiative with PAGES on coordinating Antarctic and Arctic ice-core drilling and the analysis of ice-core records, known as PICE. It was the original intention of GLOCHANT in 1991 to also develop a sister project such as ANTIME on Palaeoenvironments from the Antarctic sedimentary record. Delegates at XXIV SCAR held at Cambridge, UK, in August 1996, approved the ANTIME initiative. The PAGES SSC formally approved the activity at its March 1997 meeting. Thus, it is now incorporated as a joint GLOCHANT and PAGES programme.

Rationale and Scientific Objectives

At present, Quaternary research is conducted around the Antarctic ice margin by scientists from a number of nations. Quaternary sequences have been cored on the continental shelf by marine geological programmes and have been partially recorded by seismic surveys conducted by the Antarctic Offshore Stratigraphy (ANTOSTRAT) programme of SCAR, although the later surveys were optimized for the pre-Quaternary, Cenozoic strata. However, most of the Late Quaternary and Holocene research has been focused on the inner continental shelf, in the coastal zone in fjords and beach sequences, and in the vicinity of the terrestrial ice margin and adjacent lakes. As with the PICE programme on ice coring, there is a strong need to coordinate international research on the variability and evolution of the Antarctic ice margin to maximize international resources and target the Antarctic areas of mutual interest. It is also important to recognize that a multi-disciplinary approach including geology, glaciology, chemistry, and biology is required to fully develop a comprehensive palaeoenvironmental history.

ANTIME will focus on two streams: Stream I (last 20,000 years) on the last deglaciation and interglacial environmental, climatic, and ice-sheet variability; and Stream II (last 250,000 years) on the environmental, climatic, and ice-sheet response to glacial-interglacial cycles. These are slightly different from the PAGES timescales used in the PEP transects, but are considered to be more appropriate to circumpolar studies. Key scientific themes that will be followed by ANTIME are:

The Extent, Timing and Regional Differences of the LGM in Antarctica

Our present state of knowledge on the timing of the LGM in Antarctica is scant and contradictory. Investigations of the marine sedimentary record on the continental shelf in East Antarctica and in the Weddell and Ross Seas suggest that the ice sheet may have been grounded near the continental shelf break sometime during the last glacial cycle. The East Antarctic onshore geologic record of isostatic and relative sea-
level changes and glacial fluctuations indicates that a much smaller ice-sheet expansion occurred at the time of the Northern Hemisphere LGM around 18,000–20,000 years BP. In fact, the maximum post-glacial emergence is an order of magnitude less than in the Arctic since the LGM. Were the glacial maxima of the East Antarctic and West Antarctic Ice Sheets in phase or were they regionally offset? This is also a crucial question for the resolution of global sea-level fluctuations and the calibration of ice-sheet models that are used to predict the future response of the ice sheets to global warming.

**What Rapid or Episodic Events Occurred During the Late Quaternary?**

The emerging bipolar data sets are suggesting that rapid change and episodic events have characterized the Late Quaternary environment, rather than slow transformations from interglacial to glacial climates. These events have been associated with a rapid response of the polar ice sheets to abrupt climatic changes over much shorter intervals than the orbitally modulated 20–100 ka Milankovitch insolation cycles and include:

- Dansgaard-Oeschger glacial interstadial (warm) events with a duration of 200–2,500 years.
- Rapid sea-level changes
- Abrupt temperature changes such as during the YD event, now believed to have been global
- Pulses of (ice-rafted) glaciomarine sedimentation, known as Heinrich events, in the North Atlantic Ocean
- Ice surges and fast flow events in the Northern Hemisphere and in the Antarctic Peninsula region.

However, we do not know how many, if any, of these episodic and rapid events occurred in mainland Antarctica, nor do we know whether they are triggered by global forcings. A coordinated effort in West and East Antarctica is required to address both the regional and bipolar climatic and sea-level histories. This is a large undertaking and will significantly benefit from a coordinated multinational effort.

**What are the Key Forcings and Feedbacks that Influence the Retreat and Readvance of the Antarctic Ice Sheet?**

We know little of the forcing mechanisms that control the retreat, readvance, and stability of the Antarctic ice sheets. It is imperative that we understand these mechanisms if we are to predict the response of the ice sheet to any future global warming. These mechanisms include: eustatic sea-level changes; warm deepwater incursions on the shelf; isostatic loading and unloading in equilibrium or disequilibrium with the ice-sheet status; glacial bed conditions and deformation; ocean circulation; and climatic changes. Only scant evidence for the timing of the post-glacial retreat, from the emergence of coastal bedrock and Holocene raised marine shorelines, has been collected at present. However, these data suggest that the isostatic response around Antarctica differed widely between regions and that the drainage basins may have responded to different forcings.
We need to develop an understanding of the regional evidence, style, rates, extent, and timing of post-glacial retreat. It is important to approach this problem by focusing on:

- Stratigraphic correlation of glacial marine retreat deposits around Antarctica
- Correlation of all emerged marine shoreline data around Antarctica and planning for additional fieldwork in unsurveyed regions.

What Changes in the Ice Shelves and Outlet Glaciers Have Occurred During the Holocene?

Little is known of the Holocene climatic record in Antarctica. How have the Antarctic ice sheet, outlet glaciers, and ice shelves responded to small climatic fluctuations during the Holocene? Do our modern observations of ice behaviour reflect these past, rather than modern, climatic fluctuations? The marine sedimentary record is proving to be an important source of data on Holocene climatic change. This has largely been due to the significant advancement in the high-resolution dating of Holocene deposits using AMS $^{14}$C techniques and to the identification of inner shelf and fjord locations with high sedimentation rates, which have made it possible to define decadal-to-century scale variability, such as the 200 year cycles interpreted in the Antarctic Peninsula sediments.

Detailed onshore geological studies have demonstrated that the ice margin and outlet glaciers have fluctuated on the timescales of 10–1,000 years during the Holocene in response to changes in mass balance. Similarly, direct observations of the modern ice grounding zones using submersible remotely operated vehicles (ROVs) are allowing a picture to develop on the physical, sedimentological and oceanographic processes controlling the location of the ice margin. The sedimentary record can also provide boundary conditions on the history of Antarctic ice-shelf bottom water production, the history of shelf break mixing, and the occurrence of coastal and offshore polynyas. In this way, ANTIME has a potential contribution to the history of Antarctic bottom water production and a linkage with deep-sea geological investigations undertaken by the IMAGES programme in the Southern Ocean and South Atlantic Ocean.

Correlation of Late Quarternary Antarctic Environmental History and Deep-Ocean Sedimentary Records

A key need for the understanding of the relationships between Antarctic glacial history and the record of past global change is for nearshore sedimentary records to be tied to continuous, well-dated, offshore sections. The advantage of this type of integrated approach is that it would maximize the benefits and cover for the shortcomings of both types of sequences. The offshore drilling and coring targets currently under consideration by ODP and IMAGES provide continuous Neogene records to which a battery of proven chronostratigraphic tools can be applied, including magneto- and biostratigraphy and orbital tuning of high-resolution isotopic, lithostratigraphic, and physical properties measurements of whole cores and discrete samples. In the late Quaternary, these types of palaeoceanographic records provide important stratigraphic tiepoints between marine and ice-core chronologies. A particularly glaring need is for nearshore-offshore transects in the Pacific Sector of the Antarctic. The Southern Ocean may show considerable regional variability, espe-
cially if the near-field effects of ice-sheet dynamics play an important role in Southern Ocean circulation (a Southern Hemisphere counterpoint to the Heinrich events of the North Atlantic). In this case the East and West Antarctic ice sheets may behave quite differently and independently and drive sector-scale variability in the flux of meltwater and ice-rafted debris.

It is proposed that linkages between the ANTIME, IMAGES, and ODP programmes will optimize the possibilities for the correlation of the Antarctic and deep Southern Ocean sedimentary records.

Implementation

To rectify gaps in our present understanding, and our divergent views of circum-Antarctic palaeoclimatic and palaeoenvironmental change, it is necessary to broaden the geographic coverage of investigations. This, in turn, requires international participation in onshore and marine programmes. ANTIME will provide the opportunity for international cooperation in marine geological and geophysical surveys: on the East Antarctic shelf basins, including the Mertz-Ninnis Trough, the Totten Trough, Prydz Bay, Lutzzow-Holm Bay, and the Rennick Trough; in the Ross Sea; in West Antarctica at Pine Island Bay and along the west coast of Graham Land; and on the South Orkney Plateau. An international effort focusing on high-resolution seismic surveys using a sparker and 3.5 kHz equipment is required, together with the drilling of long sediment cores and more detailed work on the recognition of glaciomarine, iceberg turbate, and subglacial diamicton facies transitions. The ANTOSTRAT project has led to the collection and establishment of a detailed seismic library on the continental shelf stratigraphy. However, the Late Quaternary is not well represented because it is a shallow sequence and is often located in the bubble pulse of the ANTOSTRAT seismic surveys, which were optimized for the earlier Cenozoic record.

It will be necessary to focus onshore studies of Late Quaternary glacial geology, palaeobiology, and geochemistry in the priority regions adjacent to high-resolution seismic surveys and marine coring sites, to enable correlations to be made and to gain a better understanding of the nature and mechanisms of palaeoenvironmental change. Regional analysis of the onshore and offshore sedimentary records, together with data on postglacial relative sea-level change and isostatic rebound, will enable the nature and extent of the coastal ice-sheet expansion to be established. It is necessary to correlate the palaeogeography and timing of the coastal ice-sheet expansion during the last glacial cycle with the marine geological evidence, to understand the response of the Antarctic drainage basins to climatic and sea-level change.

It is difficult to draw continent-wide conclusions from regional ice-shelf and outlet-glacier fluctuations, particularly in regard to the climatic and oceanographic forcings, especially because the East and West Antarctic ice sheets may have responded independently. Consequently, a coordinated international effort is required to ensure a focused and representative regional coverage. Suitable sites include:
• Prydz Bay and the Vestfold Hills
• Vincennes Bay and the Law Dome
• Palmer Deep and Livingston Island, Antarctic Peninsula
• Western Ross Sea and the Trans-Antarctic Mountains.

Our knowledge of past glacial and climatic events would also be enhanced if technological aspects could be coordinated amongst SCAR nations. The following aspects will be addressed in proposed workshops:

• Continent-wide chronological comparisons of glacial and climatic events have been difficult due to the uncertainty in the radiocarbon $^{14}C$ reservoir corrections and their changes with time throughout the Late Pleistocene and Holocene. It is important to develop a strategy to determine calibrated reservoir corrections for the terrestrial and marine Antarctic environments with respect to the palaeoceanographic circulation

• Improvements in seismic stratigraphy and stratigraphic interpretations could be made through a technology comparison of international high-resolution sub-bottom imaging techniques

• Similarly, an international approach to the standardization of sedimentological description in Antarctic terrestrial, lacustrine, and marine environments would permit the continent-wide comparison and correlation of geological events

• Planning the cooperative use of submersible ROV and the further development of this technology would significantly increase our knowledge of the morphology and sedimentation at modern grounding zones and beneath ice shelves

• Ship platforms and the capability to drill long sediment cores are highly specialized. The planning of international cruises and the sharing of technology amongst SCAR nations would significantly increase the potential for solving many of the key scientific questions.

This initiative began by holding a GLOCHANT/PAGES sponsored International Workshop, in Hobart, Australia from 6–11 July 1997, in conjunction with the Symposium on Antarctica and Global Change. The aim of the workshop was to: discuss the state-of-the-art palaeoenvironmental data on the Late Quaternary in Antarctica; plan future multi-national field programmes; and plan for the coordination of technology and stratigraphic correlations. Representatives from all the marine and glacial geological programmes in SCAR countries participated in the workshop, together with representatives from PAGES projects with an interest in Antarctica.
Figure 9

Map showing the twelve areas selected as priorities for ANTIME research. Courtesy of ANTIME (project leader; Ian Goodwin).
Introduction

Palaeoenvironmental records derived from the analysis of polar ice cores are unique in several ways. Polar ice-core records are the only archives which, along with highly resolved evidence of past climate change, including air temperature and snowfall rate, also preserve information on the atmospheric concentration of the principal greenhouse gases, on the concentration of atmospheric aerosols, and on a wide range of major and minor chemical constituents in the atmosphere. Antarctic ice is the most suitable for extending the ice record back to cover several complete glacial cycles and for investigating past atmospheric CO₂ changes. However, a bipolar approach is needed to clarify linkages and climate coupling between the Northern and Southern Hemispheres.

Ice-core research has already made substantial contributions to our understanding of the mechanisms driving global climatic changes. For instance, ice cores from both Antarctica and Greenland provide strong evidence that the atmospheric concentration of greenhouse gases has closely paralleled pre-anthropogenic global climatic changes throughout the last glacial to interglacial cycle. These studies have provided the only firm data to demonstrate the increase of greenhouse gases since the pre-industrial period. Also, several discoveries were totally unexpected, and had not been predicted by any models. Thus ice cores from Greenland have revealed the existence of a series of major, abrupt climatic shifts both during and at the end of the last glaciation. Major shifts are found to have occurred during time intervals of a fraction of a human life.

Comparison with results from deep-sea sediments suggests that the ice-sheet-surface-changes were connected with a re-ordering of the deep-ocean circulation, and therefore may have global implications. Based on the methane record from both Greenland and Antarctic ice, and on growing evidence from deep-sea and terrestrial climate records, it can be concluded that these climate fluctuations not only affected the North Atlantic and adjacent regions, but also mid-lower latitude regions.

PICE has drawn together proposals for a series of national and multinational projects over the next decade involving deep ice-core drilling in different parts of East and West Antarctica and in Greenland.

Taken together, the various proposals aim to ensure that representative climate records are achieved for the principal climatic zones of the polar ice sheets, and that these records will give maximum resolution during the two time-streams identified as priority targets by PAGES. These encompass high-resolution reconstructions of the Holocene and long-range reconstruction of climate and related changes in at-
mospheric chemistry through the more extreme climate changes occurring over glacial cycles. This coordinated effort (GLOCHANT/PAGES) should lead to major advances that will reduce the uncertainty in predicting future global environmental change.

History of the Programme

Deep-ice coring on the Antarctic Ice Sheet has been part of several national programmes since the late 1960s. In 1993 GLOCHANT established a planning group to correlate ice-core data on palaeoenvironmental changes. It was the original intention that this planning group would focus on palaeoenvironmental changes in Antarctica, as deduced from ice cores and the marine and terrestrial sedimentary record, as outlined in the original SCAR Report (1993), ‘The Role of Antarctica in Global Change’. As a first step towards this goal, PICE was established under the chairmanship of Dominique Raynaud, Laboratoire de Glaciologie and Geophysics de l’Environnement, St. Martin d’Hères, France. The other members of PICE are: D. Peel (Secretary, UK), J. White (USA), V. Morgan (Australia), V. Lipenkov (Russia), J. Jouzel (France), and O. Watanabe, H. Shoji (Japan). The members held their first meeting in Cambridge, UK, on the 4–5th September 1993. The second meeting was held in Col de Porte, France on the 24–25th February 1994. It was decided at the latter meeting that there was a considerable overlap between the group’s objectives and those of PAGES. Consequently, a proposal was prepared and submitted to the PAGES SSC for joint sponsorship of the group. This was approved in late 1994.

Rationale and Scientific Objectives

During 1995, the members of PICE began work on a science and implementation plan for an international strategy for ice-core drilling in Antarctica. This was a focus of the third annual meeting of PICE in Boston, USA, on 15–16th September 1995. At the Boston meeting it was recognized that ice coring in Antarctica needed to be integrated with ice-coring activities in Greenland and the Arctic, both from a logistical viewpoint, and because many of the ice-coring expertise and much of the drilling equipment was used in both regions. Issues related to data analysis also underscored this need. Thus, a GLOCHANT bi-polar document has recently been completed, “An International Strategy for Ice-Core Drilling in Antarctica and Greenland – Reducing Uncertainty in Global Environmental Change.”

The scientific objectives of PICE relate to: climate variability; forcing factors, feedbacks and mechanisms; coupling between the Northern and Southern Hemispheres; and ice sheet stability and control on global sea level. Some key questions are:

Climate Variability

Are the rapid climate changes of the last climatic cycle global events, or have they been restricted to a region of the Northern Hemisphere? Are rapid climate changes also observed in previous climatic cycles? What factors can contribute to the speed of the climate changes observed in Greenland? Is the apparent stability of the Holocene climate in Greenland an exception for the past 500,000 years?
Forcing Factors, Feedbacks and Mechanisms
What are the causes of natural variations in greenhouse gas concentration observed during the last and earlier glacial-interglacial cycles and to what extent was global climate driven by these changes? How has atmospheric chemistry changed in response to climate? Is there evidence of any feedback via, for example, interference with the oxidation capacity of the atmosphere, that regulates the levels of certain greenhouse gases such as methane? How important are the marine biogenic aerosols of the Southern Ocean in climate forcing?

Coupling Between the Northern and Southern Hemispheres
What is the phasing of climate between the Northern and Southern Hemispheres in the various stages of the last glacial cycle? Are global climate changes triggered in the Northern Hemisphere or is the opposite sequence possible? How are global climate changes coupled between the two hemispheres? What is the link between ice core and marine sediment records from other latitudes?

Ice-Sheet Stability and Control on Global Sea Level
What were the long-term linkages between climate, snowfall rates, and ice sheet history, and how are these related to global sea level?

The answers to these questions are important for the prediction of future climate. New ice cores from optimal locations both in Antarctica and Greenland are needed to complement the existing records. For instance, additional Antarctic records will enable us to investigate the rapid climate events in a global context. Considering the complex structure of the atmosphere over Antarctica and the interactions with the surrounding ocean, ice cores from several locations will be needed to answer these important questions. These archives will also provide unique evidence related to climate forcings (such as: greenhouse gases; atmospheric oxidation capacity; atmospheric turbidity; biogenic feedbacks; and solar variability), climate variability, climate mechanisms, the long term climate/ice sheet interactions, and the role of Antarctica in sea-level change. These ice-coring activities are planned as national and multinational enterprises and are listed in Table 5 below.

Implementation

Strategy for Future Drilling/Methodology
The Antarctic ice sheet spans an area larger than the USA and comparable to Europe. Thus it covers a wide range of both climatological and glaciological regimes. No single site can be presumed to deliver a climate record that is representative of the whole continent, nor can it yield a record of optimal resolution of both climate parameters and gas mixing ratios across the whole time range of interest. Alternative sites possess a variety of physical attributes that determine the resolution and long-term stability of the records attainable. Different sites also experience different sensitivities to climate/circulation changes in adjacent ocean and continental areas. Significant differences have been observed already in, for example, the characteristics of the deglaciation sequence recorded in different Antarctic cores. These differences may have important implications for coupling the Antarctic and Greenland records. Plans are being formulated for a series of national and multinational drilling projects.
during the next decade in different parts of East and West Antarctica, the records from which cover time-scales ranging from centuries up to several hundreds of thousands of years. The existing and planned ice-coring activities are listed in Table 5.

**Antarctica**

The major dome sites in East Antarctica have been targeted to achieve the longest possible records, benefiting from a combination of very low annual snow accumulation rate and minimal long-term ice flow disturbance. Such sites will also provide the best opportunity to correlate the ice-core records with the marine sediment records and other terrestrial records, contributing to a more coherent global picture. The Vostok core, already at 3,350 m in depth as of January 1996, the deepest ice core and the longest continuous ice-core record so far achieved, has led to many major advances in ice-core research. Although there are still 350 m to be drilled, the record extends through at least four complete glacial cycles. As the depth increases, corrections for ice-flow also increase, and the record may become more difficult to interpret unambiguously. Furthermore, drilling must be terminated about 25 m above a subglacial lake.

**Table 5**

Existing and planned Antarctic ice-coring activities.

<table>
<thead>
<tr>
<th>Project</th>
<th>Nations</th>
<th>Region</th>
<th>Timelines</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. WAISCORES (Siple Dome), USA</td>
<td>USA</td>
<td>W. Antarctic</td>
<td>[1995–1998]</td>
</tr>
<tr>
<td>3. Vostok, Russia</td>
<td>Russia</td>
<td>E. Antarctic (plateau)</td>
<td>[1990–1997]</td>
</tr>
<tr>
<td>4. Dome Fuji, Japan</td>
<td>Japan</td>
<td>E. Antarctic (central)</td>
<td>[1995–1998]</td>
</tr>
<tr>
<td>5. EPICA Dome Concorde, Euro</td>
<td>Euro</td>
<td>E. Antarctic (Pacific/Indian)</td>
<td>[1996–2000]</td>
</tr>
<tr>
<td>7. Wilkes Land, Australia</td>
<td>Australia</td>
<td>E. Antarctic (plateau)</td>
<td>[&gt;2000]</td>
</tr>
<tr>
<td>8. WAISCORES (Byrd Basin), USA</td>
<td>USA</td>
<td>W. Antarctic</td>
<td>[1996–2099]</td>
</tr>
</tbody>
</table>
Planned drilling in West Antarctica and in Dronning Maud Land is more closely focussed on the last glacial cycle and is designed to achieve records of comparable resolution to the Greenland records. These records will be especially valuable for documenting the amplitude and phasing of Antarctic climate shifts through the sequence of Dansgaard/Oeschger events and the deglacial and early Holocene sequences. These sites are likely to be most sensitive to changes in the extent of the West Antarctic ice sheet and are likely to provide the strongest evidence on questions relating to the stability of the West Antarctic ice sheet and its relationship to climate. Such sites are not located near existing manned stations, which were selected for logistic reasons, and will require much more demanding logistics to establish. These planned activities include two major programmes; European Ice Coring in Antarctica (EPICA); and the US West Antarctic Ice Sheet Initiative (WAISCORES 2000).

The EPICA programme involves a consortium of 10 European nations: Belgium, Denmark, France, Germany, the UK, Italy, the Netherlands, Norway, Sweden, and Switzerland. EPICA is a long-term (ca seven years) project to derive high resolution records of climate and atmospheric composition through several glacial-interglacial cycles. The project is designed to complement the highly successful central Greenland projects and it will allow extension and full documentation of the East Antarctic record, so far essentially limited to the analysis of the Vostok core. Thus the focus of EPICA is the cooperative site survey and deep ice coring at two locations in East Antarctica: a 3,500 m ice core at Dome Concordia in Wilkes Land in the Indian Ocean sector; and in Dronning Maud Land in the Atlantic Ocean sector.

The US WAISCORDES programme will address several fundamental questions which revolve around the nature and causes of climate change, the past variability of climate, and the stability of the West Antarctic ice sheet. The goals of WAIS are to: (i) improve the understanding of how instabilities in the West Antarctic ice sheet may cause a rise in sea level; and (ii) improve the understanding of the climate and palaeoclimate of West Antarctica, and the interhemispheric timing and characteristics of climate change. The WAISCorDES programme will involve the retrieval of several shallow (150 m) ice cores and a deep ice core (1,000 m) in the coastal Siple Dome area, which should contain a >100,000 year palaeoenvironmental record. Following the Siple Dome ice coring, a deep ice core will be retrieved from an inland site along the Byrd divide in West Antarctica. The Byrd divide core should span at least one to two glacial cycles.

**Greenland and the Arctic**

Further deep drilling is also planned in North Greenland in an effort to discover whether an undistorted stratigraphic record of the last interglacial can be found in another part of the Greenland ice sheet, to allow proper comparison with the Antarctic records. Evidence from a recent combined study of the GRIP and GISP2 ice cores from Summit, Greenland, now strongly suggests that the deepest parts of both cores, extending before 110,000 years ago, have been disturbed by ice flow. Whilst it is believed that ice from marine isotope stage 5e, the Eemian period, can be identified in both cores, the prospects for establishing an unambiguous and detailed stratigraphic record of Eemian climate from these cores are remote. Nevertheless, there appears to be some corroborative evidence for structure in the Eemian climate in several marine sediment sequences from the eastern North Atlantic region and
the Nordic seas. If climate instability in this previous warm period is real, then this would have major significance for understanding present climate. Renewed efforts are now needed to obtain an independent high resolution record of the Eemian climate in Greenland, suitable for comparison with the Antarctic records. A new deep drilling project in Northern Greenland (North GRIP), mainly funded by Denmark, is now underway. A German geophysical survey has located an optimum drilling site in an area of lower accumulation rate (15 cm ice/year), where it is anticipated that the Eemian ice will lie significantly further above bedrock compared with Summit. It should offer the best opportunity for achieving an undistorted Eemian record and a resolution of the uncertainties at Summit. The prospect of extending the ice-core records through two glacial cycles should also be pursued in order to match the available Antarctic records.

Outside Greenland, the collection of ice cores from the Arctic region has been until now largely un-coordinated, yet modelling studies indicate that this region is globally one of the regions most sensitive to anthropogenic forcing. ICAPP (see pages 130–136) aims to address these issues, through the integrated evaluation of existing and newly-drilled ice-core records in the circum-Arctic region (particularly the Canadian and Russian Arctic records). ICAPP will focus on the characterization of past climate variability, on time-scales ranging from centuries to tens of thousands of years.

Contact:
Domique Raynaud
LCGE/CNRS
BP 96
38402 Saint Martin d’Hères
Cedex
France
Tel: (33-4) 76 82 42 45
Fax: (33-4) 76 82 42 01
Email: raynaud@glaciog.uif-grenoble.fr
Detailed survey of the bedrock and surface topography around Dome C has enabled the choice of a deep ice-drilling site for EPICA at 75°06′06″S; 123°23′42″E, with an elevation of 3,233 m and an ice thickness of 3,250 m. The area close to the topographic summit satisfies several important criteria for a deep drilling site, combining a subdued bedrock morphology with horizontal internal layering, a lack of ice-folds down to 2,200 m depth, and no adjacent sub-glacial lake. Figure supplied by David Peel (British Antarctic Survey).
FOCUS III

Human Interactions in Past Environmental Changes

Activity 1  Human Impacts on Fluvial Systems

(See PAGES Workshop Report 96-2)

**Project Leader:** Robert J. Wason

**Introduction**

Global change is both systemic (involving changes to whole-Earth systems such as the atmosphere and oceans) and cumulative (involving many local and/or regional changes that in aggregate have a global effect). Land use and climate change are inter-related, with land cover changes contributing to systemic changes by means of gas exchanges and horizontal riverine transport of C, N, P and sediment with an effect on the fertility of oceans; and climate change affecting both the possible range and productivity of particular land uses and the hydrology of the continents. Land-use/cover changes, modulated by climate change, are of direct concern to the entire human population, with profound effects on terrestrial and coastal ecosystems.

Fluvial systems play a key role in both systemic and cumulative human impacts. Rivers are the primary agents of horizontal transport of biogeochemically important materials from the land to coasts. The fluvial system is also susceptible to changes of land use and climate, reflecting adjustments to the hydrological cycle and fluxes of materials such as sediment and nutrients.
The key role of the fluvial system in the horizontal transport of water and biogeochemically important materials in the Earth system has been recognized by PAGES, BAHC, LOICZ, and GCTE. This recognition is reflected in planning meetings held in 1994 for PAGES and 1995 for BAHC, LOICZ, and PAGES. Two science plans have been produced from these meetings: P1 “Land Use and Climate Impacts on Fluvial Systems During the Period of Agriculture” (PAGES Workshop Report 96-2), and P2 “Modelling the Transport and Transformation of Terrestrial Materials to Freshwater and Coastal Ecosystems” (BAHC, PAGES, LOICZ). (See IGBP Report no. 39).

**Scientific Objectives**

For both planning meetings, the key scientific objectives were formulated within the following general framework:

- To quantify landform change and river-borne fluxes of water, sediment, micronutrients, C, N, and P, both today and in the past
- To identify the controls on the fluxes of these materials in the catchment cascade, both today and in the past
- To identify the feedback on human society and biogeochemical cycles of changes in the fluxes of these materials.

PAGES activities will contribute to defining the temporal trends of landform change and fluvial fluxes, controls, and feedbacks, paying particular attention to the interaction of climate change and land-use change during the period of greatest human impact on the planet – the agricultural period. P1 is concerned with sediment and those biogeochemically important materials that leave a palaeorecord, namely P and C. Specifically, the scientific questions identified by the PAGES planning meeting are:

- What is the sensitivity to climatic change of the spatial distribution of sediment, P and C fluxes in different climatic/vegetation regions?
- How do sediment, P and C flux sensitivities to land use under climatic shifts reflect stages of land-use history?
- How are fluvial system response sensitivities under various land uses influenced by the direction of climatic change?
- What are the thresholds and response times of fluvial systems for different combinations of land use and climatic change?
- How do engineering and other human related modifications, including dams and reservoirs, channel morphology alteration, and wetland drainage, enhance or suppress climatic impacts on sediment flux in various climate/vegetation regions?
Operating Plan

The planning meetings of PAGES, BAHC, and LOICZ have identified key scientific questions and some of the strategies and methods for answering these questions. The two projects (P1 and P2) will be managed concurrently, while maintaining the distinct character of each project.

The operating plan for P1 has the following components:

- A global classification of fluvial catchments based on relief and stage of regional environmental transformation has been constructed. This classification will be used to both organize existing data relevant to the project and to choose representative catchments for case studies.

- The leaders of existing relevant research groups will be invited to participate in the project. The currently targeted areas for case studies are: India; China; Russia; USA; Switzerland; Sweden; Australia; South Africa; West Africa; New Zealand; UK and/or Italy. Others will be added to this list if appropriate.

- A small working group meeting was held in Bern, Germany, March 1997. This identified potential leaders for many of the case studies currently proposed and it was agreed to plan a Workshop for 1999 at which the leaders of the case studies will be asked to agree on (at least) the following matters:
  - Protocol of studies so that case studies can be compared, additional case studies
  - Reporting method and schedule for work
  - Strategy for synthesis of the case studies
  - Modelling strategy to both generalize the results and provide a catalogue of fluvial system responses to future land use and climate that can be used to estimate future responses

- A symposium will be held three years after the project starts, at which results are presented. A monograph will be produced from this symposium, along with a version suitable for policy-makers.

- Each research group will be responsible for its own management and funding, but assistance may be provided by the convenors to stimulate fund raising. A newsletter will be provided each six months to maintain contact among project members.

Methods

1. Each case study will be based on a mass balance of the major components of catchments that act as sources, sinks or transit zones for sediment, P and C. Histories of either each or groups of these components will be constructed using stratigraphic and documentary evidence. Catchment outputs will be reconstructed by using lake, estuarine, or coastal deposits. Good chronologies will be essential, demanding considerable reliance upon high resolution techniques such as optically stimulated luminescence dating.

2. Reconstruct land-use/cover changes in the case study catchments using pollen, microfossils, documentary evidence.
3. Reconstruct climate in the case study catchments using whatever proxy data are appropriate.

4. Analyze each of the series (of catchment components, land use, and climate) for their covariance. Using models of the most likely interactions between these series, interpret the covariance causally. This is not a simple exercise, and the kind of analysis will depend upon local circumstances and quality of time series. A first step towards standardization of methods was taken at the March 1997 workshop. The most likely analytical framework will center on the sensitivity of landscape elements to changes in the external variables of climate and land use, and to combinations of these variables.

5. The analysis of external (forcing) variables and of the consequent responses of catchments and their components will be related to the catchment classification, outlined in section 6 (Project Strategy) of the workshop report. But this is not sufficient to produce a truly global analysis. For this project, global models are required. The data gathered for this project will be used to test and extend existing global models, e.g., total terrestrial fluxes to the oceans of sediments and biogeochemically important materials; and relationships between land use and exports of nutrients. Importantly, a new kind of global model will be constructed, indicating the expected responses to changes of land use and climate of different types of fluvial systems. This model will be based on the concept of landscape sensitivity, whereby responses to external forces (climate and land use) of fluvial systems will be documented, and their time constants and response types used as the basis of quantitative models. All of these models will be of benefit to policy-makers trying to anticipate the direction and rate of significant global changes.

**Linkages**

Attention has already been given to linkages between PAGES, BAHC, LOICZ, and GCTE. These are likely to remain the strongest linkages with this project. However, linkages have also been established with IAHS, UNESCO, IAEA, and IHDP/IGBP LUCC.

**Outputs**

Already completed studies from various parts of the world have demonstrated that it is feasible to carry out the individual case studies required by this project. The major new output of this project will be a globally coherent set of documented responses to land use and climate change that, by analogy at least, will provide a means of anticipating (if not predicting) future global changes in fluvial systems.

In addition, truly global models of the major biogeochemical cycles will be tested and their terrestrial component will be enhanced through provision of greater temporal depth and resolution. Global biogeochemical databases will also be enhanced. A new global model based on landscape sensitivity will also be developed.
The strategy of building a global picture from regional case studies allows capacity building in various parts of the world while not losing the global perspective. It also allows what might be otherwise parochial case studies to take on a global significance. This is akin to the philosophy adopted by PANASH.

**Project Management**

The convenors of the PAGES planning meetings (R.J. Wasson, D.E. Walling, A.Yu. Sidorchuk) have agreed to act as the managers and steering committee for the project. The leader of P2, C. Vorosmarty, is liaising with R.J. Wasson to ensure concurrent development of the two projects. Funds are currently being sought for a final planning workshop in 1999, and for providing the linkage between case study groups. Resources for each of the case studies will be sought nationally.

---

Report prepared by Robert J. Wasson

**Contact:**

Robert J. Wasson  
Department of Geography  
School of Resources and Environmental Management  
Australian National University  
Canberra, ACT 0200  
Australia  
Tel: (61-6) 62492745  
Fax: (61-6) 62493770  
Email: robert.wasson@anu.edu.au
Focus III  
Activity 2  Human Impacts on Terrestrial Ecosystems

The details of this Activity have still to be defined and agreed. One of the first initiatives within this Activity is the proposed PAGES contribution to the large-scale Biosphere-Atmosphere Experiment in Amazonia (LBA). A joint initiative in this area with BAHC and GCTE was discussed at the Siberian Transect Workshop in Krasnoyarsk, Russia, September 1997.

The proposed initiative will link PAGES research more closely to the IGBP Transects where GCTE is currently working. The following are the some of the objectives that will be considered:

- Reconstruction of the immediate antecedents of the present day terrestrial vegetation, including the use of pollen assemblages to identify and reconstruct the distribution of key functional types following the GCTE typology

- Reconstruction of pollution, erosion and soil degradation histories for the recent past. This requires multi-disciplinary sediment study using a wide range of analytical methods. One outcome of such work can be some quantification of the changing biogeochemical fluxes associated with the changes identified under 1. In this aspect of the research, there is inevitably a close connection between the implications of the results for both terrestrial and aquatic ecosystems and for their coupling

- Fire histories from charcoal and, under more restricted circumstances, mineral magnetic analysis

- Past incidence, periodicity and impact of extreme events like floods and erosional hazards

- Extension of the climate record beyond the 'instrumental' period, where suitable palaeothermometers exist

- Reconstructions of variations in past carbon sequestration in peatlands

- Historical insight into biodiversity issues.
FOCUS IV

Climate System Sensitivity and Modelling

Activity 1  Climate Forcing and Feedbacks
Task 1  Climate Impacts of Explosive Volcanism

(See PAGES Workshop Report 96-3)

Project Leader: James E. Beget

Introduction

Volcanic eruptions play an important role in modulating global climates. The recent volcanic eruptions of El Chichon (Mexico) in 1982 and Pinatubo (the Philippines) in 1991, both with Volcanic Explosivity Index (VEI) of 5, were accompanied by El Niño events and have been linked to global weather and climate disturbances which followed each eruption for 2–3 years. Older large eruptions during the past 200 years which produced large stratospheric aerosol layers, including Tambora (Indonesia) in 1815, Krakatau (Indonesia) in 1883, and Katmai (Alaska) in 1912 (all VEI=6), produced significant but less well-documented climatic effects.

In order to understand and model the evolution of climate since 1880, an interval during which global average climate warmed by more than 0.5 °C concomitant with anthropogenic increases in atmospheric CO₂ and other greenhouse gases, it is necessary to fully understand the effect of volcanic eruptions on climate. Indeed, indi-
vidual large volcanic eruptions can produce transient cooling of greater magnitude than the warming produced by all anthropogenic greenhouse gases in the atmosphere today.

The question of the impact of volcanic eruptions on climate has attracted much attention across multiple scientific disciplines, including meteorology, volcanology, ice core studies, palaeoecology, and palaeoclimatology. A series of international meetings involving interdisciplinary groups of scientists have been convened over the last several years. Among them, a workshop was convened by the Commission on Tephrochronology (COT) of the International Union for Quaternary Research (INQUA) and hosted by Meiji University, Tokyo, in Tokyo, Japan (1–5 December 1993). This meeting was also sponsored by PAGES and financially supported by the US NSF.

Scientific Aims

An important opportunity now exists to document both the record of past explosive volcanic eruptions and the climatic effects of these eruptions through a careful analysis of multiple varieties of high-resolution palaeoclimatic records, and numerical modelling studies of the effects of their aerosols on the climate system. Studies of such records have the potential to reveal a detailed history of volcano-climate interactions on annual time scales during the last two millennia, through most of the last 10,000 years of the Holocene, and at lesser resolution through the last 150,000 years of the most recent glacial-interglacial cycle. Of particular interest are those prehistoric eruptions which are larger than any yet seen during the last few hundred years (i.e., VEI = 7), as the magnitude and duration of climatic effects associated with such eruptions are not well documented. Therefore, this project seeks to:

- Determine age and magnitude of major volcanic eruptions around the world
- Determine chemical characteristics of major eruptions and resultant aerosols
- Test correlations between individual volcanic eruptions and apparent climate response
- Test correlations between specific volcanic eruptions and annual proxy climate records in ice cores, tree rings, and corals, and also high-resolution palynology and other palaeoclimatic data sets
- Improve understanding of mechanisms of volcanic impact on atmosphere and climate
- Develop new models for volcanic impact on atmosphere, ocean, and climate.

Project Strategy

Past workshop meetings and conferences have been designed to facilitate the communication and collaboration across national and disciplinary boundaries necessary to understand the impacts of volcanic eruptions on global climate change. Over the next three years we have the following goals:
• Document globally for selected major tephra eruptions:
  - Stratigraphy
  - Chronology
  - Mineralogy
  - Geochemistry
  - Distribution
  - Eruption magnitude and volume
  - Climatic impact.

• Address these topics by ongoing working groups within COT, including:
  - Database of widespread tephra layers (CATALOG)
  - Microtephra identification techniques and evaluation
  - Climatic impacts of tephra eruptions
  - High resolution dating of tephras
  - Reconstructing palaeoenvironments using tephrochronology
  - Tephra record and education in developing countries
  - Hazards and impacts from tephra eruptions.

It is important to note that while some geographic areas are well studied and the characteristics of their major tephra layers are well known, e.g., Japan, Western Europe, coterminous US, New Zealand, and Iceland. Some important areas are much in need of additional work, especially Indonesia, central and southern America, former USSR, Alaska, the Philippines, and Africa.

• Support complementary efforts to elucidate the impact of tephra eruptions on climate which are going on in many venues. Volcanologists at the Smithsonian Institution (USA), within the International Association for the Study of Volcanism and the Chemistry of the Earth’s Interior (IAVCEI), and the Queens University in Belfast (Northern Ireland), are all producing catalogs of explosive volcanic activity with differing emphases.

The new GRIP and GISP2 cores from Greenland represent major advances in obtaining high resolution records of past climate and volcanism. Annual and even seasonal variation are recorded farther back in time than in previous ice cores, and detailed records of global volcanism are present in aerosols preserved in the ice. A similar deep coring project in Queen Maud Land in east Antarctica is underway.

Climate model experiments of the effects of volcanoes on climate are just beginning. Models have only recently had the capability to include the effects of aerosols on climate. Model runs calibrated with instrumental estimates of aerosol loading produced during the Pinatubo and El Chichon eruptions are in general agreement with the magnitude of observed climate effects. In climate modelling, a standardized volcano experiment with all existing climate models, i.e., a Volcano Modelling Intercomparison Project (VMIP), would be useful.

Dendrochronologists are encouraged to use the International Tree Ring Data Bank (ITRDB), held at the WDC-A for Palaeoclimatology, as a repository for their data sets. This practice facilitates the comparison of multiple tree-ring records, and also allows intercomparisons of tree rings with other proxy climate records, including ice cores.
Palynologists are just beginning to look at volcanic effects. In general, most pollen records from bogs or lakes do not have annual resolution, although with careful work decadal time scales may be attainable. The sensitivity of pollen records to short-term climate events associated with volcanic eruptions is also not well known.

Research on the degassing of sulfur and other volatiles during explosive eruptions is in its infancy, and needs major strengthening, with emphasis on building up a database on sulfur and other gas emissions from important eruptions. This continues to be a major emphasis of work independently done as a focus of IAVCEI.

**Outputs**

**Results to Date**

- Field conference on tephrochronology, Mt. Tateyama, Japan (1992), convened by H. Machida, K. Okumura, and S. Fujii
- PAGES-COT workshop on “Climatic Impact of Explosive Volcanism”, Tokyo, Japan (1993), convened by H. Machida and J. Beget
- United Kingdom/European Biannual Tephra Meetings, Belfast, Northern Ireland (1992), convened by V. Hall; and Cheltenham (1994) convened by J. Hunt
- Multidisciplinary meeting and field conference, “Tephra, Loess, Palaeosols”, Hamilton, New Zealand (1994), convened by D. Lowe
- XIV INQUA Congress, Symposium on “The Importance of Tephrochronology for Reconstructing Climatic History and Environmental Changes in the Quaternary” Berlin, Germany (1995), convened by H. Machida and J. Beget
- INQUA Congress excursion, “Quaternary Volcanism” Eifel, Germany (1995), convened by P. Bogaard
- Dedicated volume of *Quaternary International* (vol. 12/14) on “Applications of Tephra” (1992), guest editor, J. Westgate
Planned Activities

- “Modern Techniques in Tephrochronology,” (1998), a workshop meeting and field conference planned for Italy in 1998 (organizer, E. Juvigne)
- Publication in *Quaternary International* of results of workshop meetings in 1997 and 1998
- Continued compilation of tephra baseline data by the working group on database of widespread tephra layers (catalogue of widespread tephra layers in the world, commonly known as CATALOG)
- Continued compilation of data and dissemination of information from other ongoing working groups: Microtephra identification techniques and evaluation; Climatic impacts of tephra eruptions; High resolution dating of tephras; Reconstructing palaeoenvironments using tephrochronology; Tephra record and education in developing countries; and Hazards and impacts from tephra eruptions.

Project Guidance

This project was overseen by H. Machida (Japan), President of COTAV from 1992–1996. In 1996 J. Beget (USA) was elected the President, V. Hall (Northern Ireland) was elected Secretary, and E. Juvigne (Belgium) was elected Vice-President, with a commitment to continuing this project. The Commission on Tephrochronology was renamed the Commission on Tephrochronology and Volcanism (COTAV).

A small amount of funding is available from INQUA to support the efforts of COTAV, which acts as a clearing house and facilitator for the separate working groups. Dedicated research support has principally come from country grants to individual investigators associated with the project and the commission. Research facilities and resources also reside in universities and national research laboratories associated with or accessible to individual investigators.

Report prepared by James E. Beget

Contact:
James E. Beget  
Department of Geology and Geophysics  
President, Commission on Tephrochronology and Volcanism (COTA-V-INQUA)  
University of Alaska  
Fairbanks, AK 99775-5780  
USA  
Tel: (1-907) 474 5301  
Fax: (1-907) 474 5163  
Email: FFJEB1@aurora.alaska.edu
Focus IV
Activity 1
Task 2  Solar Influences on Climate

Although a central feature of the PAGES project since its inception, the task on Solar Influences on Climate has not as yet had an initiating workshop and a Science and Implementation Plan has not been written.

This Task addresses the modulation of the geosystem due to intrinsic variations of the Sun as a star. There has been a growing interest within the science community in exploring the relationship between solar variability and its impact on climate. Recent studies of changes in global temperature and in solar irradiance over the last 400 years point to significant linkage, though by no means perfect coupling. A growing number of studies of longer-term climate proxies, in systems where annual resolution and precise chronologies are possible, also record signatures that can be linked to solar cycles. The palaeosciences will have a key role in establishing a deeper understanding of the long-term record of this elusive but potentially significant relationship. This Task also addresses the effects of orbitally-induced variations in insolation through the Milankovitch effect and related feedback mechanisms. PAGES hopes to move forward with this Task in the near future.

Key References


Focus IV
Activity 1
Task 3    Greenhouse Gases and Aerosol Influences

This Task will be subsummed within the GAIM/PAGES/IGAC “Palaeotracegas Challenge” initiative to be coordinated by Colin Prentice. A joint workshop is being planned for the Northern Hemisphere autumn of 1998 in Jena, Germany.
Focus IV
Activity 1
Task 4  Abrupt Climate Change and Internal Climate System Dynamics

The first steps towards undertaking this Task are outlined in the Workshop Report of the joint IGBP/WCRP Workshop held in Venice, Italy, November 1994, THE PAGES/CLIVAR INTERSECTION, notably in Section 2 of the Report that includes sub-sections on: “Dynamics of low-latitude climate change”; “Global ocean thermohaline variability”; “Regional- to global-scale hydrologic variability”; and “Dynamics of abrupt events”. Further consideration is given to these themes in the Section on PAGES/CLIVAR Interactions, Focus 1, Activity 5.
Focus IV  
**Activity 2**  
Climate Model-Data Intercomparisons  
**Task 1**  
Palaeoclimate Modelling Intercomparison Project (PMIP)

**Project Leaders:** Sylvie Joussaume and Karl Taylor

**Introduction**

Atmospheric general circulation models are continually improving in their ability to simulate the major features of today’s climate. Many of these models are being used to predict future climate change and although there is broad agreement among the models, there are also many differences in the details of their predictions. In order to determine whether some models can better simulate climatic conditions much different from today, the models can be used to simulate palaeoclimates, and palaeo-data can be used to evaluate the results. PMIP was initiated in order to coordinate and encourage the systematic study of AGCMs and to assess their ability to simulate large changes of climate such as those that occurred in the distant past. It also serves to encourage the preparation of global reconstructions of palaeoclimates that can be used to evaluate climate models.

The PMIP effort developed out of a NATO Advanced Research Workshop, convened in 1991, which led to a cooperative and coordinated effort to compare model simulations using palaeoclimate data. The workshop participants agreed to focus initially on two specific periods in the past, the LGM and the mid-Holocene.

The first years of the project were devoted to the definition of the common boundary conditions to be used in the numerical experiments. An important boundary condition for the LGM is ice sheet extent and thickness, which was agreed upon following a workshop sponsored by the US NSF through COHMAP. The data were then archived at the NGDC in Boulder, USA, and have been electronically distributed to the PMIP modelling groups.

The first step to develop a strategy for coordinating the collection, analysis, and synthesis of palaeoclimate data to expand its usefulness to PMIP was taken in the autumn of 1993 when a NATO Advanced Research Workshop was convened in Aussois, France.

The project is now well under way, and first results have been discussed at a workshop sponsored by NOAA and the EU in Collonges la Rouge, France in October 1995, where the participants in PMIP decided on a strategy for further analysis. PMIP results from the individual modelling groups have been presented at various scientific conferences, including the European Geophysical Society (EGS) meeting in 1995 and a special session at the AGU meeting in December 1995.
Scientific Objectives

Project aims are to:

- Identify common responses of AGCMs to imposed palaeoclimate “boundary conditions” and understand how different representations of physical processes in models can lead to differences in simulated climates. This intercomparison of models under palaeoclimate conditions complements other GCM intercomparison projects (notably, AMIP)

- Compare model simulations with palaeoclimate data to identify and understand the consistencies and inconsistencies, and to provide climate model output to help in the interpretation of palaeoenvironmental data. Results should help to better understand the range of the uncertainty of current estimates of climate sensitivity. They will also help to identify regions of the globe where intensified efforts to refine palaeoclimate reconstructions might be most useful in evaluating climate models.

Implementation Strategy

The PMIP project is organized around the study of the climates of the LGM and the mid-Holocene. Model simulations of these periods (with specified glacial ice distribution, carbon dioxide concentration, and insolation pattern) are being collected and intercompared. The model output will be compared with palaeodata.

The number of modelling groups participating in PMIP has grown to eight: USA, Canada, France, the UK, Germany, P.R. of Korea, Japan, and Australia. Some groups are carrying out all the PMIP simulations, while others will limit their participation to only one of the two PMIP time periods.

For the next two years, the project efforts will be devoted to the analysis of the model results. As with any complex numerical experiment, careful examination of the model results is necessary to verify that in fact the simulations were properly carried out. Thus, the initial PMIP effort focuses on model-model comparisons, from which will be derived an understanding of which simulated features are robust and understood, and which are model dependent and uncertain. This intercomparison of model results is being organized through the formation of individual sub-projects dealing with climate sensitivity, monsoon changes at 6 ka BP, mid-latitude circulation changes at both 6 and 21 ka BP as well as impact of simulated changes on the ocean and ice sheet mass balance. First results were discussed at a second model-model workshop held in San Francisco in November 1997. At the same time, preliminary comparisons between model output and palaeoclimate reconstructions were initiated. The methodologies appropriate for model-data comparisons will be applied, first by a small group coordinated by the PMIP Data-Model subcommittee, but expanding to a much wider community as a general understanding of the model results is reached. Model diagnostics will be produced in a way that allows for direct comparison with palaeodata.

After the initial comparisons between palaeoclimate data and models have been carried out using existing data, a much broader effort to improve the palaeoclimate reconstructions should develop. This effort will involve an increasing number of sci-
entists from the palaeodata community. A first model-data workshop was held in Dourdan, France, in May 1996 focusing on the climates of Europe and Africa, organized within the framework of the EU climate programme. A second workshop open to the palaeodata community is planned when a summary of the model-model comparisons should be available.

Related to PMIP's interest in model-data comparisons, links are developing with other PAGES projects devoted to data acquisition and synthesis for the two key periods considered.

On the modelling side, PMIP is also endorsed by the relevant committees within the WCRP (currently, Working Group on Numerical Experimentation [WGNE] and potentially in the future, CLIVAR). These committees recognize the role that palaeoclimate modelling can play in improving our knowledge of climate models.

Output

Most of the participating groups have now performed the PMIP simulations and the model output is being archived at the Programme for Climate Model Diagnosis and Intercomparison (Lawrence Livermore National Laboratory [LLNL], USA). In order to check and analyze model results before they are more widely distributed, the database will initially be accessible only to PMIP contributors and to scientists involved in sub-projects. Individual modelling groups have begun to publish results of their simulations, and a paper containing a synthesis of the PMIP model results will be prepared soon.

Project Management/Guidance

Coordination is the responsibility of Sylvie Joussaume (Laboratoire de Modelisation du Climat et de l'Environnement [LMCE] Saclay, France) and Karl Taylor (Programme for Climate Model Diagnosis and Intercomparison [PCMDI], Livermore, USA). Both may be reached by email at: palaeo@asterix.saclay.cea.fr

Guidance is being provided by an Advisory Committee, which includes scientists involved in climate modelling and in palaeodata analyses (ocean, lake levels and pollen/biomes).

Larry Gates (PCMDI, Livermore, USA)
John Kutzbach (CCR', Madison, USA)
Suki Manabe (GFDL', Princeton, USA)
John Mitchell (UKMO', Bracknell, UK)
David Rind (GISS', New York, USA)
Colin Prentice (Lund University, Sweden)
Alayne Street-Perrot (University of Oxford, UK)
Warren Prell (Brown University, Providence, USA)

1 See List of Acronyms
To strengthen the data-model intercomparison component of PMIP and to provide an interface for facilitating interaction between the PMIP modellers and the data community, a Data-Model Intercomparison Sub-committee has been formed:

Sandy Harrison (Lund University, Sweden)
Joel Guiot (LBHP, Marseille, France)
Pat Bartlein (University of Oregon, USA)
Dominique Jolly (Lund University, Sweden)
Stefan Kroepelin (Free University of Berlin, Germany)
Anne de Vernal (Geotop, Canada)

Support is provided by the EU for the European contributors to PMIP (including modellers and the data-model sub-committee).

Supplemental support was provided by US NOAA for the organization of the first PMIP workshop in Collonges la Rouge, France. PCMDI is contributing to the development and maintenance of the PMIP model output archive and NGDC collects and distributes palaeoclimate data needed for model boundary conditions and model evaluation. Individual groups participating in PMIP are supported through their own funding. Support for future planned workshops will have to be found if the project is to continue to be a success.

Electronic newsletters keep the PMIP participants formally informed of the status of the project. Anyone interested in receiving this newsletter should contact the project coordinators.

**Future Directions**

Model-data comparisons for the 6 ka BP and 21 ka BP periods, which are being studied within PMIP, will require expanded data synthesis efforts, such as Biome 6,000, PMAP, and the NOAA plan to develop a global lake level data base.

It is also crucial for simulations of the LGM to construct within the next two years a revised version of the CLIMAP (1981) dataset of sea surface temperatures and sea ice. This would help in understanding possible inconsistencies between observed and modelled tropical sea surface temperatures.

---

Report prepared by Sylvie Joussaume and Kerry E. Taylor

Contact:
Sylvie Joussaume
Laboratoire de Modelisation du Climat et de l'Environnement (LODYC)
Direction des Sciences de la Matiere (DSM)
Orme des Merisiers, Bat 709, CE Saclay
91191 Gif sur Yvette Cedex
France
Tel: (33-1) 69 08 56 74
Fax: (33-1) 69 08 77 16
Email: SYLJOUS@ASTERIX.SACLAY.CEA.FR
For the mid-Holocene climate, 6,000 years BP, changes in temperature are averaged over the Northern Hemisphere continents only. All 15 models display a consistent amplification of the seasonal contrast between summer and winter, following changes in Earth’s orbital parameters. Courtesy of PMIP (project leaders; Sylvie Joussaume and Karl Taylor).
For the LGM, 21,000 years BP, all the simulations simulate a global mean cooling, for all seasons, due both to glacial ice sheets and the lowering of atmospheric CO$_2$ concentration. Differences between models are, however, less for eight simulations performed with prescribed sea surface temperatures (SST) estimated from CLIMAP (1981) [CLIMAP Project Members. 1981. Seasonal Reconstruction of the Earth’s Surface at the Last Glacial Maximum. GSA Map and Chart Series MC-36, Geological Society of America, Boulder, Colorado] (the eight first ones on the left) rather than for the six models coupled to a mixed layer ocean model (six ones on the right). Courtesy of PMIP (project leaders; Sylvie Joussaume and Karl Taylor).
Introduction

The overarching goal of the palaeoenvironmental multiproxy analysis and mapping project is to advance the understanding of the climate system, and thus contribute to the development of a reliable climate prediction capability for both seasonal-to-interannual and longer-term forecasts. This capability requires an understanding of the full range of possible climate dynamics; determination of how the climate system responds to significantly altered forcing; and use of the knowledge gained to improve predictive models. The interdisciplinary nature of the palaeoenvironmental multiproxy approach provides an important means to extend our understanding of modern climate dynamics beyond the relatively short instrumental record, and to evaluate the ability of models to simulate climate change and variability in response to the significantly altered forcing of the past. In addition, the palaeoenvironmental multiproxy approach plays an important role in the evaluation of climate models by highlighting areas where the palaeoclimate reconstructions are more uncertain.

Background

A first planning meeting for the PMAP activity was held in San Francisco, CA, USA, in early December 1994. The goal of the meeting was to bring a cross-section of international scientists together to assess the current status of multiproxy palaeoenvironmental mapping. This meeting concentrated on the compilation of Stream II multiproxy data. Attention was focused on designing a framework that will help maximize coordination among on-going data compilation efforts while working to eliminate unnecessary duplication. It was recognized that many groups both within PAGES, INQUA, IGCP, and UNESCO, and as part of national efforts, independently and sometimes redundantly, spend considerable expense and effort to generate the basic datasets they need to reconstruct palaeoenvironmental conditions.

Some sharing of datasets is common, and data coordination efforts through PAGES, the WDC-A for Palaeoclimatology, and many national geological surveys are often tapped for compilation of the best datasets. However, complete access to all data is not uniformly available to all groups. Many of the groups are already focusing funded data compilation efforts on time intervals of specific interest to PAGES and PMIP: the LGM; the mid-Holocene; and the last interglacial. However, the research-driven data compilation for these targeted time periods is often designed to satisfy
immediate needs and thus extracts only snapshots of derived secondary and tertiary level data. Out of this initial planning meeting PMAP was established, a document was drafted describing the goals of the project, and Robert Webb and Joel Guiot were appointed as co-chairs of the project.

A second planning meeting was held in San Francisco, CA, USA, in early December 1995, to assess on-going multiproxy palaeoenvironmental mapping activities for North America in support of PMIP. At this second meeting, the draft of the PMAP document was reviewed, results of the recent PMIP workshop in central France were presented, and discussions focused on how to generate the value-added science products from multiproxy palaeoenvironmental data that will be useful for evaluating late Quaternary palaeoclimate simulations.

**PMAP Scientific Objectives**

- To document past change and to understand changes in terrestrial environments, to examine global climate processes and variability, and to validate Earth system models
- To help maximize coordination among on-going data compilation efforts and eliminate unnecessary duplication among various research groups within the international community
- To establish standards for the use and acceptability of multiproxy palaeoenvironmental data that will meet the needs of all five PAGES Foci and subactivities at both Stream I and II resolutions
- To provide leadership in the compilation of global maps of past biome distributions, in the reconstruction of past environmental and climate conditions and variability, and in the analysis of global scale vegetation dynamics and ecosystem responses to both continuous and abrupt palaeoclimate change.

**Goals**

A consistent set of high standards will be necessary to ensure that the resulting primary data (e.g., fossil pollen or diatom counts, raw tree-ring measurements, isotopic measurements), secondary data developed from the raw data (e.g., tree-ring chronologies, fossil percentages, isotopic ratios as a function of age), and tertiary information inferred from the primary and secondary data (e.g., palaeoclimate estimates, sea-surface temperature or palaeovegetation reconstructions) are acceptable across all PAGES multiproxy activities.

The compiled datasets will need to be stored digitally in formats that are easily available, and convertible, to meet the needs of the different research activities. PMAP compilation, archiving, and distribution activities can be achieved in collaboration with the PAGES Data Coordination Center at the WDC-A for Palaeoclimatology.

Objective methods for rescaling the various palaeoenvironmental multiproxy indicators into estimates of climate variability must be developed to enable data integration, analysis, and mapping.
The maps generated as part of the PMAP effort must contain data and information about the data at discrete locations. The resulting generalized maps based on interpretation of the data from a collection of sites will be the product of individual research projects or researchers.

PMAP Stream I activities will need to focus on coordinating interaction among research groups working around the world to ensure compatibility of global digital proxy datasets and interpretations of historical records.

As part of the Stream II activities, PMAP will work to ensure that the specific palaeoenvironmental data requirements (both data and scientific expertise) for the evaluation of PMIP through data-model comparisons are met in a timely manner.

**Implementation and Strategy**

PMAP will not only play a role in facilitating the compilation, analysis, and mapping of palaeoenvironmental data, but must play an essential role within PAGES as the link between various on-going palaeoenvironmental data compilation projects and the climate modelling community. PMAP should focus on archiving primary (raw) palaeoenvironmental data. For most Stream II data, these take the form of information from a single geographic point with associated latitude, longitude, elevation, good chronostratigraphic control (radiocarbon dates or better), and data referenced to stratigraphic depth. A primary concern for PMAP is the establishment of a systematic approach to carefully evaluate each archived proxy data record in order to ensure standardization of the quality of the information inferred. The following criteria have been identified as essential information required to consistently evaluate the different proxy types and avoid mixing incompatible proxy data types in the analysis and mapping of these data.

**Age Control**
How well can a record or sample of a data type be dated given the limits of the chronostratigraphic technique used?

**Spatial Resolution**
What is the geographic range monitored by the data type?

**Temporal Resolution**
What are the temporal limits of the data type (the recording system and the modern calibration of the proxy data) to accurately resolve changes in the environment or climate?

**Spatial/Geographic Coverage**
Over how much of the world is the data type available for use in PMAP?

**Temporal Coverage**
Over what time span is the data type available for use in PMAP?
Environmental Signal
What type(s) of palaeoenvironmental information (quantitative and qualitative) can be inferred from the data type?

Climate Signal
What type(s) of palaeoclimate information (quantitative and qualitative) can be inferred from the data type?

Honest reporting of this essential information for each data type/palaeoenvironmental record used in a PAGES Activity or Task will allow for the informed use of the range of multiproxy data by other Task or Activities without having to determine a priori the suitability of proxy types for archiving by PMAP. This approach allows individuals or groups using the PMAP archive to select which data to use, and which to exclude, based on criteria related to the specific needs of an individual Activity or Task.

In most cases PMAP will sanction the archiving of secondary and tertiary (value-added derived information developed from the primary data) palaeoenvironmental data only if the primary data is archived as well. For most Stream II data, these are either data such as a record containing percentage values with a preferred chronology based on interpolation between radiocarbon dates, or areal interpolation of a geologic feature and related features which are contiguous with one or more sites that contain primary data (e.g., moraine, sand dunes, palaeosols, elevated beach deposits). For many spatially defined geomorphic features, and some stratigraphically inferred records (e.g., lake status records), it is not practical to archive the primary data that are used to generate the palaeoenvironmental record. Interpretative secondary data without the accompanying primary data can be considered acceptable by PMAP only if accompanied by explicit narratives describing the primary data sources, latitudes, longitudes, elevations, chronostratigraphic control, and methods of interpretation. These explicit narratives must provide sufficient information to allow any investigator to reproduce the interpretation or develop an alternative interpretation (for examples see “Lake Status Records from the Former Soviet Union and Mongolia: Database Documentation”, Tarasov et al. 1994, or “Lake Status Records from Europe: Database Documentation”, Yu and Harrison, 1995).

Modern calibration datasets for all multiproxy data are essential and a high priority for PMAP. An effort must be made to compile the most up-to-date and accurate climate and environmental datasets and provide gridded datasets for use in calibration exercises. Careful attention must be paid to the temporal and the spatial compatibility of multiproxy datasets and the modern calibration data to ensure common time periods, microclimates, and environments.

Schedule – Current Plans
Two workshops are planned to expedite PMAP goals:
PAGES PMAP Stream I Workshop (Last 2,000 Years)

Ever increasing attention is focused on climatic change of the last 2,000 years as a key to understanding and predicting future climatic change. In addition to the important work of many individual investigators, larger synthetic efforts focused on the climate dynamics of the last several centuries are becoming more numerous. Emerging efforts such as the PAGES/CLIVAR initiative are now working to utilize seasonally- to annually-dated palaeoclimate time series to develop an understanding of the seasonal to century-scale variability. Efforts such as these will be most concerned with climates of the last several centuries. A key aspect of these Stream I projects will be to improve our understanding of the full range of natural variability in the ENSO and the African/Asian and American monsoon systems, the ocean thermohaline system and its relation to climate, and the hydrologic system at regional to global scales. Interest in the hydrologic system includes its relation to ENSO, monsoon systems, and ocean thermohaline circulation. These palaeoclimate data will also play an important role in the detection of significant environmental change, in particular ongoing efforts focused on early detection of anthropogenic-induced climate change with emphasis on the attribution of observed changes to specific natural and non-natural forcings. Many of these Stream I data are now available in digital format, although not necessarily in the public-domain, and climate modelling groups are increasingly using their models to investigate the patterns and causes of climatic change during the last millennium. Note that the goal of this workshop will be expressly scientific – to build an international group of scientists to meet PAGES goals. The workshop objectives will be to:

- Identify palaeoclimate time series that may be of use for mapping the patterns of climatic variability over the last 2,000 years; these data include time series of hypothesized forcing
- Determine how best to document these time series in a public-domain database for use by the PAGES community
- Determine the best ways for getting data into the public domain, building on links between existing database efforts
- Use the data to reconstruct global climate variability for specific time intervals (e.g., the last 400 years)
- Compare reconstructed climates with those simulated using climate models, and attributing observed changes to known causes.

A goal of the workshop could be to provide a state-of-the-art assessment of whether the observed global temperature increase of the last 150 years can be attributed to natural climate variability. Other scientific goals would be identified and group research strategies planned as incentives to gain participation and data sharing of leading scientists around the world.
PAGES PMAP Stream II Workshop
(Palaeoclimate reconstructions for PMIP model-data comparisons).
A challenge to the global climate models being applied to simulate future climate is whether these models have the sensitivity to simulate the climate conditions inferred from the geologic record. PMIP GCM simulations for the mid-Holocene (6 ka BP) and the LGM (21 ka BP). The 6 ka climate represents a time of significant changes in the seasonal distribution of the solar forcing with only minimal changes in terrestrial ice sheets. Modelling 6 ka climate is an important test of land-surface parameterizations and the ability of climate models to accurately simulate the energy and moisture fluxes that strongly influence continental climates. Terrestrial data for 6 ka is abundant and accurately dated, permitting detailed comparisons between palaeoenvironmental data and climate models. A persistent challenge in palaeoclimate modelling has been to simulate the 21 ka climate using known boundary conditions. Though not as abundant as for 6 ka, palaeoenvironmental data for 21 ka are plentiful for this period. Many of these Stream II data are now available in digital format through efforts of PAGES and the WDC-A for Palaeoclimatology, although not necessarily in a format that is easily compared with climate model simulations. The workshop objectives will be to:

• Characterize the record of conditions for specific geographic areas identified to be of primary interest based on the results of the initial intercomparisons
• Evaluate the sensitivity and consistency of model simulated changes from a global synthesis of data
• Determine how best to take advantage of new and upcoming developments in Geographic Information System (GIS) technology to generate synthesis maps of multiproxy data for use by the PAGES community
• Generate a global map showing the geographic distribution of signal-to-noise estimates for palaeoenvironmental multiproxy data that can be used to guide future model-model comparisons and palaeoenvironmental data acquisition.

Methodologies
The multiproxy approach is an extension of the now widely accepted approach to multivariate analysis elegantly presented by Imbrie and Kipp (1971) for quantitative palaeoclimate reconstructions. Instead of using multiple taxa of the same type of organism as described by the above authors, the multiproxy approach uses a suite of faunal, floral, and geologic environmental indicators. Combining all available indicators from the complete range of bioclimatic regimes will ensure not only more complete global coverage, but also reconstructions that should be more continuous across steep environmental gradients, and thus in time and space as conditions have changed in the past. The preferred multiproxy approach is to use indicators extracted from the same stratigraphic sequence (e.g., same sediment sample); however, blending palaeoenvironmental information from proxy indicators collected separately can prove to be equally effective.

Footnote
2 21 ka BP = 18 ka radiocarbon years BP
The value of the multiproxy approach to climatic reconstructions is that the combined effect of using a number of data types: (i) can solve the problems (e.g., indeterminacy: extrinsic-climate; intrinsic-proxy) encountered when one uses individual palaeoclimate indicators that respond to several loosely correlated climatic variables; and (ii) should result in more robust reconstructions than those based on an individual palaeoclimate indicator.

Objective methods for rescaling the various palaeoenvironmental multiproxy indicators into estimates of climate variables must be developed to enable data integration, analysis, and mapping.

**Linkages**

The PMAP goal of assembling a global database of multiproxy palaeoenvironmental data will reduce redundant compilation activities of the same data. This goal can only be met by setting high minimum standards for the basic multiproxy data, and for information about the data. In this way the needs of individual groups or research projects may be met. Although these high minimum standards will require a more conscientious effort in the initial compilation of data that may exceed the needs of specific research objectives, the extra work in meeting a common set of archiving standards for PMAP data will ultimately be more efficient. Not only will current projects using the exact same data for different purposes be able to capitalize on each others’ efforts, but subsequent projects not yet designed or establish can use previously archived data as a starting point for improving the global coverage of multiproxy data. The overall objective of this effort is to assemble ‘atmospheric scientist /climate modeller-friendly’ data bases. In particular, a multi-parameter approach is important for highlighting areas where the palaeoclimate reconstructions are less certain.

The PMAP effort will ensure access to high quality data while maintaining a central focus on the basic PAGES scientific research questions. This activity will directly contribute to a better overall understanding of:

- The spatial and temporal changes recorded in palaeoenvironmental data for the last 125,000 years, and thus the spatial and temporal changes in Earth system dynamics over this time period
- Climate model performances by using terrestrial palaeoenvironmental data in the evaluation and validation of Earth system model simulations of past change, 125,000 to present.

Within Stream I, there is the recognized opportunity for PMAP to contribute to the PAGES/CLIVAR initiative by identifying all palaeoclimate time series that may be of use for mapping the patterns of climatic variability over the last 2,000 years; these data include time series of hypothesized forcing. The data can then be used to reconstruct global climate variability for specific time intervals (e.g., the last 200 or 400 years), compare reconstructed climates with those simulated using climate models, and improve capabilities for attribution of observed changes to known causes. A goal will be to provide a state-of-the-art assessment of whether the observed global temperature increase of the last 150 years can be attributed to natural climate variability.
A second Stream I PMAP effort will be to provide a 400–500 year long global dataset of change in land use/land cover based on multiple palaeoenvironmental proxies. An IGBP-DIS effort is underway to generate a 200 year long global dataset of change in land use/land cover based on the historical record. PMAP and the palaeoenvironmental community have an important role to play by taking the lead in providing the extended database of land-use/land-cover change.

PMAP can also play an important role by generating Stream II inferred climate products for 6 ka BP and LGM that will be immediately useful for PMIP. Paralleling the BIOME 6000 vegetation reconstruction, PMAP can generate temperature, precipitation, precipitation-minus-evaporation, wind strength, and other parameters using multiproxies. These global reconstructions will be able to capitalize on a number of already successful on-going efforts such as: (i) the global database of lake status reconstructions and inferred precipitation-minus-evaporation; and (ii) the US NSF-sponsored Testing Earth System Models with Palaeoenvironmental Observations (TEMPO) consortium project.

**Outputs**

Publication of the PMAP document summarizing the effort is a very near term goal of the project leaders.

A longer-term goal is the publication of maps that are in a digital format showing information at individual site locations. This will be useful in data-model comparisons. The expectation of PMAP is that there will more than one set of maps generated from the data compilation under the auspices of PMAP, and that different groups or individuals will probably choose to use different subsets of the total multiproxy data available to address specific scientific questions. PMAP will encourage the publication of maps based on multiproxy data in peer review journals.

**Project Management/Guidance**

**Leadership**
Robert Webb and Joel Guiot

**Steering Committee**
E. Grimm, Sun Xiangjun, A. Velichko, G. Hope, S. Harrison

The data management needs in support of PMAP will be met by the WDC-A for Palaeoclimatology in Boulder, Colorado, USA.

**Key References**

Tarasov, P.E., Harrison, S.P., Saarse, L., Pushenko, M. Ya., Andreev, A.A.,
Aleshinskaya, Z.V., Davydova, N.N., Dorofeyuk, N.I., Efremov, Yu. V.,
Khomutova, V.I., Sevastyanov, D.V., Tamosaitis, J., Uspenskaya, O.N.,
Yakushko, O.F., and Tarasov, I.V. 1994. Lake status records from the Former Soviet


---

Report prepared by Robert S. Webb

*Contact:*
Robert S. Webb
NOAA Paleoclimatology Program
NGDC E/GC
325 Broadway
Boulder, CO 80303
USA
Tel: (1-303) 497 6967
Fax: (1-303) 497 6513
Email: rwebb@ngdc.noaa.gov
Focus IV  
Activity 2  
Task 2a: BIOME 6000  

(Jointly sponsored by IGBP-DIS, GAIM, GCTE, and PAGES)  

Project Leader: Colin Prentice  

Background  

Biogeophysical feedbacks in the climate system arise because energy and water fluxes across the land-atmosphere interface are mediated by vegetation. Recent work on the sensitivity of climate models to changes in vegetation distribution has established that biogeophysical feedbacks can be of major significance. Modelling of Late Quaternary climate allows the possibility of quantifying the importance of these feedbacks by comparing three-dimensional model “snapshot” simulations with palaeoenvironment data, e.g., on sea-surface temperatures, lake levels, and vegetation for key times such as 6,000 year BP. Various modelling activities (including PMIP) have focused on the 6,000 year BP time slice because the boundary conditions are well defined (known orbital forcing; ice sheets as present; atmospheric composition close to pre-industrial). The GAIM 6,000 year BP experiment aims to use palaeodata for 6,000 year BP as the yardstick by which to compare simulations of the first effects of orbital forcing, as in PMIP, with simulations that incorporate biogeophysical feedback through interactive coupling of climate and ecosystem models. Thus, both the PMIP and the GAIM 6,000 year BP experiments call for systematically constructed and properly documented global palaeodata sets, which can be used to carry out rigorous comparative evaluations of model results.  

The GAIM 6,000 year BP experiment spawned the data project, BIOME 6000, as an answer to this call. The need for a global synthesis of palaeovegetation data (primarily pollen, but also plant macrofossil data) is especially acute because of the manifest inadequacy of published palaeovegetation maps, the dispersed nature of publication in palaeoecology, the lack of a global repository for palaeoecological observations, and the need for regional floristic knowledge in order to interpret palaeoecological information in a globally applicable framework for plant functional types and biomes.  

The inaugural workshop of BIOME 6000 was held in Hörby, Sweden, in May 1994. An excellent cross-section of palaeoecological experts representing all the continents attended the workshop. A report from the workshop will appear shortly.  

Aims and Approach  

The primary aim of BIOME 6000 is to assemble the existing palaeovegetation data for 6,000 year BP on all of the continents, and to use these data to construct a palaeobiome map using a standard “biomization” method to assign a biome to each data point. The method is based on prior assignments of taxa to Plant Functional Types (PFTs) in consultation with regional experts.
Looking ahead to likely future cross-cutting IGBP projects concerned with ecosystem changes and trace-gas composition during glacial as well as interglacial times, BIOME 6000 has adopted a secondary aim of developing a palaeobiome map for the LGM using the same methods.

**Implementation**

The following is an updated summary of the main points of the plan adopted at the Hörby workshop.

- Only those data sources that directly record plants will be used as evidence for past vegetation, because other systems (e.g., lakes, geomorphic systems) respond to different aspects of the environment than do plants. BIOME 6000 is thus envisaged as complementary to other proxy mapping activities.

- The target dates for data extraction will be 6,000 and 18,000 radiocarbon years BP, for consistency with previous data compilation efforts.

- Primary data (e.g., actual pollen counts) will be used to the greatest extent possible. For some regions the data will be obtained through collaboration with the managers of existing data repositories, such as the European Pollen Data Base. For regions lacking such organizations, data assembly will rely on a network of individual scientists and laboratories.

- The most appropriate techniques to identify the sample or samples closest to each target date may vary with sedimentation conditions, and will involve some investigator judgement.

- Biome reconstructions will be carried out at Lund University, Sweden, or elsewhere, according to agreements made between the project coordinator and the regional contact persons. An operational PFT classification will developed. The regional contact persons will provide the required information on the assignments of initial biome reconstructions.

- The evolving products of the project will be accessible to active participants throughout. The first global product for 6,000 year BP is available for comparison with model results.

**Products**

The main products will be two data sets, one for 6,000 and one for 18,000 year BP, in which each site is assigned a database reference number, geographic coordinates, and a biome. Backing up these products will be: (i) a database containing the primary data used to create the products; and (ii) a meta-database including documentation of source, dating control and biomization procedure. 6,000 year BP palaeobiome data sets already exist for Europe and Africa, and are under construction for Australia and eastern North America.

Primary publication will be in a special issue of a Quaternary science journal, hierarchically structured with articles from each of 20–30 regions and short summary articles for each continent. In addition, a multi-authored “flagship” publication is expected to arise out of collaboration with palaeoclimate modellers.
FOCUS V

Cross-Project Analytical and Interpretive Activities

Activity 1  Chronology

Introduction

This Activity has remained in the background during the early stages of PAGES implementation, although chronology underlies most PAGES work. A very important meeting was held in conjunction with the 15th International Radiocarbon Conference at Glasgow, Scotland, August 1994 at which many of the chronological techniques relevant to PAGES were reviewed. The papers presented at this meeting appeared in *Radiocarbon* (1996).

The importance of chronology is now coming to the forefront with the progress of the PEP transects. Many of the questions concerning leads and lags between the hemispheres will require an accurate chronology in both hemispheres. This may be possible in *Stream II* using orbital parameters, but in the short timescale, where the *Stream I* aims are for an annual resolution, accurate chronology will be more of a problem. At present there is not even a Southern Hemisphere radiocarbon calibration – this must surely be a priority for the PEP transect projects. The Southern Hemisphere tree-ring projects are making good progress in New Zealand, Tasmania, South Africa, and South America. These new chronologies will provide some needed precise annual time control for the PEPs but will likely not provide the link to pollen and other studies. For this radiocarbon still has an important role to play.
An exciting recent advance has been the finding of micro-tephras in organic deposits in many parts of the world, including the major ice caps. These marker layers open up the possibility of correlation directly from land to ice without depending on existing chronologies and also provides a precise time control in deposits such as peats where this has traditionally been difficult.

**Objectives**

**Near Term**
- To gain a greater understanding of the global variability of radiocarbon and the production of local calibration curves. This in turn depends of the completion of long, continuous, tree-ring chronologies in appropriate areas.
- To develop a global grid of microtephra information that will allow correlation over long distances combined with the essential geochemistry that will permit the accurate identification of such layers.

**Long Term**
- A search for further global time markers such as cosmic dust and sub-micron tephras that will allow correlation of deposits that otherwise have no possibility of annual resolution.

**Implementation**

Rapid progress is being made by a number of groups. It would be appropriate to hold another PAGES workshop at the next radiocarbon conference specifically addressing the problem of global correlation using radiocarbon. PAGES could assist with the advancement of microtephra work by holding a meeting in 1998 or 1999 to draw together work by terrestrial and ice-core researchers and to look for Northern/Southern Hemisphere tephra links along the PEP transects.

**Output**

The outcome of the radiocarbon calibration work will be series of calibration curves appropriate to different areas (or at least separate Northern and Southern Hemisphere calibrations. (The results of the tephra studies will appear in the TephraBase (see data handbook [Global Palaeoenvironmental Data. *PAGES Workshop Report* 95-2]).
Focus V
Activity 2  Development of New Proxies
Task 1  Isotope Calibration Study

(See “GNIP – Global Network for Isotopes in Precipitation” Booklet, jointly published by PAGES, IAEA, WMO, and IAHS)

Project Leaders:  Thomas Edwards

Introduction
The first precise determinations of stable isotope ratios of oxygen ($^{18}$O/$^{16}$O) and hydrogen ($^{2}$H/$^{1}$H) in meteoric waters, performed in the early 1950s, revealed large variability in the isotopic composition of precipitation both in time and space. Since 1961, the IAEA in cooperation with the WMO has conducted a world-wide survey of the isotopic composition of monthly precipitation. The programme was launched with the primary objective of collecting systematic data on the isotope content of precipitation on a global scale, characterizing spatial and temporal variability and, consequently, providing basic isotope data for the use of environmental isotopes in hydrological investigations. It was soon apparent that the data collected were also useful in other fields such as oceanography, hydrometeorology and climatology.

The data gathered during three decades of operation of the global IAEA/WMO network, supplemented by numerous local studies, provide a fairly detailed picture of spatial and temporal variability of isotopic composition of meteoric waters worldwide. This variability is controlled by numerous, mutually related factors including surface air temperature, relative humidity of the atmosphere, amount of precipitation, latitude, distance from the coast and the elevation of the given area above sea level. Like many other atmospheric properties, the isotopic composition of precipitation exhibits a broad spectrum of variations.

Scientific Objectives

- To assess the potential contributions of isotope studies in the hydrological cycle to PAGES and to the other global change programmes of the IGBP and WCRP
- To interpret quantitatively isotope records preserved in continental archives in order to support model simulations.

The Global Network for Isotopes in Precipitation
The first of these objectives places strong emphasis on GNIP. A number of GNIP planning and coordination meetings have been held:

The main aims of this meeting were to:

- Make a first attempt at coordinating present and planned monitoring activities within the ongoing global change programmes, with the main focus on linking the GNIP to these programmes
- Plan interaction and cooperation regarding monitoring activities of the water cycle
- Make recommendations to the global change monitoring programmes.

PAGES/WMO/IAEA/IAHS Workshop on Tracing Isotopic Composition of Past and Present Precipitation – Opportunities for Climate and Water Studies.

The recommendations of the working groups formed during the meeting addressed, among other issues, the following:

- There should be close liaison with WMO stations that measure other atmospheric parameters. Cooperation with such programmes as Global Atmospheric Watch and Global Climate Observing System was recommended. Isotope monitoring of river outflow from major continental basins should be initiated. This could be realized in cooperation with the UNEP-World Health Organization (WHO) Global Environmental Monitoring System-Water Programme
- Funding agencies should be approached to provide funds for strengthening GNIP and national networks which could in turn contribute to the global data archives.

As a direct outcome of the Rüttihubelbad meeting, a booklet “Global Network Isotopes in Precipitation (GNIP)” was produced in 1996 with financial support from PAGES, IAEA, and WMO.


This meeting focused on:

- Specific steps to be taken towards implementation of the recommendations of the Rüttihubelbad meeting
- Strengthening the operation of the network by ensuring broader participation and the support of national and international bodies dealing with water and climate
- Drafting a Memorandum of Understanding on the joint operation of GNIP.

IAEA/WMO-WCRP/IGBP-PAGES Meeting on the Reorganization of GNIP.

The main purpose of this Meeting was to set up the GNIP SSC and to agree upon the memorandum of understanding. It also allowed discussion of proposed reference stations for the GNIP core network.
Implementation and Output

The first key proposal is for securing and enhancing the network of ‘isotopes in precipitation’ measurements. These form the main point of reference and calibration for translating stable isotope records from major palaeoarchives into quantitatively defined parameters of the water cycle (temperature, precipitation, evaporation, recharge mechanisms etc.).

The SSC, established in 1996, is responsible for ensuring that the network is properly designed, operated and maintained.

The organizations represented on the SSC include the specialized UN agencies IAEA, WMO, UNEP, WHO; the global change research programmes IGBP (most directly through PAGES) and WCRP; and the scientific union IAHS. The participating organizations would be responsible for the following:

**IAEA**
Analytical aspects, quality assurance and control, laboratory intercalibrations, data archiving and management.

**WMO**
Precipitation sampling, station maintenance, provision of samples to laboratories, liaison with national agencies.

**WMO/UNEP/WHO**
River sampling, station maintenance.

**IGBP-PAGES/WCRP**
Along with other members of the GNIP SSC, conduct reviews at three to five year intervals to re-assess the network and ensure that it is of maximum relevance to global change research.

Calibrating Continental Archives: The Role of ISOMAP

Achieving the second of the objectives defined above requires not only a strengthening of GNIP, but also a complementary emphasis on the factors that modify isotopic signatures in precipitation as they become recorded in natural archives ranging from groundwaters and sediments to speleothems and tree rings.

There is a spectrum of complexity and consequent uncertainty within the field depending on how far the archive material is removed by chemical and/or biological processes from the initial stable isotope signature in the water molecule. In the case of non-melting polar ice at one extreme, the case is relatively more simple. Moreover, the presence of both oxygen and deuterium measurements allows for mutually constrained inferences based on isotopes alone. Complexity and uncertainty both increase as one passes from seasonal or periodical melting and/or carbonate-contaminated ice, through marine biogenic carbonates (where a different set of relatively simple assumptions seems to be operationally viable), to groundwaters and to archives like speleothems, lake sediments, peat and aggradational soils and tree rings where eventually not only does one often lose the deuterium-based information, but the system becomes increasingly complicated by ecophysiological proc-
esses. PAGES priorities with respect to these calibration issues favour making the best possible use of the more complex signatures, since relatively coherent and effective research communities are already dealing with the relatively more straightforward systems.

This provides a strong rationale for emphasizing continental archives, especially since they will inevitably receive more prominence as palaeoscientists learn to cope with, integrate and ultimately benefit from their diversity. In these archives, the main sources of error and uncertainty are often not those linked to instrumental precision or statistical treatment, but those requiring a fuller understanding of the environmental and ecophysiological systems involved. Moreover, in these contexts, isotopes alone will rarely form a satisfactory basis for quantitative inferences; they need to be seen as part of a multi-proxy approach to palaeoenvironmental reconstruction.

The ISOMAP (Isotope Mapping) group has recently been identified as the PAGES leaders for these aspects of isotope calibration. The first step will be to hold a workshop that addresses the problems outlined above with respect to at least the following archives:

- Lake sediments
  - (a) non-biogenic carbonates
  - (b) biogenic carbonates (ostracods etc.)
  - (c) organic matter
  - (d) diatom silica
- Groundwater
  - (a) unsaturated zone
  - (b) saturated zone – stable isotopes – noble gases
- Tree rings and organic matter in aggradational soils
- Glacier Ice Cores
- Speleothems
- Corals (since they provide high resolution records that link closely with continental sequences).

The main outcome of this workshop is expected to be a series of articles devoted to stable isotope signatures in different continental environmental archives. These articles could be collected into a special issue or published as a book, but all should be peer reviewed to meet the high international standards. Moreover, these articles will emphasize definition of the state of the art in each area of isotope application for palaeoresearch rather than presentation of individual case studies.

The ultimate aim of the group is to develop a mapping capability for key periods in the past based on an evolving database so that the isotope records for these timeslices can be used to constrain and validate model simulations of isotopic ratios for the same time intervals.
Report prepared by Hans Oeschger, Ulrich Schotterer, Frank Oldfield, and Thomas Edwards

Contact:
Thomas Edwards
Department of Earth Sciences
University of Waterloo
200, University Ave. West
Waterloo, ONT N2L 3G1
Canada
Tel: (1-519) 888 4567 ext 3231
Fax: (1-519) 746 0183
Email: twedwar@uwaterloo.ca
Figure 12a

Composite trend curves of oxygen-18 and atmospheric temperature (expressed as deviations from the long-term mean after removing the seasonal trend) from selected European GNIP stations. The close correlation indicates that changes in precipitation patterns or seasonality are of little significance. From: PAGES/WMO/IAEA Publication *Global Network for Isotopes in Precipitation (GNIP)* 1996 (lead author; Ulrich Schotterer).
The global relationship between $\delta^{18}O$ in precipitation and mean annual temperature shows a linear trend for many samples. Where the relationship breaks down, for example in the tropics and in continental interiors, the $\delta^{18}O$ signal often reflects the influence of different moisture sources rather than of atmospheric temperature. The implications of $\delta^{18}O$ measurements are therefore just as important in studies of the hydrological cycle as in studies of temperature variations. From: PAGES/WMO/IAEA Publication *Global Network for Isotopes in Precipitation (GNIP)* 1996 (lead author; Ulrich Schotterer).
Focus V
Activity 2
Task 2  Continental Drilling for Palaeoclimate Records

(See PAGES Workshop Report 96-4)

Project Leader:      Steven M. Colman

Introduction
This Task developed from a growing need for continental palaeoclimate records within the PAGES Project. A global network of palaeoclimate records, including continental areas, is necessary to achieve truly global reconstructions of past climates. In addition, continental palaeoclimate records reveal changes on temporal and spatial scales that are pertinent to human activities, and they provide a record of how climate change has affected landscapes, fauna, and vegetation.

Long, high-resolution cores for palaeoclimatic reconstructions have been obtained in many different environments, but the results of studies based on marine and ice-sheet cores have been particularly visible and influential in palaeoscience. For completeness and for relevance to human activities, it is essential that long, high-quality palaeoclimate records be retrieved from terrestrial locations as well. Finally, as climate-simulation models become more advanced and marine and ice-core records improve, a network of high-quality, continental palaeoclimate records is especially important.

This Task is largely a support function for other PAGES scientific objectives and projects, especially those related to the PANASH project (PAGES Focus I) and its PEP transects. Part of the impetus for the activity was generated by the proposal and implementation of the ICDP, originally intended to be a continental analog of the Ocean Drilling Project. One of seven themes for ICDP is “Earth History and Climate.”

Scientific Objectives
The primary scientific objectives of the continental drilling activity are to facilitate the acquisition of long, high-resolution palaeoclimate records from the continents by:

- Preparing the international continental palaeoclimate community to participate in research requiring large-scale, multi-disciplinary efforts
- Developing an operational framework for the collection of palaeoclimate records in the three PEP transects
• Creating recommendations and guidelines for all phases of coring and drilling projects, including coordination and planning efforts; drilling operations; core handling and archiving; and sampling, analytical, data, and publication protocols.

Additional objectives of this activity are to:
• Develop strategies for initial organization of drilling projects
• Consider ways of developing technology related to continental drilling
• Encourage national support for drilling projects aimed at global change objectives.

**Project Implementation**

A small, international group of scientists representing 15 countries met in Potsdam, Germany, from June 30 – July 2, 1995 for the main organizational workshop for this Task. The workshop focused on the scientific objectives listed above and produced material for a report (*PAGES Workshop Report Series 96-4*).

The workshop participants decided to focus on lake sediments, because of their relative continuity, time resolution, and sensitivity to climate change, and because of the general ability to compare ancient lake sediments with their modern counterparts in the same lake.

A significant outcome of the workshop was the formation of a *Lake Drilling Task Force* to plan a global network of lake drilling sites. The Task Force solicited initial planning documents for lake drilling sites from the international continental palaeoclimate community and met in October 1995 to begin to develop a 5–10 year programme for retrieving 50–500 m of continuous cores from a wide variety of continental archives, including drilling sites in remote areas. The planning documents and expanded materials were compiled into a prospectus and submitted to the ICDP in 1996.

The Lake Drilling Prospectus was well received by the ICDP but did not fit well into their structure and operational plans. Consequently, ICDP convened a workshop at Lamont Doherty Earth Observatory in December 1996 to facilitate coordination between ICDP and PAGES lake drilling interests. This workshop greatly benefited proposals that were among the first submitted for funding by ICDP in January, 1997. The workshop recommended that a member of the PAGES community be included in the ICDP Advisory Group, which reviews proposals, and Steve Colman was appointed to that task. During 1997, Colman also gave presentations concerning these developments to workshops associated with the Eastern Asia Continental Drilling Programme (China) and the US Continental Drilling Programme. Based on review of 1997 ICDP proposals, ICDP funded a workshop in Florida, USA, in October 1997, to develop engineering plans for lake drilling systems.

The most direct linkages encouraged by this Task are between the three PAGES PEP transects and the ICDP. The Task will also foster linkages between the PEP transects and many other PAGES projects, such as CAPE and IMAGES. Actual drilling operations are likely to involve connections with regional global change networking groups such as IAI and START.
Output (accomplishments or expected results)


The report from the Potsdam Workshop (PAGES Workshop Report Series 96-4) contains recommendations that serve as a set of guidelines or “templates” for continental drilling projects aimed at the recovery of palaeoclimatic records. These guidelines provide several things to the global change community, including:

• A basis for evaluating proposed drilling projects by the scientific organizations and by funding agencies
• An incentive for advance planning and coordination
• Support for the scientific synergy that emerges from large, interdisciplinary projects.

A preliminary 5–10 year prospectus for retrieving long, continuous drill cores from a wide variety of lakes has been developed and the drill sites have been prioritized. A preliminary version of this prospectus was submitted to the International Continental Drilling Programme at its founding meeting in Tsukuba, Japan, in February 1996.

Project Management

On-going operations of this Task are being conducted by the Lake Drilling Task Force. Members are Vera Markgraf (PEP I), John Dodson and Liu Tungsheng (PEP II), Françoise Gasse (PEP III), Doug Williams (BDP), Jorg Negendank (ELDP), Suzanne Leroy (PAGES), Tom Johnson (IDEAL), and Steve Colman (PAGES and USGS). The Task Force leader is Steve Colman (see address below). The Task Force has required only modest resources for a planning meeting (October 1995) and proposal reviews. The group met at the Lamont workshop in December 1996, and occasional meetings of the Task Force are anticipated.

Future Directions

Future directions depend largely on the development of mechanisms for logistics, operations, and technology for continental drilling projects, preferably in conjunction with ICDP. An ideal arrangement would involve co-funding of large, international drilling projects by ICDP and by national and international science agencies. In such an arrangement, ICDP would provide operational support for projects, including drilling equipment, technical expertise, and actual drilling operations. Some support might also be provided for pre-drilling site surveys. Scientific support, including salaries and travel for scientists and all expenses related to analysis of the recovered drill cores, would be provided by national or international science agencies. ICDP is an increasingly recognized programme with growing activity and
membership. It will provide funding along the lines described above for lake-drilling projects. Other arrangements could be made for operational support of drilling projects, for example, by establishing operational capabilities at one or more scientific laboratories. The Task Force intends to pursue these and other options. However, centralized drilling operations seem most efficient and cost-effective, and given the mandate of ICDP, the suggested partnership is the first choice.

Report prepared by Steven M. Colman

Contact:
Steven M. Colman
US Geological Survey
384 Woods Hole Rd.
Woods Hole, MA 02543
USA
Tel: (1-508) 457 2341
Fax: (1-508) 457 2310
Email: scolman@usgs.gov
Figure 13

World map showing lake drilling sites identified by PAGES Lake Drilling Task Force along with initial priorities. Modified from: Continental Drilling for Palaeoclimate Records Workshop Report 96-4, Ed. Steven Colman.
Focus V
Activity 3  International PalaeoData System

(See PAGES Workshop Report 95-2)

Project Leader:  Jonathan Overpeck

Background

At the earliest stages of PAGES planning, it was clear that a strong palaeoenvironmental data management foundation would be key for the success of PAGES. Many data needed by PAGES already existed and had to be made available in a useful form. It became clear that PAGES efforts to fortify a palaeodata system would result in a rich legacy of new palaeoenvironmental data and information. It was in response to this early need that the WDC-A for Palaeoclimatology was established in 1992, and formally designated as the PAGES Data Coordination Center in 1993. Thus, PAGES included a strong and active commitment to data management from the onset of the project.

Since 1992 a great deal of progress has been made as the PAGES International PalaeoData System became fully implemented. Dozens of regional, national, and topical database efforts from around the world are now coordinated. Public-domain data from over 7,000 sites around the globe are now available, along with many observed and simulated (e.g., by 3-D climate models) regional to global arrays of data. Both raw data and information derived from the raw data are widely available. All of the data are available over the Internet, as well as on a range of magnetic media. User data requests exceed 2,500 per month, and have been received from scientists in over 60 countries.

The success of the PAGES International PalaeoData System stems, to a large degree, from the broad involvement of the PAGES science community. Numerous regional and topical data management workshops have been held, and most PAGES planning workshops included discussions of data management needs. Planning culminated with the 1993 PAGES-sponsored workshop on “Global Palaeoenvironmental Data,” co-convened by Jonathan Overpeck and Jonathan Pilcher. The results of this workshop, including a detailed PAGES data management plan, have been published as Report 95-2 of the PAGES Workshop Report Series 95-2. However, PAGES data management activities continue to be updated, expanded and improved via the involvement of PAGES scientists, numerous data-specific advisory panels, and exchange of ideas with other IGBP and WDC data management efforts. What follows in this report is a summary from PAGES Report 95-2, as updated where appropriate by more recent improvements. It is estimated that the current PAGES International PalaeoData System has benefited from input provided by hundreds of scientists from dozens of countries.

The most recent status of the PAGES International PalaeoData System can be obtained via URL: http://www.ngdc.noaa.gov/paleo/paleo.html; by contacting the PAGES IPO; or:
Scientific Objectives

- Provide easy, well-documented and free access to all forms of palaeoenvironmental data and information
- Provide assistance to regional, topical or national palaeoenvironmental database efforts
- Coordinate with regional, topical or national database efforts to provide an integrated global and interdisciplinary database
- Provide data support and advice to all ICSU, IGBP, and WCRP science efforts producing or using palaeoenvironmental data
- Work with the PAGES community to ensure that data are acquired, managed, and distributed in the way that best serves the global change community.

Operating Plan/Project Strategy

The PAGES International PalaeoData System is fully functional and already serving a wide range of PAGES Activities and Tasks, each of which has a specific data management plan that includes overall coordination by the WDC-A for Palaeoclimatology. The WDC and PAGES both adhere to ICSU and WDC principles that have been proposed and accepted by the SC-IGBP. In abbreviated form, these include commitments to:

- Establishment, maintenance, validation, description, accessibility and distribution of high-quality, long-term datasets
- Full and open sharing of all data – with no restrictions
- Long-term safe archive of all data
- Clear and widely available information about data holdings
- Data quality standards as set by the scientific community
- Distribution of data at the lowest possible cost – all PAGES data is free over the Internet, or available at the cost of reproduction on magnetic and optical media
- Limiting any exclusive use periods for data from one to three years.
Recognizing the importance of raw as well as derived data, the PAGES/WDC data holdings are organized to distinguish several levels and types of data:

- **Primary (“raw”) data** (e.g., raw tree-ring measurements, fossil counts, isotopic measurements)
- **Secondary data developed from the raw data** (e.g., tree-ring chronologies, fossil percentages, other time series)
- **Tertiary information inferred from the primary and secondary data** (e.g., quantitative palaeoclimate estimates, sea-surface temperature or palaeovegetation reconstructions)
- **Modern calibration data needed to convert primary and secondary data into quantitative estimates of past climate, ocean, or biosphere conditions**
- **Time series of hypothesized climate forcing** (e.g., solar, volcanic, trace-gas, or astronomical changes)
- **Climate boundary conditions through time** (e.g., ice extent and height, land surface characteristics)
- **Output from atmosphere, ocean and biosphere models**
- **Metadata (documentation) regarding all of the data holdings.**

Although PAGES/WDC data management efforts focus primarily on data relevant to the PAGES temporal streams, data holdings are not restricted to the late Quaternary. Instead, the WDC-A serves to facilitate the exchange and archiving of all palaeoenvironmental data relevant to understanding past climate system (i.e., atmosphere, ocean, biosphere, cryosphere) dynamics. The WDC-A manages data from all sources, including:

- Cave and spring calcite
- Corals
- Eolian deposits
- Fluvial deposits
- Fossil insects
- Fossil pollen
- Glacier mass balance
- Historical documents
- Ice cores
- Ice wedge/periglacial features
- Lake level variations
- Loess
- Long instrumental records
- Molluscs
- Noble gases in groundwater
- Ocean sediments
- Packrat middens
- Palaeolimnological data
- Palaeosols
- Plant macrofossils
- Sea level variations
- Tree-ring data
- Treeline movement data
Up-to-date descriptions of data, guidelines for data submission, and methods for data exchange should be obtained from the WDC-A for Palaeoclimatology. The WDC is also committed to providing tools for easy data access, both over the Internet, as well as via magnetic or optical media. The hope is that PAGES data and information can be available to all scientists of the world, not just those with the most modern electronic capability.

The PAGES International PalaeoData System and WDC-A for Palaeoclimatology were established to serve many national and international palaeoenvironmental research efforts, including those of the IGBP and WCRP. Funding for the WDC-A for Palaeoclimatology is provided by the US NOAA, but funding for the many regional, national, and topical palaeoenvironmental data efforts comes from other agencies, both within the US and in other countries. It is the goal of PAGES that international coordination of palaeodata management efforts becomes even stronger in the coming years, perhaps with the establishment of additional WDCs focused on palaeoenvironmental data in several regions of the world.

Report prepared by Jonathan Overpeck
Contact:
Jonathan Overpeck
WDC-A for Palaeoclimatology
National Geophysical Data Center
325 Broadway E/GC
Boulder, CO 80303
USA
Tel: (1-303) 497 6146
Fax: (1-303) 497 6513
Email: jto@ngdc.noaa.gov
Figure 14

Global Databases.

Another unique achievement of PAGES has been the development of a successful global palaeoenvironmental data management system. The coordination of scientific and database efforts around the world will continue to grow, and will provide a key resource for PAGES/CLIVAR interaction. From: World Data Centre A (WDC-A) for Palaeoclimatology.
Focus V
Activity 4 Regional Education and Infrastructure Efforts (REDIE)

Introduction
This Cross-Project Activity was established by the PAGE SSC in 1994. It brings together efforts in diverse areas designed to strengthen the broad palaeoscience community and to encourage national support for PAGES-related research.

A major goal of PAGES is to understand natural palaeoenvironmental variability on a global scale. This requires an understanding of past environmental variability over all continental regions. Such a goal cannot be realized without the involvement of scientists from many of the developing countries. Under the broader umbrella of IGBP, and with support from START and IAI, PAGES encourages scientists from all parts of the world to be involved in palaeoenvironmental research.

Objectives
Since much of the REDIE effort focuses on developing regions, the objectives tend to be long-term and open-ended. The objectives of REDIE are:

- To enlist scientists and technicians to strengthen the cadre of palaeoenvironmental scientists
- To encourage national support for regional and educational efforts
- To educate and inform the public on the rationale, objectives and accomplishments of the PAGES project
- To promote long-term development of infrastructure within the developing countries.

Implementation
No single implementation meeting will suffice for the REDIE activity. Rather, specific regions or educational activities will be targeted for planning and implementation efforts. As appropriate, these efforts will be in association with START and IAI. An example of this is the PAGES/START Workshop on Past Global Changes in Africa held in Mombasa, Kenya, in 1993. The workshop report (October 1994) delineates the requirements for educational, infrastructure and regional research for the advancement of PAGES-related activities in Africa.

Because of the IGBP, PAGES has been able to organize the international palaeoscience community to plan and implement global-scale scientific efforts. The PEP I research activity has already brought scientists together from South and North America for a major planning exercise in Panama and a regional science meeting in Argentina in association with a meeting of the PAGES SSC. PEP II has developed through planning meetings in Taiwan, Australia, P.R. of China (two meetings), and a
workshop in Nepal. The PEP III activity has brought regional scientists together in Kenya and Uganda, as well as Switzerland and France. Circum-polar research has been advanced by a PALE meeting in eastern Russia. In each of these meetings, the IGBP has enabled scientists from developing countries to work together as partners with the wider scientific community, a strategy that will permit greater collaboration in the future. PAGES has further enhanced these international linkages by promoting a global data management system that is accessible to scientists in all countries (not just those with routine Internet access).

**Future Directions**

“New Ideas” are difficult to identify in the context of a service-oriented activity. IDEAL is an example of a PAGES project that has included a strong training and development focus as part of its mandate. IDEAL has two primary goals. The first is palaeoclimate research, the second is:

“Providing a comprehensive training programme for African students and scientists that will result in collaborative efforts between African and Northern Hemisphere limnologists and palaeoclimatologists, and provide the scientific infrastructure within East Africa to facilitate the proper monitoring and guardianship of the East African lakes after the termination of IDEAL.”

The first steps in this direction have recently been taken through the establishment of the Nyanza Project, funded by the US NSF. This is an African Lake Study Programme in which US university undergraduate students and young African researchers will study tropical lake science in a summer programme based in Tanzania, on the shores of Lake Tanganyika, for the next five years. This Research Experience for Undergraduates programme will be based on Tanzania Fisheries Research Institute facilities at Kigoma, Tanzania. At the same time, the programme faculty will run an identical course for young African scientists with funding and research support from the United Nations Global Environmental Facility. The joint Nyanza Project fulfils part of the training mission of IDEAL.

The clear identification of educational and infrastructure objectives within a major international research project provides a valuable and instructive paradigm for other field projects within developing regions. In association with IAI, PEP I is also moving in this direction.

---

**Contact for REDIE:**
Frank Oldfield  
PAGES IPO  
Bärenplatz 2  
CH-3011 Bern  
Switzerland  
Tel: (41-31)312.3133  
Fax: (41-31)312.3168  
Email: oldfield@pages.unibe.ch

**Contact for IDEAL Nyanza Project:**
Andrew Cohen  
Department of Geosciences  
University of Arizona  
Tucson, AZ 85721  
USA  
Tel: (1-520)621 4691  
Fax: (1-520)621 2672  
Email: acohen@geo.arizona.edu
PAGES Management

PAGES Project Guidance and Administration

The PAGES Project is guided by an international SSC which is appointed by the SC-IGBP. Members are chosen from active scientists who represent the major disciplines in the palaeosciences and also provide regional/geographic representation. Meetings of the PAGES SSC are held once per year; specialists and project leaders are routinely invited to take part in these meetings to provide additional expertise and to expand geographic representation.

The PAGES SSC has created, from within its membership, a PAGES EXCOMM to act on its behalf between regular meetings, especially when a rapid response is required. In addition, PAGES proposes to convene a group comprising the main Activity and Task leaders as a “Leaders Group” with the mission to implement and disseminate PAGES science and to promote closer interaction and integration between the different Activities. This Group met for the first time in November 1997.

The NSF of Switzerland and of the USA have agreed to support a jointly-funded IPO for PAGES which began operation in Bern, Switzerland, in early 1992. The joint agreement was renewed for a further five years from 1 January 1996. Under the review of the SSC and EXCOMM, the PAGES IPO performs the following functions:

- Initiates and organizes planning meetings and international workshops to implement scientific activities of the project
- Provides day-to-day scientific oversight, as needed, for organized PAGES project activities
- Publishes a periodic newsletter and distributes it internationally
- Compiles and issues scientific reports describing the activities and results of the project
- Advises national funding agencies, as appropriate, regarding proposed individual, national and international initiatives that may relate to the project
• Composes general and review articles for scientific journals that report aims and opportunities to aid in recruiting scientists and technicians to work in the project

• Acts as a multi-national advocate for the project

• Maintains active contact with national programmes that will work to implement PAGES activities

• Organizes and maintains an active international directory of scientists and institutions relevant to PAGES activities

• Assists in establishing data repositories for various types of palaeodata that can be readily accessed by the international scientific community

• Serves as the point of contact for PAGES activities with the IGBP Secretariat and with the IPOs of other IGBP, IHDP, and WCRP projects

• Provides facilities, and if possible salary support, for visiting scientist to work on PAGES planning and scientific activities.

The PAGES IPO works with within the IGBP structure to integrate and coordinate research activities with corresponding project offices for the other IGBP programme elements, the projects of the IHDP and WCRP, and the START International Secretariat. PAGES liaison activities with other global change projects encourages collaborative research efforts which are deemed valuable at the international level.

The PAGES IPO provides the administrative functions that are essential for the coordination of palaeoscience research on global scale and ensures that the complex of international projects are well-focused and well-coordinated without duplicative efforts. The PAGES IPO is engaged in developing a modern communications network with the international palaeoscience and global change research community. A functioning directory-mailing list has been established which currently lists over 2,200 scientists participating in the activities of the PAGES Project.

Organizing the participation of key scientists to focus on global issues and the encouragement of multi-disciplinary interaction is an essential function of the PAGES IPO. To advance its goal, PAGES supports community workshops and publishes the resulting recommendations and implementation plans. These are listed in Appendix I (pages 221–222). PAGES publishes its Newsletter approximately three times per year. The first Newsletter of 1997 marked a new departure. It expanded in size from six to 16 pages and now includes a much greater emphasis on reporting PAGES science. This reflects the shift in emphasis within PAGES from agenda-setting towards implementation. All scientists listed on our mailing list have, to date, received copies of the PAGES Newsletter as well as copies of all other PAGES publications. Because of the great expense of distribution, we now propose to make the expanded Newsletter the main vehicle for general circulation and to develop a more targeted approach for PAGES reports, which are more specialized or regional in character.
The public and the global change community may access PAGES information (including Newsletters) via the PAGES Home Page:

http://www.pages.unibe.ch/pages.html

or through the “palaeo-page” of the WDC-A:

http://www.ngdc.noaa.gov/paleo/paleo.html

Plans are in progress, linked to computer upgrades in the PAGES IPO, to house and further develop the PAGES web site there.

The establishment of a palaeoscience data repository is generally regarded as the key element in encouraging a unified multi-proxy approach to the global change problem. PAGES and the WDC-A for Palaeoclimatology have established a close working relationship to continue to provide this essential service, in a readily accessible format, for the entire scientific community.

PAGES Director: Bruno Messerli
PAGES Executive Director: Frank Oldfield
PAGES Past-Chairman: Hans Oeschger
Interproject Scientific Activities

The BIOME 6000 / PMIP Collaboration with GAIM/GCTE/IGBP-DIS

One of the PAGES Activities (4.2) focuses on the use of palaeoenvironmental data to evaluate the performance of state-of-the-art predictive models. Toward this end, PAGES has established two Tasks – PMAP and PMIP. Crucial to these tasks is the comparison of modeled palaeoclimates to palaeoclimate proxy data retrieved through observation and analysis. One of the most promising approaches is being pioneered by a joint PAGES/GCTE/GAIM/IGBP-DIS effort to convert global palaeovegetation data, being assembled by PMAP, into the linkage of climate model output and through a vegetation model being developed as part of GAIM and GCTE. At present, 13 climate modelling groups are participating in PMIP and stand to benefit from this interdisciplinary IGBP interaction.

PAGES/CLIVAR

The goal of CLIVAR is to determine the variability and predictability of the physical climate system on time-scales of seasons to a century. This cannot be accomplished without the PAGES palaeoclimate perspective, both for understanding the total range of natural climate system variability and for evaluating how well predictive models simulate this variability. For this reason, PAGES and CLIVAR have sponsored the first joint IGBP/WCRP workshop as a first step toward defining and implementing joint research activities. As part of a collaborative research endeavour, the CLIVAR Programme will focus climate dynamics expertise on palaeo-environmental problems central to PAGES.
PAGES/IGAC

“The Role of Polar Regions in the Changing Atmospheric Composition” is a component of the IGAC Core Project. Its goals are to: (i) achieve a comprehensive understanding of atmospheric chemical processes in the polar regions; (ii) understand the relationship between the composition of air and that of snow and ice; and (iii) deduce records of the past chemical climate of the atmosphere from glacial deposits. It is clear that these goals are closely related to PAGES activities and, in particular, to ice core studies from the polar ice sheets. PAGES and IGAC are currently exploring mutually beneficial linkages between the projects for defining scientific programmes and their implementation. Both projects are cooperating with SCAR in developing global change research in the Antarctic. In addition to this, PAGES has been in contact with IASC to explore global change research in the circum-Arctic region.

PAGES/BAHC/LOICZ

In the field of landscape/fluvial system coupling, PAGES co-sponsored a workshop on modelling the delivery of terrestrial materials to freshwater and coastal ecosystems. The workshop was designed to develop a cooperative science and implementation plan focusing on the mobilization, transport and processing of constituents through the aquatic domain. PAGES participates in this collaborative effort through its Fluvial Systems Activity.

PAGES/GAIM/IGAC 150k Year Challenge

Current plans for all three project elements include a joint focus on the reconstruction of trace gas behaviour over the last 150k years. The thrust of this joint initiative will be to improve our understanding of the role trace gases have played during periods of major, rapid climate change and to provide a better basis for modelling their role in future climate change. Such a task involves a wide range of scientists concerned with, for example, the behaviour of trace gases in the atmosphere, the ice core record of both trace gases and atmospheric temperature, the role of the oceans and the terrestrial biosphere in the global carbon dioxide and methane budgets and the modelling implications of new insights as they arise from all the work now in progress.
Appendix I

List of PAGES Workshop Reports and Other Publications

Some reports and PAGES newsletters available from PAGES homepage:

http://www.pages.unibe.ch/pages.html

 Copies may be obtained from:

PAGES IPO
Bärenplatz 2
CH-3011 Bern
Switzerland
Tel:  (41-31) 3123133
Fax:  (41-31) 3123168
Email: pages@ubeclu.unibe.ch

93-1
High Resolution Record of Past Climate from Monsoon Asia: The last 2,000 Years and Beyond. Edited by R. Bradley, 1993.

93-2

94-1
94-2
INQUA/PAGES Workshop, Palaeomonsoons in Africa and Surrounding Oceans: The last 2,000 Years. Edited by S. Kroepelin

PAGES/START Workshop, Past Global Changes in Africa. Edited by Eric O. Odada.

94-3
International Marine Global Change Study (IMAGES) Science and Implementation Plan. Issued by IMAGES Planning Committee.

95-1

95-2

1996
The PAGES/CLIVAR Intersection. Providing the palaeoclimatic perspective needed to understand climate variability and predictability. Edited and Co-organized by J.-C. Duplessy and J. Overpeck.

1996

96-1

96-2
Land Use and Climate Impacts on Fluvial Systems During the Period of Agriculture. Edited by R.J. Wasson.

96-3
Climate Effects of Explosive Volcanism. Edited by J. Beget et al.

96-4
Continental Drilling for Palaeoclimate Records. Edited by S. Colman.

1997

97-1
ITASE workshop report (International Trans-Antarctic Scientific Expedition).

97-1
PEP III. The Pole-Equator Pole Transect through Europe and Africa
# Acronyms and Abbreviations

<table>
<thead>
<tr>
<th>Acronym</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>AARI</td>
<td>Arctic and Antarctic Research Institute (Russia)</td>
</tr>
<tr>
<td>ACACIA</td>
<td>Arid Climate, Adaptation and Cultural Innovation in Africa</td>
</tr>
<tr>
<td>AGCM</td>
<td>Atmospheric General Circulation Model</td>
</tr>
<tr>
<td>AGU</td>
<td>American Geophysical Union</td>
</tr>
<tr>
<td>AMIGO</td>
<td>America’s Interhemisphere Geo-Biosphere Organization</td>
</tr>
<tr>
<td>AMIP</td>
<td>Atmosphere Model Intercomparison Project</td>
</tr>
<tr>
<td>AMNGR</td>
<td>Arctic Marine Oil Gas Reconnaissance (Russia)</td>
</tr>
<tr>
<td>AMS</td>
<td>Accelerator Mass Spectrometry</td>
</tr>
<tr>
<td>ANU</td>
<td>Australian National University</td>
</tr>
<tr>
<td>ARTS</td>
<td>Annual Records of Tropical Systems</td>
</tr>
<tr>
<td>ARW</td>
<td>Advanced Research Workshop (NATO)</td>
</tr>
<tr>
<td>AWI</td>
<td>Alfred Wegener Institute (Germany)</td>
</tr>
<tr>
<td>AWS</td>
<td>Automatic Weather Stations</td>
</tr>
<tr>
<td>BAHC</td>
<td>Biospheric Aspects of the Hydrological Cycle (IGBP)</td>
</tr>
<tr>
<td>BAS</td>
<td>British Antarctic Survey</td>
</tr>
<tr>
<td>BDP</td>
<td>Lake Baikal Drilling Project</td>
</tr>
<tr>
<td>BMBF</td>
<td>Bundesministerium für Bildung, Wissenschaft, Forschung und Technologie (Germany)</td>
</tr>
<tr>
<td>BP</td>
<td>Before Present</td>
</tr>
<tr>
<td>BPRC</td>
<td>Byrd Polar Research Center</td>
</tr>
<tr>
<td>CAPE</td>
<td>Circum-Arctic PalaeoEnvironments</td>
</tr>
<tr>
<td>CCR</td>
<td>Center for Climatic Research (USA)</td>
</tr>
<tr>
<td>CEA</td>
<td>Commissariat à l’Energie Atomique</td>
</tr>
<tr>
<td>CEREGE</td>
<td>Centre Européen de Recherche et d’Enseignement de Géosciences de l’ Environnement (France)</td>
</tr>
</tbody>
</table>
CFR  Centre des Faibles Radioactivités, Laboratoire Mixte du Centre National de la Recherche Scientifique et du Centre de l’Energie Atomique (France)
CLIMAP  Climate Mapping, Analysis, and Prediction
CLIP  Climates of the Past
CLIVAR  Climate Variability and Predictability Research Programme (WCRP)
CNRS  Centre National de la Recherche Scientifique (France)
COHMAP  Cooperative Holocene Mapping Project
COMNAP  Council of Managers of National Antarctic Programme
COT  Commission on Tephrochronology and Volcanism (INQUA) (Formally “Commission on Tephrochronology” (INQUA))
COTAV  Commission on Tephrochronology and Volcanism (INQUA)
CTD  Oceanographic instrument measuring Conductivity, Temperature and Depth

DFG  Deutsche Forschungsgemeinschaft (Germany)
DGXII  Délégation Générale XII (EU)
DHM  Department of Hydrology and Meteorology (Nepal)
DIS  Data and Information System
DSM  Dirécction des Sciences de la Matière

EC  European Commission
ECCOP  European Committee on Ocean and Polar Science
ECM  Electrical Conductivity Measurements
ECOFIT  Ecologie et Palaeoécologie des Forêts Intertropicales (an ORSTOM, France Research Initiative)
EGS  European Geophysical Society
ELDP  European Lake Drilling Program
ENRICH  European Network for Research in Global Change
ENSO  El Niño-Southern Oscillation
EOS  Earth Observing System
EPA  Environmental Protection Agency (USA)
EPECC  European PalaeoEnvironment, Climate and Circulation Programme
EPICA  European Programme for Ice Coring in Antarctica
ERICA  Recherche sur l’environnement et le climate intertropical en Afrique
ESF  European Science Foundation
ESH  Earth System History
EXCOMM  Executive Committee
EU  European Union
FSU  Former Soviet Union
FTP  Fast Transfer Protocol
<table>
<thead>
<tr>
<th>Acronym</th>
<th>Abbreviation/Full Name</th>
</tr>
</thead>
<tbody>
<tr>
<td>GAIA</td>
<td>Global Analysis, Interpretation and Modelling (IGBP)</td>
</tr>
<tr>
<td>GCM</td>
<td>General Circulation Model</td>
</tr>
<tr>
<td>GCTE</td>
<td>Global Change and Terrestrial Ecosystems (IGBP)</td>
</tr>
<tr>
<td>GFDDL</td>
<td>Geophysical Fluid Dynamic Laboratory (USA)</td>
</tr>
<tr>
<td>GFZ</td>
<td>GeoForschungs Zentrum</td>
</tr>
<tr>
<td>GIL</td>
<td>Geophysical Isotope Laboratory (Denmark)</td>
</tr>
<tr>
<td>GIS</td>
<td>Geographic Information System</td>
</tr>
<tr>
<td>GISP2</td>
<td>Greenland Ice Sheet Project Two (USA)</td>
</tr>
<tr>
<td>GISS</td>
<td>Goddard Institute for Space Studies (USA-NASA)</td>
</tr>
<tr>
<td>GLOCHANT</td>
<td>Global Change in Antarctica (SCAR)</td>
</tr>
<tr>
<td>GNIP</td>
<td>Global Network for Isotopes in Precipitation</td>
</tr>
<tr>
<td>GOC</td>
<td>GRIP Operation Center</td>
</tr>
<tr>
<td>GRIP</td>
<td>Greenland Icecore Project (European)</td>
</tr>
<tr>
<td>GSC</td>
<td>Geological Survey of Canada</td>
</tr>
<tr>
<td>HCC</td>
<td>Himalayan Climate Center</td>
</tr>
<tr>
<td>HIPP</td>
<td>Himalayan Interdisciplinary Palaeoclimate Project</td>
</tr>
<tr>
<td>HIREAM</td>
<td>High Resolution Reconstruction of East Asian Monsoon</td>
</tr>
<tr>
<td>IAEA</td>
<td>International Atomic Energy Agency</td>
</tr>
<tr>
<td>IAHS</td>
<td>International Association of Hydrological Sciences</td>
</tr>
<tr>
<td>IAI</td>
<td>Inter-American Institute for Global Change Research</td>
</tr>
<tr>
<td>IASC</td>
<td>International Arctic Science Committee</td>
</tr>
<tr>
<td>IAVCEI</td>
<td>International Association for the Study of Volcanism and the Chemistry of the Earth’s Interior</td>
</tr>
<tr>
<td>ICAPP</td>
<td>International Icecore Circum-Arctic Palaeoclimate Program</td>
</tr>
<tr>
<td>ICDP</td>
<td>International Continental Drilling Project</td>
</tr>
<tr>
<td>ICIMOD</td>
<td>International Center for Integrated Mountain Development</td>
</tr>
<tr>
<td>ICP</td>
<td>International Conference on Palaeoceanography</td>
</tr>
<tr>
<td>ICSU</td>
<td>International Council of Scientific Unions</td>
</tr>
<tr>
<td>IDEAL</td>
<td>International Decade for the East African Lake</td>
</tr>
<tr>
<td>IG</td>
<td>Institute of Geography</td>
</tr>
<tr>
<td>IGAC</td>
<td>International Global Atmospheric Chemistry Project</td>
</tr>
<tr>
<td>IGBP</td>
<td>International Geosphere Biosphere Programme</td>
</tr>
<tr>
<td>IGC</td>
<td>International Geological Congress</td>
</tr>
<tr>
<td>IGCP</td>
<td>International Geological Correlation Program</td>
</tr>
<tr>
<td>IHDP</td>
<td>International Human Dimensions Programme on Global Environmental Change</td>
</tr>
<tr>
<td>IMAGES</td>
<td>International Marine Past Global Changes Study</td>
</tr>
<tr>
<td>INAA</td>
<td>Instrumental Neutron Activation Analysis</td>
</tr>
<tr>
<td>INQUA</td>
<td>International Union for Quaternary Research</td>
</tr>
<tr>
<td>INSTAAR</td>
<td>Institute of Arctic and Alpine Research (USA)</td>
</tr>
<tr>
<td>IOS</td>
<td>Institute of Oceanographic Science</td>
</tr>
<tr>
<td>Abbreviation</td>
<td>Full Form</td>
</tr>
<tr>
<td>--------------</td>
<td>-----------</td>
</tr>
<tr>
<td>IPCC</td>
<td>Intergovernmental Panel on Climate Change</td>
</tr>
<tr>
<td>IPO</td>
<td>International Project Office (formally Core Project Office of the IGBP (CPO))</td>
</tr>
<tr>
<td>IPPCCE</td>
<td>International Project on Palaeolimnology and Late Cenozoic Climate</td>
</tr>
<tr>
<td>ISOMAP</td>
<td>Continental Isotope Indicators of Palaeoclimate</td>
</tr>
<tr>
<td>ITASE</td>
<td>International Trans-Antarctic Scientific Expedition</td>
</tr>
<tr>
<td>ITRDB</td>
<td>International Tree-Ring Data Ban</td>
</tr>
<tr>
<td>JABIRP</td>
<td>Japanese Association for Baikal International Research Program</td>
</tr>
<tr>
<td>JGR</td>
<td>Journal of Geophysical Research</td>
</tr>
<tr>
<td>JGOFS</td>
<td>Joint Global Ocean Flux Study (IGBP/SCOR)</td>
</tr>
<tr>
<td>JOI INC.</td>
<td>Joint Oceanographic Institution (USA)</td>
</tr>
<tr>
<td>KVA</td>
<td>Kungliga Vetenskapsakademien (Royal Swedish Academy of Sciences (translation))</td>
</tr>
<tr>
<td>LAPD</td>
<td>Latin American Pollen Data Base</td>
</tr>
<tr>
<td>LBA</td>
<td>Large-Scale Biosphere Atmosphere Experiment in Amazonia</td>
</tr>
<tr>
<td>LBHP</td>
<td>Laboratoire de Botanique Historque et de Palynologie (France)</td>
</tr>
<tr>
<td>LGGE</td>
<td>Laboratoire de Glaciologie et Geophysique de l’Environnement (France)</td>
</tr>
<tr>
<td>LGM</td>
<td>Last Glacial Maximum</td>
</tr>
<tr>
<td>LIA</td>
<td>Little Ice Age</td>
</tr>
<tr>
<td>LLNL</td>
<td>Lawrence Livermore National Laboratory (USA)</td>
</tr>
<tr>
<td>LMCE</td>
<td>Laboratoire de Modelisation du Climat et de l’Environnement (France)</td>
</tr>
<tr>
<td>LOICZ</td>
<td>Land-Ocean Interactions in the Coastal Zone (IGBP)</td>
</tr>
<tr>
<td>LODYC</td>
<td>Laboratoire d’Oceanographie Dynamique et de Climatologie (France)</td>
</tr>
<tr>
<td>LUCC</td>
<td>Land-Use / Land-Cover Change (IHDP-IGBP)</td>
</tr>
<tr>
<td>MAGICS</td>
<td>Mass balance of Arctic Glaciers and Ice sheets in relation to Climate and Sea level change (IASC)</td>
</tr>
<tr>
<td>MEDIAS</td>
<td>MEDIterranée et Afrique Subtropicale</td>
</tr>
<tr>
<td>MESH</td>
<td>Marine Earth System History</td>
</tr>
<tr>
<td>MIT</td>
<td>Massachusetts Institute of Technology</td>
</tr>
<tr>
<td>MOU</td>
<td>Memorandum of Understanding</td>
</tr>
<tr>
<td>MSA</td>
<td>Methanesulfonate</td>
</tr>
<tr>
<td>MWP</td>
<td>Medieval Warm Period</td>
</tr>
<tr>
<td>NAD</td>
<td>Nansen Arctic Drilling Program</td>
</tr>
<tr>
<td>NAFCOM</td>
<td>Northern Africa Committee (START)</td>
</tr>
<tr>
<td>Abbreviation</td>
<td>Full Name</td>
</tr>
<tr>
<td>--------------</td>
<td>-----------</td>
</tr>
<tr>
<td>NAMOC</td>
<td>North Atlantic Mid Ocean</td>
</tr>
<tr>
<td>NASA</td>
<td>National Aeronautics and Space Association (USA)</td>
</tr>
<tr>
<td>NATO</td>
<td>North Atlantic Treaty Organization</td>
</tr>
<tr>
<td>NAUSICAA</td>
<td>Namibia/Angola Upwelling System and the Indian Connection to Austral Atlantic</td>
</tr>
<tr>
<td>NCAR</td>
<td>National Center for Atmospheric Research (USA)</td>
</tr>
<tr>
<td>NGDC</td>
<td>National Geophysical Data Center</td>
</tr>
<tr>
<td>NIPR</td>
<td>National Institute of Polar Research (Japan)</td>
</tr>
<tr>
<td>NISIS</td>
<td>Nagaoka Institute of Snow and Ice Studies (Japan)</td>
</tr>
<tr>
<td>NOAA</td>
<td>National Oceanic and Atmospheric Administration (USA)</td>
</tr>
<tr>
<td>NRC</td>
<td>National Research Council</td>
</tr>
<tr>
<td>NSF</td>
<td>National Science Foundation</td>
</tr>
<tr>
<td>NSIDC</td>
<td>National Snow and Ice Data Center</td>
</tr>
<tr>
<td>NSS</td>
<td>Non Sealsalt Sulfate</td>
</tr>
<tr>
<td>ODP</td>
<td>Ocean Drilling Program</td>
</tr>
<tr>
<td>ORSTOM</td>
<td>Institut Français de la Recherche Scientifique pour le Développement et Coopération</td>
</tr>
<tr>
<td>P/C WG</td>
<td>PAGES/CLIVAR Working Group</td>
</tr>
<tr>
<td>PACS</td>
<td>Pan American Climate Studies</td>
</tr>
<tr>
<td>PAGES</td>
<td>Past Global Changes</td>
</tr>
<tr>
<td>PALE</td>
<td>PalaeoClimates of Arctic Lakes and Estuaries</td>
</tr>
<tr>
<td>PANASH</td>
<td>Palaeoclimates of the Northern and Southern Hemispheres</td>
</tr>
<tr>
<td>PARCA</td>
<td>Programme in Arctic Regional Climate Assessment (USA)</td>
</tr>
<tr>
<td>PASC</td>
<td>Polar Atmospheric Snow and Chemistry (IGAC)</td>
</tr>
<tr>
<td>PASH</td>
<td>Palaeoclimates of the Southern Hemisphere</td>
</tr>
<tr>
<td>PB</td>
<td>PreBoreal</td>
</tr>
<tr>
<td>PCMDI</td>
<td>Programme for Climate Model Diagnosis and Intercomparison</td>
</tr>
<tr>
<td>PCOM</td>
<td>Policy Committee (ODP)</td>
</tr>
<tr>
<td>PEP</td>
<td>(North-South) Pole-Equator-Pole (Transects)</td>
</tr>
<tr>
<td>PEP I</td>
<td>The American Transect</td>
</tr>
<tr>
<td>PEP II</td>
<td>The Austral-Asian Transect</td>
</tr>
<tr>
<td>PEP III</td>
<td>The Afro-European Transect</td>
</tr>
<tr>
<td>PFT</td>
<td>Plant Functional Types</td>
</tr>
<tr>
<td>PICE</td>
<td>Palaeoenvironments from Ice Cores (SCAR-GLOCHANT/IGBP-PAGES)</td>
</tr>
<tr>
<td>PM II</td>
<td>Palaeomonsoons Project Two</td>
</tr>
<tr>
<td>PMAP</td>
<td>Palaeoenvironmental Multiproxy Analysis and Mapping Project</td>
</tr>
<tr>
<td>PMIP</td>
<td>Palaeoclimate Modelling Intercomparison Project</td>
</tr>
<tr>
<td>PPBV</td>
<td>Parts per Billion Volume</td>
</tr>
<tr>
<td>PPM</td>
<td>Parts per Million</td>
</tr>
</tbody>
</table>
PPMV Parts per Million Volume
RASE Russian Arctic Landshelf Interaction
REDIE Regional, Education and Infrastructure Efforts
ROV Remotely Operated Vehicles
B-RAS Siberian Branch, Russian Academy of Sciences
SC Scientific Committee (IGBP)
CICOM or SCC - Scientific Committee for IMAGES
SCAR Scientific Committee on Antarctic Research
SCOR Scientific Committee on Oceanic Research (ICSU/UNESCO)
SFB Sonderforschungsbereich (Cooperative Research Project)
SO-JGOFS Southern Ocean Joint Global Ocean Flux Study (IGBP/SCOR)
SSC Scientific Steering Committee
SST Sea Surface Temperature
STA Science and Technology Agency of Japan
START Global Change System for Analysis Research and Training (IGBP, IHDP, and WCRP)
TEMPO Testing Earth System Models with Palaeoenvironmental Observations
TESH Terrestrial Earth System History
TOGA The Tropical Ocean and Global Atmosphere Project (WCRP)
TOGA-COARE TOGA Coupled Ocean Atmosphere Response Experiment
TOGA-TAO TOGA Tropical Atmosphere and Ocean
UKMO UK Meteorological Office
UNEP United Nations Environment Program
UNESCO United Nations Educational, Scientific, and Cultural Organization
UNH University of New Hampshire(USA)
USGS United States Geological Survey
VEI Volcanic Explosivity Index
VMIP Volcano Modelling Intercomparison Project
WAISCORE 2000 US West Antarctic Ice Sheet Initiative
WCRP World Climate Research Program
WDC-A World Data Center-A
WG 100 Working Group 100
WGNE Working Group on Numerical Experimentation
WHO World Health Organization
WMO World Meteorological Organization
YD Younger Dryas
List of IGBP Publications

IGBP Report Series. List with Short Summary

IGBP Reports are available free of charge from:
IGBP Secretariat, Royal Swedish Academy of Sciences, Box 50005, S-104 05 Stockholm, Sweden. Tel: 46-8 16 64 48; Fax: 46-8 16 64 05; E-mail: sec@igbp.kva.se

Report Nos. 1-11 and reports marked * are no longer available.
Report Nos. 12-19 are available in limited numbers.
Reports marked ** are currently under production.

No. 20*
This report outlines a proposal to produce a global data set at a spatial resolution of 1 km derived from the Advanced Very High Resolution Radiometer primarily for land applications. It defines the characteristics of the data set to meet a number of requirements of IGBP’s science plan and outlines how it could be created. It presents the scientific requirements for a 1 km data set, the types and uses of AVHRR data, characteristics of a global 1 km data set, procedures, availability of current AVHRR 1 km data, and the management needs.

No. 21*
The objectives of GCTE are: to predict the effects of changes in climate, atmospheric composition, and land use on terrestrial ecosystems, including agricultural and production forest systems, and to determine how these effects lead to feedbacks to the atmosphere and the physical climate system. The research plan is divided into four foci: ecosystem physiology, change in ecosystem structure, global change impact on agriculture and forestry, and global change and ecological complexity. Research strategies are presented.
No. 22
The report presents general recommendations on global change research in the region, thematic studies relating to IGBP Core Project science programmes, global change research in studies of eight countries in the area, and conclusions from working groups on the participation of the region in research under the five established IGBP Core Projects and the related HDGEC programme.

No. 23
The Report describes how the aims of JGOFS are being, and will be, achieved through global synthesis, large scale surveys, process studies, time series studies, investigations of the sedimentary record and continental margin boundary fluxes, and the JGOFS data management system.

No. 24
The report presents the main findings of the joint Working Group of the IGBP and the International Social Science Council on Land-Use/Land-Cover Change; it describes the research questions defined by the group and identifies the next steps needed to address the human causes of global land-cover change and to understand its overall importance. It calls for the development of a system to classify land-cover changes according to the socioeconomic driving forces. The knowledge gained will be used to develop a global land-use and land-cover change model that can be linked to other global environmental models.

No. 25
Land-Ocean Interactions in the Coastal Zone (LOICZ) Science Plan. Edited by P.M. Holligan and H. de Boois, with the assistance of members of the LOICZ Core Project Planning Committee (1993). IGBP Secretariat, Stockholm, 50 pp.
The report describes the new IGBP Core Project, giving the scientific background and objectives, and the four research foci. These are: the effects of global change (land and freshwater use, climate) on fluxes of materials in the coastal zone; coastal biogeomorphology and sea-level rise; carbon fluxes and trace gas emissions on the coastal zone; economic and social impacts of global change on coastal systems. The LOICZ project framework includes data synthesis and modelling, and implementation plans cover research priorities and the establishment of a Core Project office in the Netherlands.

The Fontainebleau Workshop, July 1992, defined a strategy to initiate a global terrestrial monitoring system for the IGBP project on Global Change and Terrestrial Ecosystems, the French Observatory for the Sahara and the Sahel, and the UNESCO Man and the Biosphere programme, in combination with other existing and planned monitoring programmes. The report reviews existing organisations and networks, and drafts an operational plan.


A presentation of the mandate, scope, principal subjects and structure of the BAHC research plan is followed by a full description of the four BAHC Foci: 1) Development, testing and validation of 1-dimensional soil-vegetation-atmosphere transfer (SVAT) models; 2) Regional-scale studies of land-surface properties and fluxes; 3) Diversity of biosphere-hydrosphere interactions; 4) The Weather Generator Project.


This Report provides an overview of the global change research to be carried out under the aegis of the International Geosphere-Biosphere Programme over the next five years. It represents a follow-up to IGBP Report No. 12 (1990) that described the basic structure of the global change research programme, the scientific rationale for its component Core Projects and proposals for their development. The IGBP Core Projects and Framework Activities present their aims and work programme in an up-to-date synthesis of their science, operational and implementation plans.


A summary is given of the conference arranged by the Global Change System for Analysis, Research and Training (START) on behalf of the IGBP, the Human Dimensions of Global Environmental Change Programme (HDP), and the Joint Research Centre of the Commission of the European Communities (CEC) that describe the global change scientific research situation in Africa today.


This report sets out the goals and directions for GAIM and IGBP-DIS over the next five years, expanding on the recent overview of their activities within IGBP Report 28 (1994). It describes the work within IGBP-DIS directed at the assembly of global databases of land surface characteristics, and within GAIM, directed at modelling the global carbon cycle and climate-vegetation interaction.
No. 31
The workshop focused on interactions between African savannas and the global atmosphere, specifically addressing land-atmosphere interactions, with emphasis on sources and sinks of trace gases and aerosol particles. The report discusses the ecology of African savannas, the research issues related to carbon sequestration, ongoing and proposed activities, and gives a research agenda.

No. 32
The goals of IGAC are to: develop a fundamental understanding of the processes that determine atmospheric composition; understand the interactions between atmospheric chemical composition and biospheric and climatic processes, and predict the impact of natural and anthropogenic forcings on the chemical composition of the atmosphere. The Operational Plan outlines the organisation of the project. The plan describes the seven Foci, their related Activities and Tasks, including for each the scientific rationale, the goals, strategies.

No. 33
LOICZ is that component of the IGBP which focuses on the area of the Earth’s surface where land, ocean and atmosphere meet and interact. The implementation plan describes the research, its activities and tasks, and the management and implementation requirements to achieve LOICZ’s science goals. These are, to determine at regional and global scales: the nature of these dynamic interactions, how changes in various compartments of the Earth system are affecting coastal zones and altering their role in global cycles, to assess how future changes in these areas will affect their use by people, and to provide a sound scientific basis for future integrated management of coastal areas on a sustainable basis.

No. 34
The Science Task Team discussed and developed recommendations for multi-Core Project collaboration within the IGBP under three headings: process studies in terrestrial environments, integrated modelling efforts, and partnership with developing country scientists. Three interrelated themes considered under process studies are: transects and large-scale land surface experiments, fire, and wetlands. Methods for implementation and projects are identified.
No. 35
*Land-Use and Land-Cover Change. Science/Research Plan.* Edited by B.L. Turner II, D. Skole, S. Sanderson, G. Fischer, L. Fresco and R. Leemans (1995). IGBP Secretariat, Stockholm, HDP Secretariat, Geneva, (IGBP Report 35/HDP Report 7) 132 pp. The Science/Research Plan presents land-use and land-cover change and ties it to the overarching themes of global change. It briefly outlines what is currently known and what knowledge will be necessary to address the problem in the context of the broad agendas of IGBP and HDP. The three foci address by the plan are: (i) land-use dynamics, land-cover dynamics - comparative case study analysis, (ii) land-cover dynamics - direct observation and diagnostic models, and (iii) regional and global models - framework for integrative assessments.

No. 36
*The IGBP Terrestrial Transects: Science Plan.* Edited by G.W. Koch, R.J. Scholes, W.L. Steffen, P.M. Vitousek and B.H. Walker (1995). IGBP Secretariat, Stockholm, 53 pp. Also available in Chinese. The IGBP Terrestrial Transects are a set of integrated global change studies consisting of distributed observational studies and manipulative experiments coupled with modelling and synthesis activities. The transects are organised geographically, along existing gradients of underlying global change parameters, such as temperature, precipitation, and land use. The initial transects are located in four key regions, where the proposed transects contribute to the global change studies planned in each region.

No. 37
*IGBP Northern Eurasia Study: Prospectus for an Integrated Global Change Research Project.* Edited by W.L. Steffen and A.Z. Shvidenko (1996). IGBP Secretariat, Stockholm, 95 pp. Also available in Russian. This report was prepared by scientists representing BAHC, IGAC, and GCTE. It is a prospectus for an integrated hydrological, atmospheric chemical, biogeochemical and ecological global change study in the tundra/boreal region of Northern Eurasia. The unifying theme of the IGBP Northern Eurasia Study is the terrestrial carbon cycle and its controlling factors. Its most important overall objective is to determine how these will alter under the rapidly changing environmental conditions.

No. 38
No. 39
This report is the major product of a three-day workshop entitled: “Modelling the Delivery of Terrestrial Materials to Freshwater and Coastal Ecosystems” held in Durham, NH, USA from 5-7 December 1994.

No. 40
Based on a draft plan written by the SCOR/IOC SSC for GLOBEC in 1994. That plan was itself based on a number of scientific reports generated by GLOBEC working groups and on discussions at the GLOBEC Strategic Planning Conference (Paris, July 1994). This document was presented to the Executive Committee of the Scientific Committee on Ocean Research (SC-SCOR) for approval (Cape Town, November 14-16 1995), and was approved by the SC-IGBP at their meeting in Beijing in October 1995. The members of the SCOR/IGBP CPPC were: B.J. Rothschild (Chair), R. Muench (Chief Editor), J. Field, B. Moore, J. Steele, J.-O. Strömberg, and T. Sugimoto.

No. 41
This report describes a science and implementation plan for the Miombo Network Initiative, developed at an IGBP intercore-project workshop in Malawi in December 1995 and further refined during the LUCC Open Science Meeting in January, 1996.

No. 42
This report is the basis for the proposed Kalahari Transect proposed as one of the IGBP’s Mega Transects.

No. 43
This report is the result of a workshop on IGBP mountain research issues held in Kathmandu, Nepal, from 30 March to 2 April 1996.
No. 44
This report describes the Implementation of START (Global Change System for Analysis, Research and Training). START involves the establishment of a system of regional networks with particular emphasis on the developing regions. The primary mission of these networks is: (i) to conduct research on regional aspects of global change; (ii) to assess the impacts of the regional findings; and (iii) to provide regionally important integrated and evaluated information to policy-makers and governments. START’s overall objective is to build, through regional research activities, a world-wide indigenous capacity to tackle the scientific and policy aspects of environmental changes and sustainable development.

No. 45
This report summarizes progress made thus far by the Past Global Changes (PAGES) programme element of the IGBP. The document also outlines the implementation plans for most of the Foci, Activities and Tasks currently within the PAGES remit. The plan first introduces the scope and rationale of PAGES science and explains how PAGES is organized structurally and scientifically to achieve its goals.

No. 46*
The IGBP Core Projects BAHC, LUCC and IGAC, in conjunction with Framework Activities GAIM and IGBP-DIS held a joint workshop to identify data and research needs for characterizing wetlands in terms of their role in biogeochemical and hydrologic cycles.

Book of Abstracts
This book of abstracts is a result of materials presented at the scientific symposium held in conjunction with the Fourth Scientific Advisory Council for the IGBP (SAC) held in Beijing, 23-25 October, 1995.

IGBP Booklet

Global Change: Reducing Uncertainties
IGBP Directory

IGBP Newsletter

IGBP Science No. 1
This executive summary presents the major findings of the synthesis of the first six years of the Global Change and Terrestrial Ecosystem (GCTE) Core Project of the IGBP. It begins by identifying the major components and drivers of global change. It then outlines the important ecosystem interactions with global change, focusing on the functioning of ecosystems and the structure and composition of vegetation. The executive summary then discusses the implications of these ecosystem interactions with global change in terms of impacts in three key areas: managed production systems, biodiversity and the terrestrial carbon cycle. The full synthesis results and conclusions, with a complete reference list, are presented as a volume in the IGBP Book Series No. 4, published by Cambridge University Press (Walker et al. (In Press). Here key references only are included.