Biotic enhancement of weathering redux

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Introduction

The role of land biota in affecting chemical weathering rates and the carbon cycle is now under active investigation (see Drever, 1994; Cochran and Berner, this volume). Estimates of the present biotic enhancement of weathering range over at least two orders of magnitude. Laboratory and field studies provide invaluable clues. Another approach has been the inversion of the temperature history of the Earth's surface, a procedure followed for the pre-vascular plant regime of the early Phanerozoic by Berner (1993, 1994). We have attempted the same approach for the Precambrian (Schwartzman and McMenamin, 1993). The possible multifold processes contributing to the biotic enhancement of weathering and its evolution over geologic time are discussed here.

Discussion

We have defined the biotic enhancement of weathering factor ('B') in a quantitative way as follows: B is how much faster the silicate weathering carbon sink is under biotic conditions than abiotic, at the same atmospheric carbon dioxide level (p_{CO_2}) and surface temperature (Schwartzman and Volk, 1989). Although some biotically related effects may locally/temporarily reduce chemical weathering (e.g., macropores in soils, microbial coatings shielding grains), the net biotic role is very likely to increase global denudation rates. There is a consensus that $B > 1$, if only because of biotic elevation of p_{CO_2} in soils (possibly significant even before vascular plants; Keller and Wood, 1993). Just how much bigger is still under contention. We have argued that B is probably on the order of 100 or even greater. Estimates to date have mainly come from field and laboratory studies of recent weathering. The classic study of Jackson and Keller (1970) indicated $B = >10$ to >100 for a lichen species growing on Hawaiian basalt, although this study has recently generated some controversy (Berner, 1992; Jackson, 1993; Schwartzman, 1993; Cochran and Berner, 1993). Cochran and Berner (1992) reported initial enhancements by vascular plants of one or more orders of magnitude. Their more recent results are reported in this volume. Berner's modeling (1993, 1994) gives an effective enhancement of about 7 times for the continents colonized by vascular plants relative to pre-vascular plants, similar to a field estimate from a comparison of vegetated to unvegetated portions of the same watershed in the Swiss Alps (Drever and Zobrist, 1992) (this agreement is probably coincidental, considering the likely differences in biota and other factors). Alpine weathering is not purely abiotic, since rock surfaces are microbially colonized, humus is blown into crevices, and frost wedging, a proposed global biotic effect, is operative. It is important to note here that B is defined relative to an abiotic rate. Since no purely abiotic weathering presently occurs on the Earth surface, indirect means are necessary to set limits on this parameter.

An indication of the possible magnitude of B comes from the ratio (about 1000) of the rate of chemical weathering in a tropical soil to that of a computed abiotic two-dimensional bare rock rate at similar temperatures and runoff conditions (Schwartzman and Volk, 1989), though several caveats are in order (e.g., the likely extent of soil cover and the contribution from porous volcanics under abiotic conditions, which probably make the ratio of 1000 an upper limit to B).

The diversity of effects on different scales entailed by biotic enhancement of weathering is shown in Figure 1. The local and direct effects are perhaps

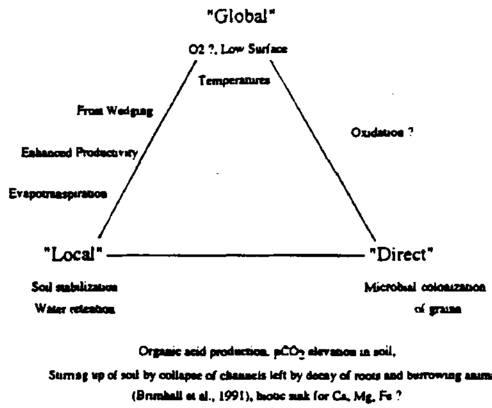

FIG. 1. Biotic enhancement of weatering: summary of proposed factors.

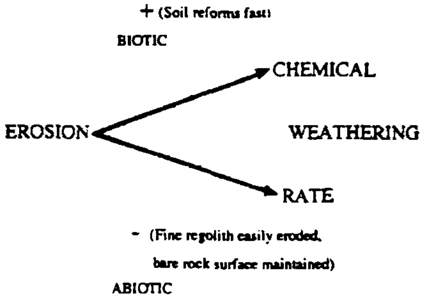

FIG. 2. The effect of erosion on chemical weathering rate under biotic and abiotic conditions.

better understood than the global (e.g. frost weathering may result from biotically-mediated global cooling). The problematic role of atmospheric oxygen includes the possible increase of productivity of land biota by virtue of an ozone shield. As land biota has evolved, enhancement of weathering has increased via the stabilization of soil under the protective cover of the first microbes (so-called 'cryptogamic' soil; note that microbially crusted soils are much more easily eroded than those stabilized by plants) and later higher plants and their living and dead associations (rhizosphere, organic debris), as well as other biotic effects including soil carbonic and organic acid elevation (Schwartzman and Volk, 1989, 1991; Retallack, 19990). On an abiotic land surface water and wind erosion are likely to preempt significant accumulation of soil, even on slight slopes. In the absence of evapotranspiration chemical denudation should be reduced from the lack of water flow-through alone (Berner, 1992; Drever, 1994). In contrast, under biotic conditions, rapid erosion on high slopes, the apparent locale for most chemical denudation (Stallard, 1992), leads to acceleration of chemical weathering since soils reform rapidly with biotic colonization and stabilization (see Figure 2).

Conclusion

If the enhancement effect of vascular plants/lichens/bryophytes is one order of magnitude over 'primitive' land biota of the Precambrian, then only another factor of 10 is required of the latter over an abiotic regime to give B $\sim$ 100, the order of magnitude we infer from inverting the Archean/early Proterozoic record from modeling the carbonate-silicate cycle, assuming a high surface temperature (50–70°C) scenario and a carbon dioxide greenhouse (Schwartzman *et al.*, 1993; Schwartzman and McMenamin, 1993; Schwartzman, in press). An additional order of magnitude for the net enhancement of land colonized by primitive biota over abiotic appears to be plausible given the range of potential effects on each scale.

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