Commission of the European Communities

Palaeoclimatic Research and Models

Report and Proceedings of the Workshop
held in Brussels,
December 15-17, 1982

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edited by

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PALAEOCLIMATIC RESEARCH AND MODELS

FOREWORD

Palaeoclimatology is presently experiencing a period of rapid growth of techniques and concepts. Studies of earth's past climates provide excellent opportunities to examine the interactions between the atmosphere, oceans, cryosphere and the land surfaces. Thus, there is a growing recognition of the need of close collaboration between palaeoclimatologists and the climate modellers.

The workshop "Palaeoclimatic Research and Models (PRaM)" was organized by the Directorate General for Science, Research and Development within the framework of the Climatology Research Programme of the Commission of the European Communities (CEC).

The aim of the workshop was to give to the members of the Contact Group "Climate Models" and "Reconstitution of Past Climates" of the CEC Climatology Research Programme and to some invited scientists the opportunity to discuss problems of mutual interest. About 35 experts from 10 countries took part in the workshop. In general, palaeoclimatologists were asked to identify and discuss the data corresponding to the three topics as defined by the programme committee:

1) Abrupt Climate Changes
2) Initiation of Glaciation
3) Glaciated polar regions and their impact on global climate.

Climate modellers were asked to give their views as to how these specific problems could be modelled, what use could be made of the available palaeoclimatic data and which complementary data are needed for modelling.

This volume contains the outcome of the workshop i.e. a report and the summaries of the presentations in the form of proceedings. The workshop report was prepared mainly by rapporteurs in collaboration with the Programme Committee (see appendix) and was later edited to make it more cogent and lucid without changing its scientific content.

This volume contains a fairly complete account, particularly from the European viewpoint, of the status of research and research needs in the areas, which were discussed.

Thanks are due to Dr. J.C. Duplessy for the suggestion of holding this workshop and Dr. Ph. Bourdeau, Dr. H. Ott and Dr. R. Fantechi (DG XII) for their support in organizing the meeting.

Brussels, July 1983

A. GHAZI

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Session A : ABRUPT CLIMATE CHANGES

A.1. INTRODUCTION

Abrupt climatic changes have been revealed by many continental and marine palaeoclimatic records. However, coring disturbances, dating uncertainties, sedimentary hiatuses and particular problems related to the indicators of past climates impede estimation of the time span of such abrupt climatic transitions.

From the existing literature no clear definition of "abrupt changes" could be found. As a working definition the following can be proposed : an abrupt climatic change has a time-scale of the order between 50 and about 200 years, while the temperature difference is of the order of about half the difference between glacial and interglacial, i.e. 2-3 K.

Climatologists expect to learn from past climate studies whether climatic conditions could change drastically within times of the order of a century or less. Therefore, the available proxy-indicators of past climates are reviewed, examples of abrupt changes are given and the related problems are discussed here. Finally, some recommendations to estimate more accurately the duration of climatic transitions are formulated.

A.2. INDICATORS OF PAST CLIMATES

Ice cores from the polar regions contain a wealth of information on past environmental conditions, including climate. Along with the snow, all kinds of fall-out from the atmosphere are deposited on the ice sheet surface. In the coldest areas, no melting occurs and all of the impurities, including samples of the atmospheric air, remain in the ice in unchanged concentrations and in an undisturbed sequence, as the annual layers sink into the ice sheet under continuous pressure. Close to the bedrock, the annual layer thickness approaches zero. An ice core drilled to bedrock in a favourable location contains a continuous sequence of hundreds of thousand annual layers.

This makes ice cores a rich source of information on the environmental system and its mechanism. Long time series of geophysical and geochemical parameters are being measured, such as :

- oxygen isotope ratios, that are indicative of surface temperature at the time of deposition;
- CO_2 concentration in the atmosphre;
- concentration of polar continental dust that is indicative of the turbidity of the polar atmosphere;
- concentration of strong acids and sulfates that are indicative of volcanic activity;
- NaCl that originates from sea spray and that may be indicative of storminess and/or ice-cover.

On the continent, dust transported in the air and weathering products accumulate locally, for instance in lakes and river. Most sediment results from the organic productivity of lakes and erosion of organic material from adjoining upland. The geochemical and sedimentological study of these deposits provides information on the climatic conditions which prevailed at the time of their deposition. However, the most promising way to obtain quantitative informations on the climatic conditions over the continents at our latitudes during the last 150,000 years is the analysis of pollen deposited in lake sediment and peat bogs. The determination of this pollen is used to reconstruct the past vegetation and to infer the climatic conditions compatible with the reconstructed vegetation cover.

Cores from the ocean floors contain material deposited at a fairly constant rate, something of the order of a few cm per thousand years. This material is constituted essentially from weathering products originating from the continent (clay) and from carbonate or silica shells of organisms (foraminefera, coccoliths, diatom, ...) that have lived in the overlying sea water. The variations of the oxygen isotopic composition of these shells reflect those of the volume of ice stored over the continent and have provided a worldwide stratigraphic framework, which can be used in all the oceans. Moreover, the composition of the fauna in ocean surface water depends mainly on the temperature and, hence, if the composition of the fossil fauna is determined by counting, it may be transformed into an estimate of the surface palaeotemperature by statistical analyses using empirical transfer functions. The standard error of such estimates is about 1.5° C.

As a consequence, deep sea records have proved capable of providing a stable chronological framework for the evolution of past climates during the last million years. More detailed climatic records can be obtained in places where the accumulation of sediment is very high (up to 50 cm per thousand years), but the length of obtainable deep sea core is technically limited to about 20 meters and the time interval covered by such cores is reduced to a few tens of thousand years. Deep sea records help to improce the reconstruction of continental climatic fluctuations, especially with regard to coastal areas.

A.3. EXAMPLES OF ABRUPT CLIMATIC CHANGES

Climatic crises of brief, but undetermined duration have been described in the Sahara, where sedimentary sequences were interrupted by periods of drying and erosion. Severe droughts, interrupting lake sedimentation, appeared to have occurred between 8,000 and 7,000 years B.P., i.e. before a general drying of the Sahara.

18,000 years ago, the high latitudes of the northern hemisphere were covered with large ice sheets, which developed over northern America, Scandinavia and northern Europe. The deglaciation, which started about 15,000 years ago, was not a slow process and may have been a succession of sudden events. At the same time, strong temperature changes were observed in the ocean. Within about 2000 years or less, the sea surface temperature along the Atlantic coast of Europe increased by some 14° C in the Bay of Biscay and temperatures were at least as warm as those of today. This complex warm phase, which includes the continental Bölling and Alleröd interstadials, was interrupted by a major spread of polar waters and in less than 1000 years (perhaps less than one century), marine temperatures were almost as low as those of the last glacial maximum. During this event, called Younger Dryas, glaciers readvanced in northern Europe. Vegetational changes in southern France and in Florida, probably in response to climate as early as 15,000 B.P. are correlated with the complex deglaciation process.

The Last Interglacial, known as Eemian, lasted only some ten thousand years, from 125,000 to 115,000 years B.P. The Eemian, which has been studied using ice cores, deep sea cores and continental deposits, is so similar to the present interglacial that a detailed study of its late phase and its termination is of great interet, the more so as the ice and deep sea cores contain evidences of abrupt climatic changes not only at the end of glacial conditions but most probably also at the end of the interglacial. However, the dating has errors of as much as a few thousand years for sediments of this age and it is not possible to estimate the duration of these transitions accurately.

A.4. THE PROBLEMS

It was observed that the standard forms of presentation of the pollen diagrams may give a false impression of sudden climatic change because of the apparently abrupt appearance of new taxa. These abrupts changes may be real, but apparently abrupt appearance of new taxa may arise from a hiatus in the sedimentation or from the dynamics of the vegetation itself. Calculations of the time required for such changes, taking into account variable sedimentation rates and variable compression indicate that in some cases 500 to 1000 years are required for a major change to take place. This is explained by the need of a migrating species to travel from one geographic region to another and to establish its population in a new region. The phenomenon of migration is a constant climate may give a spurious impression of climate change at one site. The need to distinguish between migration and vegetation response on one hand and to select particularly sensitive sites with a good sedimentary record on the other appear decisive to interprete the observed abrupt changes in the pollen content of continental deposits.

In the ocean, all kinds of sedimentary records may be disturbed by mechanical mixing of the upper few centimeters of the sediment due to the activity of benthic organismes that live in the oxygenrich bottom water. The consequent temporal smoothing of the climatic records is of course most serious in areas of low sedimentation rate, and complications can occur if a noticeable productivity change is correlated with the climate change.

The acquisition of high quality ice cores is difficult. The Greenland site of Camp Century was a poor drilling site, because this area may very well have been exposed to higher altitude changes more than most other areas in Greenland. This is one of the reasons why the Camp Century isotopic record has never been provided with a temperature scale. The new deep ice core from South Greenland (Dye 3) was drilled in an area with some summer melting, making its dating difficult even for the recent past. Furthermore, it reaches only 90,000 years back in time in a continuous sequence, which means that the last interglacial is not adequately represented in this core. Moreover, an experimental dating of the ice is at present only possible by counting annual layers. Even if there is no summer melting, these layers disappear by diffusion in the ice older than 10,000 years and the dating of ice cores is possible only by models.

A.5. RECOMMENDATIONS

During the U.S.-Danish-Swiss joint effort, Greenland Ice Sheet Program, it became obvious that Central Greenland is, scientifically, the most favourable location for deep ice core drilling because :

- the bedrock topography is smooth, which ensures simple ice flow modelling;
- the ice is frozen to the bedrock, which ensures a very long time range of a deep ice core (possibly more than a million years).
- The accumulation rate is high enough to allow absolute dating at least back to the termination of the last glaciation, to ensure a continuous layer sequence throughout the last glacition and, most likely, through several preceeding ones.
- No melting occurs at the surface, which means that the air trapped in the bubbles of the ice has the same composition as the atmosphere at the time of deposition.

Hence, a new deep ice core should be drilled in Central Greenland.

At lower latitudes, priority should be given to the study of continuous sequences in which a high resolution climatic record can be obtained. Attention was drawn to the advantages of studies of lake sediments with annual laminae when exact chronological control was required and to the possibility of obtaining high resolution marine records by coring in the continental margin, where detrital input is high.

In the effort to choose periods which were critical to illustrate sudden climatic changes, it was agreed that the Younger Dryas period was the best example of such a change. The new development of the carbon-14 dating method linked to the use of accelerators should be applied to determine the precise chronology of this event, both in ice core and in continental or marine sediments. A collaboration between geologists, physicists and biologists seems most appropriate to simulate an interdisciplinary study of these samples and to avoid the pitfalls described above.

Opportunities to link studies in palynology with other palaeoclimatic studies are specially strong in relation to marine core and ice core studies, as well as various physical measurements which provide evidence of past climatic environments. This suggests that emphasis might be in future on :

- Long continuous records, especially where good dating possibilities exist. These might be on the Atlantic coast because west european climate is largely determined by the ocean and this is the best region to link ocean and land records. Another possibility could be the Mediterranean, because it is still much less known than northern Europe and offers good chances to obtain long records.

- Technical improvements, especially in understanding the significance of the data obtained from fresh-water sediments. Studies of pollen influx after the best possibilities at presend and the extensive use of surface samples to establish transfer functions providing estimates of past climates could allow for significan advances this field.

Since the two warming events (mentioned under A.3.) are correlated with an abrupt increase of atmospheric CO_2, the hypothesis of a feedback effect : warming → weaker Hadley circulation → prevailing downwelling and rapid increase of CO_2 and H_2O from equatorial oceans → further warming (see FLOHN, this volume) should be investigated. A reversed feedback mechanism could occur after a glacial iceberg-meltwater surge causing colling and stronger circulation → prevailing upwelling decreased atmospheric CO_2 and H_2O.

There is a great need to apply methodologies such as transfer functions and other mathematical quantitative models used in ice- and deep-sea core and land record studies. Utilization of the geological date e.g. evidence of climatic change from palaeosoils, sedimentation pattern and landscape surfaces could be useful to complement information, yielded from other studies about past atmospheric conditions acting on the lithosphere and the biosphere.

Session B : INITIATION OF GLACIATION

B.1. BACKGROUND

Glacial-interglacial alternations have been characteristic of the past 2.5 million years of earth's history. By obtaining continuous records of past temperatures and ice volumes, primarily from deep sea sediments, scientists have established that probably the primary cause of these quasi-cyclic alternations is changes in the earth's orbital geometry. This mechanism was first formulated in a clear way by M. Milankovich. Thus one aspect of any study of the initiation of glaciation must be the investigation of this mechanism in more detail. However, the particular situation in which the earth had no ice on North America or Fennoscandia poses additional problems, especially in view of the evidence that ice accumulation was very rapid. Thus we hope that a considerable amount may be learned by the careful study of the evolution of climate about 120,000 years ago; this is the last time that the earth went through this crucial phase. It seems likely that a focus on this particular episode will be the most fruitful research area for furthering our understanding of the initiation of glaciation. However, we also have to consider whether it is valid to assume that the manner in which climate responds to orbital forcing has been sufficiently consistent that we can afford to take only one glacial inception as a model, or whether other predictable or unpredictable factors intervene. This requires that we continue attempts to model all aspects of the glacial-interglacial record, and to evaluate model output by careful reference to the geological record.

B.1.a. The orbital forcing

Until quite recently only quite naive interpretations were made of the insolation variations deriving from orbital variations; meteorologists tended to assume that their effects would be trivially small. However, if one looks at particular months and particular latitudes one can find insolation variations up to 30 % ! There is still scope for more formulations of the orbital effects : in some contexts insolation gradients are important. For some systems (plants) insolation hours may be important, and so on.

B.1.b. The climate response

Very exciting work is in progress modelling climate parameters as a function of orbital forcing; atmosphéric circulation, ice-sheet growth, sea ice cover, snow cover. These studies must continue; interaction between the groups should be stimulated. Communication with geologists is very important, so that modelers take account of new information on the boundary conditions and their changes; for example, the recent information that during the last glacial maximum the atmospheric concentration of CO_2 was about half of its present value.

B.2. THE LAST INTERGLACIAL TO GLACIAL TRANSITION

The Last Interglacial (referred to as isotopic substage 5e in the oceanic record and as the Eemian over the european continent) lasted about 10,000 years, starting about 125,000 years ago and ending about 115,000 from now. Its end was marked by a new phase of ice-accumulation over the continents, which culminated about 110,000 years ago. At that time, the sea level had dropped by about 60 meters and large ice caps covered Northern America and Northern Europe. The occurrence of these large volume of ice, strongly depleted in oxygen-18, resulted in a worldwide increase of the ocean water $^{18}O/^{16}O$, which was well reflected in the oxygen isotopic composition of planktonic and benthic foraminifera. Consequently, this phase is referred in the oceanic record as isotopic substage 5d.

The transition between isotopic substages 5e and 5d should be studied both by modelling and by a very precise search of the climatic parameters which may have changed first during this climatic transition.

Modelling of this transition should use both orbital data and boundary conditions of this epoch. However some of them are still poorly known, such as the continental albedo and the sea-ice extent. Special attention should be paid to the following parameters :

a) Sea-ice changes during the 5e/5d transition may be important in Labrador Sea area and in the Norwegian Sea.

b) The climatic evolution of Antarctica and of the Southern Ocean arond Antarctica is still poorly understood and should be studied in great detail. For example, some faunal and isotopic data suggest that this area was already much colder than now at the end of isotopic substage 5e, before the initiation of the ice-growth phase over the northern hemisphere continents. Such a behaviour of the southern hemisphere climate should be checked carefully.

c) The ice-accumulation rates are still unexplained. Isotopic and continental field evidence indicate that the ice accumulation during the intiation of the glaciation was a rapid process. Less than ten thousand years have been necessary for the 60 meters sea level drop and the advance of continental glaciers. Such a heavy accumulation of snow and ice over the high latitude continents requires snowfalls at least four times heavier than those known today and a modelling effort should be made to find a realistic mechanism able to produce them.

d) We need to have a much better understanding of the vegetation and of the continental climate as ice began to accumulate. Was it already changing ? How fast ? Although free migration rates confuse the interpretation of the vegetational succession linked to a glacial to interglacial transition and to the following interglacial to glacial transition, it should be possible to develop transfer functions to describe the last part of an interglacial. These transfer functions should be applyed to the main pollen sequences such as Grande Pile, les Echets or Padul and perhaps to annually banded diatomites.

e) The atmospheric concentration of CO_2 is an important aspect of the atmospheric heat budget, because CO_2 is transparent to visible radiation, but absorbs in the infra-red region of the radiation emitted by the earth's surface. It therefore contributes appreciably to heat the atmosphere (greenhouse effect). Ice core studies have shown that the atmospheric concentration of CO_2 was about half of its present value during the last glacial maximum. However we do not know when and why the atmospheric CO_2 concentration began to change. If it would appear that the drop in CO_2-concentration leads the climatic change, then this variation could be a cause of the glaciation by reducing the greenhouse effect. If, more probably, the CO_2 concentration lags behind the climatic change, then this CO_2-variation could be a response of the global carbon dioxide cycle to the climate. Consequently, the resulting decrease in greenhouse effect would amplify the glaciation (see also A.5.).

B.3. LONGTERM RESEARCH NEEDS

We need ice sheet models able to explain the evolution of ice sheets under various accumulation rate conditions. Since oxygen isotopes provide a detailed time-record of the volume of ice stored over the continents during the last million years, the comparison of the model output with observational records is most valuable. This modelling effort must focus on the relationship with real record, rather than on the development of esoteric models that produce output that is visually similar to the geological record, but do not show appropriate coherency with the orbital forcing. Then, we need to know whether a long (several hundred-thousand years) geological record can be simulated by a model with specified parameters, or whether one has to consider a certain amount of parameter-changing, which would reduce the predictive value of such models.

C.1. THE PROBLEM

Evidence for very cold climatic conditions have occured several times during the Phanerozoic. Because of specific plate-tectonic settings which resulted in polar positions of either small ocean basins or continents, the Paleozoic spells of cold climates led to unipolar glaciations. Only during the Cenozoic a plate-tectonic situation evolved which led to ice shields on Antarctica and around a possibly ice covered Arctic Ocean.

Flohn reported on the important problem of the climatic asymmetry between the southern and the northern hemisphere which seemed to characterise the early history of Cenozoic glaciations. The volume of the Antarctic ice-shield seems to have fluctuated considerably through time, but it is generally believed that it was a persistent feature since Miocene times at least. The earliest indications for ice in Antarctica can be traced back to the Oligocene, to a time when plate-tectonic movements led to the separation of Antarctica and Australia.

The history of glaciation on the northern hemisphere is considerably less well known, but it is believed that the ice shileds which developed on the continents around the Arctic Ocean and of the Arctic sea ice cover have been intermittent features only. Our lack of ability to document the history of northern hemisphere glaciation with data from the Arctic Ocean (because of the virtual unavailability of samples of pre-Pliocene age), from the Norwegian-Greenland Sea and from the Bering Sea as well as from the adjacent land areas in the real obstacle for understanding this development.

Thiede explained that late Cenozoic sediments from the bottom of the presently ice-covered Arctic Ocean have up to now eluded an easy explanation of their depositional environments. They contain few or only sporadic fossils and they seem to accumulate at very solw rates (0.5 - 2 mm:10^{-3}y). In general, they consist of fine-grained grayish terrigenous muds which contain varying proportions of coarse-grained ice-rafted detrital material. Hypotheses about the history of the Late Cenozoic Arctic Ocean palaenoenvironements therefore range from a permanent ice cover, to intermittent and/or loose sea-ice cover, to long ice-free stages, despite evidence of long spells of cold glacial climates from the surrounding continents.

Two aspects of Late Cenozoic Arctic Ocean depositional environments are of particular interest :

1. Fossiliferous intervals in the sediment cores are marked by a dramatic increase of planktonic as well as benthic fossils (both calcareous and non-calcareous ones). Especially calcareous fossils (planktonic and benthic foraminifers, ostracods, molluscs, echinoderms, etc.) are well preserved, even in samples from abyssal water depths. These intervals can be correlated over wide distances and seem to indicate times of high plankton productivity in near-surface waters, and the respons of higher standing stocks of benthic organisms. The fossiliferous zones coincide or overlap sometimes, but not always with times of intensive ice-rafting.