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Volcano anatomy: Comparing geodetic, seismic, and geochemical constraints on inner structure and magma transport at Eyjafjallajökull volcano

Freysteinn Sigmundsson (1), Kristin Vogfjord (2), Sigurlaug Hjaltadottir (2), Bryndis Brandsdottir (1), Jon Tarasewicz (3), Bob White (3), Martin Hensch (1), Jakob K. Keiding (4), Olgeir Sigmarsson (1), and Andy Hooper (5)

(1) Nordic Volcanological Center, Institute of Earth Sciences, University of Iceland (fs@hi.is), (2) Icelandic Meteorological Office, Reykjavík, Icealnd (vogfjord@vedur.is), (3) Bullard Laboratories, University of Cambridge, United Kingdom (jptt2@cam.ac.uk), (4) GFZ German research Centre for Geosciences, Potsdam, Germany (jakob@gfz-potsdam.de), (5) Delft Institute of Earth Observation and Space Systems, Delft University of Technology, Delft, The Netherlands, (a.j.hooper@tudelft.nl)

Magmatic emplacement and transport within the Eyjafjallajökull volcano have been inferred by three different methods that can be compared: i) interpretation of ground deformation measured by GPS and InSAR, ii) earthquake hypocenter locations, iii) geobarometry with geochemical techniques.

Geodetic data have been interpreted under the assumption of a homogenous elastic halfspace. In this model magma intruded into sills under the eastern flank of the volcano at about 5 km depth prior to the 2010 eruptive activity, as well as in a tilted dike in March prior to the effusive flank eruption. The total volume of the intruded magma prior to eruptions is about 0.05 km3. During the explosive eruption, pressure decrease occurred at similar depth, but under the summit area in a separate source.

Seismicity preceding and during the eruption was recorded by the SIL Icelandic national network operated by the Icelandic Meteorological Office. This network has three stations within 15 km distance from the volcano's summit and the fourth station was added during the flank eruption. In addition, six more temporary stations were also installed temporarily by Institute of Earth Sciences, University of Iceland. The data have been interpreted with two approaches: i) Data from the SIL stations have been relatively located, ii) Hypocentral locations of 9000 earthquakes recorded by the temporary and SIL stations have been estimated by Coalescence Microseismic Mapping (CMM) using a slightly different velocity model.

The data provide constraints on the routes of magma transport. The main seismicity cluster in January and early February prior to the eruptive activity is located at about 9-11 km depth, just east and northeast of the summit. Interpretation of the SIL-data indicates that in late February the seismicity partly migrated towards SSE, interpreted as the formation of a series of dykes at 4-8 km depth and again on 3-4 March with dramatic rise in seismicity and the foci forming an E-W trending segment extending eastwards from the main cluster. The CMM mapping gives shallower location than the other approach (about 5 km). Both interpretations find evidence for multiple discrete clusters of earthquakes. These do not fit to a simple sill and dike as modelled from the deformation data alone, indicating that joint analyses of seismic and deformation data are required in order to reveal the geometry of multiple sheet intrusions.

Geobarometry has been conducted through the examination of mineral and co-existing melt compositions from tephra samples, in order to place preliminary constraints on magma storage depths and crystallization temperatures during the eruption. Pressure estimates based on clinopyroxene geobarometry yield mean pressures of 4-6 kbar (± 1.5 kbar) for the flank eruptive products and lower average pressure (0.6-1.8 kbar) (± 1.8 kbar) for the summit eruption products. The density structure of the volcano is not well known, but for an average density of 2700 kg/m3 this would correspond to 11-16 km depth, and 2-5 km.

The geobarometric depth range for the summit eruptive products overlaps with the inferred depth of pressure decrease estimated from the deformation data. The depth range for the basaltic flank eruptive products is significantly deeper than both the inferred depth of deformation sources and main seismic activity in the weeks

preceding the eruption. This result may indicate that magma erupted during the flank did not come from the pre-eruptive intrusive complex; rather deep magma flow continued to feed the volcano. The absence of significant co-eruptive subsidence during the flank eruption is also consistent with this interpretation.