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Mafic intrusions triggering eruptions in Iceland

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The last two eruptions in Iceland, Eyjafjallajökull 2010 and Grímsvötn 2011, were both provoked by an intrusion of more mafic magma into pre-existing magmatic system. Injection into the latter volcano, which is located in the main rift-zone of the island, above the presumed centre of the mantle plume and is the most active volcano of Iceland, has been gradual since the last eruption in 2004. In contrast, at Eyjafjallajökull volcano, one of the least active volcano in Iceland and located at the southern part of a propagating rift-zone where extensional tectonics are poorly developed, mafic magma intrusion occurred over less than a year.

Beneath Eyjafjallajökull, a silicic intrusion at approximately 6 km depth was recharged with mantle derived alkali basalt that was injected into residual rhyolite from the penultimate eruption in the years 1821-23. The resulting magma mingIing process was highly complex, but careful sampling of tephra during the entire eruption allows the dynamics of the mingling process to be unravelled. Short-lived disequilibria between the gaseous nuclide 210Po and the much less volatile nuclide 210Pb, suggest that basalt accumulated beneath the silicic intrusion over approximately 100 days, or from early January 2010 until the onset of the explosive summit eruption on 14 April. Due to the degassing, crystal fractionation modified the composition of the injected mafic magma producing evolved Fe-and Ti-rich basalt, similar in composition to that of the nearby Katla volcano. This evolved basalt was intruded into the liquid part of the silicic intrusion only a few hours before the onset of the explosive summit eruption. The short time between intrusion and eruption led to the production of very heterogeneous (of basaltic, intermediate and silicic composition) and fine-grained tephra during the first days of explosive eruption. The fine grained tephra resulted from combined effects of magma fragmentation due to degassing of stiff magma rich in microliths in the volcanic conduit and the thermal shock when the mingled magma came into contact with the ice-cold melt water. Two weeks later, a fresh recharge occurred when mantle derived basalt rose from the mantle/crust boundary during a day or two and brought quantity of sulphur as evidenced by the presence of sulphides in the tephra of 5 May. An important plume of SO_2, increased plume height, the appearance of zoned olivine crystals with Fo-rich core similar to those of the earlier flank eruption , changing magma mingling end-member compositions and a small but significant inflation of short duration testify to this renewed magma recharge. Several other recharge events, although of less intensity, occurred until the end of the eruption around 22 May. The proportion of basaltic mixing end-member declined during the eruption and its exhaustion caused the eruption to stop.

At Grímsvötn, a magma chamber with a closed-system behaviour, since the Laki eruption in 1783-84, has been inferred from very regular concentration increase of the incompatible element Th in an otherwise homogeneous qz-normative basalt measured in tephra from the last two centuries. The 2011 eruption was of short duration, or a week, but its eruption column rose higher than 20 km during the first hours and therefore penetrated into the stratosphere. Such forceful eruption has not been documented before at Grímsvötn volcano although the tephra record suggests several large explosive eruptions during Postglacial time. A significant emission of SO_2 was remotely detected which testify to important degassing of the basaltic magma. A clear negative correlation is observed between the residual S concentration in the tephra glass and degree of microlite crystallisation. Moreover, disequilibrium crystallisation most likely occurred in the conduit and only shortly before magma quenching due to contact with the subglacial lake, since the ferromagnesian crystals dominate this late-stage crystallisation. Earlier gabbroic fractionation of plagioclase, clinopyroxene and rare olivine crystals led to more evolved compositions and saturation of iron-titanium oxides. Significant variations in glass compositions indicate several liquid-lines-of-descent, possibly at somewhat different pressure, with MgO and K2O concentrations ranging from 4.6-5.7% and 0.46 to 0.60%, respectively. These variable magma differentiation trends and the abundant microlites suggest degassing over a considerable depth range and remobilizing of magma pockets at different depths with somewhat variable compositions. This is coherent with the magma plumbing system beneath Grímsvötn being recently recharged with a deeper-derived and gas-rich basaltic melt. This basaltic intrusion resulted in mingled basaltic magma with higher gas content than before and the sub-plinian character of the last Grímsvötn eruption.

The last two eruptions in Iceland therefore were both triggered by an injection of more mafic magma 1)rapidly into a solidifying silicic intrusion beneath Eyjafjallajökull and 2) more slowly disrupting a closed-system magma chamber behaviour beneath Grímsvötn volcano.