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Imaging the magmatic plumbing system at Eyjafjallajökull volcano, Iceland, through 18 years of surface deformation observations

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Repeated geodetic measurements reveal how active volcanoes deform at the surface, and data inversion facilitates inferences about the related volume changes and probable geometry of underlying deformation sources. Under favourable conditions a combination of the two space geodetic methods, CGPS and InSAR, is optimal for mapping the full extent of not only spatial but also temporal complexities in the deformation field during a volcanic unrest episode.

The typical pattern of surface deformation observed prior to, spanning and following eruptions of Iceland's frequently active volcanoes, relates to melt accumulation, drainage and renewed replenishment from crustal magma chambers. However, such a simple model cannot explain the complex behaviour observed at the moderately active Eyjafjallajökull volcano.

Over the last 18 years, Eyjafjallajökull has been experiencing intermittent unrest, where several episodes of elevated seismic energy release have been associated with crustal deformation. GPS and InSAR observations are available throughout the period, with a strongly enhanced data quality and quantity during the most recent unrest episode spanning 2009-2010. A set of inverse models calculated from the entire set of pre-eruptive surface deformation data has revealed a complexity of the subsurface magma plumbing.

The deformation observations from the two unrest episodes in the 1990s can best be explained by two sill intrusions at depths of 4 to 6 km. Although the horizontal extent of the two best-fitting sources overlap, the two deformation episodes cannot be related to a single source at depth, as would be expected from a volcano with an established shallow magma chamber. Furthermore, the complex spatio-temporal behaviour of the surface deformation during the 2009-2010 pre-eruptive interval, indicates that the plumbing system consist of a complex network of sills around 5 km depth, as opposed to a single crustal magma chamber.

SAR images were acquired by the TerraSAR-X satellite mission every 3 to 11 days before, after and during the eruptions and were provided by the German Space Agency (DLR) under project number GEO0609. The deformation patterns observed in the co-eruptive period in 2010 provide further evidence of a complex plumbing system. A feeder dike, connecting the sill complex at about 5 km depth with the surface, must have formed before the March 20th flank eruption, as no measureable deformation was observed the onset of the flank eruption. During the entire span of the flank eruption, primitive mantle derived melts were erupted (olivine-basalts), and surface deformation were at a minimum, indicating the intrusions were not acting as melt sources, but rather channelling melts from greater depths. Two days before the eruption ceased, minor surface subsidence were detected at a few GPS stations, but this pattern immediately inverted to uplift at the cessation of the flank eruption, indicating renewed pressure increase within the volcanic system, hence continued inflow from great depth.

After a two-day pause, a second eruption began, this time from the volcano's summital crater. Surface subsidence immediately followed this eruption, centred at a separate, distinct location compared to the intrusive uplift, indicating that again the pre-eruptive intrusive complex were not acting as melt sources. As the eruptive products were of a much more evolved composition during the top-crater eruption, it is likely that the continued inflow of primitive melts from depth has triggered the summit eruption. Eruption triggering through the encounter of hot, primitive mantle melts with colder, evolved melts residing adjacent to the pre-eruptive intrusive complex is

a likely scenario, according to the surface deformation observations.

The continued inflow of melts from great depth throughout the sustained summit eruption is suspected due to a large discrepancy between the inferred volume changes at depth and the volume of the erupted products. This inference is also consistent with a two day inversion of the surface deformation over a two-day interval following a seismic swarm at about 20 km depth.