Rock crystals from the deep give microscopic clues to earthquake ground movements

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Chunks of exotic green rocks from the mantle erupted from the San Carlos Volcanic Field, Arizona. Credit: James St John

Microscopic imperfections in rock crystals deep beneath Earth's surface play a deciding factor in how the ground slowly moves and resets in the aftermath of major earthquakes, says new research involving the University of Cambridge.

The stresses resulting from these defects—which are small enough to disrupt the atomic building blocks of a crystal—can transform how hot rocks beneath Earth's crust move and in turn transfer stress back to Earth's surface, starting the countdown to the next earthquake.

The new study, published in *Nature Communications*, is the first to map out the crystal defects and surrounding force fields in detail. "They're so tiny that we've only been able to observe them with the latest microscopy techniques," said lead author Dr. David Wallis from Cambridge's Department of Earth Sciences, "But it's clear that they can significantly influence how deep rocks move, and even govern when and where the next earthquake will happen."

By understanding how these crystal defects influence rocks in the Earth's upper mantle, scientists can better interpret measurements of ground motions following earthquakes, which give vital information on where stress is building up—and in turn where future earthquakes may occur.

Earthquakes happen when pieces of Earth's crust suddenly slip past each other along fault lines, releasing stored-up energy which propagates through the Earth and causes it to shake. This movement is generally a response to the build-up of tectonic forces in the Earth's crust, causing the surface to buckle and eventually rupture in the form of an earthquake.

Their work reveals that the way Earth's surface settles after an earthquake, and stores stress prior to a repeat event, can ultimately be traced to tiny defects in rock crystals from the deep.

"If you can understand how fast these deep rocks can flow, and how long it will take to transfer stress between different areas across a fault zone, then we might be able to get better predictions of when and where the next earthquake will strike," said Wallis.

The team subjected olivine crystals—the most common component of the upper mantle—to a range of pressures and temperatures in order to replicate conditions of up to 100 km beneath Earth's surface, where the rocks are so hot (roughly 1250oC) they move like syrup.

Wallis likens their experiments to a blacksmith working with hot metal—at the highest temperatures, their samples were glowing white-hot and pliable.

They observed the distorted crystal structures using a high-resolution form of electron microscopy, called electron backscatter diffraction, which Wallis has pioneered on geological materials.

Their results shed light on how hot rocks in the upper mantle can mysteriously morph from flowing almost like syrup immediately after an earthquake to becoming thick and sluggish as time passes.

This change in thickness—or viscosity—transfers stress back to the cold and brittle rocks in the crust above, where it builds up—until the next earthquake strikes.

The reason for this switch in behavior has remained an open question, "We've known that microscale processes are a key factor controlling earthquakes for a while, but it's been difficult to observe these tiny features in enough detail," said Wallis. "Thanks to a state-of-the-art microscopy technique, we've been able to look into the crystal framework of hot, deep rocks and track down how important these miniscule defects really are."

Wallis and co-authors show that irregularities in the crystals become increasingly tangled over time; jostling for space due to their competing force fields—and it's this process that causes the rocks to become more viscous.

Until now it had been thought that this increase in viscosity was because of the competing push and pull of crystals against each other, rather than being caused by microscopic defects and their stress fields inside the crystals themselves.

The team hope to apply their work to improving seismic hazard maps, which are often used in tectonically active areas like southern California to estimate where the next earthquake will occur. Current models, which are usually based on where earthquakes have struck in the past, and where stress must therefore be building up, only take into account the more immediate changes across a fault zone and do not consider gradual stress changes in rocks flowing deep within the Earth.

Working with colleagues at Utrecht University, Wallis also plans to apply their new lab constraints to models of ground movements following the hazardous 2004 earthquake which struck Indonesia, and the 2011 Japan quake—both of which triggered tsunamis and lead to the loss of tens of thousands of lives.

More information: David Wallis et al, Dislocation interactions in olivine control postseismic creep of the upper mantle, *Nature Communications* (2021). DOI: 10.1038/s41467-021-23633-8

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