A statistical approach to the volcanic – plutonic connection

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The geochemical relationship between volcanic and plutonic rocks - whether the two are geochemically identical, or if the choice between eruption and intrusion is correlated with magma chemistry - represents a major unanswered question in igneous petrology. In one endmember scenario, felsic to intermediate plutons are proposed to represent the unerupted crystal mush from which crystal-poor eruptible melts are extracted. At the other end of the spectrum, it is argued that a nearly the entire volume of magma is evacuated during large silicic eruptions, and that the probability of eruption versus intrusion is instead largely a function of magma flux.

In the first scenario, parental magmas originating at depth experience substantial fractionation during volcanic melt extraction, leading to complementary volcanic and plutonic reservoirs. In the second endmember scenario, volcanic/plutonic fractionation is negligible, but geochemical differences on average between volcanic and plutonic rocks are still possible if high- and low-flux melts have distinct geochemical characteristics that are correlated with the eruptibility of a magma.

We have compared the geochemistry of ~300,000 volcanic and plutonic rocks by Monte Carlo analysis in order to produce maximally representative average compositions that reflect the influence of meaningful physical processes. The results indicate that while volcanic and plutonic rocks in general show remarkably similar major element trends, intermediate to felsic plutonic rocks, for a given silica content, display clear enrichments in Sr and Ba and depletions in Zr, Hf, and HREEs relative to their volcanic equivalents. More subtly, intermediate volcanic rocks are found to exhibit small but distinct enrichments in FeO and depletions in K2O relative to equivalent plutonics. These results suggest that, in the first endmember scenario above, volcanic/plutonic fractionation of plagioclase must be a key factor; while for the second scenario to hold, average water content must differ substantially between extrusive and intrusive equivalents. Further examination of trace element systematics combined with geochemical modelling allows for the discrimination between the influence of late stage crystal fractionation, versus the influence of water to suppress plagioclase relative to the ferromagnesian minerals and to delay the crystallization of most silicate minerals relative to zircon saturation.

Sulfur isotope systematics of geothermal fluids, Krafla, Iceland

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Sulfur is among the major components in geothermal systems. It is present in various oxidation states ranging from sulfide (S^{-II}) to sulfate (S^{+VI}) and present in solid phases and fluids (water and vapor). The source of the various sulfur compounds and the processes affecting their chemistry and fluxes are complex and in many respects not fully understood. In an effort to study the complex geochemistry of sulfur in this system, we obtained new chemical and isotopic data for fluids sampled from the Krafla field, NE Iceland, an active volcanic geothermal system. High-temperature well fluids discharging water and/or steam were collected having enthalpies ranging from 852 to 2774 kJ/kg. The fluids were analyzed for various sulfur compounds including, H_2S, SO_3, S_2O_3 and S_2O_3 in the water phase and H_2S and SO_2 in the vapor phase and for sulfur isotopes including ^{32}S, ^{33}S, ^{34}S and ^{36}S on H_2S and SO_4 in the water phase and H_2S in the vapor phase. For the sulfur isotope analysis the various sulfur oxidation states were sequentially precipitated as ZnS and $BaSO_4$, converted to Ag_2S and analyzed by Fluorination-GC-IRMS.

The observed concentrations in the waters were SO_4 = 5.1-280 ppm, H_2S = 27.6 to 120 ppm and S_2O_3 = 0-39.1 ppm. The concentrations in the vapor were H_2S = 46-2617 mg/kg condensate. No other sulfur phases were detected. The $\delta^{34}S$ in SO_4 and H_2S in the waters were +3.4 to +13.4‰ and -1.8 to -0.2‰, respectively, and H_2S in the vapor were +0.1 to +1.3‰. The $\Delta^{33}S$ and $\Delta^{36}S$ follow the theoretical value for mass-dependent fractionation in all cases.

The results indicate that the $\delta^{34}S$ for H_2S in the total discharged fluid are very close to 0.0‰, suggesting magmatic origin, either through magma degassing and/or magmatic sulfide leaching. The $\delta^{34}S$ ratio between H_2S in the water and vapor is considered to reflect boiling temperatures. For SO_4, the positive isotope shift observed may be explained by H_2S oxidation to SO_4 and/or SO_4 originated from the surface either through meteoric water and/or sulfate mineral leaching and/or mixing of these two different sources.

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