Ascent, degassing, crystallization and eruption of H_2O-rich mafic arc magma: A melt inclusion perspective

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Mafic cinder cones are common in subduction-related volcanic arcs. Such cones exhibit a wide range of eruptive styles and are often violently explosive, but the mechanisms driving explosive cinder cone eruptions are still poorly understood, as is the nature of their underlying plumbing systems. Melt inclusions in phenocrysts from tephra deposits provide a record of ascent, degassing and crystallization processes beneath these cones and show evidence for temporal changes in plumbing systems that mirror changes in eruptive style and magma composition.

We have analyzed major elements and volatiles in olivine-hosted melt inclusions from 14 cinder cones in the central and western Trans-Mexican Volcanic Belt (TMVB), including the historic eruptions of Paricutin and Jorullo. Melt inclusions from each cone have highly variable H_2O (typically <1 wt% to maximum values of 4 to 5.5 wt%) and CO_2 (<50 to 5000 ppm), corresponding to crystallization pressures of <100 bars to ~5 kb. This indicates that olivine crystallized from variably degassed melts over a range of depths extending from the mid-crust to very shallow levels. The highest CO_2 contents (≤5000 ppm) are found in potassic minettes and basanites from the western TMVB, whereas values ≤1500 ppm are typical of calc-alkaline basalts and basaltic andesites. Modeling of major element variations and comparison to phase equilibria demonstrate that olivine crystallization was driven by H_2O loss from melts during ascent. Olivine-melt geothermometry suggests temperatures of 1100-1200°C for these melts at depth. However, such geothermometers must be applied with caution because degassing-induced crystallization during ascent occurs increasingly below the equilibrium liquidus temperature as the melts ascend.

A puzzling feature of the inclusion data is that CO_2 does not decrease as rapidly with degassing as predicted by degassing models. A likely explanation involves open-system degassing in which relatively CO_2-rich vapor fluxes upwards through the conduit from degassing magma at greater depths. The high magmatic H_2O recorded by the inclusions is sufficient to drive explosive violent strombolian eruptions and produce vesicular ash and lapilli. Decreases in olivine crystallization depths over time at some cones reflect evolution of the conduit systems. During early stages, olivine crystallizes over a range of depths and is re-entrained by ascending batches of magma. In later stages, a dike-like storage region of degassed, crystallizing, and more differentiated magma forms at shallow depths beneath the cone.

Silicate weathering in anoxic marine sediments

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Two 25 m long sediment cores were taken at the continental slope of Sakhalin. Pore fluids and solids were analyzed to determine the down-core changes in dissolved cations, total alkalinity and particulate metal concentrations. The pore fluids showed consistent enrichments in dissolved Mg, Na, K and alkalinity while the particulate Mg/Ti and Na/Ti ratios decreased with sediment depths. A numerical transport-reaction model was applied to derive rates of silicate weathering from both pore water and solid phase data. The rates derived from pore water data were as high as the rates derived from the independent solid phase data. The depth-integrated rates expressed in tems of CO_2 consumption per area and time are close to the average rate of silciate weathering on land. These results imply that silicate weathering in anoxic marine sediments may be as high as continental weathering rates. The pore water modeling further indicates low pH values (6.2 – 6.8) and high concentrations of total dissolved inorganic carbon (100 – 200 mM) in the deeper methanogenic section of the sediment cores. UV adsorption measurements suggest an increase in dissolved humic acid concentrations with sediment depth. Silicate weathering rates were low within the upper sulfate-bearing sediment section and strongly increased below the sulfate penetration depth. It thus seems that silicate weathering may be promoted by low pH values and high concentrations of dissolved inorganic and organic carbon in the methanogenic zone. Most of the silicate minerals deposited in the slope sediments were delivered by the Amur River. The Amur River Basin is charaterized by low temperatures and permafrost conditions that may suppress the rates of continental weathering in the drainage area. Our results thus suggest that silciate weathering is shifted from the continental to the marine realm if continental weathering is inhibited by unfavorable climatic conditions and if the silicate minerals are deposited in anoxic marine sediments. This would imply that the negative feed-back between silicate weathering and climatic conditions may not be as strong as commonly believed since siliciate weathering is not limited to continental areas. Our results further imply that the sequestration of CO_2 in marine sediments could be a favorable option since CO_2 may be rapidly neutralized in marine sediments.