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Seismic anisotropy and the state of stress in volcanic systems

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The active magmatic and hydrothermal systems of volcanoes can lead to complicated stress patterns that can vary over short spatial and temporal scales. An attractive approach to studying the state of stress in such systems is to investigate seismic anisotropy using shear-wave splitting in upper-crustal earthquakes. Anisotropy can be caused by a range of mechanisms, including crystal preferred orientation and fine scale layering, but the dominant mechanism in volcanic systems is likely the preferred alignment of fluid-filled cracks and fractures. In general, cracks and fractures in the near surface tend to align parallel to the dominant direction of maximum horizontal stress. However, the observed patterns in volcanoes indicate more complicated stress patterns, which sometimes even change in time. A challenge is to untangle the magmatic versus hydrothermal control on stress.

Here I summarise observations of seismic anisotropy across several volcanoes in different settings. Seismic anisotropy of the upper crust in the vicinity of the Soufrière Hills volcano - on the island of Montserrat in the Lesser Antilles – has been studied using shear wave splitting (SWS) analysis of shallow volcano-tectonic events. Clear spatial variations in anisotropy are observed, which are consistent with structurally controlled anisotropy resulting from a left-lateral transtensional array of faults that crosses the volcanic complex. Corbetti and Aluto are two volcanoes located roughly 100 km apart in the Main Ethiopian Rift. Their evolution is strongly controlled by pre-existing structural trends. In the case of Aluto, the anisotropy follows the Wonji fault belt in a rift parallel nearly N-S direction, but significantly oblique to the older border faults. In contrast, the shear-wave splitting at Corbetti is more complicated and supports ideas of the influence of a much-older pre-existing cross-rift structure known as the Goba-Bonga fault. Ontake volcano in Japan is another arc volcano. It exhibits a complicated stress system, as revealed by earthquake source mechanisms and patterns of shear-wave splitting. Ontake has seen two recent eruptions, a minor phreatic eruption in 2007 and a more significant eruption in 2014. The pattern of seismic anisotropy shows no temporal variation with the first eruption. However, with the second eruption there is a clear change in both the magnitude of the shear-wave splitting and the orientation of the fast shear-wave, suggesting that there is a critical stress threshold where the anisotropy changes.

In summary, with a good seismic network, shear-wave splitting measurements are relatively easy to make. They capture details of changes in the stress system across a volcano, which may be a useful monitoring tool. Furthermore, they also provide a good reconnaissance tool that provides insights into structural controls on the formation of volcanoes.