The Greenland Ice Core Project

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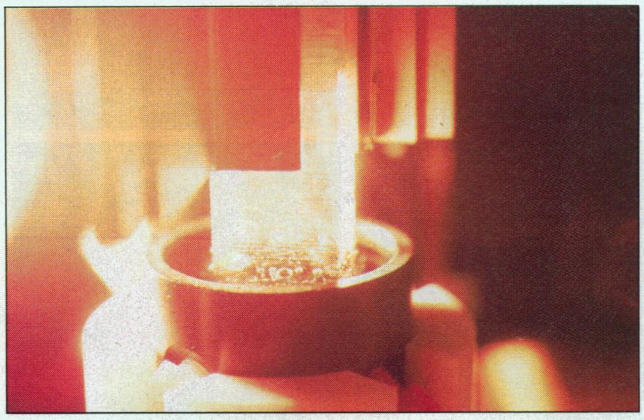
It is one of the great challenges of basic research to investigate the principal mechanisms that control global climate changes. One way to learn more about these complex mechanisms is through the reconstruction of past climate changes. The analysis of polar ice cores, consisting of well-stratified layers of precipitation during the last several hundred thousand years, allows a very detailed reconstruction of the climate as well as of some important environmental parameters. Building on previous work, the European Greenland Ice Core Project (GRIP), a multinational research effort, is working to unlock some of these past secrets.

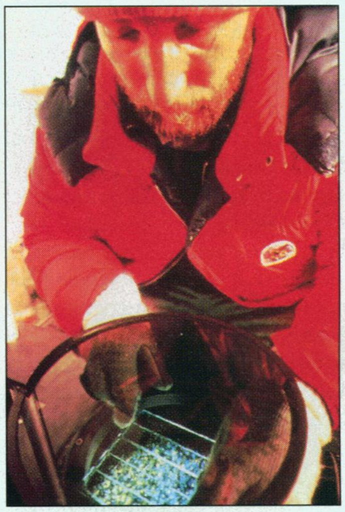


Icy secrets. (Above) View of ice core taken from the Greenland ice sheet. Air bubbles trapped in the ice are being analyzed to extract data about past changes in Earth's climate. (Below right) Researcher checks samples in cold storage. [Ivars Silis]

Interesting results have been available from ice cores from Antarctica and Greenland before the creation of GRIP. Two of the most important pieces of information are past temperature and atmospheric composition. The stable isotope ratio $^{18}O/^{16}O$ or $^{2}H/^{1}H$ is the main proxy for the temperature at the time of the corresponding snow fall and the composition of the air enclosed in the tiny bubbles has the same atmospheric composition as the atmosphere at the time of ice formation. The ice core from Vostok (Antarctica) covered the last 160,000 years and showed convincingly a very close correlation between climate changes and changes of the concentration of the two most important greenhouse gases, carbon dioxide and methane (*1*). Other cores from Antarctica allowed a reconstruction of the anthropogenic increase of the two gases in the last 200 years.

Two Greenland ice cores from Camp Century and Dye 3 showed in their climate record features that were very puzzling for climatologists. Fast and large climatic changes have been recorded during the late part of the last glaciation, and the transition from the last glaciation did not occur in a slow, smooth manner but in two short, dramatic episodes (*2*). Such fast changes have not been predicted by climate models and were unexpected. The results had the disadvantage that the ice representing the time period in question was found in both cores in the lowest 200 m above bedrock so that an artifact caused by an irregular flow of the ice could not be excluded with certainty.

Many researchers, not only specialists working in this field but also many other climatologists, asked therefore that an additional ice core be drilled at a location with conditions that would finally confirm or disprove the fast climatic variations. Scientists from the United States and Europe came to the conclusion that the central part of the Greenland ice sheet would be best suited but that two ice cores would be needed to get a definitive answer. It was therefore decided to launch two independent but well-coordinated projects.



The European GRIP was accepted as a European Science Foundation (ESF) Associate Program in 1988. Eight nations are participating: Belgium, Denmark, France, Germany, Iceland, Italy, Switzerland, and the United Kingdom. Financial support is given by national funding agencies, partly through ESF and partly through the principal investigators. Additional funding is provided by the Commission of the European Community through their EPOCH program.

Fieldwork started in summer 1989 at Summit (72°37'N, 37°37'W) in the center of the Greenland ice sheet at an altitude of 3200 m above sea level with the construction of the camp and the excavation for the drill platform. A GRIP Operation Center was established at the Geophysical Institute in Copenhagen, which is responsible for all logistic aspects as well as for the core drilling. The drill used was an updated version of the one that was already used in the American-Danish-Swiss Greenland Ice Sheet Project (GISP 1) operation at Dye 3 from 1979 to 1981.

The 11-m-long electromechanical drill is lowered on a thin steel cable into the borehole. The electrical conductors in the cable allow control of the down-hole drilling from the surface and provide the necessary power. The core diameter is 100 mm, and the typical core length recovered in one run is about 2.5 m. At the surface, the drill and drill tower can be tilted to a horizontal position to facilitate the extraction of the core and the preparation of the drill for a new run. Working in three shifts, it is possible to drill about 150 m per week. In 1990, a depth of 769 m, and in 1991, a depth of 2321 m, were reached. On 12 July 1992, the drill hit bedrock 3028.8 m below the surface of the snow. The ice at this depth is more than 250,000 years old.

It was one of the characteristic features of GRIP that certain analyses were performed in the field. Measurements in the field are done to select samples for special analyses and to exclude the risk of contamination, such as from hydrogen peroxide, formaldehyde, ammonium, and organic acids. Continuous measurements along the core included dc and ac electrical properties (related to hydrogen ion and total neutral salt concentration) and the concentrations of microparticles, 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. Some are important environmental parameters. The calcium and microparticle concentrations are a measure of the atmospheric dust concentration, and the results show that they were more than ten times larger during the last glaciation. The mean ammonium concentration is assumed to be a measure for the large-scale bioactivity, and large, narrow peaks of that concentration are caused by forest and grassland fires (*3*).

The large remaining parts of the ice cores, which were not used for analyses performed in the field, were transported frozen to Copenhagen, and from there ice samples are distributed to the different laboratories. The analysis of the entire core will take several years. However, first results are already available and give hope for a rich scientific harvest.

The stable isotope record down to 2321 m, representing the temperature during the

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past 40,000 years, confirms the results from the two ice cores from Dye 3 and Camp Century concerning the fast variations and the transition from the glacial to the post-glacial epoch (*4*). The transition can be investigated in great detail. It is possible to count annual layers back at least 13,000 years, and the thickness of an annual layer is still over 5 cm at the upper end of the transition. The fast climatic variations and the stepwise transition are also confirmed by our American colleagues, who started drilling for their GISP 2 project in summer 1990, about 32 km (ten times the estimated ice thickness) west of Summit. They are using a newly developed drilling technique and in 1992 reached a depth of 2252 m. They will probably reach bedrock in 1993.

From 23 to 25 March, about 50 scientists from GISP 2 and GRIP met in Annecy, France, to compare and discuss the results obtained so far. They did agree that there is ample evidence that the "flickering" of climate during the Ice Age and the termination of the Ice Age in drastic steps are real. The episodic mild periods during the Ice Age were about 7°C warmer than the cold periods but still 5°C colder than the present temperature. The mild periods started with a fast temperature increase within a few decades or even less than a decade, lasted between 500 and 2000 years, and changed afterwards gradually back to the cold climate. It is assumed that these climate changes have been large-scale climatic events, probably typical of the whole North Atlantic region.

The transition from the last glaciation to the post-glacial epoch shows in many respects a similar pattern. There was a fast and drastic temperature increase about 14,500 years ago. After about 1000 years, the temperature started to decrease again and reached cold glacial values again about 12,500 years ago. This return to a cold phase is observed also in peat bogs and lake sediments in Europe and in eastern parts of North America and is called the "Younger Dryas" period. It lasted on the order of 1000 years. About 11,700 years ago, the temperature abruptly increased again, according to the Summit core, by about 6°C.

There is some evidence that the fast climatic changes correlate with changes in the deep water formation in the North Atlantic (*5*). When sea ice disappears, deep water formation increases in the North Atlantic. This again allows an efficient oceanic heat transport into the region by the Gulf Stream, leading to large and fast temperature increases. The mild periods could be terminated by the discharge of considerable amounts of melt water from the expansive continental ice sheets on both sides of the Atlantic, which can reduce the deep water formation and lead to a more extensive ice cover.

If fast climatic changes occur only according to this mechanism, it would be rather good news for mankind. Fast variations would depend on large ice sheets covering North American and Fennoscandinavia that are missing at present. However, with the results from the deeper part of the Summit core, the good news comes to nothing. The last interglacial period, called in Europe the Eem, lasted from about 135,000 to about 115,000 years before the present. It is represented in the Summit core in a depth interval between 2780 and 2870 m below the surface.

The stable isotope record (*6*) indicates that rather drastic climate variations occurred also during this period that were on the order of 2°C warmer than today and which are often suggested as an analog to our climate after a greenhouse warming. It will be a major task for climate modelers to model the fast climatic changes.

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Who Are the Europeans?

Alberto Piazza

In many parts of the world, populations are vanishing as a result of acculturation, urbanization, and migration (*1*). In Europe, populations are moving toward increasing and irreversible amalgamation. Because genetic differences between extant populations are an irreplaceable source of information about our own evolution, the population geneticist is pressed to document existing genomic variation. Fortunately, with molecular biological analyses of variation in DNA, the precision with which populations, their origins, and their interrelations can be defined increases enormously—even with relatively small samples. The populations of Europe are of particular interest: European history, archaeology, and languages are extraordinarily well documented. Moreover, genetic information is being obtained from the copious human fossil records in Europe, raising the possibility of testing hypothetical continuities between old and modern records of human evolution to reconstruct our past more accurately.

In Europe as a whole, the gene frequencies of 34 classical (non-DNA) genetic loci and 95 alleles are intermediate with respect to those of other continents (*2*). However, compared with the aborigines of other continents, Europeans are more homogeneous. The genetic differences between populations, as measured by F_{ST} values (*3*), are lower in Europe (an average of 0.0142) than in other parts of the world (Africa, 0.0520; Asia, 0.0668; America, 0.0755; and Australia, 0.0393). When the genetic information from 26 European populations (Austrian, Basque, Belgian, Danish, Dutch, English, Finnish, French, German, Greek, Hungarian, Icelandic, Irish, Italian, Lapp, Norwegian, Polish, Portuguese, Russian, Sardinian, Scottish, Spanish, Swedish, Swiss, and the former Czechoslovakian and Yugoslavian) is summarized in a phylogenetic tree (*2, 4*), two conclusions are of note: There are seven particularly deviant populations (Lapps, Sardinians, Greeks, Yugoslavians, Basques, Icelanders, and Finnish), and the remaining populations lack a tree-like structure. Both of these findings have a simple interpretation; the European populations have not evolved according to a tree of descent. A basic assumption for giving phylogenetic trees evolutionary meaning is that each of its branches evolves independently from the other ones. This can in principle be true for distant or isolated populations, but it is very unrealistic for Europe, where migrations in both prehistorical and historical times have occurred.

Among the genetically most deviant populations, Lapps, Sardinians, and Basques are of special interest. Although Lapps are heavily mixed with Scandinavians, a fraction of them retain a phenotype characteristic of northern Siberian people, in particular the Samoyed, who speak a language of the same non–Indo-European (Uralic) family. Classical genetic polymorphisms show Lapps to be an admixture, in which European genes predominate, but genes in common with people from the Uralic region may reach between 20% and 50% (*5*).

The island of Sardinia has been settled for at least 10,000 years (*6*). The local population had reached substantial numbers (200,000 or more) 3000 years ago, before other foreign colonizers, the Carthaginians, arrived in the south of the island. There were no Greek settlers in Sardinia at the time of

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