search & discovery

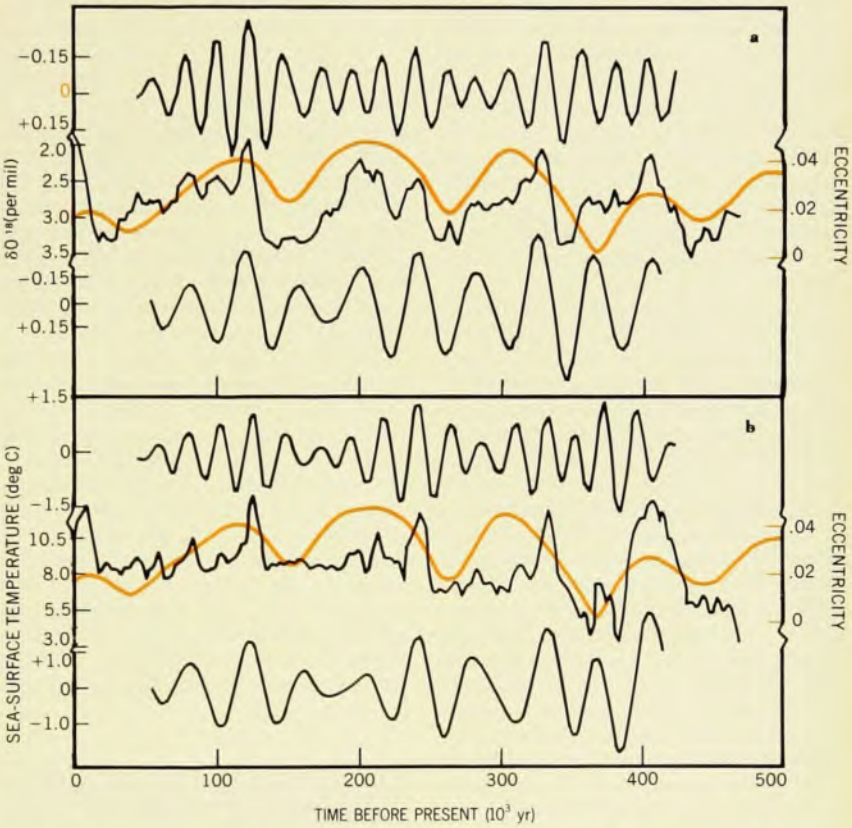
Sea-floor data link glaciation to Earth's orbital motion

The old theory that ice ages are triggered by orbital motion of the Earth around the Sun has received additional support from recent oceanographic studies. The experimenters, James D. Hays (Lamont–Doherty Geological Observatory), John Imbrie (Brown University) and Nicholas J. Shackleton (Cambridge University) have reported evidence[1] that periodic changes in the shape, tilt and seasonal positions of the Earth's orbit triggered ice ages.

History. A hundred years ago J. Croll argued that glacial periods are caused by changes in orbital motion. He said that the precession of the equinoxes (with a period of 21 000 years), changes in the obliquity of the Earth's ecliptic (with a period of 41 000 years) and changes in the eccentricity of the orbit (with a period of 92 000 years) would combine to produce a changing distribution of solar radiation at high latitudes. This changing distribution of solar radiation over the Earth, he claimed, would produce glacial and interglacial ages.

However, Croll's argument fell into disfavor because of the work published in 1909 by Albrecht Penck and E. Brückner. After studying the northern slopes of the Alps, they estimated that there had only been four major glaciations, each 100 000 to 200 000 years long, with the last glaciation ending 25 000 years ago.

Then in a series of papers published in 1920, 1930 and 1938, Milutin Milankovitch of the University of Belgrade in Yugoslavia did extensive mathematical calculations (without benefit of a computer, of course) on the theory that orbital changes were responsible for glacial periods over the past 600 000 years. He produced a curve showing the climatological changes at high latitudes due to changing solar radiation distribution over the past million years. The Milankovitch curve showed, not a handful, but 25 oscillations in that period.



Variations in eccentricity and climate over the past 500 000 years. The center curve of **a** shows variations in δO^{18}, and the colored curve is a plot of orbital eccentricity. The upper and lower curves are the 23 000-year and 40 000-year frequency components, respectively, extracted from δO^{18} by band-pass digital filters. In **b** the colored curve again indicates orbital eccentricity, but here the center curve represents variations in estimated sea-surface temperature, T_s. The upper and lower curves are again the 23 000-year and 40 000-year frequency components extracted via band-pass digital filtering, this time from T_s.

Milankovitch argued that if one has many cool summers in succession over the

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New evidence supports supernova origin of solar system

Measurements of isotopic anomalies in meteorites have stimulated theoreticians to consider new models for the formation of the solar system. Several groups suggest that a supernova explosion was the trigger. Observational evidence for a supernova having triggered star formation provides support for this view.

Recent experimental results on isotopic anomalies were obtained primarily by two groups, both using mass spectrometry. One is Gerald J. Wasserburg, Typhoon Lee and Dimitri A. Papanastassiou (Caltech), the other Robert N. Clayton, Toshiko K. Mayeda and Lawrence Grossman (University of Chicago).

In a paper presented at the annual meeting of the American Physical Society in February, Clayton surveyed several isotopic anomalies—relative to terrestrial values—found in meteorites. The largest, in number of atoms, is an O^{16} excess of up to 5%. Excesses of Mg^{26}, Ne^{22} and isotopes of Xe are also found, and there

Assousa, a radio astronomer, discovered a neutral-hydrogen shell coincident with the nebula. Earlier, Assousa and J. W. Erkes (Carnegie Institution) had found such expanding shells around old galactic supernova remnants. Discovery of the shell in CMa R1 helped identify the nebulosity as a supernova remnant.

The age of the remnant was estimated from the radius of the hydrogen shell (30 parsec) and its expansion velocity of about 32 km/sec (obtained from the Doppler shift of one of the hydrogen lines). It turned out to be about 600 000 years, in good agreement with the estimated age of the young stars. Herbst and Assousa state that their observations confirm the process of supernova-induced star formation, and thus strengthen the argument for a solar system triggered by a supernova.

Cameron characterized his work with Truran as "trying to make a synthesis of a lot of different ideas into a single picture, and perhaps it was too ambitious an attempt." It seemed to describe the formation of the lighter elements, but he thought perhaps they had gone too far in attempting to explain the heavy-element anomalies.

Wasserburg was even more decided about his indecision than Cameron. He said, "The discovery of new isotopic effects, which are related to nuclear, chemical, and kinetic effects, is taking place very nearly on a weekly basis. Therefore, anyone trying to play God is in a crap game with very rapidly changing rules."

Grace Marmor Spruch

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2. A. G. W. Cameron, J. W. Truran, Icarus **30**, 447 (1977).
3. T. Lee, D. A. Papanastassiou, G. J. Wasserburg, Astrophys. J. **211**, L107 (1977).

Perfect VBA site found?

World collaboration on a Very Big Accelerator is now being actively discussed. If it were a fixed-target proton accelerator, for example, it would reach energies of 10 TeV or higher (PHYSICS TODAY, August 1976, page 61). In March at the Particle Accelerator Conference in Chicago, Leon Lederman (Columbia University) described his own concept for the site requirements:

- "Availability of power and water
- Inaccessible to general public (island?)
- Nearby educational resources
- UN presence
- Geology that permits tunneling—natural tunnels even better
- Long enough for 10-km straight sections
- A high-rise central lab building
- Site should be readily ceded by national government
- Should have a stirring symbol of aspirations of people everywhere—or at least, accelerator users."

For a look at Lederman's perfect site for the Very Big Accelerator, see page 20.

Glaciation

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Northern latitudes, the snow cover will expand even during the summer, and of course will accumulate even more during the winter. Once glaciation begins, even though the kick is a small one, the process is self-generating.

Some observers believed that the way to find out just how many glaciation periods actually occurred was to look in deep-sea sediments. The first systematic effort to collect long sediment cores on a worldwide basis was made by the Swedish Deep-Sea Expedition in 1947–48, using the piston corer developed by Borje Kullenberg for such exploration of the deep-sea floor. Studies of this material by Gustaf Arrhenius (then at the University of Stockholm and now at La Jolla) demonstrated the existence of at least nine major climatic oscillations during an extrapolated time period of one million years.

In 1950 Cesare Emiliani (then at the University of Chicago and now at the University of Miami) started using such cores. The ocean floor is continually collecting the shells of single-cell organisms (roughly ½ mm across), contributing to a sediment layer which grows about one inch in 1000 years. Emiliani determined the ratio of O^{18} to O^{16} in samples spaced along the depth of the sediment cores. The isotope-temperature method had been developed by Harold Urey, then at Chicago.

Emiliani recently explained to us that the ratio depends on two effects that are additive. Firstly, the lower the temperature of precipitation of calcium carbonate is, the greater the amount of O^{18} in the sediment. Secondly, during an ice age, water is removed from the oceans by evaporation and concentrated as ice on land, preferentially carrying with it O^{16}. Each of the two effects contributes roughly half to the sum. Emiliani used a time scale based on radiocarbon dating, which goes back 30 000-40 000 years, and then, he explained, because the rates of precipitation on the ocean floor are approximately constant, he extrapolated backwards in time.

From his 1950 observations, Emiliani obtained a curve closely resembling that of Milankovitch. Over the next ten or fifteen years he did more analysis and obtained the same result, regardless of latitude.

During the last decade Wallace S. Broecker (Lamont–Doherty) and his collaborators studied raised coral beaches in Barbados, which were formed at sea level during the ice ages and subsequently became raised in interglacial periods. By measuring the ratio of uranium isotopes, they obtained discrete points at 127 000, 105 000, 82 000 and 60 000 years; that is, they were roughly separated by 20 000 years. Broecker's ages also fit the Milankovitch curve.

For the past ten years or so a controversy raged over whether the oxygen isotope record primarily reflected changes in ocean temperature or in global ice volume. Two years ago Shackleton and Neil Opdyke (Lamont–Doherty) studied a very deep core from the equatorial Pacific, which penetrated the sediments laid down since the last terrestrial magnetic-field reversal. Earlier work by Alan Cox, Richard Doell and Brent Dalrymple (US Geological Survey) had established through potassium–argon dating that the last reversal occurred 700 000 years ago. The core studied by Shackleton and Opdyke could therefore be used to anchor the early portion of the Milankovitch curve to a fixed date. Their work indicates that most of the signal was in fact due to changes in ice volume. On the time scales being worked with, this means that the ocean mixes relatively rapidly. So the oxygen isotope signal is globally synchronous, allowing one to use a time scale developed anywhere in the world. The two experimenters observed a 90 000-year periodicity, suggesting that most of the astronomical influence on climate is from the Earth's eccentricity.

In the new work, reported by Hays, Imbrie and Shackleton, the experimenters studied two cores from the Southern Hemisphere, raised from the floor of the Southern Indian Ocean, equidistant from Africa, Australia and Antarctica so that they would scarcely be influenced by variations of erosion products from these continents. These cores were studied as part of the CLIMAP (Climate: Long-range Investigation, Mapping and Prediction) project, currently headed by Hays. The cores were characterized by accumulation rates greater than 3 cm/1000 years, fast enough to resolve climatic fluctuations with periods below 20 000 years.

The experimenters measured three things: One was an estimate of summer sea-surface temperatures at the core site, derived from a statistical analysis of the abundance of microorganisms called "radiolaria." The second measurement was of the ratio of O^{18} to O^{16} in the fossilized shells of planktonic foraminifera. From previous work, changes in this ratio could be related to global ice volume. The third determination was of the relative abundance of a single species, *Cycladophora davisiana*, which the experimenters believe reflects the change in temperature and salinity structure of the Antarctic Ocean.

To obtain these dates, the group used the 700 000-year age determined by Cox, Doell and Dalrymple for the last reversal of terrestrial magnetic field in the equatorial Pacific core studied by Shackleton and Opdyke and interpolated a 440 000-year age that could then be correlated with the Southern Hemisphere cores through the O^{18}/O^{16} records. They also used the 127 000-year age from raised coral beaches, used carbon-14 dating for the last 10 000 years, and interpolated between the three points. Then they did a power-spectrum analysis to determine what frequencies are present.

From the power-spectrum analysis, the experimenters find three discrete spectral peaks at periods of 23 000, 42 000 and roughly 100 000 years. These peaks, they say, correspond to the dominant periods of the perturbations of the Earth's orbital elements and contain respectively about 10%, 25% and 50% of the variance in climate. The 42 000-year cycle would correspond to the variations in the obliquity of Earth's axis and maintains a constant phase relationship with it. The climatic cycle with an average period of 21 000 years is divided into two cycles, one with a period of 23 000 years and the second with a period of 19 000 years. These match the two main periods of the quasi-periodic precession index. The 100 000-year cycle would correspond closely and be in phase with the period of change of the eccentricity of the orbit.

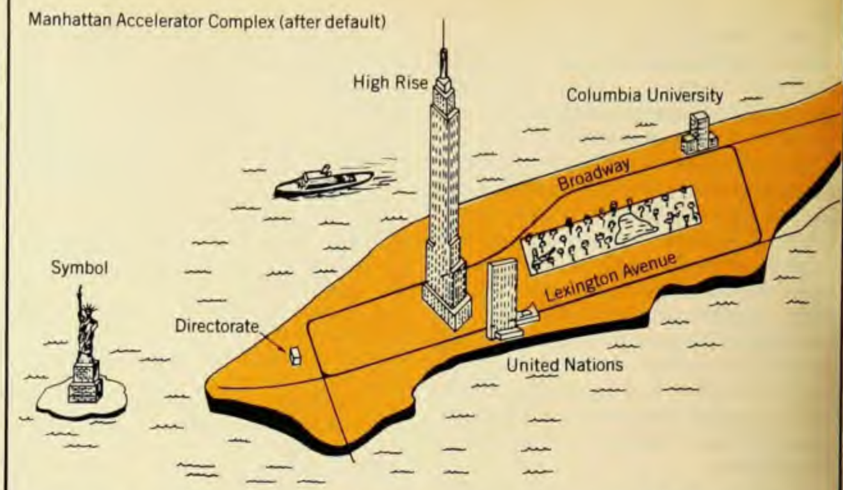
The experimenters conclude that changes in Earth's orbital geometry are the fundamental cause of the timing of the ice ages. Furthermore, if the effects of Man on climate are ignored, they predict that the long-term trend over the next several thousand years is toward extensive glaciation in the Northern Hemisphere.

Other theories have, for example, proposed the ice ages were produced by variations in radiation from the Sun itself, reductions of solar radiation reaching Earth caused by interstellar or volcanic dust, cyclic phenomena affecting the flow of heat from the tropics to the polar regions through the air and the ocean, and the deep circulation of the oceans.

—GBL

Reference

1. J. D. Hays, J. Imbrie, N. J. Shackleton, Science **194**, 1121 (1976).



Lederman's proposed site for the VBA. The Broadway and Lexington Avenue subway lines would provide ready-made tunnels for the accelerator's straight sections. The high rise is the Empire State Building, and the stirring symbol is the Statue of Liberty. Inaccessibility to the public is assured by the traffic jams at toll bridges. Justification for the cession of Manhattan Island to the VBA complex by the US Government could be financial default by New York City.

Survey satellite to map high-energy sources

The first in a series of High Energy Astronomy Observatory satellites, HEAO-A, will be inserted in June into a low circular orbit about the Earth from NASA's Kennedy Space Center. The new satellite will spend its six-month mission lifetime surveying and mapping x-ray sources throughout the celestial sphere, and also measuring low-energy gamma-ray fluxes; its purpose is to amass experimental data related to radio galaxies, neutron stars, pulsars, quasars, stellar explosions and supernovas. The HEAO-A carries a payload of four experiments. In 1978 and 1979 NASA expects to launch other High Energy Astronomy Observatories to complete the $237-million, three-mission HEAO program.

The HEAO-A (after launch it will be called "HEAO-1") is approximately 5.8 m in length and has a mass of more than 3000 kg, of which 1350 kg is the experimental payload. The satellite rotates slowly (about 2 rpm) end over end as it moves in its 420–460-km orbit above the Earth; this leisurely ballet will enable it to scan the whole sky in six months.

Experiment package. Three of the experiments are concerned with the detection of low-to-medium-energy x-rays from discrete sources and from the diffuse cosmic background. The Large-area X-ray Survey Experiment, for which Herbert Friedman (Naval Research Laboratory) is principal investigator, is to search the sky for x-ray sources in the 0.15–20-keV range. The largest of the four experiments, it will map such sources and determine the energy spectrum, intensity and periodic or random time structure of each.

The Cosmic X-ray Experiment, for which Elihu Boldt (Goddard Space Flight Center) and Gordon Garmire (Caltech) are responsible, is to measure emissions and absorptions of diffuse x-rays—0.2–60 keV—and correlate its results with visible-light and radio emissions. Precise determination of positions on the celestial sphere of certain cosmic x-ray sources in the 1–15-keV range is the purpose of the Scanning Modulation Collimator Experiment; Herbert Gursky (Smithsonian Astrophysical Observatory, Harvard University) and Hale Bradt (MIT) are principal investigators for this package, which will also study the size and structure of sources.

The Hard X-ray and Low-energy Gamma-ray Experiment is to determine the positions, spectrum and time variations, intensities and other properties of x-ray and gamma-ray sources in the range of 10 keV to 10 MeV. This experiment, for which Laurence Peterson (University of California, San Diego) and Walter Lewin (MIT) are responsible, relies mainly on scintillation counters for its higher-energy work—the three lower-energy studies use gas-proportional counters as their primary detecting elements.

The HEAO-B (HEAO-2 after launch) is intended to examine over long periods the sources mapped by the HEAO-1, and the HEAO-C (HEAO-3) will study gamma-ray emissions, plus cosmic-ray particles from our own galaxy. The two satellites are expected to have useful lifetimes of one year and six months, respectively. —FCB

in brief

ERDA has selected Lawrence Berkeley Laboratory to develop the neutral-beam injectors for the Tokamak Fusion Test Reactor, now under construction at Princeton University for a total cost of $228 million. The neutral-beam project, headed by Walter Hartsough, Wolf Kunkel and Kenneth Fowler, is expected to cost $12 million and to be shipped to Princeton in 1981. □