Geodetic evidence for lateral magmatic connections at Chilean volcanoes

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Knowing the location, volume and mobility of eruptible magma stored in the crust is critical for forecasting volcanic eruptions. Volcanic hazards threaten human life, health and livelihoods, so improvements to the way we interpret monitoring datasets, including deformation, have potential for real world impacts. This project will investigate the geodetic signals that characterise lateral magma transport for different crustal settings, using a combination of InSAR measurements and analytical models with an initial case study of contrasting deformation patterns at two Chilean volcanoes.

The majority of volcanic eruptions are fed from magma reservoirs beneath the site of eruption. However, some historical eruptions are known to have been supplied by magma stored beneath neighbouring volcanoes, evidenced by distal summit collapses[1] and/or similarities in the compositions of erupted material. For example, deformation during the recent Bardabunga eruption (Iceland) has demonstrated that magma can flow 10s of km through a laterally propagating dyke before finally erupting[2]. In contrast, in mature 'mush dominated' magmatic systems, the transport of magmatic fluids is expected not to cause any surface deformation[3]. Recently, satellite radar measurements of ground deformation around volcanic systems have demonstrated that surface movements attributed to magmatic or hydrothermal fluids are commonly significantly offset from the nearest active volcanic vent[4,5,6]. This includes at least five cases where deformation can be tied to a specific eruption through temporal correlations between eruption or vent-localised deformation and the distal deformation signal[6]. Unlike a dyke opening in the shallow crust, which generates a distinctive deformation pattern, these cases do not produce deformation associated with magma transport towards the vent, but show localised volume loss in the source region.

This project will take advantage of the unique insights provided by such examples of laterally offset co-eruptive deformation, as well as investigating the origin of offset deformation sources more generally. End-member scenarios for magma transfer are the opening of a dyke through intact crystalline rock versus the flow of fluids through a crystal mush. Other possibilities include the movement of magmatic fluids through a pre-existing conduit or deformation caused by the transfer of pressure through a hydraulically connected network. The student will use case studies where geodetic evidence requires a shallow, interconnected magmatic zone and test what mechanisms are consistent with observations. This will draw on simple analytical modeling, comparison to other evidence for the presence of magma (e.g., seismicity or degassing) and consideration of petrological evidence where samples are available or obtainable.

This project will involve several strands of investigation:

- The first year of the project will be spent investigating two potential instances of lateral connectivity at Chilean volcanoes. The first, Puyehue-Cordon Caulle volcanic complex, comprises a silicic caldera, fissure complex and stratovolcano and is thought to have an extensive hydraulically connected body > 20 km^2. Distal deformation occurred during the 2011-12 eruption[4]. The second contrasting case, Villarrica, is a frequently erupting stratovolcano that showed post-eruptive uplift about 7 km southeast of the volcano's summit after an eruption in March 2015[7].

- Collation and analysis of independent evidence of magma storage conditions from monitoring data and rock samples, where available. The composition and texture of erupted material can provide evidence about the later stage storage and transport of magma important for assessing shallow storage conditions.

- The student will analyse global datasets of Interferometric Synthetic Aperture Radar (InSAR) as well as historical eruption accounts to identify further examples of co-eruptive distal deformation. They will have the opportunity to use blind source separation methods to test the relationships between apparent deformation signals and may also draw on automatically flagged deformation to find new signals.

Objectives:

- For the two Chilean test cases: (1) to conduct robust tests of the plausible range of mechanisms for distal deformation using analytical modeling constrained by geodetic data and (2) analysis of independent monitoring and petrological data. This will allow an assessment of the degree to which laterally offset deformation is linked to magma transport as opposed to either shallow or deep hydraulic connections.

- To identify further examples of evidence for lateral connectivity from the global InSAR archive using the outputs of novel machine learning and source separation methods. To make assessments of prevalence of laterally extensive interconnected magmatic networks at other volcanoes and how their characteristics vary with tectonic setting and system maturity.

Potential for high impact outcome

Geodetic time series are a key data set for monitoring and therefore for forecasting eruptions. Improvements to our understanding of how to interpret volcanic deformation therefore have the potential for significant impacts in terms of both scientific understanding and the applied science used in volcano observatories. This is a challenging problem, and by testing and assessing models for a range of processes at a particular system, this project will make an advance to the way that widely used geodetic data are interpreted that will potentially be useful to any scientists interpreting volcanic monitoring data.

Training

The student will work under the supervision of Dr Susanna Ebmeier in the Institute of Geophysics and Tectonics volcanology group.   The student will be trained in processing and analysing SAR deformation data, as well as modelling deformation using elastic and viscoelastic analytical solutions.   Dr David Ferguson will provide advice on available petrological data, and Chilean volcanism. The student will be encouraged to expand their scientific horizons by participating in training programmes supported by international volcanological and geophysics networks such as IAVCEI and UNAVCO. The successful PhD student will have access to a broad spectrum of training workshops put on by the Faculty of the Environment at Leeds (http://www.emeskillstraining.leeds.ac.uk/).

Student profile:

The student should have an interest volcanology and be enthusiastic about processing and analysing large volumes of geodetic data. They should also be confident in learning new software and keen to develop skills in geophysical modeling. The student should have a background in a quantitative science, preferable with some general knowledge of volcanology.

References

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[6] Ebmeier et al., (2018). J. App. Volc., 7(2),
[7] Delgado et al., (2017). JVGR, 344, 270-288.