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ELEMENTAL ARC OUTFLUX AND ARC GROWTH RATES

Theme: Subduction Factory

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In order to understand the impact of subduction zone magmatism on the broader global geochemical cycles, the MARGINS Subduction Factory Science Plan (pg. 75-77, 86-87) emphasized the necessity of quantifying the elemental outflux ('material output rate') of volcanic arcs. Despite major strides towards understanding subduction processes, the progress towards the quantification of the arc fluxes has remained slow. This is due to the uncertainties inherent to the key variables in the arc outflux equation such as the arc growth rates and petrological variables.

The elemental outflux of volcanic arc is calculated as follows:

elemental outflux = element abundance * arc density * arc growth rate

The arc density is the density of the melts and has a limited range of (~2.3-2.8 g/cm^3). The elemental abundance is the concentration of an element in the primary mantle melt, as a function of the extent of mantle melting and the solid/liquid partition coefficients of the relevant mantle lithologies. While the abundances of most elements in primary arc melts can now be estimated with roughly a factor of 2, larger uncertainties remain with respect to the extent of melting and the nature of primary arc melts (basaltic vs andesitic). The arc growth rate is the mass of melt added per unit time (or gain of arc mass per unit time). It is commonly given in units of km^3/per km of arc length/Myr (shortened to km^2/Myr). The arc growth rate is least well known. Estimates may vary about a factor of 5 and more within single arcs and between different arc settings.

In general, two methods are used to determine arc growth rates. The methodology of Reymer and Schubert (1984) estimates the increase in net crustal growth per unit time from geophysical measurements of the present-day crustal thickness, the duration of volcanism and simplified models of crustal accretion. Average numbers for net arc growth rate range between 20-40 km^2/Myr, but higher values of 90-180 km^2/Myr have also been calculated, with or without accounting for crustal loss by erosion (Stern and Bloomer, 1992; Dimalanta et al., 2002; Jicha et al., 2006). The second method determines the volcanic output rates by dividing the volcanic output volumes by the duration of the activity (Crisp, 1984; White et al., 2006). Assuming an average arc length of 1000 km, values between 10 and 100 km^2/Myr are derived that are then converted to arc growth rates by estimates of the intrusive:extrusive ratios.

Either method has shortfalls. The Reymer and Schubert (1984) approach depends on the crustal accretion model and does not account for crustal loss by erosion, delamination or tectonic thinning, nor for episodic growth during the lifespan of arcs. Arc growth rates derived from volcanic output volumes are limited to young volcanic arcs and are subject to considerable uncertainty owing as the intrusive: extrusive ratios may vary between 1:1 and 1:200 (White et al., 2006).

The current data on arc growth rates allows for first-order estimates of the arc outflux, but remain overall limited in their potential by the sum of inherent uncertainties. Because of the nature of these uncertainties, there is no easy way out. However, a concerted effort of towards better determining the variables in the arc outflux equation will likely make progress. Owing to its overall importance for the quantification of arc fluxes, the issue of elemental fluxes and arc growth rates should deserved a thematic focus in the successor program to the MARGINS 'Subduction Factory'.

An important aspect of the elemental outflux and arc growth rates equations is that their variables are interrelated. This is because the volumes of the extrusive series are directly related to the magma volume generated by partial melting that in turn plays a vital role in controlling the magnitude of outfluxes of volcanic arcs. The extent of melting is influenced by tectonic parameters, such as crustal thickness, convergence rate, distance from trench, but it is also reflected in the major element compositions of arc magmas that make up the bulk of the magma volume produced. Understanding the interrelation of compositional, physical and structural variables that influence the major element composition of arc magmas should result in better constrained rates of the arc outfluxes through time.

Thus, this problem can be addressed by closer integration of geochemistry with geology and volume of extrusive series emplaced through time. One way to proceed could be a comprehensive, regional (per subduction zone) and global evaluation of existing data, now partly pre-compiled in the online data bases accessible through EarthChem (http://www.earthchem.org/). Such data evaluation could weigh known arc growth rates against the most recent data on arc crustal thickness and composition, as well as compositional and volumetric data of intrusive and extrusive series and a broader variety of subduction zones parameters. Another important avenue is to conclusively identify the processes that control arc magma formation and differentiation. The composition of arc magmas is globally unique despite the physical and thermal diversity of subduction settings worldwide (Plank and Langmuir, 1988). Yet, there is no consensus on the key processes of arc magma genesis (slab melting, mantle melting, mantle metasomatism, melt-rock reaction, crustal contamination and assimiliation). Understanding the dominant processes of arc magma genesis will provide better constraints on the intrusive:extrusive ratio of magmatic rock series and improve quantification of the relative contributions from slab, crustal and mantle reservoirs. When combined with extrusive volumes, improved estimates of material flux rates will result from well-chosen study areas.

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