

Enhancement of chemical weathering

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Much attention has focused in recent years on the relative efficacy of plant communities in accelerating the chemical breakdown of rocks on land. The scale of vegetative weathering enhancement as it occurs today varies locally with a multitude of parameters: minerals being weathered, and hence substrate lithology; slope and aspect of terrain; successional stage of a plant community (primary, secondary, climax); ecosystem (e.g. taiga, temperate forest, grassland, bog); micrometeorology; depth to bedrock; and on and on. Carbon dioxide feedbacks on plant activity (e.g. differences in productivity, shifts in biomass bulk chemistry, altered root mass and root to shoot growth ratios) are complicated (Bazzaz, 1990; Rogers *et al*, 1994). We would expect such feedbacks under varied levels of atmospheric CO₂ in Earth's past to alter the capacity of plants to solubilize minerals. Botanical evolution must also be considered. The transition from more primitive biota to vascular plant communities in the Upper Silurian and the Devonian represents a sweeping transformation of the continental weathering regime, but the subsequent appearance of angiosperms and grasses may also have led to marked shifts in the degree of vegetative enhancement of chemical weathering (Knoll and James, 1987). The intricacies of the natural world notwithstanding, we believe that those working in this field have done much in recent years to narrow the range of reasonable values for vegetation's effects on global weathering rates (Schwartzman, 1994; Drever, 1994; Berner, 1992).

We have already presented some aspects of our Hawaiian and Mt. St. Helens work which bear on this problem (Cochran and Berner, 1993; Cochran and Berner, 1992). The sandbox experiment at the Hubbard Brook Experimental Forest in the White Mountains of New Hampshire commenced ten years ago and continues today. Bormann *et al* (1987) have described the mechanics of the experiment. Three pits measuring 7.5 m square by 1.5 m deep were impermeably lined and filled with a well-mixed, relatively unweathered granitic sand. One was planted with two grass species, little bluestem (*Andropogon scoparius* Michx.) and switchgrass (*Paricum virgatum* L.). Another was

planted with red pine (*Pinus resinosa* Ait.). The control plot was to have been kept unvegetated by covering with a tarp during the hottest weeks of summer; instead, lichens, algae and mosses colonized this plot and are thriving in it. This is fortuitous: as a control, it probably comes much closer to pre-vascular plant (lower Paleozoic) conditions than would a sterile box of sand. The boxes are outdoors and receive natural rainfall. Leachate waters draining the plots have been collected over most of the last ten years.

We have performed chemical analyses on more than 120 of these waters as of this writing. Highly accurate measurement of leachate fluxes from the plots were only begun recently. Lacking these, we must calculate elemental fluxes indirectly, since although precipitation input to each plot is identical, evapotranspiration causes different amounts of water to drain from each. We correct for this by scaling to chloride. This assumes similar input of Cl to each plot in precipitation (plus throughfall for vegetated plots), negligible storage of Cl in secondary phases (confirmed) and plants (botanically reasonable for these species but not yet verified), and negligible Cl supply from the primary minerals being weathered (which are Cl-poor). Ca, Mg, K, and Si are utilized and stored to an appreciable degree in many plants (see Epstein, 1994, for a discussion of Si) so cannot be used as direct weathering proxies without knowing the amount and chemical composition of bulk biomass. Na, however, is typically released to solution. Once corrected for precipitation input the ratio of Na to Cl leaving the plots in solution should be directly proportional to the amount of sodic plagioclase weathering which has occurred.

For the samples we have measured to date, which span the ten years of the study, weathering-derived sodium scaled to chloride varies widely but averages 1.8 times as great from the grassed plots and 7.3 times as great from the pine covered plots as from those with primitive vegetation. These numbers generally exhibit a rising trend over the course of the experiment. Actual water flux data and many more water analyses are essential before we can specify the precise degree to which these grasses and pines have accelerated the weathering

of plagioclase in the sandboxes. But the sense of their action is unmistakable. Once we know primary mineralogy and biomass composition, a full mass balance treatment (as described by Velbel, 1986) should enable us to calculate weathering acceleration terms for each major mineral group in the sandbox substrate. The amount of vegetative weathering enhancement reflected in our measurements, it should be noted, is likely reduced in this experiment by several factors: The rain at Hubbard Brook is anthropogenically acidified. Its pH (3.9 to 4.5) falls in a range where kinetic laws for silicate dissolution rates display pH dependence. Acid rain would be expected to act more on the bare plot than beneath trees or grasses since acidity of waters impacting plants tends to be partially or wholly neutralized before it reaches the ground as throughfall. The relative youth of the trees also suggests the observed effect is a minimum, since they have not had time to saturate their substrate with roots. Several studies have shown that the amount of chemical alteration in the rhizosphere immediately beneath trees is linked to the presence of fine roots (April, 1990; Cochran and Berner, 1993). We must emphasize that these are results from an ongoing collaborative study, and as such are preliminary.

The sandbox experiment is one examination of several plant species in one location on one fresh substrate. It gives us a good sense of what plants can do when they colonize a newly exposed area, but cannot tell us what they actually are accomplishing today in anything like a global sense. Catchment-scale studies such as those of Drever and Zobrist (1992) and Velbel (1992) broaden our sense of the effects of mature, diverse plant communities in nature. It is plausible that such studies may reveal a quantitative link between some measurable feature of modern plant communities and their substrate-

weathering efficacy. The potential connection between net primary productivity or some related parameter (such as actual evapotranspiration as suggested by T. Crews, personal communication) and the need for plants to extract new nutrient inputs from bedrock might provide the basis for such a link.

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