Study explains unusual deformation in Earth's largest continental rift

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Computer models confirm that the African Superplume is responsible for the unusual deformations as well as rift-parallel seismic anisotropy observed beneath the East African Rift System.

In continental rifting, there's a mix of stretching and breaking that reaches deep into the Earth, said geophysicist D. Sarah Stamps. Continental rifting involves the stretching of the lithosphere—the outermost, rigid layer of the Earth. As the lithosphere stretches thin, its shallow regions experience brittle deformation, with the breaking of rock and earthquakes.

Stamps, who studies these processes by using computer modeling and GPS to map surface motions with millimeter precision, compares a rifting continent's different deformation styles with playing with Silly Putty.

"If you hit Silly Putty with a hammer, it can actually crack and break," said Stamps, associate professor in the Department of Geosciences, part of the Virginia Tech College of Science. "But if you slowly pull it apart, the Silly Putty stretches. So on different time scales, Earth's lithosphere behaves in different ways."

Whether in stretching or breaking, the deformation that comes with continental rifting usually follows predictable directional patterns in relation to the rift: The deformation tends to be perpendicular to the rift. The East African Rift System, the Earth's largest continental rift system, has those rift-perpendicular deformations. But after measuring the rift system with GPS instruments for more than 12 years, Stamps also observed deformation that went in the opposite direction, parallel to the system's rifts. Her team at the Geodesy and Tectonophysics Lab has worked to find out why.

In a recent study published in the *Journal of Geophysical Research: Solid Earth*, the team explored the processes behind the East African Rift System using 3D thermomechanical modeling developed by the study's first author, Tahiry Rajaonarison, a postdoctoral researcher at New Mexico Tech who earned his Ph.D. at Virginia Tech as a member of

Stamps's lab. His models showed that the rift system's unusual, rift-parallel deformation is driven by northward mantle flow associated with the African Superplume, a massive upwelling of mantle that rises from deep within the Earth beneath southwest Africa and goes northeast across the continent, becoming more shallow as it extends northward.

Their findings, combined with insights from a study the researchers published in 2021 using Rajaonarison's modeling techniques, could help clear up scientific debate on which plate-driving forces dominate the East African Rift System, accounting for both its rift-perpendicular and rift-parallel deformation: lithospheric buoyancy forces, mantle traction forces, or both.

As a postdoctoral researcher, Stamps began observing the East African Rift System's unusual, rift-parallel deformation using data from GPS stations that measured signals from more than 30 satellites orbiting Earth, from about 25,000 kilometers away. Her observations have added a layer of complexity to the debate around what drives the rift system.

Some scientists see the rifting in East Africa as driven primarily by lithospheric buoyancy forces, which are relatively shallow forces attributed mainly to the rift system's high topography, known as the African Superswell, and to density variations in the lithosphere. Others point to horizontal mantle traction forces, the deeper forces arising from interactions with mantle flowing horizontally beneath East Africa, as the primary driver.

The team's 2021 study found through 3D computational simulations that the rift and its deformation could be driven by a combination of the two forces. Their models showed that lithospheric buoyancy forces were responsible for the more predictable, rift-perpendicular deformation, but those forces couldn't account for the anomalous, rift-parallel deformation picked up by Stamps's GPS measurements.

In their newly published study, Rajaonarison again used 3D thermomechanical modeling, this time to focus on the source of the rift-parallel deformations. His models confirm that the African Superplume is responsible for the unusual deformations as well as rift-parallel seismic anisotropy observed beneath the East African Rift System.

Seismic anisotropy is the orientation or alignment of rocks in a particular direction in response to mantle flow, melt pockets, or pre-existing structural fabrics in the lithosphere, Stamps said. In this case, the rocks' alignment followed the direction of the African Superplume's northward mantle flow, which suggests mantle flow as their source.

"We are saying that the mantle flow is not driving the east-west, rift-perpendicular direction of some of the deformations, but that it may be causing the anomalous northward deformation parallel to the rift," Rajaonarison said. "We confirmed previous ideas that lithospheric buoyancy forces are driving the rift, but we're bringing new insight that anomalous deformation can happen in East Africa."

Learning more about the processes involved in continental rifting, including these anomalous ones, will help scientists chip away at the complexity behind the breaking of a continent, which they've been attempting for decades. "We're excited about this result from Dr. Rajaonarison's numerical modeling because it provides new information about the complex processes that shape the Earth's surface through continental rifting," Stamps said.

More information: Tahiry A. Rajaonarison et al, A Geodynamic Investigation of Plume-Lithosphere Interactions Beneath the East African Rift, *Journal of Geophysical Research: Solid Earth* (2023). DOI: 10.1029/2022JB025800

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