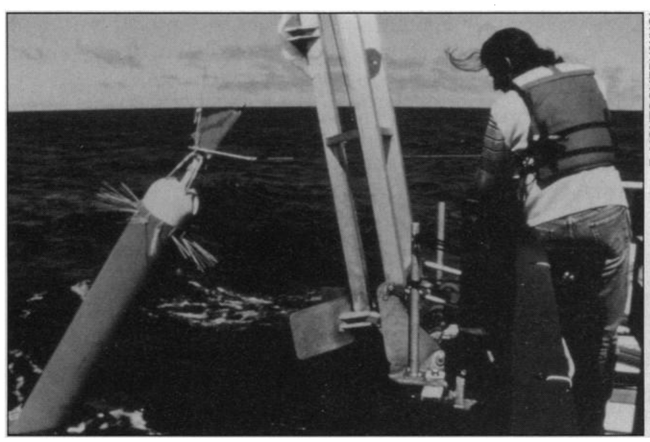
MEETING BRIEFS

Ancient and Modern, Rock and Fluid Meet in San Francisco

With 6000 attendees and 4700 presentations, the annual fall meeting of the American Geophysical Union (AGU) in San Francisco last month was the biggest yet. And that made room for even more diversity than usual. Only the AGU could accommodate news of asteroid impacts and extinctions one-third of a billion years ago and a progress report on the first direct measurements of centimeter-scale ocean mixing, an ongoing study in the Atlantic.

A Look at Ocean Mixing

The greenhouse effect is not just an atmospheric problem. How fast the warming develops will depend in part on the ocean—in particular on how fast its surface layers mix with its deeper regions, carrying away both atmospheric heat and carbon dioxide. But oceanographers have never had a direct view of this smallscale mixing; they've had to infer it by measuring tiny variations in water density and velocity that are thought to propel it. No longer: With the help of a few kilograms of a harmless industrial chemical serving as a tracer and a supersensitive detector, oceanographers have directly measured mixing in a quiet swath of the eastern Atlantic.


E. MONTGOMERY/WHOI

A preview of mixing. This instrument package measured the density and velocity variations that drive ocean mixing.

For oceanographers, the success of the experiment, announced at the AGU meeting, came as a relief. "It's exciting that they were able to find the tracer again" almost 6 months after its release, says physical oceanographer Raymond Schmitt of Woods Hole Oceanographic Institution (WHOI), who led an oceanographic survey of the area before the tracer was released. "A lot of people had serious doubts."

Schmitt also has a more personal reason for celebration: The slow mixing implied by the tracer results is just what he and his colleagues predicted, based on his pre-release measurements of density and velocity. "That is comforting," says oceanographer James Ledwell of WHOI, who released and tracked the tracer with Andrew Watson of Plymouth Marine Laboratory in England. "It looks like we're making progress understanding what controls mixing." Now he and his colleagues will be able to turn to a new puzzle: The measured rate of mixing is only about one-tenth of what models of ocean circulation require to match the observed temperatures and salinities of deep and shallow waters.

Addressing that puzzle should be easier now that oceanographers know they can rely on the chemical tracer technique. That technique has been a long while in development. Chemical oceanographer Wallace Broecker of Columbia University toyed with the idea of studying mixing by dumping a tracer in the ocean as long ago as the mid-1970s, but no one could come up with a satisfactory tracer that was inert but easily detected even when drastically diluted.

An answer to Broecker's dilemma came about 10 years ago when he ran into independent scientist and Gaia originator James Lovelock. Lovelock had invented a laboratory instrument, the electron capture detector, that is exquisitely sensitive to halogens such as chlorine and fluorine, leading him to suggest the use of a heavily halogenated compound as an ocean tracer. The eventual tracer of choice—sulfur hexafluoride—can be easily and quickly detected at concentrations of less than 1 gram of the chemical in a cubic kilometer of seawater.

It took 10 years for Broecker and Lovelock's conversation to bear fruit in a full-scale experiment, but last spring a team of oceanographers from the United States, Canada, and Britain congregated 1200 kilometers west of the Canary Islands to begin the North Atlantic Tracer Release Experiment. To make his pre-release survey of the conditions that drive mixing, Schmitt used a one-of-a-kind, free-falling instrument package that can measure density and current velocity variations centimeter by centimeter over depths of thousands of meters. Then the researchers towed a sled, which automatically maintained a depth of about 310 meters, back and forth across a 25-kilometer-wide patch of ocean, releasing ribbons of tracer as it went—139 kilograms in all. After resurveying the test area to make sure that tracer had ended up in a layer no more than 15 meters thick, the researchers left.

Returning in October, oceanographers found that, as Schmitt and his colleagues had predicted, vertical mixing had been slight: Gentle turbulence kicked up by winds, storms, and tides had thickened the 15-meter layer only to 40 meters. But if some oceanographers feel vindicated by the result, those who model the oceans as a whole should be perplexed: The rates of mixing they postulate for oceans would have left a tracer layer 400 meters thick.

And that leaves oceanographers wondering what other mechanisms are speeding up mixing elsewhere in the ocean. Quantifying them will be crucial to predicting how the oceans, and thus climate, will respond as the greenhouse warms. One part of the picture is advection, a process that occurs when the generally horizontal water layers of the ocean are slightly tilted. That arrangement lets water mix several meters vertically simply by sliding laterally for hundreds of kilometers. In addition, the subtle turbulence that drove mixing at the experimental site is amplified in other parts of the ocean. Schmitt and his colleagues have found heightened vertical mixing, for example, around seamounts that jut into ocean currents and in a strong eddy that spun off the Gulf Stream. In exploring all these possibilities, there will be plenty more work for dollops of sulfur hexafluoride.

Ancient Impact-Extinction Link Tightened in Belgium

Twice before, geological detectives had stumbled on traces of the fatal blow not far from where the victims were last seen alive. But the investigators had difficulty working out the timing of the tale in a way that would put the perpetrator at the crime scene. Now, however, sleuths on the case, a geological whodunit, have found the same telltale traces—droplets of glass splashed from the crater of an asteroid or comet impact—right at the scene of the crime. That scene is the point in the geological record dividing the Frasnian and Famennian stages some 367 million years ago, when 70% of all invertebrate species in the oceans died out.

The discovery of the droplets was announced at the meeting by geochemist Philippe Claeys of the University of California (UC), Davis, and paleontologist Jean-

Georges Casier of the Royal Institute of Natural Sciences of Belgium, who made the discovery in collaboration with the late Stanley Margolis of UC Davis. The new find makes the Frasnian-Famennian (F-F) boundary one of the strongest candidates in the geological record for a time when an asteroid impact led to a mass extinction—second, in fact, only to the more precisely worked out Cretaceous-Tertiary mass extinction of 65 million years ago.

Casier uncovered the first clear evidence of an impact near the F-F boundary when he noticed droplets of glass, apparently blown out of an impact crater, among tiny fossils collected in Belgium. The connection between the impact glass and the extinctions was fuzzy, however. Paleontologists locate the F-F boundary—traditionally recognized as the time of the extinctions—by looking for changes in the form of teeth-like fossils called conodonts, all that remain of eel-like animals. But conodonts are scarce at the site where Casier first found the impact glass, and therefore the positioning of the boundary wasn't very precise. Casier's best estimate was that the impact debris fell 7 meters above the boundary—too late by several hundred thousand years or more (*Science*, 29 May 1992, p. 1280).

Now Claeys and Casier have largely closed the gap between impact and extinctions with new samples from Hony, in southern Belgium, where impact glass falls 10 centimeters or less from a more precisely defined boundary. Uncertainty persists because the layer containing impact glass lies within a 30-centimeter layer between the last conodonts of the Frasnian and the first conodonts of the Famennian. Still, the gap is probably no more than some tens of thousands of years—a blink of an eye in geological terms.

That's exciting news to F-F paleontologist George McGhee of Rutgers University, but he thinks there's probably more to the F-F impact story. He and others believe that major extinctions also took place over millions of years around the boundary. "I'm convinced you can't explain what happened with one event. If you're going to explain it all with impacts, there had to be multiple impacts."

And so there were, according to earlier reports—and fresh evidence presented at the meeting. Paleontologist Kun Wang of the University of Alberta had previously reported impact glass from a site in China that, judging by the conodonts, fell 1 million or 2 million years after the boundary. And at the AGU meeting, paleontologist Susan Boundy-Sanders of UC Berkeley and her colleagues told how they stumbled on poorly dated impact glass among microfossils that may be at least 3 million years older than the F-F boundary. All of which should keep the F-F sleuths busy sharpening their view of what hit when and who may have fallen victim.

–Richard A. Kerr

PLANETARY SCIENCE

Magnetic Ripple Hints Gaspra Is Metallic

When the Galileo spacecraft whizzed by the tiny asteroid Gaspra last August on its circuitous journey to Jupiter, few astronomers anticipated any surprises from the spacecraft's magnetometer. "The expectation was very modest," recalls magnetometer team leader Margaret Kivelson of the University of California, Los Angeles. In fact, team members expected "that we wouldn't see anything at all," says Kivelson. After all, Gaspra is just 13 kilometers across and Galileo was going to pass no closer than 1600 kilometers, which the team assumed would be too far to detect any magnetic signs of the asteroid. Nonetheless, says Kivelson, "we had a very strong feeling that if you were going by a new kind of body for the first time, you should at least take a look." So the Galileo team allotted precious on-board data storage to the magnetometer readings.

That commitment to the spirit of exploration paid off just before Thanksgiving when Galileo finally beamed back the Gaspra magnetometer data through its crippled communications system: Gaspra seemed to have left its signature on the magnetometer record. Barring an ill-timed coincidence that masqueraded as a signal from Gaspra, Kivelson surmises that the tiny asteroid is metal-rich and magnetized, which would make it the first small body of the solar system known to possess a magnetic field. This chance discovery may also help resolve the central mystery surrounding Gaspra: whether the asteroid is a chunk of rock largely unchanged since the earliest days of the solar system (and thus a possible source of the most common type of meteorite falling on Earth) or a highly metallic remnant of a body that was heated until metal separated from rock (*Science*, 2 February 1990, p. 527). The magnetometer readings could tip the scales toward the second possibility.

In order to resolve questions like that, however, Kivelson and her team want to ascertain whether Gaspra really did trigger two squiggles in Galileo's magnetometer record. One minute before Galileo's closest approach to the asteroid, the magnetic field carried by the outward-rushing solar wind abruptly rotated toward Gaspra. Three minutes later it swung back to its original orientation. Such field rotations are common, Kivelson notes, but in the 2 hours around the closest approach they were occurring once or twice per hour, while these two rotations neatly bracketed the encounter. Moreover, rotations are normally random, but these two produced a clear nod in Gaspra's direction, strongly suggesting that Gaspra was the cause. "My own hunch at the moment is that it was Gaspra," says Kivelson. "I think we saw a disturbance like the wake of a ship" trailing out behind Gaspra as it plowed through the solar wind.

If that's indeed what the magnetometer picked up, Kivelson concludes that Gaspra is strongly magnetized. An unmagnetized Gaspra would be much too small to create such a wake, but a strong magnetic field would be pulled around and behind the asteroid by the solar wind in the classic teardrop shape of a magnetosphere. If these assumptions are correct, Kivelson calculates that Gaspra's magnetic field is at most one hundred-millionth as strong as Earth's. That may not sound impressive, but it would make Gaspra a magnetic powerhouse—for its size.

"That's fantastic; it's a *very* interesting finding," says David Strangway, a magnetics expert and president of the University of British Columbia, one of the few researchers who professes to be unsurprised by the results. "I would have predicted it if anyone had asked me," he says. "There's hardly a meteorite that hasn't had a substantial magnetization, so if hand-sized samples have it, why not a large one?"

Meteoriticists are eager to hear more details of the encounter and begin assessing the implications. One possibility, says Strangway, is that, while it was being formed in the nebula that produced our solar system, Gaspra was imprinted by a strong magnetic field generated by swirling ionized gases. That would make Gaspra primordial, and the class of asteroids to which it belongs—so-called S-type asteroids—would be a candidate source for the primordial ordinary chondrite meteorites that fall so often on Earth. Alternatively, Gaspra may be a fragment of a large asteroid that acquired a magnetization as it cooled down from a heating so severe that metals like nickel and iron were concentrated in a metal-rich core.

Galileo's brief visit had seemed to offer little hope of resolving the debate among meteoriticists and astronomers over whether Gaspra and the other S-type asteroids are primordial or altered (*Science*, 18 October 1991, p. 381). But the prospect of a magnetic field for the asteroid changes things, because Gaspra's suspected magnetic field is on a par with that of iron meteorites—bits of the metallic cores of large asteroids—Kivelson says. Yet she is quick to point out that the argument is far from settled, since her current estimate of Gaspra's magnetization has a range of more than an order of magnitude—probably enough to encompass ordinary chondrites as well. More analysis, and next summer's Galileo encounter with the S-type asteroid Ida, may help.

–Richard A. Kerr