Do Anticracks Trigger Deep Earthquakes?

Experimentalists have taken another step toward solving the central mystery of deep earthquakes: How can rock break at all at a depth of hundreds of kilometers? At those depths the rock is under such high pressure that, by the usual rules, it should deform slowly rather than breaking abruptly enough to generate an earthquake. There's no way to go down for a look, but now researchers are trying to create deep earthquakes right in the lab. And for the first time, they have directly observed fracturing in rock squeezed to deep-Earth conditions.

In nature, most deep earthquakes take place in slabs of oceanic plate, neatly tracing out the sloping descent of the slabs into Earth's interior. Researchers have long suspected that the earthquakes might be driven by the transformation of minerals in the sinking rock from one crystalline form to another. Such phase changes are brought on by the gradual increase in pressure. But that possibility led to a further question: Why do deep quakes stop at a depth of 670 kilometers, where the upper mantle gives way to the lower? An answer could have broad implications for understanding Earth's internal workings.

One barrier to the study of deep earthquakes in the laboratory has been that the most convenient devices for subjecting samples to mantle pressures and temperatures—the fist-sized presses called diamond-anvil cells—hold samples no bigger than a grain of sand, too small for fracturing to be seen directly. "Earthquakes" in the cells have been detected only indirectly, by listening for tiny acoustic pings that might indicate faulting. Handling a sample big enough for faults to be readily identifiable has required a 3-meter-high, multiton press costing half a million dollars. Only one such press exists in the United States, at the State University of New York at Stony Brook, and that has been in operation only a few years.

Faced with these obstacles, many researchers have studied materials that, at pressures much lower than those of the deep slabs, undergo what may be similar phase changes. For example, Harry Green of the University of California, Davis, and Pamela Burnley of Cornell University looked at phase changes in magnesium germanate, an analog for the mantle mineral olivine. The two researchers observed faulting that was apparently produced when the samples developed "anticracks": tiny lenses filled with the high-pressure form of magnesium germanate. Stephen Kirby of the U.S. Geological Survey in Menlo Park and his colleagues have observed what they think is the same process, called transformational faulting, operating in another medium, ice—work discussed in an article in the 12 April *Science*.

All well and good, but these are analogs, which had left skeptics to ask: Could transformational faulting take place in real rock, under the conditions that prevail 300 to 670 kilometers down, where the deepest earthquakes strike? And there was some reason to remain skeptical. When Charles Meade of the Carnegie Institution of Washington's Geophysical Laboratory and Raymond Jeanloz of the University of California, Berkeley, used a diamond-anvil cell to compress real olivine to pressures at which it transformed to spinel, a high-pressure form, they heard no signs of faulting. Meade and Jeanloz favor a different mechanism, one that has not yet been linked to faulting but has produced abundant pings in a diamond cell: the sudden conversion of crystalline serpentine, a slab mineral, to its noncrystalline, glassy form at high pressures.

But even though transformational faulting failed to make itself heard in diamond-anvil tests, it came back strong in a new press, capable of subjecting much larger samples to realistic mantle conditions. Harry Green and Thomas Young of UC Davis, working with David Walker and Christopher Scholz of Columbia University's Lamont-Doherty Geological Observatory, squeezed olivine to pressures of 15 gigapascals—typical of a depth of 400 kilometers—and heated it to 1600°C, all in a press invented last year by Walker: a hatbox-sized device that costs about what you would pay in sales tax on a big press. After three mechanical failures and three test runs in 10 days, the group hit the right conditions. When they opened the press, the researchers found anticracks and a fault in their olivine sample, even though it had just been exposed to conditions in which conventional faulting is impossible.

As Meade and Jeanloz pointed out in an article in the 5 April *Science*, transformational faulting has one more hurdle to clear before seismologists will have to start looking for evidence of it in seismic data. Clearly, transformational faulting can happen—but does it happen fast enough to produce seismic waves, or is it a slower, quiet process? To convince doubters, Green and the Lamont group are wiring their presses for sound, just as soon as they can quiet the background noise of the machinery.

If anticracks prove viable as a mechanism for deep earthquakes, they could help resolve a long-standing geophysical puzzle about Earth's 2900-kilometer-deep mantle. To some geophysicists, the earthquake cutoff at a depth of 670 kilometers indicates that the mantle is divided into two layers that do not mix. Descending slabs, they say, are trapped in the upper mantle. Other researchers can imagine the slabs heading right through the purported barrier while the quakes peter out at the boundary. That is what would happen if the quakes were triggered by transformational faulting in olivine, say Kirby and Green. If so, what happens in the pellet-sized sample of a lab press could help point the way to the resolution of a planet-scale problem.

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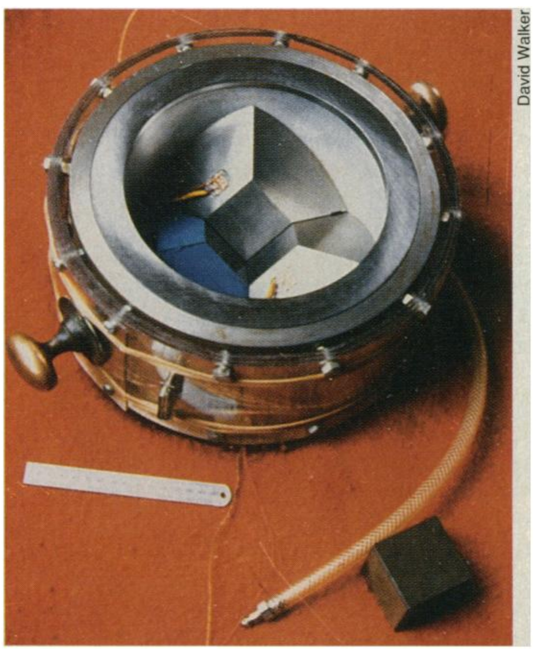

A cheaper squeeze. *The press (here disassembled) that may have mimicked deep quakes.*

ADDITIONAL READING

H. W. Green *et al.*, "Anticrack-Associated Faulting at Very High Pressure in Natural Olivine," *Nature* **348**, 720 (1990).