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An experimental perspective on the diversity of (lower) arc crust: The role of equilibrium and fractional crystallization, water contents and oxygen fugacity

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We present and discuss experimental results designed to better understand fundamental differentiation processes operating in deep crustal magmatic systems. While investigations of intermediate to acidic plutons and volcanic products in the upper crust indicate that magma mixing, hybridization and interaction with and remobilization from crystal mushes are important processes, the question remains where and how the principal variety and differentiation is produced and how voluminous granitoids in island arcs and continental arcs are generated. We discuss results from nominally dry to hydrous experiments designed to understand crystallization driven differentiation processes, with an emphasis on the roots of magmatic arcs (Ulmer et al., 2018). An evaluation of the major element composition indicates that the cumulate line of descent (CLD) of hydrous systems is fundamentally different from dry systems (Müntener & Ulmer, 2018). Cumulates derived from hydrous experiments display elevated CaO and $Al2O_3$ contents at low SiO_2, producing voluminous andesitic to rhyolitic liquids, while dry systems follow plagioclase dominated, very different fractionation paths. The mineralogical and chemical composition of cumulates converges for very different hydrous primary magmas, indicating that fundamental phase equilibria under the conditions prevailing in the roots of magmatic arcs exert a strong control on the compositions of derivative andesitic to rhyolitic liquids. Oxygen fugacity increases through differentiation crystallization via efficient depletion of ferrous iron relative to ferric iron, resulting in an increase of fO_2 by about 2 log units in hydrous magmas, potentially providing an explanation for the generally more oxidized character of hydrous arc magmas. Enhanced stability of amphibole and garnet ($\pm$spinel) relative to plagioclase + pyroxene makes hydrous systems more efficient in producing Si-rich magmas. Melting experiments on amphibolite equally produce granitic – rhyolitic liquids yet their restites do not present the same variability of the cumulates of hydrous fractional crystallization experiments. Trace element modeling was performed along the liquid line of descent (LLD) of primary hydrous arc basaltic magmas based on experimentally determined partition coefficients and directly measured trace element contents of experimental glasses. Modelled trace element concentrations reveal that differentiation at $\sim$25 km depth (0.7 GPa) dominated by amphibole crystallization and delayed plag saturation results in concave REE patterns and elevated Sr/Y ratios. Differentiation at the base of the crust (35-50 km, 1.0-1.5 GPa) involves additional garnet producing intermediate to Si-rich liquids with trace element patterns that share the typical characteristics of Archean TTG gneisses such as strongly depleted HREE concentrations. Melting of mafic lower crust is thus not the only mechanism for generating crust in the Early Earth.

References

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