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New insights on dyke width and upward velocity

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Striking observations have been made that challenge our understanding of magma migration through the Earth's crust. How may a volatile rich magma stall at shallow depth as a growing crypto-dome such as during the 1980 Mount Saint Helens eruption? How can we explain the width of the 2005 mega-dyke intrusion in Afar, that attained more than 8 meters with a very small amount of magma emitted at the surface? We show that changes in the geometry and the dynamics of the propagation can be attributed to density variations in the host rocks, to solidification, to volatile exsolution and expansion or to changes in the input flux of magma at depth. We focus on the relationship between dyke width and ascent rate.

Shallow levels are commonly made of low density rocks or volcanic deposits with strong impact on dyke ascent. The dynamics and width of the upper part of the dyke (the nose region) are determined by a local buoyancy balance, independently of the total buoyancy of the magma column between source and tip. In such conditions, the dyke swells and slows down and, in some cases, may not breach the surface.

Using laboratory experiments we show that solidification of the magma may lead to a regime of intermittent propagation, even with constant physical conditions at the source. Interestingly the time between two steps can be related to the input flux at the source region.

With volatile-bearing magmas, dyke propagation proceeds in two markedly different ways depending on whether or not fragmentation occurs. With no fragmentation, magma expansion leads to acceleration and thinning of the dyke. With fragmentation, the sharp drop of head loss that occurs in gas-rich fragmented material generates large internal overpressure and swelling of the nose region, leading to deceleration of the dyke.

All the above effects lead to rapid and large changes of ascent rate. Large variations of magma flux at the source would be required to have similar impacts on dyke propagation. In an extreme case, arrest of the feeding at depth leads to a gradual decrease of upward velocity and thinning of the dyke.

Variations of dyke ascent velocity make monitoring of volcanic unrest and prediction of eruption onset uncertain and potentially erroneous. Our models emphasize, however, that such variations are linked to changes of dyke dimensions and width that can be determined using geophysical networks and that allow identification of the physical mechanism at work. Data and physical models, when used in combination, therefore allow useful diagnostic tools for assessing the likelihood and time of an eruption.