

Speed limits to soil weathering and CO₂ withdrawal

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Weathering fluxes in soil-mantled landscapes are capped by a global maximum that has important implications for Earth's long term climate. We identify the empirical, statistical and theoretical limits to climate, weathering and uplift feedbacks using a new global compilation of long term, soil-based denudation and weathering rates from cosmogenic nuclides and short term, river-based sediment and dissolved loads. Weathering accelerates by the increased exposure of minerals to erosion, and recently it was suggested that 50% of the global CO₂ withdrawal occurs in the world's active mountain belts [1]. The observation that chemical weathering rates and physical erosion rates are tightly correlated has vindicated this hypothesis. But this relationship is predominantly valid for soil-mantled landscapes, and not rapidly uplifting mountain belts. We show that the rate of soil production obeys a global 'speed limit' of 270 t km⁻² y⁻¹, and the associated soil weathering flux a limit of 135 t km⁻² y⁻¹, corresponding to denudation and weathering rates of 100 and 50 mm ky⁻¹, respectively. Erosion rates may far exceed the soil speed limit, and are typically associated with landscapes of high relief and hillslope gradients [2]. There, erosion is governed by mass wasting processes typical of non-soil-covered landscapes in active mountains [3]. Yet chemical weathering rates from dissolved loads of rapidly eroding mountain rivers suggest that these landscapes also obey or fall below the limit of weathering observed for soils. Considering that such mountain belts are a small component of the continental land surface, we quantify that even if weathering fluxes in such areas were higher than today, they would represent a minor contribution to global CO₂ withdrawal. Therefore, Earth's long term climate sees little drawdown and more drawbacks from uplifting areas where denudation drives above the soil speed limit.

[1] Hilley and Porder (2008) *Proc Nat Acad Sci* **105**, 16855-16859. [2] Montgomery and Brandon (2002) *Earth Planet Sci Lett* **201**, 481-489. [3] Dibiase *et al.* (2010) *Earth Planet Sci Lett* **289**, 134-144.

Why do earthworms synthesize ACC?

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From the early work by Darwin [1] several hypotheses have been proposed to answer this question, namely pH buffering of the blood and the ingested plant material, respiratory functions, egg formation or simply spurious mineralization.

In this study we investigated the microstructural transformations which take place during the carbonate formation inside the calciferous gland of the earthworm species *Lumbricus friendi* Cognetti. We firstly identified the presence of ACC [2] by FTIR and then we followed the different evolution stages of calcium carbonate in the precursor fluid previous to the formation of the solid phases by performing *in situ* XRD experiments.

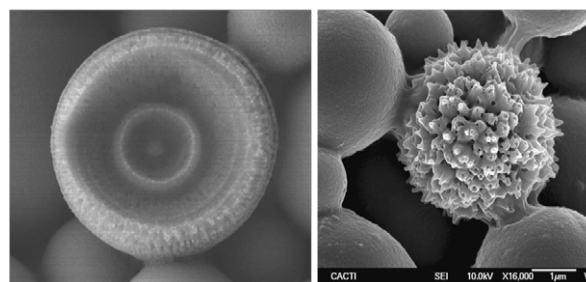


Figure 1. Two transformation stages from ACC to crystalline phases in earthworm's spherulites.

The results presented here shown that the formation of crystalline polymorphs of calcium carbonate in earthworms is preceded by the precipitation of ACC in a process that seems to follow a truly biomineralization mechanism, controlled by the organism. The high solubility is beneficial for temporal storage of calcium carbonate ions which could then get dissolved and used elsewhere according to the organism's requirements. Stabilisation of ACC seems to be achieved thanks to the presence of macromolecular constituents in the organic matrix, which also could be selectively used to promote the elimination of carbonate excess by nuclei induction of the crystalline phases and thus providing an efficient mechanism for Ca⁺² control in the intracellular fluids.

[1] Darwin, C., (1881). John Murray, London [2] Gago-Duport *et al.* (2008) *J. Structural Biology*, **162**, 3, 422-435.