Fractional crystallization experiments from olivine-tholeiite to rhyolite at mid-crustal conditions and consequences for liquid extraction and magma transport

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Piston cylinder experiments starting from primary, hydrous olivine tholeiite at 0.7 GPa simulating near perfect fractional crystallization at mid-crustal levels were conducted to constrain phase assemblages, modes of cumulate phases, liquid compositions and trace element partitioning between liquid and solid phases along the liquid line of descent. Derivative liquids range from hydrous arc tholeiite (3 wt. % H_2O) at 1170C to andesite (980C) to rhyodacite (880C) to high-silica rhyolite (690C). The evolution of the melt fraction as a function of decreasing temperature is highly non-linear. Two ranges of extensive crystallization over a short temperature interval have been recorded: (1) between 1070 and 1000C the crystallization of cpx, opx, plag and amph + magnetite leads to a decrease of residual liquid from 80 to 40% driving the liquid composition from basalt to andesite; (2) below 700C where the final 20% liquid (relative to initial tholeiite) solidifies at the granite (eutectic) minimum within a few degrees. The crystallization behavior between 950 and 700C, i.e. from dacite to rhyolite, is of particular interest. Over this 250C interval only 44% of amphibole + plagioclase + magnetite (+ apatite below 900C) precipitate; the liquid compositions are strongly controlled by saturating phases, e.g. Ti, P, Ca and Mg contents decrease systematically providing excellent geothermometers to derive temperatures of derivative silica-rich liquids.

Complementary rheologic experiments were conducted to address the behavior of crystal-liquid-bubble systems under simple shear at high temperature-pressure conditions (Pistone et al., this conference) employing hydrous rhyolitic liquid, quartz crystals and a limited number of CO_2-rich bubbles. These experiments constrain the conditions that control weather magmas are likely to stall within the crust with potential extraction of interstitial liquids that can further rise or if they move as crystal-rich magmas through the crust ultimately forming shallow level plutons or generating large-explosive eruptions.

Combining the two complementary studies implies that mantle-derived, hydrous arc magmas will most likely encounter two stages where a sudden increase in crystallinity and, thus, bulk viscosity results in stalling of magma ascent thereby enabling effective extraction of interstitial liquids from crystal mushes (most likely by shear deformation of the mush and the consequent formation of melt enriched shear planes that allow escape of melt): (1) at ca. 1000C where the liquid is andesite saturated with cpx, opx, amph, plag and magnetite, and (2) close to the granite minimum at 700C where the liquid is a high-silica rhyolite saturated in plag, alkali-feldspar, quartz, biotite, apatite and Fe-Ti-oxide. In both cases, crystal-poor liquids can be extracted from the crystal mushes that further ascend and either form shallow level plutons or discharge as volcanics at the surface.