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Rates, mechanisms and environments of fractional crystallization of basaltic magmas

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Fractional crystallization of basaltic magmas is driven by crystallization caused by cooling, at rates that depend on the temperature difference between the magma and its immediate surroundings. The size of the magma body and the processes of heat loss and crystal-liquid separation also influence the fractionation rate. All of these parameters vary between different parts of the transport and storage systems of basaltic volcanoes. This paper describes the fractional crystallization processes and rates in basalts in environments ranging from the mantle roots of volcanic fields, through crustal magma chambers to surface lava lakes, and unifies them under an over-arching model related to the thermal environment of the magma.

Fractional crystallization in the deep root zones of monogenetic volcanic fields may be exemplified by the high pressure fractional crystallization of clinopyroxene that accounts for compositional variations (Mg# 59 to 67) within a small volume alkali basalt eruption from the Auckland Volcanic Field. This eruption was fed by a dyke that traversed the lithosphere from near the depth of magma segregation (70 to 90 km depth). Fractional crystallization of liquidus clinopyroxene on the dyke walls was driven by the low undercooling along the dyke/mantle contact where the magma's liquidus temperature was close to the geotherm. At shallower depths, the greater magma/wall-rock temperature contrast produces a chilled margin, with no further fractional crystallization of the rising magma. Inferred magma transport times of hours to weeks constrain the duration of fractional crystallization in this environment.

Magmas that have lodged in chambers at low to medium pressure (e.g. many MORB)

undergo fractional crystallization involving plagioclase-bearing assemblages and yield trends of decreasing (^{226}Ra)/(^{230}Th) disequilibrium with increasing degree of fractionation. The slope of these trends depend on the fractionation rate, which is a function of heat flux and volume of the chamber. Rates of ca. 2 to 6 $\times$ 10^{-4} yr^{-1} derived from the isotopic data are consistent with the independently determined sizes (ca. 10^2 m thick) and heat fluxes (ca. 2 W m^{-2}) of mid-ocean ridge chambers. Under these conditions, evolved basalts may take thousands of years to be produced.

In the surface environment, the closed system Makaopuhi lava lake, Hawaii, is shown to have fractionated at a rate of ca. 8 $\times$ 10^{-2} yr^{-1} over 2 to 3 years, commensurate with its size (10^2 m) and very high heat flux (250 W m^{-2}).