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Time scales of magma mingling during the 2010 eruption of Eyjafjallajökull, Iceland

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Injection of basaltic magma into higher-level silicic magma chambers provokes magma mingling, mixing and eruption of intermediate magma with compositionally zoned minerals. The details of the magma mixing processes can be hard to elucidate from the geological record whereas active volcanoes give further insight into this important magmatic process. Relevant time scales of the magma mixing can be estimated in different manners such as from intra-crystalline elemental diffusion, mineral-melt reactions and short-lived disequilibria in the 238U-series in favourable cases.

The 2010 eruption of Eyjafjallajökull volcano, Iceland, permitted detailed sampling of the tephra as it fell from the eruptive column. The eruption started with a flank eruption of slightly alkaline and relatively primitive basalts with 8-9% MgO. The basalts contain less than 5% olivine, often with chromite inclusions, and plagioclase phenocrysts. The olivines range in compostion from Fo87 to Fo71. A day after the basaltic activity ceased, an explosive eruption of mingled benmorite occurred at the summit crater on 14 April. The tephra produced contained three glass types with SiO2 concentrations of 49-51%, 60-61% and 69-70% that illustrate a mechanical magma mingling without enough time for homogenization before the explosive eruption. This tephra shows important mineral compositional zoning (Fo 63.5-50.1; An 68.5-45.3; Cpx-#Mg: 67.8-53.4) without clear evidence for elemental diffusion. However, 5% 210Pb-excess over 226Ra measured in the same sample suggests significant gas-transfer of 222Rn from the intrusive basalt into the silicic magma a few months before the eruption.

At the end of April, the magma output rate had decreased by an order of magnitude, but rose again 5 May, two days after the occurrence of a deep seismic swarm migrating upwards from the mantle/crust boundary (www.vedur.is). The tephra emitted 5 May contains olivine with a core with Fo80 zoned to a rim of Fo50 indicating Fe-Mg exchange during 5-6 hours. A different olivine exposes Hopper crystal habit indicating crystallisation at significant undercooling (basalt injection into cooler silicic magma) and hypersthene overgrowth, which width suggests 6-18 hours of crystallisation if hypersthene growth rate is 1-3 square micrometers per hour (Coombs and Gardner, 2004). The time scale derived from the minerals is thus fully consistent with new injection of primitive basalt. This same tephra sample has 10% 210Pb deficit relative to 226Ra, which cannot be explained by radon degassing (several years to a decade of radon degassing would be needed). We speculate that the mantle derived basalt injected from approximately 25 km depth into the silicic magma chamber at approximately 5 km depth had similar 210-226Ra disequilibria as measured in the early Surtsey basalts (Sigmarsson, 1996) that erupted a few tens of km further south some five decades ago. Taken together, the magma mixing time-scales estimated in Eyjafjallajökull products is on the order of hours to days. Injections of gas-rich basalts into the silicic magma provoked a near-immediate explosive mixture of benmoritic magma.