12-2003

Current Perspectives on Energy and Mass Fluxes in Volcanic Arcs

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A longstanding question concerns the relative roles of subducted sediments, oceanic crust, and hydrated subducting mantle versus heterogeneous wedge mantle in producing the observed spectrum. Important questions remain concerning (1) how to discern effects of compositional heterogeneity in the mantle and slab inferences of melting processes; (2) transport properties and element partitioning among hydrous fluids, silicate melts, and mantle slab minerals; and (3) the existence of competing evidence for slab melting. Large effects in young magmatic arc lavas often correlate with anomalies in other robust "slab tracers" (e.g., "Be") and provide strong evidence for short (e.g., 10^9 year) time scales for magma formation and transport from near slab depths. Implications of these data concerning mechanisms of elemental mobility, melting processes, and magma transport remain to be fully explored.

Chromologies and rates, mass contributions, and impacts of crustal level processes that influence arc magmatism. A clear message is that many and perhaps most, arc lavas (infiltrating apparently primitive basalt) may experience some form of open system modification that may obscure details of sub-crustal magma petrogenesis. However, the extent to which this is evident depends, element by element, on the leverage exerted by the "crystal filter" through which magma ascends. U-Th/He isotopic studies, petrographic crystal size distributions, and element diffusion profiles provide important constraints on time scales of magma differentiation, storage, and transport. Many studies document the entrainment of older crystal populations, magma mingling, and other open system processes that attest to complexities in the formation of many evolved arc lavas. An outstanding question concerns the extent to which such magmas inherit their isotopic disequilibria from mantle sources, as opposed to higher levels processes. Unraveling subtle compositional effects due to magma-crust interaction is a widespread problem, as evidenced by complex isotopic and elemental variations in arc lavas from other high level processes. Travelling sub-crustal compositional effects are widespread, widespread, and difficult to understand.

Endogenous and dynamics of magma feeder systems. Mantle-derived basaltic magmas likely provide the fundamental energy driving arc volcanism. However experimental studies suggest that many arc magmas, similar in composition to oceanic crust (e.g., gneissoid/andesite), form by means of water-saturated melting of mafic to intermediate amphibolite protoliths. Such melting may occur in response to upwelling of mixed plume and subduction-related hot basaltic liquids. Numerical models incorporating thermal diffusion and time scales place restrictive bounds on the details of this process. Crustal contributions to erupted magmas and volatiles often are difficult to distinguish from sub-crustal inputs, but must be resolved and quantified to understand fully the composition of mantle reservoirs, as well as the physical behavior of arc volcanoes.

Moreover, the evolution of specific arc magma suites can differ from one volcano to another, even on small spatial or time scales. Energy-constrained models, simultaneously combining thermodynamics and kinetics, are helpful in understanding cooling fractionation, open system interaction between magmas and wall rocks or other assimilant material, and potentially provide realistic and self-consistent tests to evaluate geochemical details of magma evolution.

Origin, budgets, and influences of magmatic volatiles. The physical effects of volatiles (mainly H2O) in driving magma ascent, vesiculation, and explosive eruptions need to be quantified. Of particular success in predicting eruptive styles hinges on a better understanding of volatile inventories and magma degassing. Volatile species (He, H2O, CO2, N2, Cl, etc.) provide additional constraints on sources and mass fluxes in subduction zones and play important roles in the behavior of arc volcanoes. Both mantle and slab sources appear to contribute to the fluxes of N2 and He; species, based on elevated CO2/H2O and N2/He ratios. However, degassing from subduction- and from ascending arc magmas combine to obscure volatile budgets.

Issues regarding work include (1) fluid degassing mechanisms (labeled to metasomatic reaction paths in subducting slabs), (2) reduction of large ("cryptic") fluxes estimated for C and S with independent (and often lower) estimates based on petrogenic constraints, and (3) the effects of devolatilization on isotopic compositions of gas species (used in certain flux calculations). These issues have important implications for gas behavior in magmatic systems, magma volumes, and recycling of volatiles from subduction zones. Improved remote sensing and compositional measuring are needed to better quantify local emissions. Also, existing monitoring should be expanded to other areas (particularly submarine volcanic plumes) and mass flux estimates (e.g., arc growth rates) should be improved to develop more representative element flux estimates. Sampling (humans, hot springs, ground/belting gas monitoring, and multiple inclusion studies) and analytical methods are varied, sometimes with different results that need to be reconciled. Estimated subduction input and diagnostic fluxes for H2O, CO2, and Cl are qualitatively similar, suggesting efficient recycling of volatiles back to the surface; however, human and plume plume signals currently are ignored for lack of adequate data.
Foukal's discussion is mainly about "slow variations," which appears to mean centennial-to-millennial time scales. However, in the "Future Directions" section, he discusses the desirability of the determination of the correlation between solar variation and climate.

Reply: Evaluation of Climate Sensitivity to Solar Influences Is an Important Goal

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The detection of an 11-year global temperature signal by Douglass and Clader and in other studies cited by David Douglas in his letter is an important achievement. However, these studies are at best the driver of the measured 11-year variations in total solar irradiance. They do not attempt to estimate the possible contributions of the equally well-measured 11-year variations in solar ultraviolet and X-rays, and in solar modulation of galactic cosmic rays. Both of these variable solar influences are under study as possible drivers of 11-year global temperature variations. [e.g., Hogg, 1996; Schwadron and Pas-Christensen, 1997].

These suggested mechanisms operate differently from the direct coupling of total irradiance to climate. So it may be premature to claim that the sensitivity to total irradiance has been measured. Also, to the extent that the sign of possible climate influences from solar UV [e.g., Shindell et al., 1999] and plasma output variations remains model-dependent, it seems uncertain in what sense the reported sensitivities represent limits.