Electron shuttling and elemental cycling in the seafloor

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The seafloor (or marine sediment) is an invaluable part for the cycles of chemical elements (carbon, nitrogen, sulphur) through planet earth. For example, more than half of the reactive nitrogen (e.g. ammonium) is converted to unreactive N2-gas in the sediment. The seafloor is also an efficient reactor that recycles 90% of the sulphur and carbon it receives, back to the water column. The settling of organic carbon, which is a reduced compound (i.e. rich in negatively charged electrons), starts a complex series of redox-reactions (oxidation of organic carbon coupled to the reduction of, e.g., oxygen). The transformations that occur when chemical species pass through the upper 10 – 100 cm of the seafloor (also called 'early diagenesis'), determines which elements and what fractions are either stored in the deep mantle or are recycled back to the ocean and atmosphere. Redox transformations are strongly affected by the presence or absence of micro- and macro-organisms. Biological activity by small critters or certain types of micro-organisms can have a large effect on geochemical cycling within the seafloor. During my PhD project, I investigated the impact of two types of ecosystem engineers on the biogeochemical cycling of carbon, iron, sulphur and associated trace elements in the seafloor: Long filamentous micro-organisms (cable bacteria) and large macro-fauna (bioturbators). Both ecosystem engineers stimulate the recycling of carbon, sulphur and iron. Cable bacteria do this by acidifying the top few centimetres of the sediment, and bioturbators by enhancing the transport of solid particles and dissolved substances in the sediment.

A field study in the coastal North Sea showed that the acidic environment generated by cable bacteria in the upper 5 cm of the sediment promotes the dissolution of acid sensitive minerals like FeS and CaCO3. The dissolution of these minerals releases iron and related trace metals (manganese, cobalt, arsenic) in the pore water. A fraction of these elements re-precipitates at the oxygen-rich sediment-water interface. However, under fluctuating oxygen concentrations (from fully oxygenated to oxygen depleted), cable bacteria actually amplify the seasonal cycle of arsenic release from the sediment, as revealed by a study in Lake Grevelingen. Animals that inhabit the seafloor stimulate the transport of solid particles by their burrowing activity (bio-mixing) and enhance the exchange of dissolved species between the pore water of the sediment and the overlying water column by the flushing of their burrows (bio-irrigation). A field study in the Blakeney salt marsh (Norwich, UK) showed how bioturbation actually limits the burial of organic carbon and reduced iron-sulphide and diagenetic modelling reveals that the geochemical effects are already noticeable at very low bioturbation activity. Implementing these results in a long-term model, showed that the evolution of burrowing could have induced a low-oxygen atmosphere in the past and might have triggered global warming by increasing atmospheric CO2 during the Cambrian explosion (when multicellular life developed in the ocean, ~500 million years ago). Finally, field data following a human-induced sediment mixing event (which is essentially equivalent to human bioturbation) from the Belgian Coastal Zone suggests that bottom trawl fishing and dredging also limits organic carbon burial, and provides a clear illustration of how human activity can inadvertently change the coastal carbon cycle.

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