Integrating multi-scale experiments and modeling to couple biotic weathering at nano 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 [1]. Soil development occurs at regional scale over millenia (ka) and coupling between ecological, geological and atmospheric systems is apparent over evolutionary (Ma) timescales [2]. We hypothesise that biologically-driven weathering reactions at molecular scale persist through scale transitions to exert strong controls on soil formation and atmospheric CO_2 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]. 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].

Here, we describe the development of numerical models for key nano-scale weathering processes coupled to stochastic, agent-based simulations of hyphal growth at the micron 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. These profile-scale data are aggregated in a continental scale process-based model [2,4] and tested for representation of the global carbon cycle at evolutionary timescales by comparing with proxy data for paleoenvironmental conditions [5].

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Strontium incorporation into carbonate granules secreted by earthworms

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Earthworms secrete significant quantities of calcium carbonate in the form of granules (0.5mg $CaCO_3$/g worm/day), which can also contain other metals depending on the soil content (Pb, Mn, Mg). This may affect metal bio-availability and impact upon element bio-geo-cycling. We have examined Sr incorporation into the granules produced by earthworm *Lumbricus terrestris* cultivated in Sr containing soil. These granules contained up to 3.5% Sr with a positive correlation between Sr concentration in pore water and Sr in the granules. Sr-μXRF maps of the granules show Sr enrichment within the outer region of the granules. These both suggest that the mechanism of Sr incorporation is either adsorption onto or co-precipitation during granule growth.

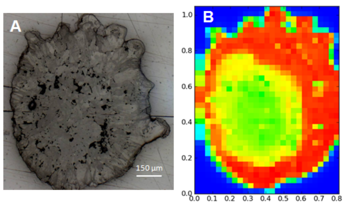

Figure 1. Slice of a calcium carbonate granule produced by ***Lumbricus terrestris*** incorporating 1.2% strontium: (A) Zeiss microscope image; (B) Sr-μXRF map: axis are in mm and the colour bar indicates: blue - low Sr and red - high Sr.

Analysis of Ca-μXANES and Sr-μEXAFS suggests that most Sr substitutes for Ca in the rhombohedral calcite structure rather than producing the orthorhombic carbonates. The results significantly improve our understanding of Sr sequestration within bio-synthesized carbonate granules in the context of its biogeochemical cycle. In terms of earthworm tolerance to Sr, earthworms showed significant mortality at soil bulk concentrations above 1000ppm.