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Geologists solve mystery of the Colorado Plateau

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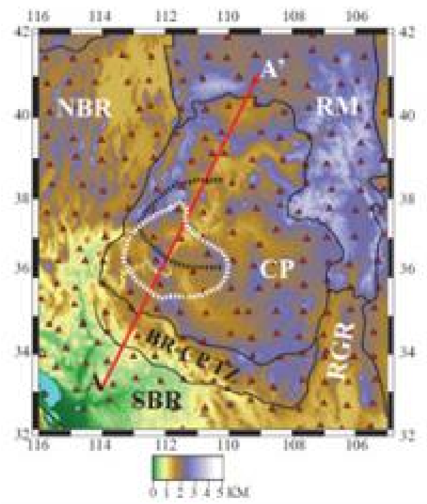


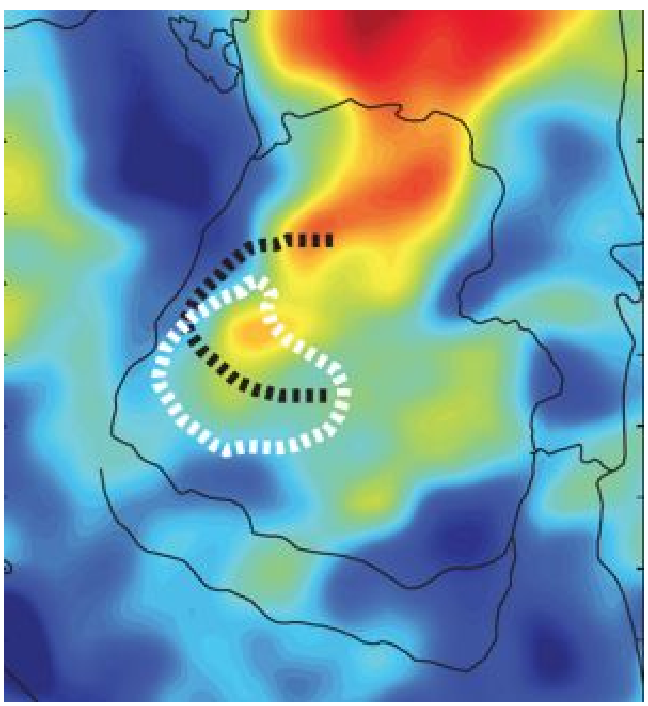
The white dotted circle in the image is the area where USC Dornsife's Meghan Miller and her team discovered active delamination of the continental lithosphere in the Colorado Plateau. Graphic courtesy of Meghan Miller.

(PhysOrg.com) -- A team of scientists led by Rice University has figured out why the Colorado Plateau – a 130,000-square-mile region that straddles Colorado, Utah, Arizona and New Mexico -- is rising even while parts of its lower crust appear to be falling. The massive, tectonically stable region of the western United States has long puzzled geologists.

A paper published today in the journal *Nature* shows how magmatic material from the depths slowly rises to invade the lithosphere -- Earth's crust and strong uppermost mantle. This movement forces layers to peel away and sink, said lead author Alan Levander, professor and the Carey Croneis Chair in Geology at Rice University.

The invading asthenosphere is two-faced. Deep in the upper mantle, between about 60 and 185 miles down, it's usually slightly less dense and much less viscous than the overlying mantle lithosphere of the tectonic plates; the plates there can move over its malleable surface.

But when the asthenosphere finds a means to, it can invade the lithosphere and erode it from the bottom up. The partially molten material expands and cools as it flows upward. It infiltrates the stronger lithosphere, where it solidifies and makes the brittle crust and uppermost mantle heavy enough to break away and sink. The buoyant asthenosphere then fills the space left above, where it expands and thus lifts the plateau.



Colorado Plateau, the view underground: Blue shows sinking of lithosphere; red is the rise of the asthenosphere

Levander and his fellow researchers know this because they've seen evidence of the process from data gathered by the massive USArray seismic observatory, hundreds of observatory-quality seismographs deployed 45 miles apart in a mobile array that covers a north/south strip of the United States. The seismographs were first deployed in the West in 2004 and are heading eastward in a 10-year process, with each seismograph station in place for a year and a half. Seismic images made by Rice that are analogous to medical ultrasounds were combined with images like CAT scans made by seismologists at the University of Oregon; the resulting images revealed a pronounced anomaly extending from the crust well into the mantle.

Levander said the combined Colorado Plateau images show the convective "drip" of the lithosphere just north of the Grand Canyon; the lithosphere is slowly sinking several hundred kilometers into the Earth. That process may have helped create the canyon itself, as lifting of the plateau over the last 6 million years defined the Colorado River's route.

Levander said USArray has found similar downwellings in two other locations in the American West; this suggests the forces deforming the lower crust and uppermost mantle are widespread. In both other locations, the downwellings happened within the past 10 million years. "But under the Colorado Plateau, we have caught it in the act," he said.

"We had to find a trigger to cause the lithosphere to become dense enough to fall off," Levander said. The partially molten asthenosphere is "hot and somewhat buoyant, and if there's a topographic gradient along the asthenosphere's upper surface, as there is under the Colorado

Plateau, the asthenosphere will flow with it and undergo a small amount of decompression melting as it rises."

It melts enough, he said, to infiltrate the base of the lithosphere and solidify, "and it's at such a depth that it freezes as a dense phase. The heat from the invading melts also reduces the viscosity of the mantle lithosphere, making it flow more readily. At some point, the base of the lithosphere exceeds the density of the asthenosphere underneath and starts to drip."

Levander said the National Science Foundation-funded USArray is already providing a wealth of geologic data. "I have quite a few seismologist friends in Europe attempting to develop a EuroArray, one of whom said, 'Well, it looks like you have a machine producing Nature and Science papers.' Well, yes, we do," he said. "We can now see things we never saw before."

More information: Continuing Colorado plateau uplift by delamination-style convective lithospheric downwelling, *Nature* 472, 461–465 (28 April 2011) doi:10.1038/nature10001
www.nature.com/nature/journal/ … ull/nature10001.html

Abstract
The Colorado plateau is a large, tectonically intact, physiographic province in the southwestern North American Cordillera that stands at ~1,800–2,000 m elevation and has long been thought to be in isostatic equilibrium1. The origin of these high elevations is unclear because unlike the surrounding provinces, which have undergone significant Cretaceous–Palaeogene compressional deformation followed by Neogene extensional deformation, the Colorado plateau is largely internally undeformed. Here we combine new seismic tomography2 and receiver function images to resolve a vertical high-seismic-velocity anomaly beneath the west-central plateau that extends more than 200 km

in depth. The upper surface of this anomaly is seismically defined by a dipping interface extending from the lower crust to depths of 70–90 km. The base of the continental crust above the anomaly has a similar shape, with an elevated Moho. We interpret these seismic structures as a continuing regional, delamination-style foundering of lower crust and continental lithosphere. This implies that Pliocene (2.6–5.3 Myr ago) uplift of the plateau and the magmatism on its margins are intimately tied to continuing deep lithospheric processes. Petrologic and geochemical observations indicate that late Cretaceous–Palaeogene (~90–40 Myr ago) low-angle subduction hydrated and probably weakened much of the Proterozoic tectospheric mantle3, 4, 5 beneath the Colorado plateau. We suggest that mid-Cenozoic (~35–25 Myr ago) to Recent magmatic infiltration subsequently imparted negative compositional buoyancy to the base and sides of the Colorado plateau upper mantle, triggering downwelling. The patterns of magmatic activity suggest that previous such events have progressively removed the Colorado plateau lithosphere inward from its margins6, and have driven uplift. Using Grand Canyon incision rates7, 8 and Pliocene basaltic volcanism patterns, we suggest that this particular event has been active over the past ~6 Myr.

Provided by Rice University