Milankovitch Climate Cycles Through the Ages

Earth's orbital variations that bring on ice ages have been modulating climate for hundreds of millions of years

FINDING repetitive cycles in the geologic record that supposedly reflect some grand controlling scheme in the world has not always been well received. The rhythmic layering of sedimentary rocks had always been obvious, but what, if any, cycles they conformed to and what controlled their formation remained uncertain.

Study of the problem was, if not disreputable, too speculative for most geologists—that is, until the past 5 or 10 years. Paleoceanographers have now presented proof that the cyclic variations in Earth's orientation and orbit, called Milankovitch variations, controlled the timing of 100,000-year ice ages during the past 1 million years. With that boost in respectability, reports are multiplying that reveal apparent climate cycles controlled during the past several hundred million years and perhaps earlier by Milankovitch variations.

One of the most recent reports of ancient Milankovitch cycles confirms a climate-orbital variation link suggested in 1964 by Franklyn Van Houten of Princeton University. He had studied the several kilometers of sedimentary rock that fills the 200-million-year-old Newark basin stretching across northern New Jersey, the remains of a lake larger than Lake Erie. It had been one of a string of then-subtropical lakes filling the valleys formed as a rift divided the Pangaea supercontinent between North America and Africa. Van Houten noted that sediment layers averaging about 6 meters in thickness are distinguished by a sequence of changing fossil and sediment type, texture, and organic matter content. These sequences repeated themselves over and over again. He suggested that a single sequence was laid down as the lake filled to its maximum depth and then retreated, at times until it was dry. As the water depth varied, the nature of the sediment varied.

As best as Van Houten could determine, the durations of these sequences and of the hierarchies of cycles that they formed are close to the periods of the precession of Earth's axis and variations in the eccentricity of its orbit. These variations change the distribution of sunlight over the globe during a given season, much as Earth's motion in its orbit changes the distribution of sunlight from month to month and brings about the changes of season. On the basis of the similarity of periods, Van Houten suggested that these sedimentary cycles are evidence of a causal link between orbital variations and climate, as suggested by Milutin Milankovitch in the 1920s and 1930s.

But a rough similarity of periods never proved sufficiently convincing to those studying ancient lake and marine sediments exposed on land. Age determination was the biggest problem. Instead, it was paleoceanographers who eventually showed that recent climate cycles recorded in well-dated sediments retrieved from the sea floor not only have the same periods as orbital variations but also are right in step during the past million years with the orbital variations calculated by celestial mechanicians. That, everyone agreed, was convincing evidence.

Given this new respectability, Paul Olsen of Lamont-Doherty Geological Observatory went back to the Newark basin to count and date cycles. Celestial mechanicians could not calculate the exact periods much less the timing of Milankovitch cycles that far back in time, but Olsen did find that the cycles of varying lake depth 200 million years ago closely resembled the present cycles. The ratios of the mean thickness of the sediments of five different cycles to the thickness of the shortest cycle (1.0, 1.8, 4.3, 5.5, and 16.3) closely matched the ratios of the present orbital periods to the shortest period (1.0, 1.9, 4.4, 5.8, and 19.0). When dated by using radiometric techniques or counts of annual sediment layers, the ancient periods were 25,000, 44,000, 100,000, 125,000, and 400,000 years versus the present orbital periods of 21,000, 41,000, 95,000, 123,000, and 413,000 years. Orbital variations apparently did force climate change in the distant past, in this case during a period of 40 million years.

Other records of ancient climate change are revealing similar evidence of orbital control. Timothy Herbert of Princeton University and Alfred Fischer of the University of California at Los Angeles, another pioneer in the field, found strong 100,000- and 400,000-year cycles in 100-million-year-old marine sediments in central Italy. The cycles showed up in the rate of accumulation of calcium carbonate microfossils, a measure of marine productivity, as well as in the oxidation state of the sediment, which could be related to productivity, the vigor of deep ocean circulation, or both. Michael House of the University of Hull has reported evidence of an approximate 40,000-year cycle in the 200-million-year-old marine sediments exposed near Lyme Regis on the southern coast of England. This cycle, says House, is likely related to variation in the tilt of Earth's axis.

Michael Arthur, University of Rhode Island

Milankovitch-induced periodicity? *The banding of these cliffs on the Normandy coast has a period of about 20,000 to 40,000 years, the same range of periodicity known to occur in variations of Earth's axis of rotation.*

A special section of 17 papers in the latest issue of *Paleoceanography*, entitled "Milankovitch Cycles Through Geologic Time," includes discussion of all sorts of sedimentary cycles. Many of the papers fail to mention Milankovitch cycles or consider them only in passing. Such hesitation is understandable. Accurate dating of sediments much older than 100 million years is still a horrendous problem, and the very nature of some cycles, whether they are a true record of conditions when the sediment formed or are later alterations, remains controversial.

Lawrence Hardie of Johns Hopkins University, Alfonso Bosellini of the University of Ferrara, and their colleagues do report in the special section that cyclic bedding in northern Italy is created by repeated flooding and exposure of shallow-water sediments and has the same pattern as created by small sea level changes of the past million years. Five cycles of sea level rise and fall, each on the order of tens of thousands of years long, are superimposed on longer sea level cycles on the order of 100,000 years long. The precession and eccentricity cycles would seem to be the only likely means of generating such a pattern, Hardie says. John Grotzinger of Lamont reports in the same issue that similar cycles appear in sediments of northwest Canada that are up to 2.2 billion years old.

Although the steady operation of orbital variations over hundreds of millions of years is not too surprising, the reliable response of Earth's climate system is. Most theories link orbital variations and climate through the behavior of polar ice caps. But according to widely held views of past climate, there were no large ice caps between 40 and 240 million years ago. Alternative linkages might include an influence on the strength of monsoons and their rainfall, as recently demonstrated in the case of the Indian monsoon of the past few hundred thousand years.

Aside from any insights into the workings of climate, the record of Milankovitch cycles in ancient sediments may allow dating of metronomic precision. Dating errors in such old sediments now amount to millions of years. Although exact ages could not be derived from Milankovitch cycles, as has been done for the past million years, the durations of geologic zones that are now often guessed at could be precisely determined. ■ RICHARD A. KERR

ADDITIONAL READING

P. E. Olsen, "A 40-million-year lake record of early Mesozoic orbital climatic forcing," *Science* **234**, 842 (1986).

M.A. Arthur and R.E. Garrison, Eds., special section on "Milankovitch cycles through geologic time," *Paleoceanography* **1**, 369–586 (1986).

Polyphosphoinositide Research Updated

Recent research clarifies the biochemistry of the polyphosphoinositide receptor system and gives new insights into its actions in cells

THE polyphosphoinositide lipids have moved rapidly in the past few years from relative obscurity to the center of the research stage. This increased interest is the result of research showing that the lipids are intermediaries that transmit the signals of a variety of hormones, neurotransmitters, and growth factors from the cell surface to the cell interior. With this key role now well established, researchers are turning more attention toward understanding the biochemistry of the polyphosphoinositide (PI) system and the physiological events caused by its activation.

The PI system has been linked to some half-dozen oncogenes, a development that has also helped to foster interest in the system. Oncogenes cause the cancerous transformation of cells.

During the past year or so researchers have obtained evidence indicating that the protein encoded by the cellular counterpart of the *ras* oncogene may be an integral component of the PI system. The first step in the activity of any of the numerous agents that work through the PI system is the binding of the agent to specific receptors located on the membranes of responding cells. As a result, the enzyme phospholipase C becomes activated and splits the membrane lipid polyphosphatidyl-4,5-bisphosphate (PIP_2) to release inositol trisphosphate and diacylglycerol, both of which act as "second messengers" for converting the signal at the receptor to an internal cellular response.

Indications are, however, that the phospholipase C is not directly connected to the various receptors, but interacts with them through a third membrane protein, one of the G proteins, which are so called because they bind the high energy compound guanosine triphosphate (GTP). The organization of PI-linked receptor complexes therefore parallels that of the well-studied β-adrenergic receptor complex. This receptor, which binds the neurotransmitter norepinephrine, is linked to the enzyme adenylate cyclase by means of a G protein. Adenylate cyclase converts adenosine triphosphate to the second messenger cyclic AMP.

The *ras* protein has certain properties in common with known G proteins, including the ability to bind GTP. A few years ago, there were indications that the *ras* protein might be a G protein that activates adenylate cyclase. Further investigation failed to support this hypothesis and the evidence now points to the possibility that the *ras* gene instead encodes a G protein for the PI system.

For example, Laurie Fleischman, Suresh Chahwala, and Lewis Cantley of Tufts University School of Medicine have found that introduction of either normal or oncogenic forms of the *ras* gene into cultured mouse cells results in increased conversion of PIP_2 to inositol phosphate and diacylglycerol. The simplest explanation of this result is that the *ras* protein stimulates phospholipase C activity.

Gene transfer experiments by Michael Wakelam of the University of Glasgow and his colleagues provide additional evidence for the possibility that *ras* gene encodes a G protein for the PI system. These investigators have found that cells in which the synthesis of the normal *ras* protein is increased show much higher production of inositol phosphates in response to growth factors that act through the PI system than do control cells. According to Wakelam, the results indicate that the *ras* protein is acting like a G protein in that it increases the coupling between the various growth factor receptors and phospholipase C.

Introduction of one of the oncogenic mutants of the *ras* gene into mouse cells results in greatly increased production of inositol phosphate even in the absence of added growth factor, the Glasgow workers find. The mutant *ras* product apparently acts on its own to stimulate phospholipase C, thereby causing the cells containing the gene to behave as if they are undergoing growth factor stimulation when they are not.

Other oncogenes have also been linked to the PI system. The connections of two of these, the *src* and *ros* genes, have become somewhat weaker during the past year. These oncogenes encode tyrosine kinases, enzymes that add phosphate groups to pro-