GEOPHYSICS

Shaking up volcanoes

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Most volcanic eruptions that occur shortly after a large distant earthquake do so by random chance. A few compelling cases for earthquake-triggered eruptions exist, particularly within 200 km of the earthquake, but this phenomenon is rare in part because volcanoes must be poised to erupt in order to be triggered by an earthquake (1). Large earthquakes often perturb volcanoes in more subtle ways by triggering small earthquakes and changes in spring discharge and groundwater levels (1, 2). On page 80 of this issue, Brenguier et al. (3) provide fresh insight into the interaction of large earthquakes and volcanoes by documenting a temporary change in seismic velocity beneath volcanoes in Honshu, Japan, after the devastating Tohoku-Oki earthquake in 2011.

Large earthquakes can affect volcanoes in multiple ways. The most far-reaching effects result from radiated seismic waves. Unlike the immediate and long-lasting static changes to Earth's stress field in the region surrounding an earthquake's rupture plane, seismic waves can disturb Earth's crust much farther away. Miyazawa (4) has shown that passing seismic waves from the Tohoku-Oki earthquake triggered small earthquakes throughout Japan, including at some volcanic centers on Honshu.

In the past two decades, a wealth of research has documented subtle changes in local seismicity, deformation, and hydrology at volcanoes after large earthquakes (1,2). Models developed to explain the interaction involve stress changes across local fractures and magma storage regions, activation of hydrous or magmatic fluids, and/or localized deformation. For example, in the hydraulic surge (see the figure) (5) and fracture unclogging (6) models, shaking from seismic waves breaches impermeable boundaries that separate compartments in the crust beneath volcanoes. This process allows high-pressure fluids to migrate along pressure gradients up and away from source regions. Because migrating fluids can induce earthquakes, some have speculated that hydraulic surges cause dynamically triggered earthquakes at volcanoes. These and other models cannot be verified, however, without better hydrologic and geodetic monitoring to track pore-fluid pressure and other crustal properties. Brenguier et al. (7) have mapped seismic velocity susceptibility over wide swaths of southern California. The method, now known as ambient noise tomography, has provided unprecedented insights into the structure of Earth's crust.

In a similar vein, Brenguier et al. (8) build on previous studies of time-dependent velocity changes at individual volcanoes (9) but expand the scope to the entire volcanic arc of Honshu, Japan. By processing thousands of station pairs from one of the highest-quality seismic networks in the world, the Japanese Hi-net array, they create a map of a new measurable quantity: seismic velocity susceptibility, or the ratio of subsurface velocity change to applied dynamic stress. Velocity susceptibility is an optimal measure of earthquake-induced fluctuations in crustal properties because changes such as crack opening and fluid intrusion can decrease seismic velocities.

The authors show that, in the days following the Tohoku-Oki earthquake, the most negative velocity susceptibilities followed a distinctive north-south trend along the volcanic central portion of Honshu. Why did the strongest effect not occur closer to the earthquake? Brenguier et al.'s explanation rests on the fact that volcanoes overlie localized regions of high pore-fluid pressure. These high pressures, the same ones that may help drive volcanoes into eruption, react more strongly to earthquake shaking than the surrounding crust and in turn control the spatial distribution of susceptibility.

Mapping seismic velocity susceptibility opens up the prospect of detecting changes in crustal properties, such as subsurface pore-pressure conditions, over wide swaths of Earth's crust. Further insight will come from large-scale measurement of time-dependent velocity changes with other spatially dense and extensive seismic arrays, such as USArray. In weighing models for earthquake-volcano interactions, understanding both changes in crustal properties and their time dependence is critical. Thus, studies like that of Brenguier et al. will help to reveal the mechanics of dynamic processes within volcanoes and allow us to more accurately address the vital question of how earthquakes affect volcanoes.

REFERENCES


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