Geophysicists detect a molten rock layer deep below the American Southwest

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A sheet of molten rock roughly 10 miles thick spreads underneath much of the American Southwest, some 250 miles below Tucson, Ariz. From the surface, you can't see it, smell it or feel it.

But Arizona geophysicists Daniel Toffelmier and James Tyburczy detected the molten layer with a comparatively new and overlooked technique for exploring the deep Earth that uses magnetic eruptions on the sun.

Toffelmier, a hydrogeologist with Hargis + Associates, Inc., in Mesa, Ariz., graduated from ASU’s School of Earth and Space Exploration in 2006 with a master’s degree in geological sciences. Tyburczy, a professor of geoscience in the school, was Toffelmier's thesis advisor. Their findings, which grew out of Toffelmier's thesis, are presented in the June 21 issue of the scientific journal Nature.

"We had two goals in this research," says Tyburczy. "We wanted to test a hypothesis about what happens to rock in Earth's mantle when it rises to a particular depth – and we also wanted to test a computer modeling technique for studying the deep Earth."

He adds, "Finding that sheet of melt-rock tells us we we're on the right track."

Deep Squeeze

In 2003 two Yale University geoscientists published a hypothesis about the composition and physical state of rocks in Earth's mantle. They proposed that mantle rock rising through a depth of 410 kilometers (about 250 miles) would give up any water mixed into its crystal structure, and the rock would then melt.

"This idea is interesting and fairly controversial among geophysicists," says Tyburczy. "So Dan and I thought we'd test it."

Geophysicists often study the planet's structure using earthquake waves, which are good at detecting changes in rock density. For example, seismic waves show that Earth's density abruptly alters at particular depths. The biggest change, or discontinuity, comes at the core-mantle boundary, some 2,900 kilometers (1,800 miles) deep. Another lies at a depth of 660 km (410 mi), while the third most-prominent discontinuity occurs 410 km (250 mi) down.

But seismic waves don't tell scientists much about rocks' chemical makeup, or about minor elements they contain, or their various mineral phases. Scientists need a different method to study mantle rocks that change composition as they shed water at 410 kilometers' depth and become partly molten in the process.

A geophysical survey technique sensitive to these factors is called magnetotellurics or geomagnetic depth sounding. "Basically," says Toffelmier, "this method measures changes in rocks' electrical conductivity at different depths." Calibrated by laboratory work, magnetotelluric methods permit scientists to estimate the composition of rocks they won't ever be able to hold in their hands.

"Rocks are semiconductors," explains Tyburczy. "And rocks with more hydrogen embedded in their structure conduct better, as do rocks that are partially molten." A common source for hydrogen, he notes, is water, which can lodge throughout a mineral's crystal structure.

But how to measure the conductivity of rocks buried hundreds of miles underfoot" The answer lies 93 million miles away.

Outsourcing

The sun emits a continuous flow of charged atomic particles called the solar wind. This varies in strength as activity on the sun rises and falls. When gusts of particles reach Earth, they induce changes in the planet's magnetosphere, causing in turn weak, but measurable electrical currents to flow through terrestrial rocks deep inside the Earth.

Toffelmier and Tyburczy used electromagnetic field data collected by others for five regions of Earth: the American Southwest, northern Canada, the French Alps, a regionally averaged Europe and the northern Pacific Ocean. Only these few data sets contained information gathered over a long-enough period to be useful in the computer modeling.

"The long-period waves tell you about deep events and features," says Tyburczy, "while short-period ones resolve shallower features." Think of it like an inverted cone extending down into the Earth, he says. The deeper you go, the wider the area that's sampled, and the coarser the resolution.

The modeling approach Toffelmier and Tyburczy used was to start with an initial guess as to rock composition at different depths, run the model, compare the results to the actual field data, and then alter the run's starting point. As they worked, they found that only the data for the southwestern United States showed signs of a water-bearing melt layer at the 410 kilometer (250 mile) depth.

"Without a melt zone at that depth," explains Toffelmier, "we can't match the field observations." But, says Tyburczy, "When we added a highly conductive melt zone, 5 to 30 kilometers [3 to 20 miles] thick, we got a much better fit." The extent of the melt sheet is unknown, however, because the data set is limited in area. There's little chance, the researchers say, that any molten rock from it would erupt at the surface.

Seismic surveys show the 410-kilometer discontinuity is global in scope. But Toffelmier and Tyburczy's work shows that melting at the 410-km depth is patchy at best and far from global. So the Yale hypothesis remains only partly confirmed.

What's next? "Our modeling has been only in one dimension," explains Tyburczy. "We need to start looking in two and three dimensions. We also need to understand better how rocks and minerals change at the incredible pressures deep inside the Earth."

Says Toffelmier, "We've seen only the tip of the iceberg."

Source: Arizona State University

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