VOLCANOLOGY

Look up for magma insights

Volcanic plumes can be hazardous to aircraft. A correlation between plume height and ground deformation during an eruption of Grímsvötn Volcano, Iceland, allows us to peer into the properties of the magma chamber and may improve eruption forecasts.

Paul Segall and Kyle Anderson

Just over a year after the air traffic chaos caused by the eruption of Eyjafjallajökull Volcano in Iceland, the eruption of nearby Grímsvötn Volcano in May 2011 generated a 20-kilometre-high volcanic plume that, again, led to the closure of airspace in northern Europe. These events highlight the significant hazard posed by volcanic eruptions to not only people on the ground, but also to planes and their passengers. Predicting the onset of an eruption, as well as forecasting its duration and erupted volume, would be invaluable for assessing the safety of air transport. However, to forecast the duration of an eruption once it has started, we need to know the size and physical properties of magma chambers deep within Earth's crust. Writing in *Nature Geoscience*, Hreinsdóttir *et al.*[1] show that during an eruption of Grímsvötn Volcano in 2011, measurements of ground deformation varied in tandem with the height of the eruption columna, and that such data can be used to constrain magma properties that are needed to forecast future eruptive behaviour.

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Figure 1 | Eruption of Grímsvötn Volcano, Iceland, in 2011. The photograph was taken about 20 minutes after the start of the eruption, at 19:21 UTC on 21 May. The plume had reached a height of about 15 kilometres above sea level. The white circular cloud around the plume marks the tropopause at about 9 kilometres above sea level. Hreinsdóttir and colleagues[1] report a close correlation between the height of the eruption plume and GPS measurements of ground deformation during the May 2011 eruption of Grímsvötn Volcano. Both measurements depend on pressure changes in the magma chamber — together they can be used to probe properties of the magma stored there. Pressure in the magma chamber began decreasing about an hour before the onset of the eruption as magma moved towards the surface, and was recorded by the GPS and tilt instruments immediately. These data can be used to provide short-term eruption warnings.

Before an eruption, magma ascends from Earth's mantle and collects in magma chambers in the crust. An eruption begins when the pressure within a chamber is sufficient to drive magma towards Earth's surface; as magma exits, pressure within the chamber decreases. The volume of erupted magma and the timescale over which the eruption rate decays depend on the volume and compressibility (change in volume per unit change in pressure) of the magma system[2], as well as any influx of new magma into the chamber. Magma system compressibility in turn depends on the shape of the chamber, the stiffness of the surrounding crust and the compressibility of the magma itself. The latter is controlled by the presence and concentration of gas-filled bubbles, and it is the rapid expansion of these bubbles that drives most explosive eruptions[3].

Changes in pressure within a magma chamber cause the surface of the Earth to deform. The rate and spatial patterns of deformation provide clues to the volume, depth and shape of the chamber. Furthermore, deformation accompanying the ascent of magma can sometimes be measured before the onset of an eruption[4–6] and, together with increased rates of earthquakes, can be used to issue short-term eruption predictions.

Combining information from ground-deformation rates during an eruption with mass-eruption rate can allow determination of the overall compressibility of the magma system[7,8]. If the chamber geometry is sufficiently well resolved, and there is no recharge of magma into the chamber during the eruption, this can permit determination of the magma compressibility, offering insight into the presence and concentration of the all-important bubbles in the magma.

Hreinsdóttir and colleagues[1] monitor ground deformation before and during an eruption at Grímsvötn Volcano in May 2011 (Fig. 1), using high-precision

Global Positioning System (GPS) data combined with a tiltmeter record of deformation on the only rock outcropping among the glaciers that cover the volcano. Radar measurements and photographs were also used to constrain the height of the eruption column, which varied over the course of the eruption. Hreinsdóttir *et al.* were able to infer the changing eruption rate by making use of theory and observations that show that eruption rate scales with column height[9]. The estimated eruption rate and the GPS measurements of deformation correlate remarkably well. The GPS data not only record the overall decline of the eruption, but also track shorter-term fluctuations in eruption rate in fine detail.

The constant proportionality between the eruption rate and GPS measurements, and hence essentially constant compressibility, has important implications. Firstly, it argues against significant changes in the volcanic plumbing system during the eruption. Secondly, it indicates that any additional bubble formation must have been modest. Decreasing magma chamber pressure causes volatile species (principally water) to separate from the melt, enlarging bubbles. It has also been postulated that crystallization could accelerate the escape of volatiles[2]. Finally, the data suggest that there was little or no influx of new magma into the chamber during the eruption because this would have resulted in relatively more erupted material and less deformation. Any of these processes would make forecasting more difficult, so the relative simplicity of the behaviour at Grímsvötn in 2011 is encouraging.

By combining deformation and eruption flux measurements with physics-based models of eruptions, important properties of volcanic systems, including magma chamber volume and compressibility, can be constrained[10]. Such an approach could potentially be extended to forecast the future eruptive behaviour of a volcano[7]. Whether such forecasts prove useful will depend on the accuracy of our conceptual and mathematical models. However, if we are to transition from empirical forecasting to approaches based on physical–chemical models of magmatic systems, it will be vital to combine deformation data with eruption-rate measurements of the sort recorded at Grímsvötn Volcano.

Hreinsdóttir and colleagues[1] demonstrate that ground deformation preceded the May 2011 eruption of Grímsvötn Volcano, Iceland — and, during the eruption, was correlated with observations of volcanic plume height. The study shows that near-real-time ground deformation data can be used to provide timely warnings of imminent eruptions and, coupled with eruption-rate data, can potentially be used to forecast future eruptive behaviour. Such information could be vital for aviation safety. ❐

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EARLY EARTH

Closing the gap

The age of the oldest Jack Hills zircons — Earth's oldest minerals — is contentious. Atomic-scale mapping of the distribution of radiogenic isotopes within a Jack Hills zircon confirms that the oldest known continental crust formed just after the Earth–Moon system.

Samuel Bowring

Our understanding of Earth's early evolutionary timeline is mostly inferred from geochemical data from meteorites and the oldest preserved crust. The first megascopic objects in the Solar System formed about 4.567 billion years ago[1]. However, the Earth–Moon system — probably created during a giant impact — is far younger, and dates back to between about 4.5 and 4.4 billion years ago[2,3]. The oldest preserved crust was previously thought to have formed around 3.8 billion years ago, 600 million years after the Earth–Moon system formed[4], but over the past few decades older remnants of crust have been identified, both in outcrop and as grains of the mineral zircon[5–8]. However, the accuracy of the oldest zircon dates has been called into question[4,9–11]. Writing in *Nature Geoscience*, Valley *et al.*[12] use high-spatial-resolution analytical methods to confirm the antiquity of the oldest known remnant of Earth's continental crust, a single grain of zircon, at 4.374 ± 0.006 billion years — closing the gap in time between the Moon-forming impact and the creation of Earth's first continental crust.

During the Hadean eon — between Earth's formation and 4 billion years ago — the Earth differentiated into a core, mantle and crust. The planet was also resurfaced by bombardment of planetesimals and asteroids, as well as some form of plate tectonics. As a result, few rocks of Hadean age remain. Every scrap of material older than 4 billion years is therefore of great interest, whether it is the oldest rock dated by zircon, the 4.03-billion-year-old Acasta Gneiss[7], or grains of zircon eroded from older crust that is no longer exposed. In the Jack Hills of Western Australia, a sandstone contains abundant grains older than 4.0 billion years[5,6], and analysis of more than 100,000 grains has yielded two