News & views

Volcanology

When it rains, lava pours

Michael Manga

Early 2018 saw unusually heavy rainfall in Hawaii. Modelling now suggests that groundwater pressure increased owing to rainfall: this might have triggered changes in the eruption of the island's Kīlauea volcano. **See p.491**

The most recent eruption of Kīlauea volcano on the island of Hawaii began in 1983. For 35 years, most of its magma emerged from a set of fissures in the volcano called the upper east rift zone. But on 3 May 2018, Kīlauea's lower east rift zone opened up, giving way to a massive outpouring of lava that devastated the southeastern part of the island[1] (Fig. 1). An important question is why this change occurred in May 2018, rather than earlier or later in the course of the eruption. On page 491, Farquharson and Amelung[2] propose that record-breaking levels of rainfall in early 2018 increased groundwater pressures which, in turn, made it easier for rock to break and hence magma to rise to the surface at new locations.

The creation of a pathway that brings magma to Earth's surface begins with the mechanical failure of rocks. This failure can occur in two ways: new cracks can open, or existing faults can slip. Both processes can be promoted by pressure changes in groundwater. For the former, increases in fluid pressure decrease the amount of stress needed to open new cracks. For the latter, faults can slip when the stresses acting parallel to the fault (shear stresses) overcome those perpendicular to the fault (normal stresses). These normal stresses act to clamp the fault shut. Increasing fluid pressure in rocks lowers normal stresses without changing shear stresses, thus promoting fault failure.

Heavy rainfall increases water levels underground and thus pressure in groundwater. The volcanic rocks in Hawaii are very permeable, which allows water to infiltrate and pressure changes to propagate to a depth of several kilometres, close to where magma is stored. Fluid-pressure changes take time to propagate from the surface to those depths. Thus, downward migration of rock failure over time, along with a time lag between the accumulation of water at the surface and failure at depth[3], would be key indicators that rainfall was the cause of rock failure at Kīlauea.

Farquharson and Amelung modelled pressure changes at Kīlauea caused by rainfall in the months leading up to the eruption on 3 May 2018. Their model showed an increase in pressure of tens to hundreds of pascals at depths of several kilometres. On the basis of these changes, along with four sets of observations indicating that eruptions at Kīlauea are associated with patterns of substantial rainfall, the authors propose that heavy rainfall promoted the rock failure that enabled magma to flow into the lower east rift zone.

Is their hypothesis plausible? The pressure changes computed by their models are small — smaller than stresses from tides. However, if rocks are already close to breaking, such changes might be sufficient to initiate failure. The 2018 eruption was accompanied by a magnitude-6.9 earthquake, and examples of earthquakes caused by pressure changes on this scale are abundant[4]. For example, the widespread increase in earthquake frequency in the central and eastern United States in the past decade results from wastewater injection into permeable rocks that increases water pressure and changes stresses[5].

The geological record also confirms that changes in stresses at Earth's surface can modulate volcanic activity. On land, volcanism is promoted by the retreat of glaciers[6]. Sea-level changes between glacial and interglacial periods can modulate eruption rates at mid-ocean ridges[7]. Stresses from large earthquakes increase the probability of volcanic eruptions[8] and can change activity at volcanoes that are already active[9].

Although it is well established that changes in water pressure promote earthquakes, they are not necessarily a direct cause of magma eruption. To begin moving through Earth's crust, magma must create large enough stresses in the surrounding rocks to open a pathway. Earthquakes triggered in the crust around that stored magma, however, can actually relieve stress — as such, they might make it more difficult for magma to erupt[10].

Ultimately, whether fault failure from water-pressure changes can occur close to stored magma, as hypothesized by Farquharson and Amelung, remains uncertain. The first magma to erupt from the lower east rift zone in 2018 was old, perhaps left over from an earlier, 1955 eruption[11], implying that the rift zone was already hot. As a result, groundwater

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Figure 1 | Lava from the lower east rift zone of Kīlauea volcano. Farquharson and Amelung[2] propose that exceptionally heavy rainfall led to the eruption of magma from this part of the volcano in 2018.

in the rift zone might have been vapour at shallow depths[12], and at greater depths it could have been a supercritical fluid (a substance that is not in a distinct liquid or gas phase, but has properties of both). The high compressibility of both vapours and supercritical fluids would dampen the magnitude of pressure changes in the authors' model, making failure less probable.

How, then, can we test the hypothesis that rainfall initiated the lower east rift zone eruption? Unfortunately, subsurface pressure measurements – and hydrogeological data more generally – are rarely part of volcano monitoring. Instead, as with many geoscience and Earth-history questions, we have to look back in time using the geological and historical record of eruptions. In support of their hypothesis, Farquharson and Amelung analysed all reported eruptions at Kīlauea since 1790, and showed that the volcano tends to erupt at the wettest time of year.

Should we increase alert levels at volcanoes after heavy rainfall? We could ask the same question about other stress changes, such as those from regional earthquakes. This is an open question. These stress changes are small, and hence, if anything, modulate the exact timing of the surface eruption. At Kīlauea, there were other sources of stress – in fact, a change in eruption behaviour had been anticipated on the basis of ground-deformation measurements and inferred magma movement. The Hawaiian Volcano Observatory issued a warning on 17 April that a new vent might open[1].

The possibility that external processes initiate volcanic eruptions is a reminder that volcanoes are part of a dynamic Earth system. Volcanic eruptions influence all surface environments, including climate and weather[13]. Changes in those surface environments, such as heavy rainfall, might also influence eruptions. We are only just beginning to understand these interactions.

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Condensed-matter physics

Permanent electric control of spin current

Stefano Gariglio

The development of low-power methods for controlling a property of electrons known as spin could help to maintain the historic rates of progress that are occurring in computational power. Just such a method has now been reported. **See p.483**

A promising technology for the next generation of computers is spintronics, a type of electronics that depends on the spin – the intrinsic angular momentum – of electrons, rather than their charge. However, available methods for controlling spin require electric currents that are too large for practical applications. On page 483, Noël *et al.*[1] report an approach that allows low-power spin control using an electric field.

The exponential progress in increasing computational power over the past 50 years has been largely driven by the relentless miniaturization of the field-effect transistor[2], the basic component of silicon chips. This consistent downscaling was anticipated[3] in 1965 by electronic engineer Gordon Moore, and has led to the staggering 2 billion transistors that are now typically found in the processors of modern personal computers. The semiconductor industry has come up with a road map outlining the technological developments in computer materials, devices and systems that will be needed to maintain these historic rates of increase in computational power (https://irds.ieee.org).

A growing section of the road map addresses a pressing problem for the field: transistors based on currently used technology cannot be scaled down much further, because the physical limits of miniaturization will soon be reached. There are no known solutions for several of the technical and materials issues associated with this problem. Materials scientists, physicists and engineers are therefore investigating an array of potential new working principles for computer technology. The development of new approaches also allows other goals to be targeted, such as lowering energy consumption, or incorporating multiple functionalities into components to speed up data processing.

One way of reducing power consumption would be to eliminate the need for a continuous power supply to maintain the logic state (ON or OFF) of transistors. This can be achieved using ferroic materials (such as ferroelectric compounds, which have a permanent electric polarization) or piezoelectric mechanical devices, which require power to switch between the logic states, but not to retain those states[4]. Spintronics technology has also seen a surge of interest, because this approach is expected to reduce electrical dissipation[5] – wasteful loss of electrical power as heat. Combinations of ferroic approaches with spintronics[6] could be particularly effective in the race to develop more-efficient computing technology.

However, many of these approaches will require new materials – for example, the semiconductors used in conventional electronic devices do not have ferroic properties. A family of compounds known as complex oxides are of particular interest, because they host permanent electric and magnetic dipoles, thereby opening the door to applications that require permanent states. Although complex oxides are not as good as semiconductors for use in classical transistors because they produce more electrical dissipation, they have remarkable properties for spintronics[7].

Interesting electronic phases have been observed to form at the interfaces between two complex oxides. Noël and co-workers focus on a phase called an electron gas: an ultrathin (a few nanometres thick) layer of conducting electrons that forms at the surface of strontium titanate (STO) that has been covered by a layer of aluminium.

STO probably provides the best illustration of the complexity of the electrical properties of transition-metal oxides. In its pure form, it is a dielectric material (an electrical insulator) that has a tendency to become ferroelectric at temperatures below 4 kelvin, but fails to do so