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Modelling the life-environment interface in ancient shelf seas

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The co-evolution of life and environment is a dynamic system of feedbacks. In Neoproterozoic and Cambrian ocean shelf seas, evolving biota and redox conditions created biogeochemical feedbacks which are hypothesized to have permanently shifted the redox state of the ocean and sediment and enabled complex ecosystems to emerge. Models can explore these feedbacks and allow hypotheses on the effects of changes to life or the environment on the other to be tested. But connecting localized, short timescale matter and energy fluxes through ecosystem components to global Earth system cycles over geological timescales is a particular modelling challenge. When modelling processes and cycles over geological timescales, smaller scale processes are often taken to be in steady state and abstracted out. However, when the small-scale feedbacks at the life-environment interface compound directionally, the assumption of steady state is violated, and the very dynamics leading to long-term ecosystem evolution can be left out of models. We introduce a 1D biogeochemical column model of a shelf sea in the PALEO modelling framework [1] to explore the compounding interactions between biology and the physical and chemical environment. The model consists of a coupled ocean-sediment system with key components of early ecological networks, such as size-structured plankton communities, benthic microorganisms, early filter feeders and simple burrowers, represented by ecological functions. Representing the biological populations explicitly presents an alternative to standard approaches in biogeochemical models, where the biological pump in the ocean or bioturbation in the sediment are parameterized from modern data, and the water column and sediment column are often explored separately without the biological link between organic reservoirs and fluxes. Our approach allows the redox profile in the ocean and sediment to be formed directly by modelled biological activity, and nutrient cycling to be linked to this activity. The model is being used to explore hypotheses on the effects of evolving filter feeders and burrowers on redox conditions and phosphorus cycling, but can be adapted for a range of time periods where there is interest in life-environment feedbacks, such as mass-extinction events.

[1] https://github.com/PALEOtoolkit