Dissecting a volcano

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Abstract: Eruption forecasting is a central goal in volcanology. In recent years, eruption forecasts have achieved great success due to the increased monitoring of active volcanoes. However, understanding the physical processes responsible for volcanic unrest remains a challenge. In the January issue of *American Mineralogist*, Viccaro et al. (2016) linked signals of seismic unrest to magma mixing events responsible for the 2010 eruption at Eyjafjallajökull in Iceland. Their study represents a multi-disciplinary effort in which integration of petrological and geophysical observations leads to a better understanding of how volcanoes work, by providing a look into Eyjafjallajökull's magmatic plumbing system and estimates of its magmatic ascent rates. This information is key to interpreting monitoring data and successfully forecasting eruptions. **Keywords:** Volcanology, Eyjafjallajökull, magmatic plumbing system, magma ascent rates

In forecasting volcanic eruptions, timing and location can usually be estimated with a higher level of confidence than eruption magnitude and hazard. This is because temporal and spatial estimates are based on pattern recognition of real-time monitoring data. Assessment of potential hazard, on the other hand, relies on numerical modeling of the physical processes operating inside the volcano of study. Two kinds of uncertainties exist for hazard models: aleatory and epistemic (Connor et al., 2015). Aleatory uncertainty results from the natural randomness inherent in geologic processes. Epistemic uncertainty is a result of our poor understanding of volcanic processes. A major goal in volcanology is therefore to minimize epistemic uncertainties in eruption forecasting.

Interdisciplinary studies combining both geophysical and petrological observations can provide valuable insights to these physical processes. Viccaro et al. (2016) took this approach to investigate the internal structure and magma ascent dynamics of the Eyjafjallajökull volcanic system. The authors studied chemical profiles in zoned olivine crystals from emission products of the 2010 eruption at Fimmvörðuháls Pass. This eruption was likely fed by magma that also contributed to the later explosive eruption at Eyjafjallajökull (Keiding and Sigmarsson, 2012). From their samples, Viccaro et al. (2016) recognized three populations of olivine with distinct core Mg-Fe compositions, indicative of their origins in isolated magmatic reservoirs. Each of these olivine populations also has chemical zoning patterns that suggest re-equilibration resulting from changes in magmatic conditions, likely due to magma mixing.

On the basis of diffusion calculations, the authors found that three timescales, ranging from days to a month, were required to produce the chemical profiles in the olivine crystals. These diffusion timescales essentially record the duration between intrusions (or magma mixing) and the eruption at Fimmvörðuháls Pass. The most Mg-rich olivines required the longest diffusion timescale, and the most Fe-rich ones required the shortest diffusion time in order to produce the observed chemical zoning. Based on composition and the calculated diffusion timescales, the authors argued that the most Mg-rich olivines must have originated from the deepest reservoir (~22 km bsl, primarily detected from post-eruptive seismicity; Tarasewicz et al., 2012), while the most Fe-rich olivines must have originated from shallower reservoirs (~5 km bsl, detected by pre-eruptive seismic and geodetic signals; Tarasewicz et al., 2012; Sigmundsson et al. 2010).

Viccaro et al. (2016) confirmed the existence of at least three isolated magmatic reservoirs under the Eyjafjallajökull volcanic system. In addition, the authors estimated ascent rates by taking the ratio of magmatic storage depths vs. diffusion timescales. The results of this calculation suggest that magma transport beneath the Eyjafjallajökull volcanic system is rapid, and that an eruption can happen within days of the initiation of magma mixing. One critical assumption in their calculations, however, is that the absolute depths of magmatic reservoirs can be assigned using the locations of microearthquakes. More robust estimates of magmatic ascent rates can be obtained if magmatic storage depths were corroborated through geobarometry and/or melt inclusion studies (Putirka, 2008; Hansteen and Klugel, 2008) using the same samples from which diffusion studies were performed.

Although not explicitly discussed by the authors, the study by Viccaro et al. (2016) also highlights a unique opportunity for the cross-calibration of petrologic and geophysical methods used in volcanology. While each discipline has its own strengths, there are certainly areas of overlap. For example, depths, temperatures, and sizes of magmatic bodies and rates of ascent may all be estimated via either geochemical or geophysical methods. Real-time monitoring of active volcanic systems, such as Eyjafjallajökull, can elucidate the circumstances under which independent approaches do or do not converge, as well as permit the testing of predictive models.

At present, about 200 volcanoes are being actively monitored (McNutt and Roman, 2015), providing the volcanology community with an unprecedented opportunity to combine petrology and geophysics in the manner taken by Viccaro et al. (2016) and Saunders et al. (2012). Through further multi-disciplinary studies, it is likely that interpretation of monitoring data will improve and a more complete picture of sub-volcanic plumbing systems will emerge.

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