studies to assess the feasibility and costs (including lost blood donations) of doing the antibody test.

The next step after the workshop is the preparation by CDC officials of a list of options for containing AIDS. This list will be submitted to Edward Brandt, assistant secretary for health in the U.S. Department of Health and Human Services, whose office will decide which options, if any, to implement.

Meanwhile, hemophiliacs who need clotting factor face an uneasy situation. Oscar Ratnoff, a hemophilia specialist from University Hospitals in Cleveland, proposes that they might minimize their risk of AIDS by using clotting factor cryoprecipitate instead of concentrate. A given lot of cryoprecipitate is made from material donated by one individual whereas each lot of concentrate contains material from an average of 5000 donors.

Cryoprecipitate may not be potent enough to control bleeding of some patients, however. The National Hemophilia Foundation recommends that new patients be given cryoprecipitate as long as possible, but that hemophiliacs who are already using the concentrate continue to do so. According to Dennis Donohue of the Bureau of Biologics of the Food and Drug Administration, an effort to prepare a safer clotting factor concentrate by removing or inactivating contaminating viruses is under way.

The biggest question of all still remains. What causes AIDS? Donald Armstrong of Memorial Sloan-Kettering Cancer Center expressed the hope that investigators not be distracted from answering that question. "I have no doubt that this is an infectious disease," he asserted. "I think we have to find the agent. A surrogate agent isn't good enough."—JEAN L. MARX

Orbital Variation—Ice Age Link Strengthened

The geological evidence is stronger than ever, and realistic mechanisms for the connection are being proposed

Palisades, New York. Climate cycles related to astronomical influences seemed to be popping up everywhere at last month's meeting* here on Milankovitch and climate. Climatic responses to variations in Earth's orbit and axis of rotation appeared in geological records of the upwelling of seawater off Arabia, the blowing of dust across the Pacific, and the flow of deep currents in the Atlantic. Researchers presented evidence that processes as diverse as the monsoon of 9000 years ago and the chemistry of a briny lagoon of 250 million years ago pulsed to the same orbital beat.

The gathering was not simply a celebration of Milutin Milankovitch's suddenly popular theory of climatic change. Researchers presented new evidence that seems finally to have laid to rest the argument that orbital variations might cause minor climate fluctuations but not major climatic changes such as the ice ages, the largest and most abrupt climatic changes known. Researchers are also beginning to postulate reasonable mechanisms to explain the amplification of the orbital signals and their reverberation throughout the climate system.

A major problem with convincing skeptics of a possible link between orbital cycles and the ice ages had been an embarrassing failure of Milankovitch's theory. The most obvious climate cycle in the geological record is the recurrence of ice ages about every 100,000 years. But the 100,000-year orbital cycle of changing eccentricity alters the total sunlight falling on Earth each year, called insolation, by 0.1 percent at most. That is hardly the makings of an ice age, critics noted. Perhaps the synchroneity of the two cycles over the past few hundred thousand years was only a coincidence?

Members of the spectral mapping group (SPECMAP), a collaboration of researchers from five universities, have used some of the orbital cycles themselves to sharpen up the geological record and demonstrate that the eccentricity and glacial cycles have been in step for at least the past 800,000 years, an unlikely coincidence. They measured the oxygen isotope composition, which reflects the amount of glacial ice in the world, down three deep-sea sediment cores. They knew that the slowly accumulated microfossils beneath the sea floor did not perfectly preserve the glacial climate record, but they knew also that shorter period orbital variations had been recorded in the same distorted isotopic records. Earth's axis of rotation had been gently nodding back and forth about its tilted position every 41,000 years or so, and the direction its axis pointed toward the stars had drifted, or precessed, in a circuit every 23,000 years. The known effects on climate of these predictable orbital variations, together with four radiometrically dated points in each core, thus provided an internal clock to which the isotope records of the three cores could be adjusted.

Once SPECMAP workers had adjusted the climatic records of the three sediment cores to make the best match with the known short-period orbital variations, they found that the amplitude of each of the main eccentricity cycles of the past 800,000 years was proportional to the amplitude of the corresponding 100,000-year glacial cycle, according to John Imbrie of Brown University and SPECMAP. The correlation between the two near the 100,000-year frequency explains about 77 percent of the climate variance. On the basis of standard statistical techniques, Imbrie concluded that orbital variations accounted for 60 ± 10 percent of climatic variability in the range from 19,000 to about 100,000 years per cycle. Orbital variations are thus "the fundamental cause of the succession of the Pleistocene ice ages of the past 800,000 years," he declared.

Although some had questioned such uncompromising statements about the control of the ice ages (*Science*, 14 July 1978, p. 144), no one rose on this occasion to object. Not everyone would stand by that specific number; most felt that the statisticians could be left to fight over the meaning of such a calculation. Instead, the geologists and paleoclimatologists, now thoroughly convinced of the connection, are eager to use orbital variations to sort out how climate varied in the past and what processes intervene between orbital variations and climate.

One of the great mysteries has been how such large climatic changes could be prompted by such small effects on insolation. Only eccentricity variations

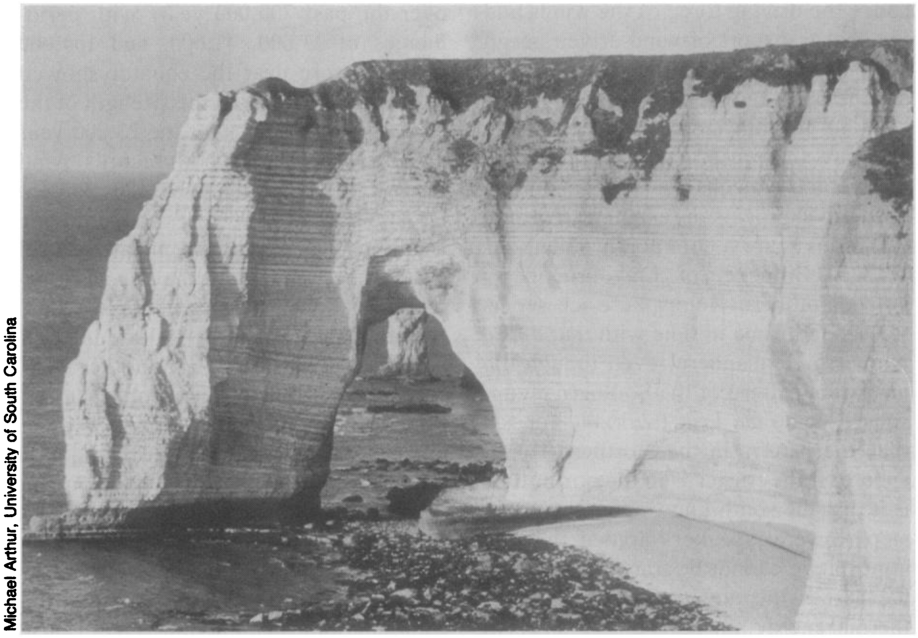
*Milankovitch and Climate: Understanding the Response to Orbital Forcing, held 30 November to 4 December 1982 at Lamont-Doherty Geological Observatory, Palisades, New York. The cochairmen were André Berger and John Imbrie.

change total insolation and not much at that; tilt and precession variations change only the way insolation is distributed with latitude. Perhaps for the first time, listeners had a choice of possible ways to increase the sensitivity of climate to orbital variations. David Pollard, most recently of Oregon State University, showed how the behavior of ice sheets might provide the needed sensitivity. He used a computer model of an ice sheet constructed from equations that specify how ice can accumulate from snowfall and flow outward under its own weight, or waste away and retreat.

Growth and decay of the northern ice sheet in the model is controlled by orbital variations, ice growth being favored by combinations of tilt, precession, and eccentricity that provide lower summer insolation at 55°N. Such cooler summers would tend to preserve each winter's snowfall from year to year. Another feature of the model is that the ice depresses the earth's crust beneath it, as real ice sheets do. Pollard's simple model generated cyclic growth and decay of the ice sheet having the 41,000- and 23,000-year periods of the tilt and precession cycles, but, as in similar models, the 100,000-year cycle was a weak and erratic one bearing little resemblance to the ice ages.

To try to duplicate the sharp termination of real ice ages, Pollard added another kind of ice sheet behavior, the calving of icebergs into a marginal lake. As the ice begins a retreat, a lake that eats away at the ice and breaks off icebergs can form in the lingering crustal depression. In fact, the accelerated retreat caused by iceberg calving in the model did create a sharp 100,000-year cycle that stayed roughly in step with the geological record of ice volume as far back as 600,000 years ago. Pollard found that the eccentricity cycle could indeed impose itself only indirectly through its accentuation of the precession cycle. When an eccentricity-strengthened precession cycle coincided with a large ice sheet, which amplified the iceberg calving effect, the desired sharp termination resulted.

Another suggestion that generated considerable interest was that geography may help explain climate's sensitivity to orbital variations. Gerald North and David Short of the NASA Goddard Space Flight Center, Greenbelt, Maryland, and John Mengel of Applied Research Corporation of Landover, Maryland, like many others, had been building simple computer models that keep track of the energy that falls on the globe. They had hoped that understanding how this energy is parceled out among the various parts of the climate system, including the ice, would help them to understand the system's sensitivity.



Michael Arthur, University of South Carolina

Ancient geological periodicity

These cliffs on the Normandy coast of France near Le Harve contain hundreds of alternating layers of 90-million-year-old chalk and chalk nodules. Each cyclic bed represents about 20,000 to 40,000 years of sedimentation, the same range of periodicity known to occur in variations of Earth's axis of rotation. Periodic variations in sea level might have been the ultimate cause.

Everyone's results from the energy balance approach had been depressing, North noted, but then they wondered if a more realistic distribution of continents and oceans on their model globe might help. Instead of a single landmass surrounded by a single ocean, they mapped out the major landmasses as precisely as the model allowed. They were reassured when, under present orbital conditions, ice covered only Greenland, as it does today. When orbital variations are used that favor increasingly cooler summers, the ice area slowly increases until the model Earth is suddenly nudged over the brink into an "ice age," having three times the ice area of the present Earth. Not only is the geographically more accurate model sensitive, but the ice appears mostly over northern Canada and Scandinavia and not on the main Eurasian landmass, which is the distribution of ice seen in the geological record.

North's group believes that the sizes of the continents are crucial to this more realistic response to the model. Central Asia is so far from the moderating influences of the ocean that every summer's heat, no matter how favorable the orbital conditions, will melt the past winter's snow far into the north, they say. In North America, on the other hand, snow persists from year to year as far south as about 65°N, which happens to be in the vicinity of the greatest effect of orbital variations. Thus, the strongest orbital influences are acting at the most sensitive spot of the climate system. There is no absolute assurance, North cautioned, that the dramatic behavior of this model is not merely a mathematical quirk. More model experiments will be required to test their conjecture, he said.

Another new suggestion for amplifying the response of northern ice to orbital variations has come from a study of the North Atlantic by William Ruddiman and Andrew McIntyre of Lamont-Doherty Geological Observatory. After studying sediment cores from the North Atlantic, they found that, once the precession cycle became favorable for ice growth, northern ice began to grow within 3000 years but North Atlantic surface water did not begin to cool until 6000 years after that. A relatively warm North Atlantic could supply increased amounts of moisture to the growing ice sheets, they noted, but the source of this heat had been unclear.

At the meeting, McIntyre and Ruddiman considered the possibility that wind-driven currents continue to pump warm surface water from the South Atlantic to the north, even after insolation in the Northern Hemisphere favors cooler summers. Comparison of two sea-surface temperature records having strong 23,000-year cycles, one in the North Atlantic and one near the equator, suggested to them that the strongest northward transport of heat occurs when orbitally influenced insolation patterns enhance the driving force of the winds and the heat transport of wind-driven ocean currents. Thus, insolation variations under the control of orbital variations may combine to both increase the supply of moisture and preserve more of it as ice.

All of these mechanisms for generating northern ice sheets in response to orbital variations share a common problem. As Wallace Broecker of Lamont-Doherty noted, Southern Hemisphere ice seems to wax and wane in time with that of the Northern Hemisphere, even though the insolation pattern of the Southern Hemisphere could be less favorable for ice than the pattern in the Northern Hemisphere. If the trigger is in the north, how is it that the south knows how to stay in step? Several speakers argued that the atmosphere cannot be transferring a signal across the equator in the form of thermal energy; the atmosphere seems to be too inefficient for that.

Broecker suggested that the interhemispheric messenger might be carbon dioxide exchanged between ocean shelf sediments and the atmosphere as northern ice cycles raised and lowered sea level. The resulting pulsations in the greenhouse effect would be worldwide. Isaac Held of the Geophysical Fluid Dynamics Laboratory in Princeton suggested that ocean currents might be the answer. The flow of North Atlantic Deep Water (NADW) begins near Greenland, he noted, and crosses the length of the North and South Atlantic oceans before rising near the surface again. Because climate variations over the North Atlantic apparently influence the flow of NADW, Northern Hemisphere climate could conceivably affect Southern Hemisphere ice through the rising of the relatively warmer NADW near Antarctica. In fact, Edward Boyle of the Massachusetts Institute of Technology reported that the flow of NADW does fluctuate in time with the 41,000-year cycle of tilt, as evidenced in the trace element composition of sediment microfossils in the South Atlantic (*Science*, 19 March 1982, p. 1490).

Glacial ice has received most of the attention, but several groups presented evidence that orbital variations also influence the behavior of the atmosphere. Thomas Janecek and David Rea of the University of Michigan found a measure of wind intensity in the dust blown across the Pacific to form deep-sea muds. The harder the wind blows, the larger are the quartz particles that it can carry into the middle of the ocean. By measuring quartz grain size throughout a sediment core at 39°N, they found that the intensity of the westerly winds over the core site fluctuated by 22 percent over the past 700,000 years with periodicities of 23,000, 41,000, and 104,000 years. A core near the equator showed similar periodicities in the strength of the trade winds, except that the 23,000-year cycle was missing. In both records, wind intensity fluctuations were 70 percent larger before 250,000 years ago, implying a shift in some part of the climate control system that modulated the effects of orbital variations.

One possible source of modulation turned up in two studies of another wind system, the Indian monsoon. Warren Prell of Brown University monitored the intensity of the monsoon during the past 150,000 years through its effect on the upwelling of deep, cold water off the Arabian peninsula and the microfossils of the underlying sediment. He found that the intensity of the monsoon varied with a periodicity of about 22,000 years, but the monsoon variations lagged the calculated insolation variations by about 5000 years and did not always respond in proportion to the magnitude of the change in insolation.

"... the connection has been viable during the past few hundred million years."

John Kutzbach and Peter Guetter of the University of Wisconsin suggested that the reason for the erratic response of the monsoon might be glacial ice in North America. They have been recreating in a computer model the atmospheric circulation of 9000 years ago, when orbital variations caused insolation to be 7 percent higher than today in the summer and 7 percent lower in the winter. On an annual basis, there was no difference, although there was greater contrast between the seasons. This increased seasonality intensified the southwest monsoon, but the increase depended on the North American ice sheet in the model. With no ice sheet, the additional heating of central Asia, which drives the southwest monsoon, amounted to 4° to 6°C. If the appropriate amount of ice lingering from the last ice age were included, the heating dropped to 2° to 4°C. Apparently, the chilling effect of the ice on the atmosphere and the ice's ability to reflect more sunlight back into space could moderate the monsoon's response to orbital variations.

Most of the evidence presented at the meeting linking orbital variations and climate came from the past million years of the geologic record, but several speakers presented evidence that the connection has been viable during the past few hundred million years. These were times thought to be ice-free, leaving the main amplification mechanism a mystery. The most reliably determined ancient climatic periodicities have varve counting as the basis for their time scales. A varve is a distinct, millimeter-scale sediment layer whose deposition is controlled by the changing seasons. One varve equals 1 year's sedimentation.

In the 250-million-year-old sediments of the Delaware Basin of southeast New Mexico, the alternation of the seasons produced varves by controlling how much calcium sulfate and calcium carbonate precipitated from the briny waters of a 14,000-square-kilometer lagoon. Roger Anderson of the University of New Mexico reported that over a span of 260,000 varves or years, the amount of calcium sulfate also varied in a cycle of about 20,000 years, apparently under climatic control.

Another varved record appears in the sedimentary rock of the Newark Basin, the 200-million-year-old remains of a huge lake that stretched from eastern Pennsylvania across New Jersey to New York. The lake swelled and shrank with changes in climate, depositing varved, organic-rich layers during high stands. Paul Olsen of Yale University used these varves to determine that cycles in the type and rate of sedimentation had periodicities of 18,600 and 24,000 years (precession actually has two cycles of 19,000 and 23,000 years), 101,000 years, and 393,000 years (eccentricity also has a cycle of about 400,000 years).

The prospect of precisely determined ancient periodicities had a special appeal to the astronomers in the audience. André Berger of the Catholic University of Louvain-la-Neuve, Belgium, had conceded that orbital calculations could not guarantee even the existence of the familiar orbital periodicities much before 10 million years ago. The problem is that even a calculation involving three bodies interacting gravitationally requires approximations, but calculating Earth's orbit and rotation involves the gravitational effects of all of the planets and the moon. As one observer put it, celestial mechanics on a geological time scale has been "a theory without observations." That may be changing.

—RICHARD A. KERR

Additional Reading

1. D. Pollard, *Nature (London)* **296**, 334 (1982).
2. J. D. Kutzbach and B. L. Otto-Bliesner, *J. Atmos. Sci.* **39**, 1177 (1982).
3. R. Y. Anderson, *J. Geophys. Res.* **87**, 7285 (1982).