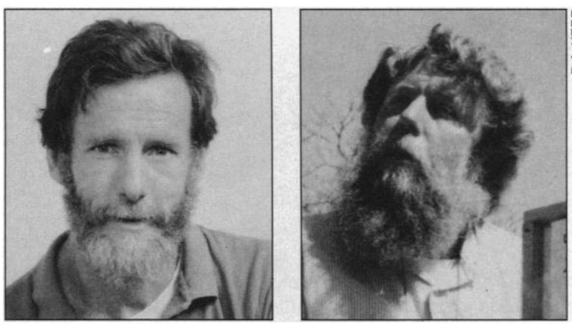
MEETING BRIEFS

Controversies Hot and Cold at Baltimore Geophysics Meeting

Longstanding controversies in the Earth sciences resurfaced at the spring meeting of the American Geophysical Union (AGU) in Baltimore last month. An oft-discounted notion that volcanoes can trigger ice ages got a new lease on life, a heretical proposal about the chemistry of the early Earth edged closer to the mainstream, and champions of two warring camps in seismology squared off in an informative–if inconclusive–debate.

Getting to the Heart of the Seismic Gap Debate

Call it the shootout at seismic gap. For several years now, the community of seismologists has been split by a sometimes acrimonious feud. On one side are those who support the conventional wisdom that long-quiet segments of a fault—seismic gaps—are the most likely sites of large earthquakes in the next few decades, while fault segments that have recently experienced a large quake should lie quiet for many decades or centuries. On the other side are David Jackson and Yan Kagan, geophysicists at the University of California, Los Angeles, who see no such predictability. At the AGU meeting, Jackson and Allan Lindh of the U.S. Geological Survey in Menlo Park, representing the mainstream view, went head to head.



R.A. KERR

Seismic gunslingers. David Jackson *(left)* and Allan Lindh differ on how complex plate boundaries, and quakes, are.

There was plenty at stake in the encounter, which was staged for the entertainment and edification of the seismology section luncheon. For most seismologists, gap theory has been the key to making long-term earthquake forecasts. But Jackson charges that in relying on it, seismologists give the public the "dangerous misconception" that one large quake wipes out the threat of another major shock soon after. "Faults don't know about this idea of immunity from big earthquakes," he says. When the smoke cleared from this latest go-round, no winner was declared. But the exchange was perhaps the most revealing look yet at the heart of the debate.

Most earlier exchanges have focused on the particulars of how individual faults rupture, or on conflicting scorecards of how well various long-term forecasts have worked out. The AGU debate, however, concentrated on the nature of the boundaries between tectonic plates, where most large quakes occur. The seismic gap theory holds that segments of a plate boundary slowly store up stress and then release most of it suddenly in a large quake, a process that repeats on a roughly regular schedule. Jackson argued that most plate boundaries, such as those that ring the Pacific Ocean, are far too complex to generate such simple historical patterns.

To prove his point, Jackson cited case after case in which one large earthquake struck shortly after another had hit the same segment of plate boundary. One example was a magnitude 7.5 quake in the New Hebrides, where the Pacific Plate dives beneath the Australian plate, that was followed 9 days later by a magnitude 7.8 that struck the same segment. That's too little time for the same fault to have re-accumulated strain after the rupture. Instead, said Jackson, the plate boundary must be riddled with separate faults or interconnected parts of the same fault, allowing two very large quakes to strike the same boundary segment in close succession. He cited other examples from the Celebes Sea, the Kuril Islands, and the west coast of Mexico. All told, said Jackson, 13 of the world's 46 most recent quakes larger than magnitude 7.5 came in tight clusters of two or three on the same segment. "The segmentation model just isn't working," he said.

To Lindh, however, those 13 quakes are evidence only that gap theory isn't perfect, not that it's wrong. "A good fraction of the data is explained a reasonable part of the time" by gap theory, he said; perhaps 80% of the time it works. "I don't believe seismic gaps explain everything, so I'm not troubled by the exceptions, especially those at complex [boundary] intersections." Lindh had an informal list of gap theory successes from Japan, Kamchatka, and western South America where obvious gaps along plate boundaries were later filled by quakes of magnitude 7.7 to 8.2. Gap theory works best in such places, Lindh said, where the historical record is long and gap-filling quakes are large. But even faults like the Calaveras fault, a branch of the northern San Andreas that generates smaller, magnitude 5 and 6 shocks, can sometimes be well behaved enough to allow successful long-term predictions using gap theory, he said.

In his rebuttal, Jackson argued that the "exceptions" overwhelm the rule. "One must look at the totality of successes and failures. And there are many dozens of exceptions to this rule. My examples are from fairly simple plate boundaries." Gap theory may still work in some cases, he said, but seismologists "need a rule as to when gap theory applies." Lindh agreed. "Dave's great contribution is forcing tightening of criteria" that determine the applicability of gap theory, said Lindh. But he and Jackson were not about to agree on how restrictive those criteria should be.

In the meantime, most seismologists are sticking with gap theory. Says seismologist Arch C. Johnston of Memphis State University: "There's no question that the simple seismic gap model doesn't take into account some of the complexity out there. It's a framework; not that it has to work every time. Is it useful? I think it's proved very useful." For now, as the debate suggests, determining how useful is useful enough may be more a matter of philosophy than hard science.

A Screwy Idea May Solve an Early-Earth Enigma

When Rama Murthy flew into Baltimore-Washington International Airport at the end of the second day of the AGU meeting, the last thing the University of Minnesota geochemist expected was a round of congratulations from his colleagues. As far as he knew, he was still on the outs with most of them for having had the temerity to claim that a puzzling anomaly in the chemical composition of Earth's rocky mantle—an excess of certain elements, such as gold and iridium—had a laughably simple explanation.

According to conventional chemistry, these elements, when in their natural combinations with other elements like oxygen, should have had an overwhelming chemical preference for iron and been carried out of the mantle and into Earth's iron core as it formed. But Murthy proposed 2 years ago in *Science* that if the newborn planet had been superheated to well beyond its melting point—as some planetary scientists had argued—the tendency of these iron-loving, or siderophile, elements to ally with iron would have been diminished and the mantle would have retained more of them. The anomaly would vanish.

Murthy's geochemist colleagues reacted

with barely constrained outrage. They were used to thinking of the early Earth as only partly molten, and in any case Murthy's calculations of the proportion of siderophiles that would be carried down by the iron seemed grotesquely simplistic. So why was everybody Murthy saw at the meeting now congratulating him? "Everybody said I was on the mark," Murthy recalls happily. Experimental results announced just that afternoon by David Walker of the Lamont-Doherty Earth Observatory had supported his prediction of the effects of extremely high temperature on siderophiles.

Murthy's explanation of the siderophile anomaly had seemed so outrageous to geochemists in part because most of them had not accepted the contention that the Earth melted completely during its formation, most likely during a bombardment by planetesimals as large as Mars. But Murthy, as a "heuristic exercise," decided to take the extremely high temperatures produced by such bombardment—3500K or so—as a given. At those temperatures, his calculations suggested, chemistry would not have counted for much. The siderophiles would have acted less siderophilic, and the mantle would have held onto a larger proportion of them.

"In a way, [Murthy] was just making an educated guess," says planetary physicist David Stevenson of the California Institute of Technology, an advocate of the idea that the early Earth melted completely. "But it was a sensible guess, and, most importantly, it has stimulated people to give more attention to a [temperature] regime that had been neglected." Even those critics who accepted Murthy's high temperature for the early Earth still disputed his conclusions, however. They argued that enough oxygen may have been present in the molten early Earth to combine with the siderophiles and segregate them into the metallic core.

But Walker wasn't so sure. "It occurred to me maybe this was nitpicking, that it was missing the point" that at extreme temperatures chemical distinctions begin to blur. So he set out to test Murthy's idea directly, by heating samples of iron and rock with their traces of siderophile elements to the experimentally unprecedented temperature of 3100K, in the range of a superheated Earth. After taking an inventory of a half-dozen elements in the cooled metal-rich "cores" and rocky "mantles" of the samples, Walker was pleasantly surprised. "I have to say [Murthy] hasn't done a bad job of predicting what goes on." Elements like gold that had seemed too abundant by a factor of 1000 in the Earth's mantle were within a factor of 2 of mantle concentrations in Walker's rock samples. Only phosphorus failed to fall into line.

"I was surprised it worked so well," says Murthy. "We still don't understand the details, but the direction is right and even semi-quantitatively correct. It boils down to a simple formulation at high temperatures." Even the staunchest critics of Murthy's approach agree that the experimental results are interesting, but they aren't willing to abandon their notions of siderophile chemistry. Walker's samples contained little oxygen, for example, but no one is certain exactly what conditions prevailed in the early Earth. "There are still some connections that need to be made between the experiments and the real world," says geochemist John Jones of the Johnson Space Center.

Out of Fire, Ice?

Climate researchers weren't surprised when the global temperature dropped a degree or so after the eruption of Mount Pinatubo 2 years ago. But while researchers have come to accept that a volcanic eruption, by spreading a veil of debris around the globe, can cool the climate for a few years, they've been less enthusiastic about theories that volcanic activity can usher in ice ages lasting millions of years. New records of climate and volcanic eruptions in sediment from the floor of the far northern Pacific Ocean, however, may force them to reconsider this more dramatic volcano-climate link.

The new records suggest that a massive volcanic outburst in the North Pacific closely coincided with the globe's abrupt descent into the Pleistocene, the most recent ice age, about 2.6 million years ago. "That doesn't necessarily mean that volcanoes caused the glaciation," says paleoceanographer David Rea of the University of Michigan, who traced the telltale layers of volcanic ash and rock particles dropped by icebergs. But Rea thinks that after years of considering ice-age triggers other than volcanism, such as sudden changes in the circulation of the ocean, "it's time [for climate researchers] to think about this again."

The provocative new records come from core samples of sedimentary "ooze" totaling more than 4 kilometers in length, drilled last summer from the Pacific sea floor between Japan and Alaska by the Ocean Drilling Program's drill ship *JOIDES Resolution*. The particularly soupy consistency of this sediment required a last-minute change in coring technique to retain the mud in the core barrel, but the *Resolution*'s scientific party, with Rea as co-chief scientist, managed to get samples from 25 holes at seven sites.

In cores from four of the sites in the northwest Pacific, the frequency of layers of ash, probably erupted from volcanoes on Kamchatka, jumps roughly 10-fold just 50,000 years before ice-carried debris makes its first appearance at the start of the ice age. In the northeast Pacific, where the Aleutian chain is the volcanic source, the interval between the eruptions and the ice was longer, more like 300,000 years, says Rea.

Even the longer lead time in the northeast Pacific doesn't rule out a link between the volcanoes and the ice, says Rea, because the outburst was probably no flash in the North Pacific pan. Instead it seems to have been the start of a long-lasting surge in activity over much of the globe, perhaps unleashed by a reshuffling of the tectonic plate boundaries that feed Pacific volcanoes. In 1975 paleoceanographers James Kennett of the University of California, Santa Barbara, and Robert Thunell of the University of South Carolina had pointed out that throughout the Pacific and most other ocean basins, ash layers were about five to 10 times more abundant during the ice age than during most of the past 20 million years. The new cores are the first, however, to show that the volcanic surge began about the same time as the growth of the ice.


EARTH SATELLITE CORP./SCIENCE PHOTO LIBRARY

Glacial trigger? Volcanic eruptions like that of the Alaskan volcano Augustine, shown in this 1986 false-color Landsat image, may have touched off an ice age 2.6 million years ago.

Before Rea concludes anything about causation, though, he wants to determine more precisely the relative timing of ash and ice in all the cores to help persuade himself that it isn't all just a fluke. And then there's the matter of a mechanism. How could volcanic debris lofted into the stratosphere for just a few years cause nearly 3 million years of ice age? Rea suspects that the burst of volcanism might have been nothing more than the final straw that broke the back of a deteriorating climate system. For tens of millions of years, the world had been sliding toward greater cold and more ice, for reasons unknown. Then it jumped off the edge into the Pleistocene ice age. "Maybe [volcanism] is just a threshold phenomenon," says Rea, "the little bit that makes all the difference."

–**Richard A. Kerr**