Paleoclimate: Ice Age Earth Was Cool and Dry

On a geological time scale, the earth's climate has been getting rapidly cooler. Whether or not this trend, marked by intermittent ice ages during the past million years or more, will continue and lead eventually to an ice-bound planet is of more than casual interest. But the mechanisms that drive climate change are imperfectly understood. The impact of man's activities that may tend to counteract the cooling—such as increasing atmospheric carbon dioxide by burning fossil fuels—is still controversial. Thus new results concerning the climate of the most recent ice age represent a major step toward elucidating past and perhaps future climates and climate change. The results suggest that the ice age climate was not nearly so forbidding as it has often been pictured.

The last ice age began about 75,000 years ago. At its peak, about 18,000 years ago, the continental ice sheet in the Northern Hemisphere extended as far south as what are now Ohio and Long Island. Information on the glacial climate can be gleaned from pollen records in lakes and bogs, from deposits of windblown dust, from ice cores, and from geological evidence of freezing-thawing cycles and other weathering phenomena. But while these data give clues to temperature at particular locations, they are not global in extent.

The most recent results come from a detailed study of sea floor sediments and other climate-related evidence known as the Climap project, undertaken by a consortium of 18 different academic and other institutions. Although not yet published (*1*), the sediment results have been widely disseminated and are already incorporated in a filmstrip produced by the National Science Foundation. In contrast to the Deep Sea Drilling Project cores, on which longer-range paleoenvironmental studies are based (*Science*, 16 January 1976, p. 168), the Climap cores were obtained by inserting a hollow tube into the sea floor. The so-called piston coring technique does not disrupt the upper layers of the sediments to the extent a drill does, and thus gives more complete samples of sediments from the past million years. From such cores, the investigators have been able to map sea surface temperature and other climate variables from 18,000 years ago with unusual precision and with nearly global coverage.

The process involves measuring in recently deposited sediments the relative abundance of species of surface-dwelling planktonic organisms whose populations are temperature-dependent. From these data, the investigators identify groupings of species that reflect different surface water conditions. These groupings are then statistically related to the present-day temperature at each location where samples were taken. Finally the statistical regression equations are applied to sediment samples deposited 18,000 years ago to estimate sea surface temperatures to within an average accuracy of 1.6°C.

Picking sediment samples of the correct age is done with the aid of measurements of the oxygen-isotope composition of the fossil sediments. Variations of the $^{18}O/^{16}O$ ratio reflect changes in continental ice volume and are essentially synchronous through the oceans. A chronology based on radiometric dating of these isotopic composition variations allowed the investigators to select samples from 249 different cores which are isochronous within about 2000 years—a much narrower range than for most marine paleontological dates.

The resulting maps of sea surface temperature—along with estimates of sea level and the extent and thickness of continental ice sheets—show some striking phenomena, according to James Hays of the Lamont-Doherty Geological Observatory in New York. In the Atlantic Ocean, the Gulf Stream shifted south and flowed not toward England but toward Spain, with cold polar water to its north. The equatorial oceans were as much as 6°C cooler than they are today, apparently as a result of increased upwelling of cold bottom water. Overall, however, the ocean temperature was not markedly different from today's, averaging only 2.3°C cooler, to the surprise of most climatologists. But the sea level was at least 85 meters lower than at present, and surface currents appear to have been more vigorous. Sea ice covered much of the high-latitude oceans, and on land ice sheets reaching 3 kilometers in thickness covered much of North America and Europe.

Sea surface temperature, the extent of the ice cover, and the continental geography appropriate to a lower sea level are precisely the data that must be specified in the large numerical models used by atmospheric scientists to study climate. Simulations of the ice age climate with such models by W. Lawrence Gates of the Rand Corporation in Santa Monica, California, and Syukuro Manabe of the Geophysical Fluid Dynamics Laboratory in Princeton, New Jersey, have turned up further phenomena of interest. Gates (*2*), for example, finds high-pressure regions over the major ice sheets, with the westerly winds shifted south of the ice. Surface temperatures in North America and Europe were as much as 15°C colder than at present in the areas just south of the ice sheets. The Asian monsoon was weaker and located to the south of the present monsoon, so that the rains did not fall on the Indian subcontinent. Overall, surface temperatures averaged only about 5°C cooler than at present, and the climate appears to have been much drier during the ice age, especially in the Northern Hemisphere. Manabe's preliminary results also show more arid conditions, with precipitation increasing over the oceans but decreasing over the continents.

The mapping of the sediment data and the computer simulations have been done only for July conditions. The other seasons and additional glacial and interglacial periods are to follow. What can be learned from these results depends on the accuracy of the paleoclimatic data derived from the sediments. Several years ago a scientist with a major funding agency, expressing what was at the time a not uncommon opinion, referred to the sediments as "bugs and mud," asking, "What can you learn from that?" But he and a growing number of investigators now believe that the sediments provide among the hardest data in the paleoclimate field. The emerging picture of ice-age earth, although bleak, is not as forbidding as earlier estimates had suggested, and it is rich with clues to what may prove to be our climatic future.

—ALLEN L. HAMMOND

References

1. A. McIntyre and members of the Climap Project, *Science*, in press.
2. W. L. Gates, *ibid.*, in press.