MEETING BRIEFS

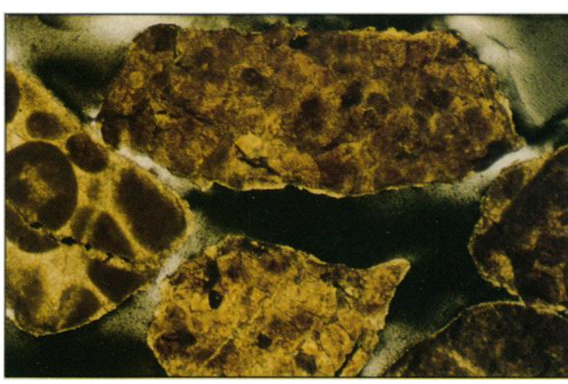
Geologists Get Together to Dissect Earth's Thin Skin

At the annual meeting of the Geological Society of America in Boston during late October, Earth's crust came in for close scrutiny. One surprise was its age: Chemical and isotopic evidence suggested the crust formed soon after the planet did. Participants also discussed features of today's crust, including a horizontal slice beneath San Francisco and the possibility that a particular kind of crustal stretching, long envisioned, may not actually take place.

Fault Finding Under the Utah Desert

To a geologist's eye, many of the most striking landforms—scarps, rifts, and even mountains—are the work of faults, places where blocks of crust slide past each other. Each of the several types of faults plays its own key role in forming the landscape. Given this central role, it takes a lot of temerity for a geophysicist to cast doubt on a whole class of faults by telling his colleagues that a prime example of the class may not be a fault at all. But that's exactly what geologist Mark Anders of Columbia University's Lamont-Doherty Earth Observatory tried to do at the meeting.

Ever since seismic surveys more than 10 years ago revealed the fault at issue—the Sevier Desert fault beneath west central Utah—geophysicists have embraced it as a striking example of a low-angle normal fault, where two blocks of crust slide apart along a gently sloping boundary. Gravity drives these faults: The wedge of rock on top of the fault simply slides downhill, thinning or "extending" the crust. But although geologists believe that slippage along such faults can explain much of the crustal extension seen across the rumpled terrain of western Utah and Nevada, theoreticians never saw how such a fault could work. The fault would never be slippery enough, they said, to let rock slide down such a shallow incline (*Science*, 3 June 1983, p. 1031). After examining the Sevier Desert fault, Anders says the doubters were right all along.


MARK ANDERS

Faultless? These undeformed carbonate concretions raise doubts about the presumed Sevier Desert fault.

The stakes are high at the Sevier Desert fault because it's one of the few such boundaries that clearly had to form at a low angle. Geologists have found other low-angle faults where there is evidence for extension. But, notes Richard Allmendinger of Cornell University, a debate is raging about whether these actually slipped at a low angle or whether they formed at a high angle, where theorists have no trouble explaining slippage, then became inactive as they rotated to a lower angle. That uncertainty has made it crucial to determine whether or not the Sevier Desert fault has actually slipped; if slip could take place along that boundary, tilted at a mere 11 degrees, geophysicists could be sure low-angle faulting could happen elsewhere.

Seismic reflection surveys near the fault showed steep faults plunging down to, but not penetrating, the shallow fault, convincing many geophysicists that the upper wedge of crust had indeed slid past the lower one, by as much as 38 kilometers. But, given the theoretical objections, Anders was uncomfortable with such indirect evidence. "Here's a fault that has never been looked at, never touched," he says. So he decided to get his hands on the fault, or at least parts of it, by examining millimeter bits of rock recovered from two Arco Oil and Gas Co. exploration wells drilled in 1980 and 1982. Although Arco had held back the samples at first as proprietary data, the company was no longer interested in the area by the time Anders approached it and was willing to release the samples.

Anders believes that his examination of the drill samples revealed a change in composition that could account for the fault-like feature seen on the seismic profiles: a boundary between Cambrian carbonates below and relatively young sediments above. That boundary could have been the site of fault slip, but if so, the adjacent rock should show some wear and tear, says Anders. The quartz grains from the upper sediments should have microcracks, as seen near other faults, and the microscopic structure of the softer carbonate below should be deformed. Anders found no such signs of slippage. Therefore, he argued, there's no fault.

Word of Anders' audacious claim spread quickly across the country, but even researchers who heard his talk at the meeting are being cautious. Says geologist Brian Wernicke of the California Institute of Technology: "If it pans out, it's very, very interesting. I think it's great that someone's directly testing that it's a fault." But he adds, "I'm very dubious that he's right."

Wernicke and others worry that Anders may have been misled by the tiny size of the samples he used or that his reinterpretation of some seismic features is implausible. But if he's right, geophysicists will have second thoughts about pinning a name on features seen in seismic images but never sampled directly. And geologists trying to understand the extended crust in Nevada and Utah will be forced to conclude that the fault was in them, not in the crust.

Was Continental Crust Born in a Geologic Moment?

Many researchers imagine the Earth 4 billion years ago as a nearly featureless ball, perhaps ocean-covered except for scattered chains of volcanic islands. At the meeting, geochemist Samuel Bowring of the Massachusetts Institute of Technology argued in favor of a different picture: continents in abundance, much like today's world.

The key difference between the two scenarios is the rate at which Earth formed continental crust—rock light enough to float above sea level on the underlying mantle. The majority of Bowring's colleagues think that in the beginning, there was very little such crust. Volcanic activity, they think, has distilled the crust bit by bit from the denser rock of the mantle over 4 billion years. But after analyzing 4-billion-year-old rocks from the Northwest Territories of Canada, Bowring is convinced that extensive crust formed not long after the Earth itself was born 4.5 billion years ago. "We're looking at massive, early differentiation" of the primordial Earth into crust and mantle, he says. And that would argue for an Earth that looked more like today's than an unpromising ball of water.

Reconstructing the history of the crust is difficult because the known geologic record gets sketchier as researchers look back in time, and it peters out entirely by 4 billion years ago. Ancient rock samples are so scarce, says Bowring, that "people's views of the early Archean [3.5 to 4 billion years ago] are strongly colored by the rocks they work on." The most studied early Archean rocks have been from Isua in western Greenland. Those rocks originated in volcanic island arcs, which today are built of magmas derived from the mantle. To many researchers, the Isua rocks seemed to be a relic of scarce early crust that had just been extracted from the mantle.

Bowring's samples, the so-called Acasta gneisses, give "a different snapshot" of the earliest known crust, he says. A rock's relative abundances of rare earth elements like cerium and europium and the isotopes of the rare earth element neodymium reflect the earlier generations of rock that partially melted to form it. Based on analyses done with Todd Housh of the University of Texas at Austin and Clark Isachsen of MIT, Bowring told the meeting that the Acasta gneisses were derived from crustal and mantle rock that had a far wider range of compositions than exists today. And that points to the existence of abundant crust at even earlier times, he says.

Since then, says Bowring, the variety of crustal compositions that went into the Acasta gneisses "has been smeared out with time" as crust was mixed into the mantle, then erupted again. Early on, that smearing may have been accomplished in unfamiliar ways, such as the foundering of crust. Even under a more conventional plate tectonic regime, continental crust could have been recycled into the mantle, perhaps in the form of sediments eroded from the continents that rode piggyback on sinking ocean crust. Stein Jacobsen of Harvard University, who thinks Bowring's proposal about early differentiation is plausible, sees signs of such smearing in other isotopic systems.

But if these ideas prove out, they lead to even deeper questions: how the early Earth formed so much crust so quickly and why, starting about 4 billion years ago, increasing amounts of crust were preserved for geologists to stand on today, as they ponder the mysterious origin of continents.

Finding a Piece of a California Jigsaw Puzzle

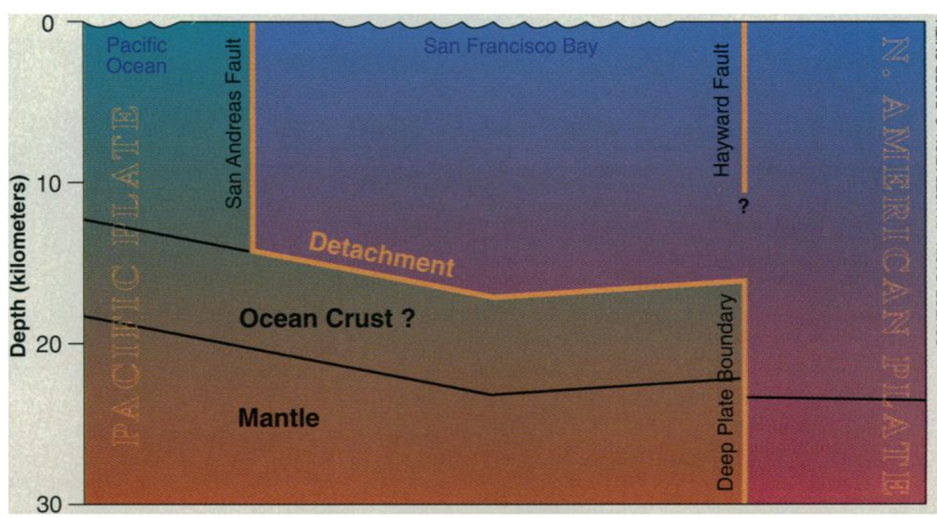
Speaking geologically, California is on the ragged edge. The edge is the boundary between two massive tectonic plates—the North American and the Pacific. Where these plates slide past each other, their edges bend, crumple, overlap, and shatter in bits whose jostling creates earthquake after earthquake. Near San Francisco Bay, the boundary even disappears completely. On the west side of the bay, the San Andreas fault marks the plate boundary down to about 20 kilometers; on the other side, a deep plate boundary is thought to continue downward from a depth of about 20 kilometers to perhaps 65 kilometers. The connection between the shallow and deep boundaries has, until now, been cloaked in mystery.

At the meeting, however, Thomas Brocher of the U.S. Geological Survey in Menlo Park and his colleagues reported that a geophysical imaging technique has revealed what seems to be the missing piece of the boundary: a horizontal fault, known as a detachment, that runs underneath the bay at a depth of about 18 kilometers, connecting the two vertical faults. What contorted the boundary into that form is not clear, but the new feature may help geologists understand —and perhaps predict—how earthquakes spread from fault to fault across one of the most complex parts of the plate boundary.

Brocher and his colleagues went searching for the plate boundary under San Francisco Bay by sending manmade seismic waves into the earth's crust and listening for echoes from deep geologic structures. The project, run by a consortium of government and university researchers called the Bay Area Seismic Imaging Experiment (BASIX), involved bringing in a ship that towed air guns around San Francisco Bay and out to sea, emitting powerful acoustic bursts into the water, while seismometers on land and the sea floor listened. The reflections from deep in the crust revealed a nearly flat feature at a depth of about 18 kilometers, extending from near the San Andreas eastward past the Hayward fault, a surface fault that runs through Oakland and Berkeley. The reflector, suggested Brocher, is the horizontal tread in a stair-step plate boundary.

Brocher thinks the plate boundary takes this odd form because the Pacific and North American plates aren't moving exactly parallel to the San Andreas fault. Instead, he believes, the plates are actually sideswiping each other. As a result, Brocher suggested at the meeting, the 18-kilometer reflector under San Francisco Bay may actually mark the dividing line between the North American plate and a sheet of Pacific Ocean crust, which the North American plate is overriding at perhaps 1 millimeter per year.

Brocher's BASIX colleague Kevin Furlong, a geophysicist at Pennsylvania State University, isn't so sure about that interpretation. He thinks the experiment has probably pinned down the plate boundary, but he doesn't see how the known plate motions of the past few million years could have brought ocean crust that far under the Bay Area. Instead, he thinks the detachment is a relic of processes begun millions of years ago, when the Pacific plate was diving into the mantle beneath the North American plate.



A stair step at the plate boundary. A horizontal fault called a detachment could be linking two vertical plate boundaries, one deep and one shallow.

When this subduction ended, 7 to 10 million years ago, says Furlong, the slab of subducted ocean crust broke off and slipped into the deep mantle. Hot mantle rock welled up beneath the North American plate to replace the departing slab, creating a deep weakened zone east of the San Andreas—the natural place for the deep plate boundary to form. The gap between the deep boundary and its shallow counterpart at the San Andreas was spanned when the mantle and stronger crust gave way along a horizontal plane, forming the detachment.

However it formed, this missing piece of the boundary might explain two pairs of events that had looked like odd coincidences: sizable quakes that struck first one side of the bay, then the other in 1836 and 1838 and again in 1865 and 1868. It's conceivable that the detachment could have triggered the second quake in each pair by channeling stress released on one side of the bay to surface faults on the other side. Researchers are anxious to check out that possibility. After all, if the 1989 Loma Prieta quake west of the bay was the first of another pair of left-right punches, it would be nice to see the next haymaker coming.

–Richard A. Kerr