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European Project for Ice Coring in Antarctica (EPICA)

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Abstract - EPICA is a long-term (~ 7 years) European deep ice-core drilling project in Antarctica 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. To achieve EPICA's goals, it will be necessary to drill at two sites, both to achieve the required resolution on different timescales and an adequate continent-wide perspective. The first four-year phase will focus on the major climate shifts that have characterized the past several glacial interglacial cycles. This will be done by analyzing a 3300 m long ice core drilled at Dome Concordia, South of the Indian Ocean in East Antarctica. During the second phase of the project, a core will be obtained from Dronning Maud Land, an area of Antarctica most strongly influenced by the Atlantic ocean. This phase of the project is designed to focus specifically on the rapid climate oscillations that have been detected across Greenland throughout the last glaciation.

A thorough knowledge of past environmental and climatic conditions is one of the keys to a better understanding of the changes currently affecting the Earth on a global scale and hopefully enable us to reduce uncertainties in the prediction of the future climate of our planet. Providing such a quantitative understanding of the past and defining the envelope of natural variability within which we can assess the anthropogenic impact on the Earth's biosphere, geosphere and atmosphere is the main objective of the PAsT Global changES (PAGES). This core project of the International Geosphere-Biosphere Programme (IGBP) focuses on specific sets of questions and issues about the influence of man activities on the climate and global environment. How can we disentangle the anthropogenic induced change from natural response to external forcing and internal system dynamics? What are the factors that are responsible for these changes? What are the limits of natural greenhouse variation and what are the natural feedbacks to the global climate system? In what sequence do changes in greenhouse gases, surface climate, and ecosystems occur? What are the important forcing factors producing climate change on societal time scales? What are the causes for abrupt climatic and environmental events? Those are important questions that have been identified and partially answered through various research programs conducted over the recent decades but we clearly need to pursue and intensify such efforts to better document the climate and environment natural variability on different timescales in order to be able to fully address those issues.

Our knowledge of past global changes relies on various and complementary sources of paleodata, on their

interpretation in terms of climate or/and environmental significance and on associated modelling. For example, deep-sea core studies give information about the volume of continental ice and about variations of oceanic temperatures and circulation whereas pollen, tree-ring and lake-level data are the main source of quantitative information in continental areas. Although there are some limitations inherent to their study, deep ice cores from Greenland and Antarctica have their own advantages and specific attributes in this effort of studying past climatic and environmental changes. They offer the opportunity to obtain high resolution (annual or even seasonal) records and give access on a continuous and largely quantifiable basis to the most important climatic parameters. Importantly, they give unique and direct access to records of changes in atmospheric composition including trace gases, chemical impurities of terrestrial and marine origin, cosmogenic products, volcanic aerosols and anthropogenic compounds. Only some of these elements (greenhouse gases, aerosols) may directly participate in climate change but all of them are of interest for a better understanding of past global biogeochemical cycles. In addition, of being the only archive which preserves both information about past climate changes and about climate forcings in the past, those polar ice sheets are active components of the climate system and their variations are the largest uncertainty in future prediction of global sea-level change.

It is in this scientific context and after the highly successful Greenland Research Ice Core Project (GRIP) in central Greenland that European scientists have built a deep-ice core drilling project in Antarctica to derive high

resolution records of climate and atmospheric composition through several glacial-interglacial cycles. Before describing the scientific goals of this Grand Challenge called EPICA (European Project for Ice Coring in Antarctica), we review the main results obtained from studies performed on Greenland and Antarctic ice cores since about 30 years.

WHAT HAVE WE LEARNED FROM ICE CORES?

Ice cores from Greenland, Antarctica and other glaciers, encompass a variety of timescales. The longer time scales are covered by deep ice cores the number of which is still very limited: only four in Greenland (Camp century, Dye 3, GRIP and GISP2) and four in Antarctica (Byrd, Vostok, Dome C and Dome B) reach back the Last Glacial Maximum ~20 000 years ago. The deepest drillings (more than 3 km long) are those from Central Greenland (GRIP and Greenland Ice Sheet Project 2 - GISP2) but the possibility of disturbances in the stratigraphy of the bottom part of the cores make the climatic interpretation difficult prior ~100 kyr BP (Grootes et al., 1993). The longest undisturbed series are those obtained at the Vostok site in Central East Antarctica which now cover the last two climatic cycles (Waelbroeck et al., 1995; Jouzel et al., in press). As far as climate is concerned, the most important discoveries coming from ice core studies concern 1) the record of recent changes in radiatively active greenhouse gases showing the clear impact of man activities, 2) the existence of a strong relationship between those greenhouse gases and the climate over the climatic cycle and 3) the existence of rapid changes which, at least in the North Atlantic and adjacent regions where they are best documented, affect on timescales of a few decades, or less, all important climatic parameters.

The greenhouse gas record for the recent period

The evolution of important trace-gases in terms of radiative balance or atmospheric chemistry has been precisely documented by direct atmospheric measurements only for the most recent period. The three greenhouse of interest here, CO₂, CH₄ and N₂O, are increasing today primarily due to anthropogenic influence. From analysis of air bubbles trapped in shallow ice cores from Greenland and Antarctica, the records of CO₂ (Figure 1) and CH₄ are documented in detail for the last 200 years (Raynaud et al., 1993 and references herein). The ice records connect well with the atmospheric records which is a strong indication of their reliability. They also provide values for the atmospheric levels just prior the time the major anthropogenic CO₂ and CH₄ emissions started. Although more scattered N₂O measurements suggest also an increasing trend over the last 200 to 300 years. The last thousand years have not yet been documented in such detail but this time period is of special interest in that it may reveal greenhouse gas variations related to minor global climatic deviations from the present day climate. There are a few published measurements (Barnola et al., 1995) suggesting that CO₂ may have experienced changes of the order of 10 ppmv (Figure 1), possibly linked with periods of climatic fluctuations like the Little Ice Age or the Medieval Warming; small fluctuations are also seen for CH₄ and N₂O prior to 1800 AD. Surprisingly, methane concentrations show significant variations - up to 15% - during the Holocene (Blunier et al., 1995).

Note also that over this last millenium, ice cores offer the possibility of examining climate variability (temperature and precipitation) at the decadal or even annual timescale and give potential access to other climatic forcings such as that due to the change in aerosol loading of the atmosphere (man made or related to the volcanic activity),

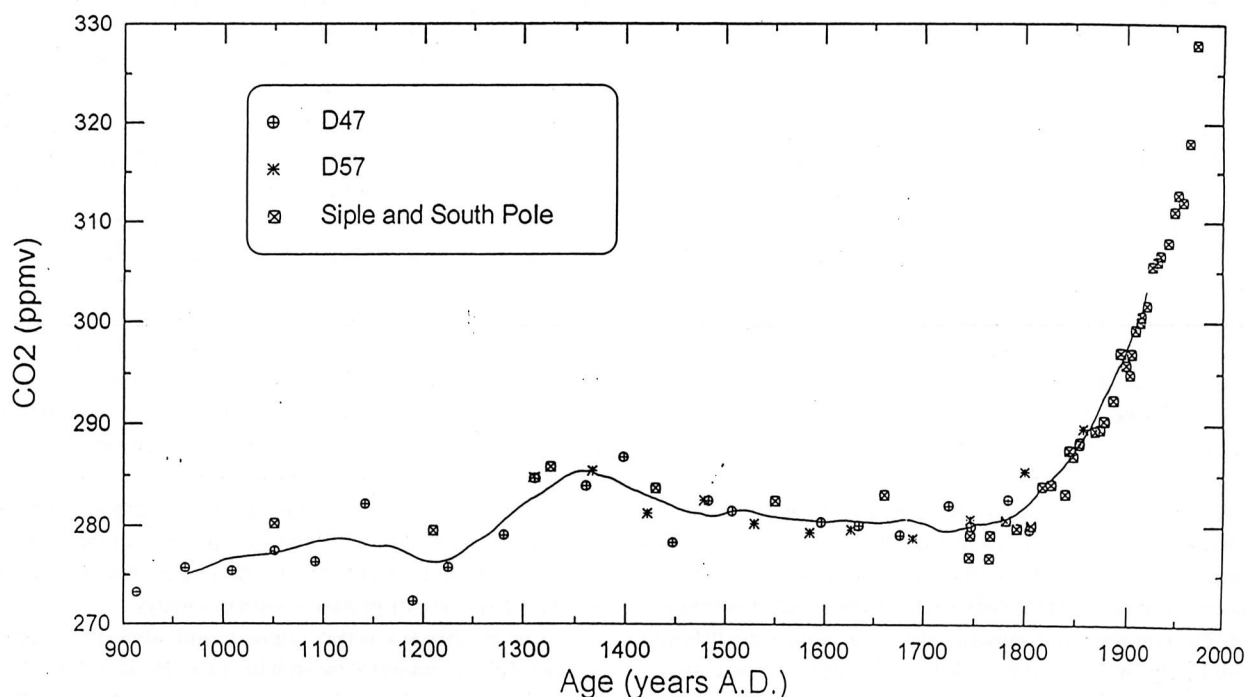


Fig. 1 - Composite record of the atmospheric CO₂ content over the last millenium inferred from measurements performed on four antarctic ice cores (adapted from Barnola et al., 1995).

and, indirectly, to the solar forcing (through the measurement of cosmogenic isotopes).

The last glacial-interglacial cycle

The remarkable correlation between glacial-interglacial temperature changes and the atmospheric composition of gases such as carbon dioxide and methane is one of the most important discoveries inferred from ice core studies. The first reliable results showed that CO₂ concentrations during the Last Glacial Maximum were lower than Holocene concentrations by 25 to 30% (Delmas et al., 1980). This change has now been documented from several ice cores and the CO₂ record has been extended back to ~ 220 kyr BP, by analysing the Antarctic Vostok core (Jouzel et al., 1993). The CO₂ record thus covers more than a full glacial-interglacial cycle. Figure 2 shows the record back to 150 kyr BP (the last glacial-interglacial

cycle) highlighting the prevailing character of the increase in CO₂ level associated with de-glaciations (Barnola et al., 1987) as illustrated in comparing this record with the change in sea-level. The record shows, in a general way, a remarkable correlation between changes in Antarctic temperature and changes in CO₂ levels which also hold true for methane analysed on the same Vostok core (Chappellaz et al., 1990). As for CO₂, atmospheric CH₄ levels dramatically increased during the last two deglaciations with concentrations nearly doubling. Superimposed on the long-term trends, rapid and large changes have also been documented for methane, and to a lesser degree, for CO₂. N₂O measurements, which presently cover only the last 50 kyr, also indicate lower values during the glacial period than for the Holocene (Leuenberger and Siegenthaler, 1992). These observed changes in greenhouse gas concentrations imply modifications in their sources and sinks that probably

involve very different processes such as ocean circulation and marine and terrestrial productivity for CO₂, fluxes of emission from natural wetlands for CH₄ and soils and ocean processes for N₂O. Ice core paleodata are indeed essential to understand the natural biogeochemical cycles of these gases and better assess the influence of human activities on those cycles.

This knowledge of the natural variations in CO₂ and CH₄ (and to less extent in N₂O) at various time scales adds to our understanding of mechanisms involved in glacial-interglacial changes. As important, this gives a new insight for estimating sensitivity to change in radiative forcing, a parameter directly related with future greenhouse warming. One first important feature of the Vostok data is that both the climate and the greenhouse gas records strongly show the presence of orbital frequencies which supports, independently of the deep sea record, the role of the orbital forcing in glacial-interglacial changes (Jouzel et al., 1987; Barnola et al., 1987). Most striking is the close correlation between greenhouse gases and climate over the last climatic cycle. This correlation, as well as the phase relationships between greenhouse gases and climatic parameters, suggests that greenhouse gases have amplified, together with the growth and decay of the Northern Hemisphere ice sheet, the relatively weak orbital forcing. About half of the Vostok temperature change over the last climatic cycle may be accounted for by the contribution of these two greenhouse gases and most of the other half may be accounted for by the Northern hemisphere ice sheet forcing. It is the merit of ice core data to show that CO₂ and more generally

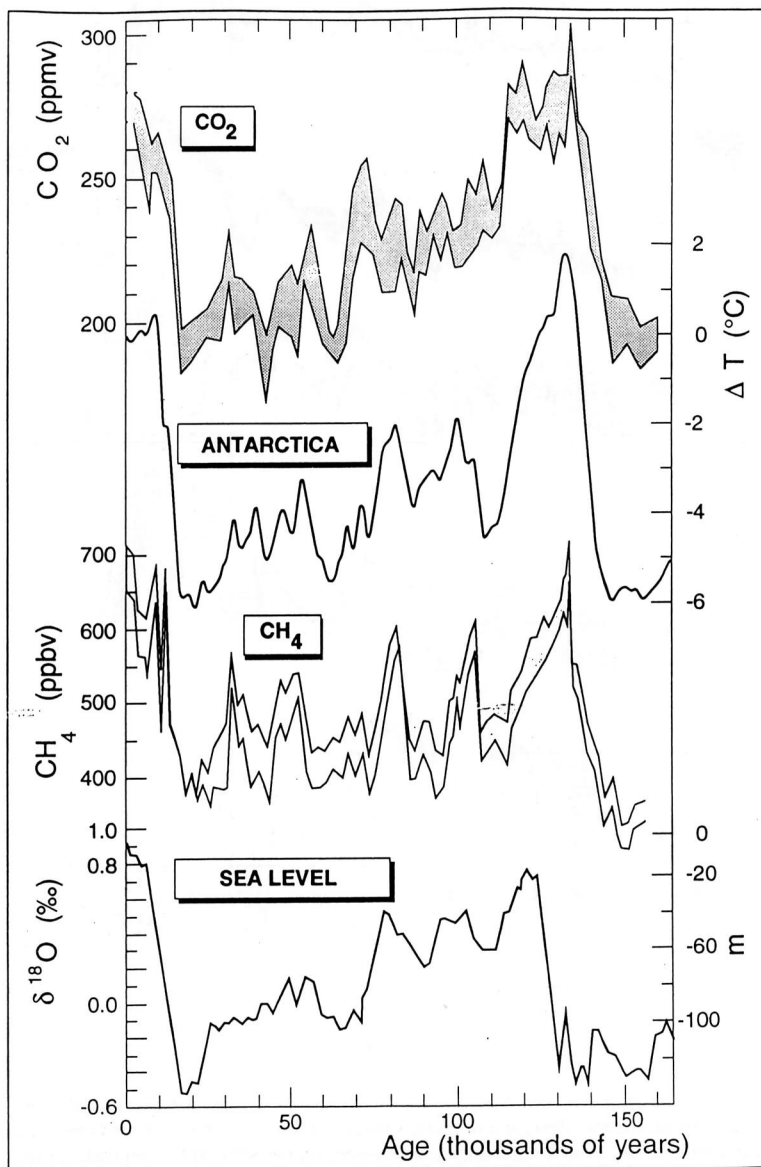


Fig. 2 - The Vostok ice core record of atmospheric CO₂ and CH₄. The temperature curve plotted in between represents the change of the temperature at the top of the inversion layer over Antarctica as deduced from the isotopic composition of the Vostok ice. The lower curve is a record of sea-level change as derived from the δ¹⁸O of foraminifera in the V19-30 marine core. This figure is adapted from Raynaud et al. (1993) and references herein.

greenhouse gases are important players in the late quaternary climate.

Due to the existence of fast feedback processes linked with water vapor, clouds and sea-ice, the equilibrium CO_2 -doubling temperature change predicted using global climate models, is substantially larger the 1.2°C warming that would be predicted if there were no such feedbacks. It ranges from 1.9 to 5.2°C showing a large uncertainty in global climate sensitivity that is reflected in the prediction on future greenhouse warming (Mitchell, 1989). Although the timescales involved in paleoclimate and in future greenhouse warming are different, it is fully recognized that paleodata contain information on global climate sensitivity. This is because greenhouse gases have contributed to the glacial-interglacial temperature change through their direct radiative forcing associated with those same fast feedbacks. From the estimated percentage of 50% contribution of greenhouse gases to glacial-interglacial changes the climate sensitivity can be back calculated suggesting that a value of $3\text{--}4^\circ\text{C}$ for the equilibrium CO_2 -doubling temperature change may be realistic value in view of available paleodata (Lorius et al., 1990). We point out that such empirical estimate, that can be also undertaken for the more recent period and constitutes one independent check of climate model predictions (and in the near future, perhaps our best hope to reduce uncertainties in global climate sensitivity), would not be feasible without ice core data.

Links between Greenland and Antarctic climates over the last glacial period

As illustrated in figure 3, Central Greenland records demonstrate the existence of rapid climatic changes all over the last glacial period (Johnsen et al., 1992). These changes are felt in the North Atlantic (Bond et al., 1993) and adjacent regions but little is known yet on their global significance. Thanks to air bubbles contained in ice cores and to the fact that air composition is well mixed throughout the atmosphere it is now possible to use changes such as those in the isotopic content of the air for correlating Greenland and Antarctic records (Bender et al., 1994). Figure 3 allows examination of how the Antarctic climate behaves when

the Greenland and more generally the North Atlantic, climates undergo rapid changes. This figure shows, in particular, that interstadial warm periods lasting more than 2 kyr in Greenland have counterparts in East Antarctica. Beyond this interesting result, it illustrates that it is now possible to correlate ice records from North and South (and also ice records with oceanic records) which is very important for understanding how the climate system works at a global scale. In contrast to the glacial period, the isotopic profiles recorded in the Greenland and Vostok ice are dissimilar during the Eemian which adds to the questions raised by the initial comparison of GISP2 and GRIP records. Recent results (Chappellaz et al., submitted) show, for the two Greenland cores, rapid and large changes

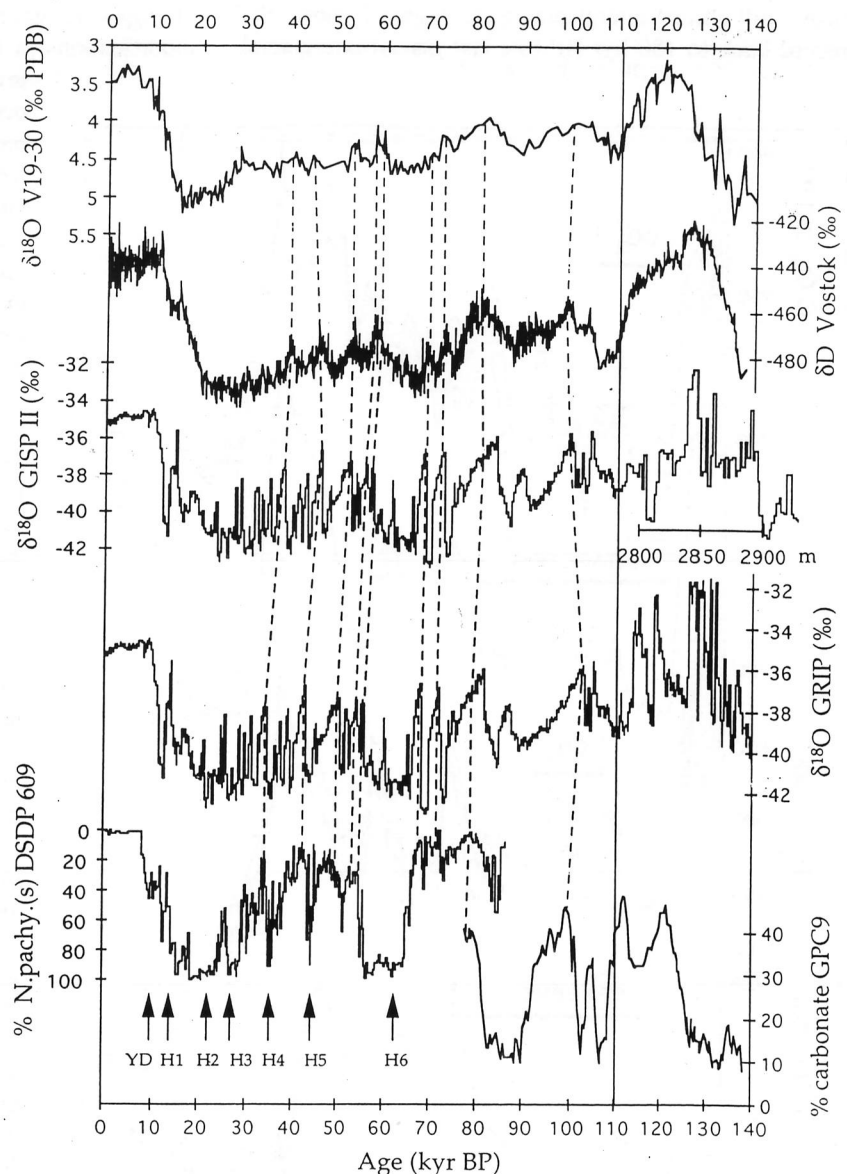


Fig. 3 - Ice core and deep-sea core climate records covering the last glacial-interglacial cycle (Figure adapted from Jouzel (1994) and references herein). The curves show: a) continental ice volume variations; b) the Vostok deuterium profile placed on the SPECMAP timescale; c) the GISP2 $\delta^{18}\text{O}$ record extended using a depth scale to illustrate the divergence between GRIP and GISP2 before ~ 100 kyr BP; d) The GRIP $\delta^{18}\text{O}$ record; e) the foraminiferal record (a proxy of sea surface temperature) from DSDP site 609; and f) the weight percentage carbonate (which likewise reflects changes in thermohaline circulation) in a North Atlantic core. The dashed lines represent common events that are recorded in the various series (Bender et al., 1994). The solid line corresponds to the 110 kyr BP level and Heinrich events are indicated in the bottom part of the plot.

in methane concentration as well in the isotopic content of the oxygen of the air, which are not observed in the Last Interglacial Vostok ice. This discrepancy reinforces the suggestion that the bottom sections of the Greenland records are disturbed.

EPICA

The findings discussed here and those relative to climate instabilities and to sea-level changes, raise key questions about our understanding of the climate system including :

- * Are the societal timescale climate instabilities that have been detected at Northern latitudes of global significance and did they occur in previous glacial cycles ?
- * What are the mechanisms and forcing factors behind the observed changes ?
- * How is climate coupled between the two hemispheres ?
- * What is the role of greenhouse gases in past climatic changes ?
- * Can we obtain the paleoenvironmental data needed to test predictive climate models ?
- * What is the role of antarctic ice in sea-level change ?

The European Project for Ice Coring in Antarctica (EPICA) aims at answering these questions by deriving high resolution records of climate and atmospheric

composition through several glacial-interglacial cycles from new Antarctic deep ice cores. Involving ten European countries (Belgium, Denmark, Germany, Italy, France, Netherlands, Norway, Sweden, Switzerland and United Kingdom), the project, coordinated by the European Science foundation is strongly supported by the "Climate and Environment" program of the European Community. Two drilling sites have been selected to achieve the required resolution on different scales and an adequate continent-wide perspective (Figure 4).

The first four year phase will focus on major climate drifts that have characterized the past several cycles, based on the analysis of a 3300 m long ice core to be drilled at Dome Concordia, south of the Indian ocean in East Antarctica. A core from this location is ideally placed to secure a very long record covering the last five climatic cycles (~ 500 kyr) with sufficient resolution and little flow disturbances. It will allow examination of the relative phasing of climate and climate-forcing across these major climate-change events and to explore their global context by comparison with the Greenland and other records.

During the second phase of the project, a core will be obtained from Dronning Maud Land, an area of Antarctica most strongly influenced by the Atlantic ocean and of somewhat higher annual snowfall rate and thinner ice cover. This phase of the project is designed to focus on the specific phenomena of the rapid climate flickers detected across Greenland throughout the last glaciation, and believed to have been associated with mode-shifts in the

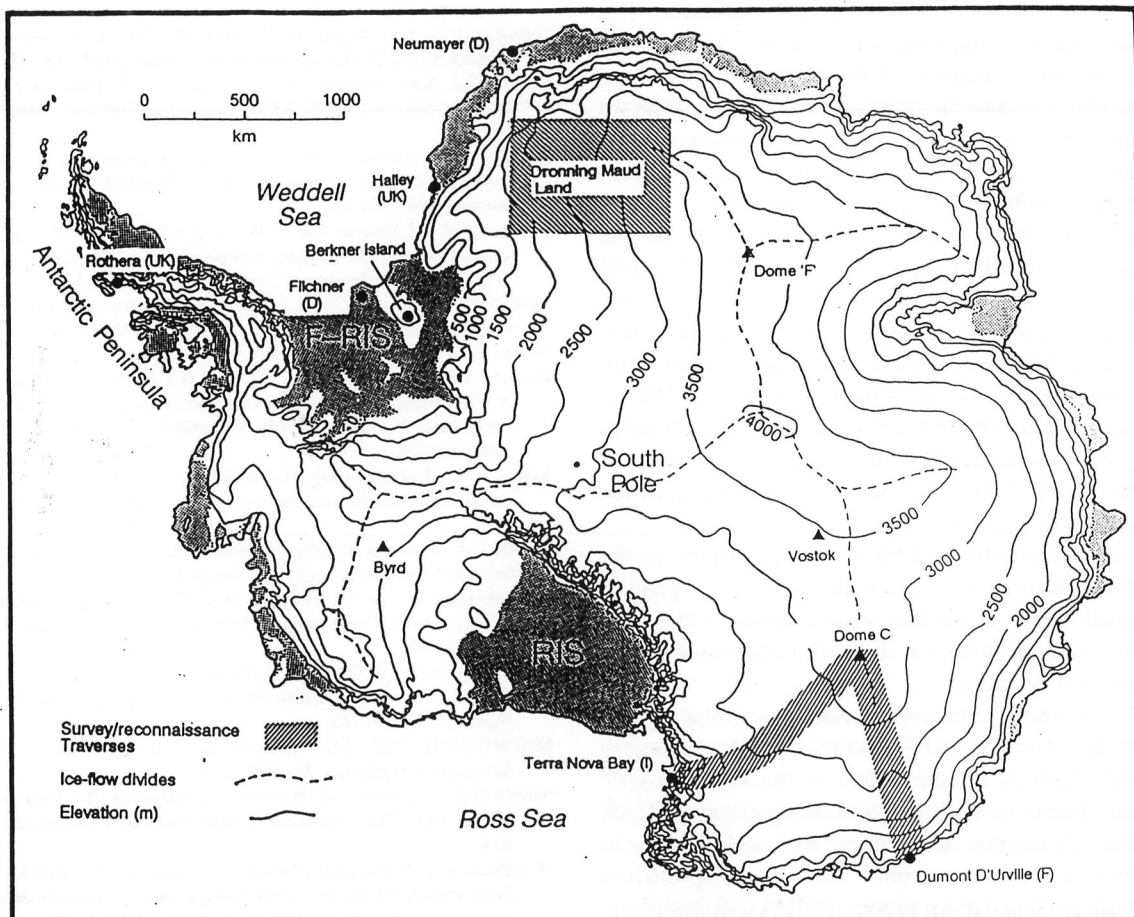


Fig. 4 - EPICA activities in Antarctica showing drilling sites and planned surface glaciological traverses.

Atlantic thermohaline circulation. This area is also one of the least explored sectors of Antarctica, hence a framework of basic geophysical survey is needed to ensure that the optimal site is selected for drilling. In order to ensure that there is no major hiatus in the project, this reconnaissance survey is being planned as an integral part of the first phase of drilling at Dome Concordia.

In addition to deep ice-core drillings, EPICA will provide opportunities to develop associated programs which have strong scientific links with the main project and will be most useful to its overall success. Traverses to the drilling sites will provide the opportunity to obtain shallow cores to study recent changes in climate and atmospheric chemistry in a wide geographic context as well as data relevant to mass balance and ice dynamics. In order to gain maximum information from the ice cores, it will be important to investigate the relationship between present atmospheric chemistry and the resulting record of chemical tracers deposited in the snow cover. Ice flow modeling should help in the selection of the drilling site and provide estimates of both the timescale and of the geographical origin of the ice. At last, atmospheric modelling is needed to assist in the process of drilling site selection as well as in the interpretation of certain ice-core parameters.

Drilling at Dome Concordia will start during the 1997-1998 field season and is expected to reach the bedrock during the 1999 - 2000 season. At this site, EPICA will largely benefit from the ongoing Dome Concordia program supported by France and Italy. The development and testing of the new deep drill system needed for this operation will be completed soon. In the 1995/96 field season, the exact location of the drilling site has been selected after a successful detailed radar survey of the ice thickness, internal layering and bedrock topography, a GPS measurement of the Dome Concordia summit topography and the establishment of a strain net.

One characteristic of this program will be the deployment of specific experiments in the field which will allow a detailed and comprehensive study of climate and environmental parameters unprecedented for an Antarctic record. During the deep drilling operation at Dome Concordia, the Geophysical Reconnaissance (1996-1999) in the Atlantic sector of East Antarctica will be realized to identify the best suited site for the second deep drilling. In a second phase (2000 - 2003), the deep drilling in the Atlantic sector will be realised.

As mentioned above, EPICA will contribute to the PAGES/IGBP core project for which the study of glacial-interglacial cycles of the last several hundred thousand years for understanding the dynamics that cause large-scale natural variation, is a priority. The study of paleoclimate and environmental variability in polar regions is one of the focus of PAGES to which EPICA will largely contribute. EPICA is also linked to the GLOCHANT (GLOBAL CHANGE in ANTARCTICA) working group of SCAR (Scientific Committee on Antarctic Research) aiming to coordinate at the international level the deep-drilling programmes planned in Antarctica. EPICA will contribute through various traverses and surveys to the objectives of

ITASE (International Trans-Antarctic Scientific Expedition) and allow studies of the fundamental aspects of global cycling of key chemical species and thus contribute to the objectives of the IGAC (International Global Atmospheric Chemistry) a core project of IGBP. EPICA is also important for IPCC (Intergovernmental Panel on Climate Change) which considers that the study of the natural variability of climate is a key for reducing uncertainties in predicting future climate changes.

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