used the laser trap to test how much power sperm cells produce as they swim through a solution. By first trapping a sperm and then lowering the laser power until the sperm could escape the trap, the researchers were able to get a measure of the force each sperm exerted. Some infertility problems in men seem to stem from a low motive force in their sperm, and this technique may offer a way to understand what causes that.

Even more important, laser surgery may offer a way to promote in vitro fertilization for men with weak sperm cells. Tadir, now back in the Department of Obstetrics and Gynecology at Beilinson Medical Center in Tel Aviv, estimates that perhaps as many as 1% of all couples have infertility problems because the man's sperm cannot penetrate the zona pellucida, which is the glycoprotein coating surrounding the egg cell.

Berns and his collaborator, Ines Rojas of the Department of Obstetrics and Gynecology at the University of California at Irvine, hope to be able to poke holes in the zona pellucida to help sperm get in that otherwise could not. After initial experiments on hamster eggs, Rojas says, "We've been able to make the holes and the eggs look fine. Now we want to see if we can get sperm to go through this little hole."

Medical researchers have tried other techniques to help weak sperm into the egg, Tadir says, but generally without success. For instance, some clinicians have used tiny needles to physically inject a single sperm through the zona pellucida, but there have been no more than a handful of pregnancies across the world using this method, Tadir adds. The few successes with microinjection indicate, however, that if the sperm can be transported across the zona pellucida without damage to either sperm or egg, the resulting embryo should be normal.

Several technical problems remain, such as the difficulty of handling a very large cell (the egg) and a very small cell (the sperm) simultaneously in a laser trap. But if laser surgery lives up to its promise for in vitro fertilization, it could be just what the doctor ordered. ■ ROBERT POOL

Marking the Ice Ages in Coral Instead of Mud

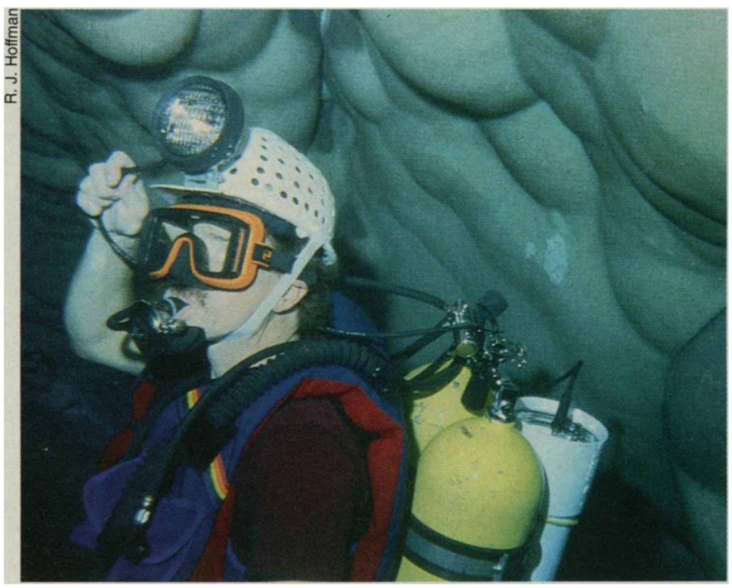
Understanding the cause of the ice ages hangs in the balance as researchers dispute land and marine climate records

FOR OCEANOGRAPHERS, the mystery of the procession of the ice ages was solved more than a decade ago: the natural orbital wobbles, wriggles, and wiggles of planet Earth cause the global climate to swing from mildness to frigidity and back again, time after time.

But late in 1988 a group of terrestrial researchers looking for climatic records beneath dry land instead of deep beneath the sea renewed a battle the oceanographers thought they had won. Fifty meters down in a water-filled Nevada crevasse called Devil's Hole, the terrestrial workers found a well-preserved record of climatic variations that they claimed flatly contradicted the deep-sea record linking Earth's orbital variations with the ice ages. That gave heart to a whole cadre of paleoclimatologists who had never been impressed by the marine evidence.

As the renewed clash enters its second year, the latest evidence seems to be shifting in favor of the oceanographers again. It comes not from the deep sea or a crack in the Nevada desert, but a sort of no man's land where both sides have been seeking the upper hand: those strips where land and sea meet, the offshore coral reefs. The decisive weapon there would be a new way to date climate records.

Marine scientists originally became convinced that orbital variations pace the ice ages by dating the climate record preserved in the carbonate sediments at the bottom of the sea (also see box on p. 32). For example, marine scientists found that the last warm interglacial period (about 127,000 years ago) roughly coincided with an orbitally induced maximum in the amount of sunlight falling on the Northern Hemisphere's arctic lands. That seemed just the thing to melt glacial ice and usher in a 10,000-year break after the ice age cold, the researchers reasoned. Similar coincidences through the previous five 100,000-year ice age cycles only strengthened their confidence in the orbital variation hypothesis.


R. J. Hoffman

Deep dive. *This carbonate deposited in a flooded Nevada crevasse challenges the idea that variations in Earth's orbit pace the ice ages.*

Many terrestrial climate researchers were never completely convinced that the oceanographers were right, but in the absence of terrestrial records as dependable as those from the deep sea, the skeptics had to accede to a truce-like quiet. Then hydrogeologist Isaac Winograd of the U.S. Geological Survey in Reston, Virginia, and USGS colleagues in Reston and Denver rolled out their big gun: a 260,000-year climate record in the carbonate deposits of Devil's Hole, 120 kilometers northwest of Las Vegas. That record looked as good as any marine record, maybe better, its discoverers claimed, because they had been able to date it more directly than any deep-sea sediment ever had been. And in this record the ice ages had not been in step with orbital variations. In particular, the previous interglacial period appeared to have ended at least 147,000 years ago—20,000 years before the oceanographers say it did.

That stung marine scientists. "There's something wrong with [Winograd's age for the previous interglacial]," asserts oceanographer William Ruddiman of Columbia University's Lamont-Doherty Geological Observatory. "There is a virtually unanimous consensus in the marine community," he told *Science*, that an age in the range of 120,000 to 126,000 years for the previous interglacial is a good one. The reasons seem clear to him. "Everything fits together so well that it would have to be a preposterously cruel joke if we were wrong." And to Ruddiman all this is no joke: "I've been known to say that if Winograd is right, I'm getting out of the field."

Ruddiman may not have to quit, thanks to ancient coral reefs and a new way to date them. The reefs grow at the water's surface, so as ice age glaciers melt into the oceans, the coral grows upward to keep pace with the rising sea level. The top of an ancient reef thus marks a sea level high, and the age of the coral is the age of a warm interglacial. That is why both sides are looking to the coral reefs to provide interglacial dates that would independently confirm their opposing positions.

At first, the results of coral dating were mixed. Some samples, such as those from Barbados, looked to be about 126,000 years old, just what the oceanographers expected. But other reefs yielded older ages on the order of Winograd's 147,000-year age from Devil's Hole. Both sides could see support here. Either coral gave different dates because the previous interglacial was long and started early, putting it out of step with orbital variations, or because the dating was sometimes simply unreliable.

The geochemical clock used to date corals is the steady radioactive decay of uranium into thorium. Until recently, the amounts of uranium and thorium in a sample, and thus its age, were determined by the rate at which alpha particles having distinctive energies were given off as decay of both elements continued in lab samples. According to Teh-Lung Ku of the University of Southern California, the older alpha particle–counting methods reported in the literature probably gave dates that could be too high or too low by 10,000 to 15,000 years. And there is a 32% chance the reported dates did not even fall in that range, he notes.

But Ku and his colleagues have recently refined the alpha particle–counting technique until it has an error of plus or minus 2000 years. And what they have found, Ku says, is a Barbados coral date that fits that of the oceanographers. "I really don't see these 140,000-year ages," Ku says.

Meanwhile, because of the earlier uncertainties in the alpha particle–counting methods, a growing number of researchers had been turning to mass spectrometry to separate and count the uranium and thorium atoms themselves rather than the less numerous alpha particles that they emit. Mass spectrometry is ten times more precise than the old alpha particle–counting methods. And it allows the use of samples that are one-thirtieth the size. That means only the most pristine bits of coral need be analyzed,

The Ice Age Bones of Contention

Marine and terrestrial scientists who have been squaring off over the date of the previous warm interglacial period harbor deep suspicions about each other's evidence, but neither side has been able to point to any fatal flaws. Physically, the terrestrial and marine climate records are much alike. Both are engraved in the isotopic composition of the oxygen in calcium carbonate, the stuff of bones. The terrestrial calcium carbonate was continuously deposited from ground waters on the walls of an open, water-filled fault called Devil's Hole in Nevada. The marine carbonate accumulated on the sea floor as the microscopic skeletons of the tiny creatures known as foraminifera settled layer by layer on the bottom.

Both kinds of carbonate deposits record how the oxygen-18 to oxygen-16 ratio varies over time, but much of the debate centers around what that record means on land. In the marine record, the proportion of oxygen-18 is known to be driven largely by fluctuations in the amount of the world's glacial ice, which in turn reflect global temperature variations. As the temperature falls, glacial ice forms, and because it is depleted of oxygen-18, the ocean waters become enriched in this isotope. That enrichment is then reflected in the oxygen contained in marine carbonates.

Similar oxygen isotope variations were recorded in Devil's Hole, says Isaac Winograd of the U.S. Geological Survey in Reston, Virginia, whose group is studying the carbonates deposited there. But at Devil's Hole the isotopic ratios were primarily determined by the air temperatures, the USGS researchers believe. Winograd is confident that the air temperature in Nevada, in turn, reflects the global climate because the ups and downs of the Devil's Hole and deep-sea records resemble each other closely in shape—although not in timing.

Oceanographers suspect, but have not proven, that this presumed link between air temperatures in Nevada and global climate is where terrestrial researchers have gone wrong. "Ground water in Nevada is not tied in any simple way to the marine isotope reservoir," says oceanographer John Imbrie of Brown University, the dean of orbital variations and climate. "I suspect something is funny there. In geochemistry there are always samples that are anomalous and no one can ever figure out why."

While the oceanographers mistrust the Devil's Hole climate record, some terrestrial researchers think that the oceanographers must have erred when they dated the marine isotopic record. Winograd and his colleagues were able to date their carbonate samples in a conventional way by measuring the radioactive decay of uranium, which gave them an age every 2300 years or so. Oceanographers were not lucky enough to have sufficient uranium in their sediment samples for that kind of analysis, so they had to use various other techniques that gave them only a half dozen firm dates, which fell on average every 130,000 years or so.

To fill the gap between conventional dates, Imbrie and a consortium of oceanographers used a different kind of clock whose ticking had been recorded in deep-sea sediments. Actually, two clocklike tickings—the nodding of Earth's axis of rotation and the wandering direction of the axis—impressed regular variations on the oxygen isotope record as the orbital variations modulated climate. Imbrie and colleagues extracted these regular beatings of the climate system and used them like metronomes to fill in between their other dates. This "tuning" process yielded a time scale accurate to 3,000 to 5,000 years back to 800,000 years ago (*Science*, 9 September 1983, p. 1041).

Nonoceanographers were generally not impressed by this marine oxygen-18 time scale. Something about the word "tuning" and the heavily statistical techniques used to extract the orbital signals from the climate record left them cold.

In their defense, oceanographers have repeatedly cited half a dozen lines of evidence that their time scale is sound. Perhaps the most accessible is climate-related records that have nothing to do with oxygen isotopes—carbon-13, sea surface temperature, and African lake diatoms blown into the Atlantic, for example. They all fall right into step with the orbital variations calculated from the oxygen-18 time scale. If Winograd's older age for the previous interglacial were right, the periodic ups and downs of these climate indicators would be out of step with orbital forcing. "It all falls apart if you stretch the last interglacial to 140,000 years," says Ruddiman. Adds Imbrie: "The real challenge is to correlate the continental record into the marine record, which is the standard." ■ **R.A.K.**

improving the chances of avoiding coral whose apparent age is altered by chemical degradation.

The first mass spectrometry dates are in, and the oceanographers have reason to smile. While working at the California Institute of Technology, Lawrence Edwards, who is now at the University of Minnesota, and his colleagues got interglacial ages between 122,000 and 130,000 years at Barbados. In papers now in press, James Chen and his associates at Caltech and Edouard Bard and his colleagues at Lamont found comparable ages for Barbados coral. The true age, says Richard Fairbanks of the Lamont group, is "not 140,000 years, that's for sure."

As if all this weren't enough, the Devil's Hole age of 147,000 years or more has come under attack from other quarters. Wang-Xing Li, Joyce Lundberg, and their colleagues at McMaster University in Hamilton, Ontario, have gone spelunking themselves, using mass spectrometry to date carbonate in a coastal cave in the Bahamas where the deposition has been interrupted only when high sea levels flooded the cave. They find that the hiatus caused by the previous interglacial came about 125,000 years ago.

And P. van den Bogaard of the University of the Ruhr in Bochum, West Germany, and his colleagues have dated a volcanic ash deposit sandwiched between glacial and interglacial soils formed not one but two glacial cycles back. Their exceptionally precise argon-argon dating technique provided an age that is "distinctly younger than" Winograd's for the same interglacial.

Winograd has no explanation for the failure of the newest studies to support his contention that the last interglacial was 147,000 years ago. "We're new to this game," he says. "We certainly don't have all the answers." But he isn't giving in yet. He is looking forward to the answers that are expected soon from studies of the ancient New Guinea reefs, where some of the older dates have been reported. New samples from those reefs are being dated by mass spectrometry. And he has a longer record from Devil's Hole in the works.

The oceanographers aren't waiting; they are confident that these studies will vindicate their orbital variations hypothesis once again. Says Imbrie: "I'm not going to worry too much about it." ■ **Richard A. Kerr**

ADDITIONAL READING

I. J. Winograd, B. J. Szabo, T. B. Coplen, A. C. Riggs, "A 250,000-year climatic record from Great Basin vein calcite: Implications for Milankovitch Theory," *Science* **242**, 1275 (1988).

What's the Sound of One Ocean Warming?

Oceanographers will make a noise in the Indian Ocean that may be "heard" in Bermuda—and used to measure global warming

If all goes according to plan, a team of oceanographers will set sail early next year to a remote, desolate island in the Indian Ocean. On arriving, they will lower a complex piece of equipment 150 meters beneath the sea and fire a "shot" that may be heard halfway around the world—underwater.

A lot is riding on that big undersea bang. If the sound waves are successfully detected off Bermuda and northern California, this test will be the forerunner of a decade-long attempt to measure global warming in the world's oceans. And at the same time it would open up a whole new bag of technological tricks for studying the ocean's large-scale structure.

The specific technical trick at hand is acoustic tomography. In that technique, sound waves are generated, then detected, and their motion is computed to yield a picture of the intervening water—much as radioactive particles are used in computerized axial tomography (CAT) scanning to yield a three-dimensional picture of the brain. Since it was pioneered a decade ago by oceanographers Carl Wunsch of Massachusetts Institute of Technology and Walter Munk of the Scripps Institution of Oceanography, acoustic tomography has been employed to study local ocean regions, but this would be the first test across five oceans at once—and one addressing a seminal question of our day: Is the earth heating up? "If this works, tomography will have been shown to be useful on a global scale," says Wunsch.

There are many pitfalls, however. So many that Munk, the father of the $1.7-million project, concedes many think it is a "slightly mad scheme." Critics point to the remote location and to technical problems in interpreting data. "We might flop terribly," Munk admits, "but the fact is, we have our money and we have our ship." The ship comes from the Navy and the money from four federal agencies (the Office of Naval Research, the National Science Foundation, the Department of Energy, and the National Oceanic and Atmospheric Administration) that think the potential payoff—the first accurate measurements of ocean temperatures—are worth the gamble.

The reason measuring the speed of sound waves underwater can indicate global warming is that sound travels faster in warm water than in cold water. Therefore the speed of sound waves traveling through the ocean can provide a gauge of temperature. Of course, there already are large amounts of data on ocean temperatures, gathered largely from ships. But ocean temperatures are notoriously tricky to measure, and Munk

Scripps Institution of Oceanography

Toast to a "mad scheme." *Walter Munk of the Scripps Institution of Oceanography fathered the plan to fire the underwater shot.*