The effects of transport scaling and reaction dynamics in the bioturbated zone as exemplified by sedimentary S, Fe, and C cycling

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One apparent trend in the geologic record is a progressive decrease in averaged sedimentary pyrite $\delta^{34}S$ from the Neoproterozoic into the Phanerozoic. This decrease tracks macrobenthic community development, and likely reflects impacts of bioturbation on biogeochemical cycling during early diagenesis. The most common models of bioturbation in muds view particle and solute transport as either diffusive (i.e., random walk) or nonlocal, both over a characteristic vertical length scale. Such models can incorporate averaged effects of increased solute exchange, labile organic matter entrainment – penetration, and a portion of reoxidation during bioturbation, all of which affect properties such as S isotopic compositions and associated C-S-Fe cycling. The preserved S/C ratio nevertheless appears to be largely independent of bioturbation. Increased sediment-water exchange alone maximizes net S isotopic fractionation and minimizes dependence on seawater SO_4^{2-} ($> \sim 0.2$ mM). However, these model simplifications obscure a wide range of biogeochemical interactions that depend on details of 3-D biogenic structure scaling and dynamics (e.g., redox excursions; oscillations). The reoxidation of reduced S associated with bioirrigation, particle reworking, and Fe, Mn-oxidant injection or transient storage further enhances net S isotope fractionation through diffusive distillation and refluxing. Critical scaling factors for both solute and particle transport-reaction relations include ventilated burrow diameters, spacing, length, and structure residence time. Scaling reflects life habit, age –size relations, feeding mode, and abundance of benthos, which vary with depositional environment. Microbial communities are intimately adapted to these factors, for example, cable bacteria are ubiquitous in bioturbated muds but their distributions reflect biogenic structure dynamics and transport-reaction sub-domains. Compositional patterns are highly dependent on transport-reaction scales and the dynamics thereof, and can be extremely heterogeneous in bioturbated deposits.