Geophysical Research Abstracts
Vol. 17, EGU2015-11135-1, 2015
EGU General Assembly 2015

Prediction of Dyke Propagation using the Minimum Potential Energy Principle

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An important aspect of eruption forecasting is the prediction and monitoring of dyke propagation. Eruptions occur where dykes propagate to the surface, with lava flows causing a major threat. When such eruption occur under ice, as is common in Iceland, they become explosive and often cause hazardous and destructive floods. Dykes have also been known to trigger explosive eruption when hot basaltic magma comes in contact with more developed volatile saturated magma. Such explosive eruptions pose a danger to both lives and property.

At divergent plate boundaries new crust is formed primarily by dyke injections. These injections usually grow laterally away from a central volcano. Lateral growth of a dyke is expected to follow the minimum potential energy principle. Assuming a closed system, a dyke will tend to be emplaced such that it minimizes the total potential energy, Θ_T, given by:

$$\Theta_T = \Theta_s + \Theta_g \tag{1}$$

where Θ_s is the strain potential and Θ_g the gravitational energy potential. Assuming that the elastic medium behaves linearly the strain potential can be calculated by numerically integrating the strain energy density over a large volume. If the dyke is assumed to be propagating at a constant depth with respect to sea level the gravitational potential energy can be turned into a two dimensional integral. We do this by integrating the predicted vertical displacements multiplied by the local topographic load above a reference surface and the acceleration of gravity.

We approximate strain and stress due to plate movements and then consider strain changes induced by the dyke formation. Opening of a dyke is energetically favourable when it releases strain energy built up at a divergent plate boundary, but once deviatoric stress in the crust adjacent to a segment is released it becomes favourable to propagate laterally. Dyke formation is associated with uplift on their flanks; the lower the topographic load over the flanks, the less energy it costs. For any given location on a volcano, the strike of a new dyke segment will influence the strain and gravitational potential energy change in a different way.

This type of model was applied to the more than 45 km long dyke formed in the Bárðarbunga volcanic system in Iceland in a rifting event in August 2014. Large observed changes in strike can be explained mostly by interplay of gravitational effects of topography and plate boundary strain. The model minimizing the total potential energy explains this propagation path. Our results suggest that by applying the total minimum potential energy principle we can forecast dyke propagation.