isotopes of microfossils. This indicator remains controversial, but it apparently provides a measure of atmospheric carbon dioxide or some other ocean-related aspect of the carbon cycle.

In each of the three Milankovitch cycles, Imbrie showed how the sequence of events in the climate system with respect to the known driving force, the change in insolation, might lead to understanding how the system works. In the case of the 41,000-year cycle of the amount of tilt of the earth's axis, the first response to maximum tilt and thus the warmest summers is a 5000-year-long increase in the flow of newly formed deep water southward through the Atlantic and in the carbon dioxide added to the atmosphere from the ocean. Only after this phase do warm surface waters push into high latitudes in both hemispheres. By about 9000 years after maximum tilt, the ice sheets have had time to shrink to their minimum size. A few thousand years later the high-latitude North Atlantic finally warms, having been kept cold longer by meltwater from the North American ice sheet.

The apparent increase in atmospheric carbon dioxide in the first phase of the response to maximum tilt was first noted by Nicholas Shackleton of the University of Cambridge and Nicklas Pisias of Oregon State University. They found that Milankovitch insolation changes might be able to elicit such carbon dioxide increases and the resulting greenhouse warming to amplify their effect on climate. SPECMAP results reveal a similar four-phase sequence of effects led by carbon dioxide and deep-water flow in the cycle of the earth's orbital eccentricity, which modulates the earth-sun distance at a given time of year. How the eccentricity cycle, the weakest of the three, managed to produce the largest climate changes, the ice ages themselves, has always been a mystery, Imbrie noted. Carbon dioxide could be a crucial intermediary. The appearance of the carbon dioxide increase and deep-water circulation changes about 15,000 years before maximum eccentricity suggests to Imbrie that there is some threshold above which the eccentricity effect takes hold.

Aside from many more analyses from more cores, the SPECMAP approach lacks one major element—some measure of how wind patterns respond to Milankovitch cycles. Analysis of wind-blown dust in marine sediments offers promise of filling that gap. ■ RICHARD A. KERR

ADDITIONAL READING

R. A. Kerr, "Orbital variation—ice age link strengthened," *Science* **219**, 272 (1983); "Precisely measuring the past million years," *ibid.* **221**, 1041 (1983); "Carbon dioxide and the control of ice ages," *ibid.* **223**, 1053 (1984).

Briefing:

OTA Touts Advanced Structural Materials

Advanced materials rank with information technology and biotechnology as one of the three most important "high-tech" industries of the future, according to a newly released technical memorandum from the congressional Office of Technology Assessment (OTA).* In particular, advanced ceramics and polymer matrix composites are expected to play an increasing role in the industrial world as structural materials during the next 25 years and may be one key to maintaining the international competitiveness of the United States in manufacturing.

Structural materials can be roughly divided into metals, ceramics, and polymers. Moreover, it is possible to form composites comprising a matrix of one type of material that is reinforced with particles or fibers of another type in the hope of combining the best properties of each. While metals have been the dominant structural material up to now, advanced ceramics and composites are already in limited use and are looming ever more important. The OTA technical memorandum is part of a larger study still in progress that will also examine policy options for accelerating the commercial use of these materials.

In sum, the report, which concentrates on ceramics, ceramic matrix composites, and polymer matrix composites, puts the importance of these materials into perspective, surveys the prospects for their use in commercial products, and outlines priorities for the research needed to ensure their timely development. For both ceramics and composites, the prime need is low-cost methods of fabricating materials with the desired properties.

Advanced ceramics are of interest for their superior resistance to wear, strength at high temperatures, and chemical stability. Their main disadvantage is their brittleness, which makes them susceptible to fracture. "Unpredictable failure caused by poor control over flaw populations is the most serious handicap to the use of structural ceramics in load-bearing structures," says the report.

At present, ceramics, such as alumina, silicon nitride, and silicon carbide are used for wear parts, cutting tools, bearings, and coatings. In the near term (10 to 15 years), the most important uses are expected to include bioceramics for dental and orthopedic implants and so-called chemically bonded ceramics (advanced concretes) for construction applications. Although discrete ceramic components for automobile engines may also appear in the near term, the Holy Grail of a ceramic gas turbine or diesel will come much later at a time dictated by the pace of government funding.

Polymer matrix composites are organic polymers that contain short or continuous fibers of another material. The fibers increase the stiffness and strength of the material along the direction of the reinforcement, but do not substantially increase the weight of the light polymer. The main disadvantage of polymers is a low service temperature, currently a little over 300°C with some prospect of someday reaching above 425°C.

Aerospace applications dominate the present market for polymer matrix composites, which is heavily oriented toward the military, although sporting goods (tennis rackets and golf clubs) are also an important segment. In the next 10 to 15 years, the materials could account for more than 65% of the weight of large transport aircraft. Moreover, limited production of composite automobile body frames could begin. Ultimately, construction applications, including bridges and buildings, and use of composite polymers in space vehicles and stations are envisioned.

The world market for advanced structural ceramics in 1983 was estimated at $250 million. Various projections for the American market by the end of the century range from $1 to $5 billion. Comparable figures for polymer matrix composites are $1.4 billion for the value of worldwide sales in 1985 and nearly $12 billion by the year 2000. However, the report emphasizes that ceramic and composite parts are only components in large systems, such as automobiles and aircraft. Hence, "the materials have a significance to the economy far beyond the value of the materials themselves."

Because of this leverage effect, the report expressed some concern over the poor transfer of information from government laboratories to private industry. The report also recommended an increased industrial investment in research, development, and commercialization of ceramics and composite materials. By contrast, it noted the long-term commitment and well-coordinated effort of Japanese companies to make advanced ceramics, to use them in commercial products, and to develop markets for these products. The projected large markets for products based on ceramics and composites cannot be taken for granted, concludes the report. ■ ARTHUR L. ROBINSON

*U.S. Congress, Office of Technology Assessment, *New Structural Materials Technologies: Opportunities for the Use of Advanced Ceramics and Composites—A Technical Memorandum*, OTA-TM-E-32, September 1986, available from the Government Printing Office, Washington, DC 20402.