hours at a time," says Montemagno. "It was seriously cool."

But whirling beads—impressive as they may be—are still a long way from nanorobots rooting through the body. So Montemagno's team is pressing ahead. They're currently working on replacing the beads with tiny magnetic bars. If the motors spin the bars, the researchers will be able to measure precisely how strong the motors are by applying an outside magnetic field: By increasing the field until the motors can no longer spin, they will be able to probe the limit of the motor's power.

What's more, the spinning bars should generate an electrical current that might eventually be used to power devices, such as chip-based drug delivery pumps or chemical weapons sensors implanted in the body. But these uses, Montemagno says, are just the beginning. "There's 100,000 different things you could do with these motors," he says.

Washington's Vogel says much the same thing about her team's contraption, a nanoscale monorail in which a collection of molecular motors all lined up on a surface pass a tiny tube hand over hand down the line. Vogel based her monorail on one of the cell's own transport systems, which consists of tracks made of microtubules, tube-shaped assemblies of a protein called tubulin, and small motors made of another protein, kinesin. In cells, the kinesin motors latch onto the fixed microtubules and churn like steam engines from one end of the line to the other, ferrying molecular cargo such as proteins and lipids. But for their experiment, Vogel and her colleagues John Dennis and Jonathan Howard reversed these roles, fastening kinesin motors to a surface and having them shuttle microtubules down the line from one motor to the next.

Biophysicists studying kinesin motors had done related experiments in the past. But in those, Vogel says, the kinesins were in random locations on surfaces. When microtubules and ATP were then added, the kinesins shuttled microtubules in all directions. To control the transport, the Washington team had to line up the kinesins. Here, the researchers took a low-tech approach. They simply rubbed a block of polytetrafluoroethylene, or PFTE, across a glass slide, causing molecules of the chainlike polymers to rub off and coat it. The scraping acted something like a hair brush, getting all the PFTE chains to line up on the surface, creating a series of grooves running for micrometers along the slide.

After submerging the slides in water and coating them with a small protein called casein, to protect overlying proteins, they added the kinesin motors, which settled into the grooves. They then sprinkled on a few microtubules, which were tagged with fluorescent compounds so they could be seen, and dropped some ATP fuel into the solution.

By turning on a xenon lamp to set the microtubules aglow and letting their cameras roll, Vogel and her colleagues could see the kinesins push their tubular cargo in one direction, moving it hand over hand down the parallel grooves. "Even though kinesins move on the nanoscale, we could watch the microtubules move on the micron scale," says Vogel.

For now, the team is using the monorail to study the performance of their motors. But down the road, Vogel says that the tiny rail lines could be used to transport replacement components for self-healing biomaterials for medical implants. If this and other efforts to motorize the nanoworld are successful, those microscope slides may soon see their first traffic jams. —ROBERT F. SERVICE

MEETING AMERICAN GEOPHYSICAL UNION

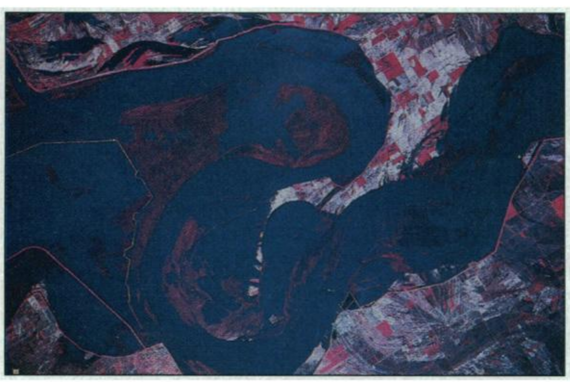
From Eastern Quakes to a Warming's Icy Clues

SAN FRANCISCO—A record 8300 researchers gathered here on 6 to 10 December for the fall meeting of the American Geophysical Union. At this smorgasbord of earth and planetary science, the topics ranged from the future of giant earthquakes in southeastern Missouri to evidence that ancient climate changes took place in lockstep in the tropics and Greenland.

No More New Madrid Quakes?

Residents of what is now southeastern Missouri suffered through the horrific winter of 1811–12, devastated not by the weather but by the Earth itself: Between December and February, the three largest earthquakes to hit eastern North America in historic times destroyed the town of New Madrid. The most violent of the quakes—which rivaled any quake in California—momentarily reversed the flow of the Mississippi River, shot plumes of sand and water 10 meters in the air, and rang church bells 1000 kilometers away in Charleston. Ever since, scientists have wondered when the next New Madrid quake will strike, and a 1992 study suggested it might be soon—in the next few hundred years. But at the meeting, geophysicists monitoring the New Madrid region for signs of strain reported that the next big jolt shouldn't hit for 5000 or 10,000 years, if then.

"I think we've vastly overestimated the seismic hazard of New Madrid," says geophysicist Seth Stein of Northwestern University in Evanston, Illinois, who led a group that has surveyed the area for the past 6 years. A damaging but smaller quake is still possible, says Stein, but "the hazard of large earthquakes is very, very small." Not everyone is quite so confident. Because geophysicists don't really understand why the New Madrid faults ruptured in the first place, notes Paul Segall of Stanford University, another magnitude 7 to 8 "can't be dismissed at this point. … The simplest assumption is, if [big quakes] happened in the past, they can happen in the future."



The last quake's mark. A spit of dry land juts above flood waters in a bend of the Mississippi, shoved there by the 1812 quake.

The new results come from satellite-based searches for movement of the land above the buried faults that zigzag across far southeastern Missouri, Tennessee, and Arkansas. If stress is building up along a locked fault, driving it toward eventual rupture in a large quake, the land on either side should be deforming, shifting the surface in opposite directions. Researchers can detect such subtle motions—a few millimeters per year across tens of kilometers—using the Global Positioning System (GPS), an array of military satellites in precisely known orbits. By comparing minute differences in arrival times of a satellite's radio signal at two sites, the distance between markers tens of kilometers apart can be determined to within a few millimeters. Researchers repeat the measurements over a period of years to spot movement of the markers and the ground.

After conducting GPS surveys of 24 sites

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across the New Madrid area in 1991, 1993, and 1997, Stein and his colleagues presented "what is undoubtedly the most boring set of GPS data you'll ever see," Stein told his audience. "We found no observable motion. All the sites we have been measuring have been staying right where they are." Motion across a fault that generated one of the big quakes is 1 ±1 millimeter per year. "It seems very unlikely we're accumulating the kind of strain we need for a magnitude 8 in the future," said Stein.

His data are a far cry from the ominous 1992 findings of Segall, geophysicist Mark Zoback of Stanford, and their colleagues. They compared their own 1991 GPS survey with a nonsatellite, 1950s survey and found that ground near the fault was moving at about 5 to 8 millimeters per year—about one-quarter of the movement seen on the San Andreas fault of California. But Segall agrees that their conclusion "doesn't seem to be supported by the more recent results," including their own continuing GPS survey.

Even 1 millimeter per year of deformation wouldn't lead to another magnitude 8 for 5000 years or more, Stein notes. The 1811–12 quakes and some earlier ones in the geologic record must have resulted from a pulse of activity that has now died out, he says. But other geophysicists add that no one knows just what's causing New Madrid seismicity and so are cautious about predictions. Because New Madrid is in the middle of the continent, far from a plate boundary like the San Andreas, "we don't have a model like plate tectonics to help us understand" what drives the earthquakes, says Segall.

It could be that strain reaccumulated rapidly in the first century or so after 1812, Segall says, and is now building very slowly toward another quake in the next century or two. Further GPS surveys in the next few years should show whether the land is absolutely motionless, or is ever so slowly inching toward the next upheaval.

Tropical-Polar Climate Link

Fifteen thousand years ago, as Earth began to shake off the chill of the last ice age, it plunged into climatic turbulence, with rapid bursts of warming and a brief return to glacial conditions. At 14,700 years ago, for example, temperatures in Greenland jumped 5°C in less than 10 years—twice the warming that greenhouse gases are predicted to produce in the coming 100 years. In search of a cause for this and other climatic jolts, researchers had been eyeing the high-latitude ocean, where abrupt changes in circulation might have triggered warming or cooling. Now, analyses of gases trapped in the ice of Greenland and Antarctica suggest that they should start looking elsewhere: to the tropics. "Greenland and the tropics march in lockstep," says geochemist Jeffrey Severinghaus of the Scripps Institution of Oceanography in La Jolla, California.

The new work, reported at the meeting by Severinghaus and geochemist Edward Brook of Washington State University in Vancouver, doesn't reveal the warming's ultimate cause, says glaciologist Richard Alley of Pennsylvania State University in State College. But he calls it "tremendous science," because "it tells a very clean story" about how events in the tropics may drive climate change at higher latitudes. And because the change happens in the blink of a geologic eye, the finding implies that the swift-moving atmosphere, not the sluggish ocean, must have carried the climate signal to high northern latitudes.

From snow to icy record. Annual layers of snow are squeezed into ice holding a gaseous record of climate change. Jeffrey Severinghaus examines a small part of the record (*right*).

Severinghaus and Brook identified the link between the Greenland warming and changes in the tropics in tiny bubbles trapped in ice drilled from the Greenland ice sheet. The temperature signal was a change in the isotopic composition of the air trapped in the bubbles (*Science*, 14 June 1996, p. 1584). Warming or cooling at the surface creates a temperature gradient in the snow blanketing the ice, affecting how the isotopes diffuse through the snow's pores. When the accumulating snow turns into ice, sealing in the gas, the temperature signature is preserved.

For example, nitrogen-15, the heavier isotope of nitrogen, tends to diffuse downward toward colder layers of snow, leaving lighter isotopes above, when the surface has suddenly warmed as it did 14,700 years ago in Greenland. In ice that researchers had dated to that time by counting annually deposited ice layers, Severinghaus and Brook found a sudden increase in the proportion of nitrogen-15 and concluded that Greenland had warmed 10°C over several decades and 5°C in less than 10 years—perhaps as little as 1 to 3 years.

While isotopes provided a thermometer, methane in the same ice provided the link to the tropics. Methane is produced by organic decomposition in everything from mangrove swamps in the tropics to tundra bogs in the Arctic. But Brook and Severinghaus fingered a tropical source by comparing the methane in Greenland ice with a new record in an ice core drilled from Taylor Dome in Antarctica. Both records show an abrupt increase of about 30% at the time of the warming, and the methane levels in the two cores differ by only 3% to 4% throughout the change. Such similar methane distributions at the two poles are only possible if the methane surge came from a site that could feed both hemispheres—the tropics. And because the beginning of the methane rise as measured in Greenland and the abrupt warming there coincide within a few decades, Severinghaus and Brook assume that the tropical and high-latitude events were connected.

Even though methane is a greenhouse gas, it could not have caused the high-latitude warming, because the methane increase did not precede the temperature change. Instead, the climate change probably came first, boosting methane by warming and moistening the tropical source regions. And Severinghaus suspects it was the tropics—the firebox of the climate engine because of the vast amount of heat and moisture there—that warmed first and triggered the immediate warming of higher latitudes.

"This is a crossroads" in paleoclimatology, says isotope geochemist James White of the University of Colorado, Boulder. "You start to understand mechanisms more than you have before." But Alley cautions that "it doesn't yet give us *the* answer," the ultimate cause for abrupt climate change. To find it, researchers will have to study more climate records—from the muddy bottoms of oceans and lakes and from high-altitude tropical glaciers as well as polar ice sheets—if they are to explain at last why Earth tumbled so erratically into its present warmth.

–RICHARD A. KERR