Surface processes, weathering fluxes and CO2 sinks in arc terranes

Chemical weathering of silicate rocks acts as a long-term sink of CO_2. Modern conceptions of the geochemical carbon cycle are built around the hypothesis that CO_2 consumption by weathering is sensitive to climate, providing a stabilizing feedback mechanism (Berner et al., 1983; Walker et al., 1981). At the watershed scale chemical weathering and CO_2 consumption rates are generally believed to depend on lithology, temperature, runoff, uplift/erosion rate, and relief, among other variables. A number of recent studies have demonstrated that in granitic or cratonic terranes, the net influence of climate on weathering and CO_2 consumption rates is not as strong as had been expected, as erosion rate, also plays an important role (Gaillardet et al., 1999; Riebe et al., 2004; West et al., 2005).

Whereas weathering rates in granitic and cratonic terranes have been well studied, information on weathering in volcanic terranes is sparse. Available data suggest that mafic – intermediate volcanic terranes play a disproportionately large role in the carbon cycle. They have high abundances of Ca and Mg silicates, the weathering of which results in much greater CO_2 consumption rates than the weathering of the alkali silicates typical of continental crust, which is an inefficient CO_2 sink (France-Lanord and Derry, 1997). They also have mineralogy (olivine, pyroxene, amphiboles) and texture (volcanic glass, ash) that weather much faster than those typical of most cratonic terranes. Additionally, most active volcanic centers are associated with arcs and hotspots that are adjacent to oceans where marine moisture and orographic effects can lead to high runoff and erosion rates, and many of the active island arcs today are located in the wet tropics (Vorosmarty et al., 2000). All of these features suggest that weathering and CO_2 consumption rates of volcanics should be high. While there are relatively few published data from streams draining active arcs that permit estimation of CO2 consumption rates, there is evidence to support the hypothesis that arc weathering is an important CO2 sink (Figure 1).

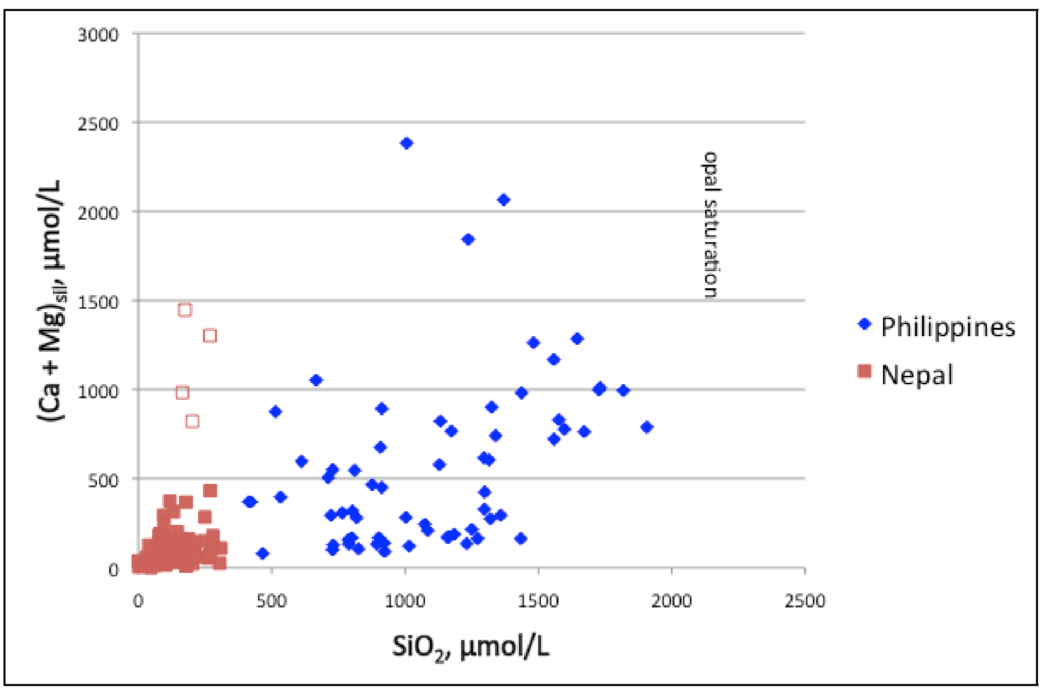

Figure 1. Ca and Mg concentrations derived from silicate weathering $[Ca+Mg]_{sil}$ in Himalayan and Philippine streams vs. silica concentrations. $[Ca+Mg]_{sil}$ is a good estimate of CO2 consumption. The Philippine data has significantly higher $[Ca+Mg]_{sil}$ (ave 563 vs 125 µmol/L)and $[SiO_2]$ (ave 1032 vs 121 µmol/L).

Recent studies suggest that basalt weathering is climate-sensitive in the way required by models of the carbonate-silicate cycle (Dessert et al., 2003). Further, high islands in the Pacific are important sources of biogeochemically important constituents to the oceans (Lyons et al., 2005; Milliman et al., 1999; Sholkovitz et al., 1999), and weathering rates on basaltic islands are high (Louvat and Allegre, 1997). All these data suggest that volcanic terranes associated with volcanic arcs or plume-related island groups are a major component of global geochemical cycles. Yet despite the fundamental importance of weathering of volcanic rocks in the tropics, data on chemical fluxes from these terranes are sparse, and there are few process level studies that can place bounds on the long-term behavior of basaltic weathering systems in the way that recent work has done for granitic terranes.

The contribution of arc terranes to global weathering budgets is poorly known in part because rivers in these settings tend to be small and have not been sampled systematically (or in most cases at all) for geochemical purposes. Unlike major continental regions, where a single large river can give information about a large fraction of both the continental surface and total runoff, island arcs are a type of “non-point source” problem. Many smaller streams deliver large loads per unit basin area, and the aggregate flux can be quite large, but no one stream samples a large region. This effect was shown to be of enormous influence for sediment load by Milliman et al. (1999), but has yet to be quantified for chemical and CO_2 fluxes. Our overall hypothesis is that the weathering contribution from arc terranes, particularly those located at low latitudes, has been systematically underrepresented in current global weathering flux estimates.

Despite intriguing patterns seen in the available data, in point of fact the data sets on arc weathering are too limited to rigorously assess the hypotheses that 1) arc weathering is a quantitatively significant contribution to global CO_2 consumption, and 2) that weathering rates in arc terranes a sensitive to climate in a way that could provide a viable climate-weathering feedback on geological time scales. Several recent studies (cited above and Dessert et al., 2009) have added importantly to our knowledge, and we are now at the point that targeted studies could provide substantial insight into the role played by arc weathering in the global carbon cycle. Furthermore, the topic of coupling between the topographic evolution of arcs (via constructional volcanisms, tectonic uplift/subsidence, and erosion) and weathering fluxes is almost completely unexplored, yet this has been a fruitful area of research in continental systems. The time seems ripe to focus on the role of convergent margins as a volatile sink as well as a volatile source.

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