Geophysical Research Abstracts
Vol. 12, EGU2010-6939, 2010
EGU General Assembly 2010

A mechanism of large volcanic eruptions and the interaction between Katla and Eyjafjallajokull

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The volume of eruptive materials may vary widely between successive eruptions in a single volcano, as well as between similar-sized volcanoes of the same type and tectonic environment. The likely maximum volume that can be issued in a single eruption from a particular volcano or a rift-zone segment has major implications for the risks associated with that volcano. There may be several reasons for the difference in the volume issued in successive eruptions. These include changes in (1) tectonic conditions, (2) magma composition and gas content, (3) size, shape, and magma content of the source chamber. In many basaltic eruptions, however, factors 1-3 are unlikely to change much between eruptions, or between similar volcanoes, suggesting a different explanation for the abrupt variations in eruptive volume.

Poroelastic models indicate that the volume of magma that flows out of a magma chamber during its rupture V_f, is normally a very small fraction of the total volume of magma in the chamber, V_t. The magma chamber is then assumed to rupture and eject magma (though a dyke or a sheet) when its excess pressure (magmatic pressure in excess of the minimum principal compressive stress in the host rock) reaches the in situ tensile strength of the host rock. These models have been used for many years to account for the volume of magma (intrusive and extrusive) flowing out of a chamber during an eruption and/or dyke injection. While useful, these models do not explain how similar-sized magma chambers and volcanoes in a given tectonic regime, and with similar types of magma or the same magma chamber, can erupt widely different volumes. In particular, they do not explain the mechanical conditions for comparatively large eruptions in a particular volcano.

Focusing on basaltic eruptions, I propose that the energy available for a large eruption depends partly on the mechanical behaviour of the layered rocks of the associated volcano or rift zone. For a certain host-rock behaviour, a much higher proportion of V_t can be driven out of the chamber, in which case the ratio of V_f to V_t becomes unusually large. Since the mechanical behaviour and properties of a volcano change with time, sometimes rapidly, the same volcano may erupt very different volumes, V_f , even if the volume V_t remains essentially constant.

This new mechanism is primarily based on consideration of the material toughness (here: resistance to feeder-dyke formation) and the elastic strain energy stored in the volcano before eruption. The elastic strain energy depends on how much "bending" or uplift the volcano tolerates before rupture and failure. The maximum bending, in turn, is a function of the mechanical behaviour of the volcano, not the chamber, in that the greater the toughness of the volcano, the more elastic strain energy can be stored in the volcano before eruption. The strain energy is then available to "squeeze" magma out of the chamber. The eruption can continue so long as more energy is released than is required to keep the eruption going, that is, so long as the eruption is energetically favourable. As a rule, the greater the amount of elastic strain energy stored in the volcano before eruption, the greater is the chance that the eruption will be unusually large.