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Using integrated experiments and mathematical modeling to upscale biotic weathering processes from pore to field and global scales

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Soil mycorrhizal fungi act through chemical interactions at nanometer scale to dissolve minerals, and transport weathering products to plant symbionts through metre scale mycelial networks at diurnal timescales [1]. Biologically-mediated soil development occurs at regional scale over millenia (ka) and coupling between ecological, geological and atmospheric systems is apparent over evolutionary (Ma) timescales [2]. Our hypothesis is that quantification of biologically-driven weathering reactions at molecular scale provides a basis for new conceptual approaches to processes such as soil formation and atmospheric CO2 evolution that occur over much larger temporal and spatial scales. To test this we have applied an integrated suite of observations at scales from nanometre to decimetre using common minerals, fungi and physical and chemical conditions. Our experiment results demonstrate that fungal hyphae-grain contact leads directly to mass loss from mineral grains over time [3,4]. Cell exudates and nanoscale cell-mineral interaction forces progressively modify mineral surfaces and alter the pore microenvironment, conditioning subsequent biotic and abiotic weathering mechanisms. Crucially, these processes are directed by mycorrhiza towards minerals which yield the best nutrient supply for plants [1,4]. Here, we describe the development of mathematical models for key nano-scale weathering processes coupled to stochastic, agent-based simulations of hyphal growth at the μm to cm scales which permit quantitative analysis of the dynamic interactions between plant carbon energy supply and soil mineral weathering rates, mediated by mycorrhizal fungi. This conceptualisation of soil profile weathering is transferred to global scale models by aggregating soil profile descriptions at continental scale [2,5]. The resulting global models thus reflect processes that are transferred from both the nanometer and soil profile scale as constraints on global weathering and its mathematical description.

[1] Leake et al. (2008) Mineral. Mag. 72, 85–89. [2] Taylor et al. (2009) Geobiology 7, 171–191. [3] Bonneville (2009) Geology 37, 615–618. [4] Schmalenberger et al. (2009). Geochim. Cosmochim. Acta, 73(13), A1177. [5] Banwart et al. (2009). Geochim. Cosmochim. Acta, 73(13), A84.