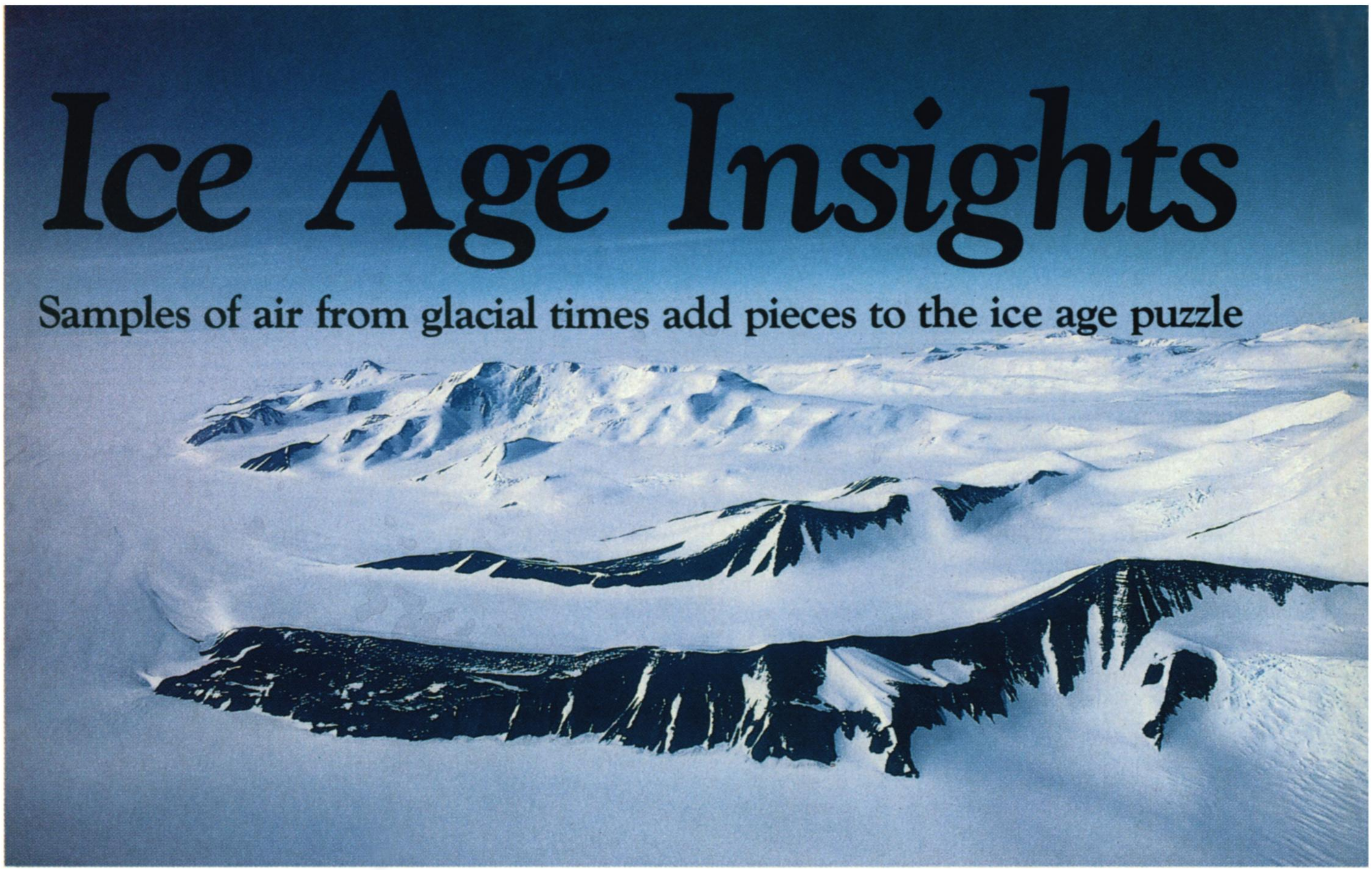
Ice Age Insights

Samples of air from glacial times add pieces to the ice age puzzle



Ann Hawthorne, National Science Foundation

By RICHARD MONASTERSKY

With all the concern about "greenhouse" gases warming the world, it may seem strange that research on the ice ages is heating up. Yet those who study the Earth view hot and cold merely as different faces of the planet's poorly understood climate. Before scientists can predict how the environmental burden of 5 billion human beings may warp the world, they need to understand how the climate behaves on its own. Topping the list of questions is the mystery of why the planet periodically slips into a deep freeze.

"The glacial cycle is the biggest climate change on Earth in the time that we human beings have been here. If you can't understand the biggest, you have a little credibility problem when you try to tell people about a couple degrees of warming because of carbon dioxide," says climatologist Stephen H. Schneider from the National Center for Atmospheric Research in Boulder, Colo.

While geologists, mathematicians and astronomers have attempted to explain the causes of the ice ages for more than a century, researchers are now riding a wave of new information about the glacial cycle. Analyses of air bubbles in the ice caps of Greenland and Antarctica reveal that the ice age atmosphere held a far different mix of greenhouse gases, dust and other particles, all of which may have played a role in cooling the Earth.

Many of the new findings emerge from a joint Soviet-French effort at the Vostok drillhole in east Antarctica. In 1985, after 14 years of difficult drilling into the ice cap, a Soviet team from the Arctic and Antarctic Research Institute in Leningrad and from the Academy of Sciences in Moscow had carefully extracted an ice core more than 2 kilometers long, the deepest ever obtained. The ongoing chemical analysis of the core is being completed in France by Claude Lorius and his colleagues at the Laboratory of Glaciology and Geophysics in St. Martin D'Heres and at the Laboratory of Isotopic Geochemistry in Gif sur Yvette (SN: 8/31/85, p.141).

"Vostok is by far the most exciting work in this field in the last decade or two decades," says geologist Isaac Winograd from the U.S. Geological Survey in Reston, Va., who is investigating the glacial cycle by studying mineral deposits in Nevada. Atmospheric scientist Robert Charlson from the University of Washington in Seattle comments, "If there were a Nobel Prize for earth sciences, Lorius and his colleagues would get it."

The Vostok core harbors some 160,000 years' worth of climate information about Antarctica and the rest of the world. That time span is important because it covers more than one full glacial cycle. Starting in the present warm period, called an interglacial, the core reaches back through the last ice age, which gripped the Earth's climate for almost 100,000 years, then into a previous interglacial and finally to the tail end of the second-to-last ice age. Four other major ice cores recovered from the Antarctic and Greenland record only part of a cycle.

In Vostok and the other cores, climate experts have struck a bonanza. Bubbles within the ice preserve tiny samples of the atmosphere from times when ice covered large patches of the globe, giving scientists their first glimpse of the part the atmosphere plays in the glacial cycle. Another prime source of climate information, cores of deep-sea sediments, can record several million years' changes in ocean temperature and ice cap volume. Yet they reveal relatively little about what goes on in the atmosphere above the ocean.

Geologically speaking, the Earth is now in the middle of an ice age. If it seems warm outside, it's just a brief reprieve during an extended glacial cycle. For about 700,000 years running, the planet has swung in and out of a full-scale chill — a sharp contrast to Earth's normally balmy state.

From geologic evidence, deep-sea cores and now the ice cores, climate experts think the principal ice age pattern goes something like this: The Earth slips hesitantly into a glacial period lasting around 100,000 years and then warms for a short interglacial time, which is what we now enjoy. The present interglacial started about 11,000 years ago and should last another few thousand years, depending on how humans alter the climate.

Many scientists believe changes in the Earth's orbit drive these climate fluctuations, a theory principally developed by Yugoslavian mathematician Milutin Milankovitch early in the 20th century.

The Milankovitch theory focuses on orbital cycles that redistribute where sunlight strikes the Earth, a property called insolation. Milankovitch and other scientists identified three important orbital effects. Over thousands of years as the Earth whirls around the sun, the shape of the elliptical orbit varies from a nearly round circle to one slightly squashed. At the same time, the Earth's axis of rotation wobbles like that of a spinning top. Third, the degree of tilt in the axis changes.

Climate experts think these orbitally induced insolation changes are the pacemaker for the glacial cycle, setting the Earth's climate swinging between warm and cold periods. "I don't think there is any question that orbital forcing gives the initial kick to the whole system," says Alan Mix from Oregon State University in Corvallis.

Yet the orbital changes cannot explain the entire story. The shifts in sunlight are slight — too weak to power the entire climate turnover. Together, they can explain perhaps a tenth of the 4°C temperature change between the coldest and warmest times, says Michael Ghill at the University of California, Los Angeles. What's more, of all the orbital cycles that alter insolation, the climate seems to respond most strongly to the weakest cycle of all, a 100,000-year-long variation in orbital shape.

This leaves scientists with a two-pronged problem: How does the climate amplify this slight orbital change, and why is Earth particularly sensitive to a 100,000-year cycle?

In trying to solve this problem, theorists have traditionally turned to the ice sheets — those hallmarks of a glacial age that once covered up to one-fourth the land surface of today's globe. According to theory, Earth's orbital gyrations allow ice sheets to grow by changing the distribution of sunlight at sensitive areas of the planet. For example, if less sunlight hits northern Canada during summer, snow may survive through the year and begin to accumulate, building an ice sheet that might eventually spread as far south as New York City.

These continental-scale glaciers apparently behave as climate amplifiers because they reflect sunlight. Therefore, as the Earth's orbit shifts and delivers less light to northern Canada, an ice sheet compounds the effect by reflecting some of the sun's waning warmth.

Ice sheets also may explain the planet's 100,000-year sensitivity, because as glacial caps grow, the land beneath them slowly sinks. Even today, Scandinavia and other once-buried areas are rising as they rebound from their depressed ice

Drawing by Anastasia Sotiropoulos from *Ice Ages: Solving the Mystery*, Imbrie and Imbrie, 1979, Harvard Univ. Press

Twenty-thousand years ago, Earth was entering the coldest part of the last ice age. Great ice sheets, kilometers thick in some places, covered much of North America, Europe, Asia and Antarctica. With so much water locked up in ice, sea levels were much lower, perhaps as much as 100 meters short of today's tidemark.

age states. Since the Earth's crust responds very slowly, on the order of tens of thousands of years, some researchers have suggested that this geologic lag time might tune the climate to a 100,000-year period.

Five years ago, many climate experts sought to explain the ice ages in terms of ice sheets and other *physical* processes that reinforce solar insolation cycles. But within the last few years, ice core work has suggested that chemical and biological changes also are catalysts in the climate cycle.

First researchers found indications that carbon dioxide levels were lower during the most recent ice age than they are during the present interglacial. Then last year, Lorius' group published data from Vostok that revealed a stronger relationship between carbon dioxide and temperature. Over the whole glacial cycle, carbon dioxide levels rise and fall, in almost perfect synchrony with temperature. At their lowest, carbon dioxide concentrations may drop to less than 70 percent of the interglacial maximum value.

As they continue to examine the cores, scientists are finding that carbon dioxide isn't the only participant in these atmospheric alterations. In the June 16 and Aug. 4 issues of NATURE, Lorius and his colleagues report that the levels of methane and sulfate particles also swing in concert with the temperature record. While methane drops during a glacial period, sulfate particles peak. Even the dust over Antarctica accumulates significantly during an ice age. Working on a shorter core from Greenland, Hans Oeschger and his colleagues at the University of Bern in Switzerland report that similar changes occurred in the North.

"The main thing we have learned from Vostok is that the large glacial/interglacial changes are concomitant with large changes in atmospheric chemistry," Lorius says.

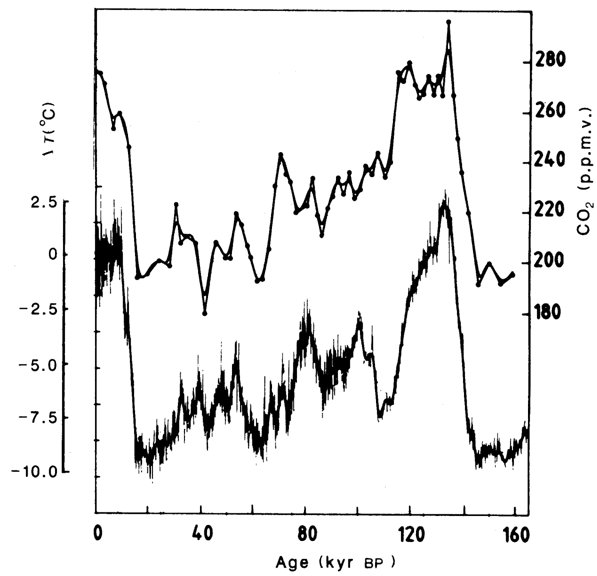
For those seeking to explain the causes of the glacial cycle, these chemical results can be a mixed blessing. On the positive side, they represent a boon of information about the state of the world during an ice age. Theorists and computer modelers now have far more data to work with when they try to recreate the climate.

Yet the sweeping atmospheric changes complicate an already intricate climate puzzle. Carbon dioxide and methane are greenhouse gases and tend to heat the atmosphere. Conversely, sulfate particles stimulate the growth of cloud particles, which reflect sunlight and thereby cool the atmosphere. Dust also reflects sunlight, although not as efficiently as cloud particles.

According to the Vostok core, the atmosphere and the climate seem to shift in tandem. For instance, when an interglacial starts and temperatures rise, the concentration of greenhouse gases also grows.

Scientists are now staring at a "chicken-and-egg" situation as they try to sort out the role of the atmosphere in the glacial cycle, says Lorius. At this point there is not enough information to separate cause from effect. It may be that the insolation changes cause alterations in the atmosphere that in turn orchestrate a shift in global temperatures. Conversely, the atmosphere may merely respond to an initial temperature change and then amplify it.

A chicken-and-egg situation: The Vostok ice core shows that carbon dioxide levels (top line) and Antarctic temperatures have fluctuated in synchrony over the last 160,000 years, suggesting that this gas and others have exerted a strong effect on the climate. Scientists are trying to sort cause from effect to determine whether changes in the atmosphere drove the temperature jumps, or vice versa.



As a conservative scientist, Lorius says simply, "We cannot explain the changes in the past climate, but we believe that the chemical changes have had a great importance."

Oregon State's Mix sums up the present state of knowledge a little differently, saying, "It's getting murkier and murkier."

In trying to decipher some of the ice age atmospheric changes, experts at least think they know where to look — somewhere underwater. The atmosphere holds less than one-fiftieth the carbon dioxide stored within the world's oceans, so oceans are most likely behind the carbon dioxide surges and dips throughout the glacial cycle, says Mix.

As oceans enter the picture, so does biology. Many computer modelers are exploring how photosynthetic marine plants affect the climate. As sea levels and ocean currents shift during the onset of an ice age, plankton may bloom and reduce atmospheric carbon dioxide through photosynthesis, which would help cool the globe. Moreover, scientists have recently proposed that certain plankton can also lower world temperatures through a sulfur chemical they produce. This molecule enters the atmosphere and forms sulfate particles that make clouds reflect more sunlight, says Charlson (SN: 12/5/87, p.362).

Like plankton during an ice age, theories about the glacial cycle seem to be multiplying. Says Mix, "We've got a lot of ideas and we're out there chasing them. We really don't know which way it's leading, but that's good. It's called science." □