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Benthic Disturbance-Recovery Dynamics in a Changing Coastal Ocean

Imaging the effects of terrestrial sediment deposits on intertidal sandflat pH and O_2 with VisiSens™ technology

Kay Vopel, Aysha Hohaia, Chris Pook, and John Robertson
Institute for Applied Ecology New Zealand, Auckland University of Technology, New Zealand

Changes in climate and land use increase the supply of terrestrial sediment (hereafter, TS) to coastal water worldwide but the effects of this increase on ecosystem functioning are not well known. Previously, we showed how millimeter-thin TS deposits can affect coastal soft sediment by decreasing the pH and oxygenation of its pore water. Here, we investigated such sediment with planar pH and O_2 sensors to understand the dynamics of these effects applying the VisiSens™ system in sediment cores and a flume experiment. We described, for the first time, two TS deposit-induced mechanisms acidifying the sediment pore water and we showed how the effect of a TS deposit on the oxygenation of a burrow environment is mediated by the burrow residents´ behavior.

Changes in land use, a rising sea level, and extreme rainfall events increase the supply of terrestrial sediment (TS) to coastal habitats worldwide, either via waterways or directly from landslides. The suspended TS eventually settles forming a deposit on the surface of the soft-sediment seafloor. This deposit, until reworked by benthic fauna or resuspended by bottom water currents, alters functions of the sedimentary ecosystem. It may affect benthic organic carbon decomposition by impeding the sediment-seawater exchange of reactive solutes, altering the behavior of benthic species and associated reaction dynamics. Experiments in New Zealand estuaries with centimeter-thick TS deposits have documented changes in benthic faunal assemblages due to migration, mortality, and recruitment failure. More commonly, suspended TS forms millimeter-thin deposits, which can still modify the sedimentary ecosystem by decreasing the pH and oxygenation of the surface sediment. A decrease in pore water oxygenation negatively affects the burial behavior of juvenile macrofaunal recruits (Cummings et al 2009) and a decrease in pH lowers the saturation of the sediment with respect to calcite and / or aragonite and so may cause dissolution mortality of shell-bearing newly settled invertebrates (Green et al. 2009). Here we tested the suitability of VisiSens™ technology to investigate short-term changes in pore water pH and O_2 during and after the deposition of TS. To do so, we deposited freshly suspended and weathered TS onto coastal sediment held in acrylic tubes or in a laboratory seawater flume to which planar pH and O_2 sensors had been attached. We investigated changes in pore water pH following this deposition to better understand the mechanisms that lead to the previously documented pore water acidification. Furthermore, we asked how this deposition affects the sediments´ subsurface O_2 supply by macrofaunal burrow irrigation.

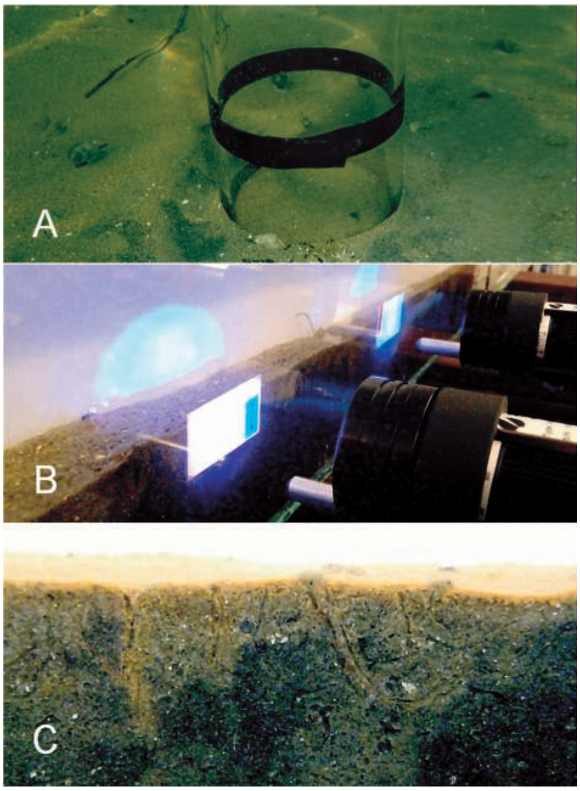

Fig. 1: Acrylic tube inserted approx. 10 cm into the sandflat; stoppers placed at bottom and top of each tube enclosed sediment core and overlying seawater (**A**). Set-up of flume experiment: Sensor foils SF-HP5R and SF-RPSu4 glued to the inside wall of the flume filled with sediment, and recirculated with seawater at a speed of approx. 1.3 cm s^{-1}. Detector units were set up, then TS was added to the flume (**B**). Thin TS deposit over bioturbated coastal sand 24 h after addition of the TS suspension; yellow burrow linings indicate that the resident macrofauna has started reworking the TS (**C**).

Materials & Methods

We collected coastal sediment from a sheltered mid-intertidal sandflat in the northern basin of Tauranga Harbour, a large tidal inlet on the northeast coast of the

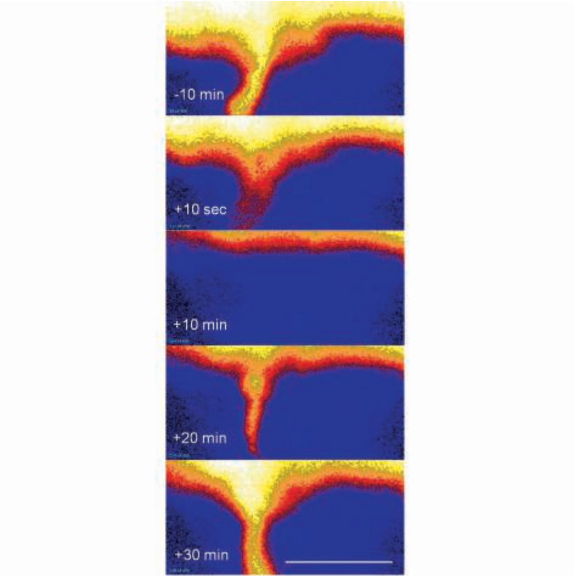

Fig. 2: Pore water oxygenation: O_2 distribution across the sediment-seawater boundary and the walls of a polychaete burrow (center of the image) changed rapidly within 30 min following the deposition of a 0.5 mm layer of TS; the vertical O_2 concentration gradient migrated upwards and the burrow environment turned anoxic. In less than 20 min, the resident polychaete had cleared its burrow opening re-establishing flow of oxygenated seawater. However, a second deposition event, which added 1.5 mm of TS to the deposit, left the burrow anoxic. Scale bar, 5 mm.

North Island, New Zealand. The fine sand had a water and organic matter content of 25 and 2.9 % and a mean particle diameter of 249 μm. We obtained TS from a landslide at Hahei Beach, Coromandel, suspended about 100 g of this sediment in 100 mL seawater, removed large particles with a 250 μm mesh and added freshly suspended TS to the seawater overlying the coastal sediment to create a 1 - 2 mm thick surface deposit (mean particle diameter, 30 - 40 μm). To make weathered TS, we used three cycles of deposition and re-suspension, decanting and replacing the overlying seawater after each cycle. To bring the sensor foils in contact with the surface sediment, we removed the seawater overlying the sediment core, glued the foil onto the inner surface of the acrylic tube just above the sediment surface, and then pushed the sediment core upwards until half of the foil was in contact with the sediment. For flume experiments, we glued the foil onto the inner surface of the flume glass wall and then filled the flume with sediment.

Effect of TS deposits on pore water pH and O2

The time-series analysis of our pH sensor foil trials revealed two mechanisms by which TS deposits lower the pH of the underlying coastal sediment: 1. The deposit of freshly suspended TS released hydrogen ions into the underlying sediment and the flume seawater for hours following its formation (Fig. 3). Consequently, the pH of the underlying coastal sediment decreased. The diffusive loss of hydrogen ions into the flume seawater gradually

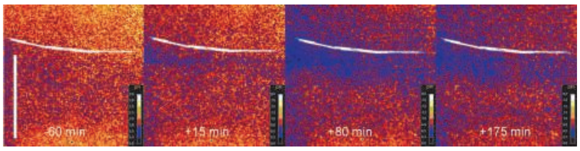

Fig. 3: Pore water pH: Deposition of freshly suspended TS (2 mm layer) reversed the flux of hydrogen ions in surface sediment. Horizontal white line, sediment surface. Vertical scale bar, 5 mm.

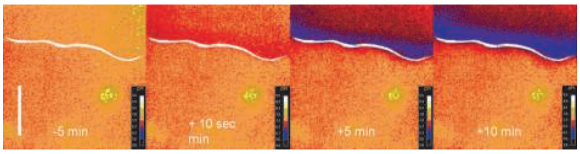

Fig. 4: Pore water pH: Deposit of weathered TS did not reverse the flux of hydrogen ions but impeded their diffusion from source to sink, that is, from the surface sediment into the free flowing flume seawater. Horizontal white line, sediment surface. Vertical scale bar, 5 mm.

increased the pH of the TS deposit and the underlying coastal sediment. This increase quickly came to a halt because hydrogen ions released by the microbial oxidation of organic matter and reduced solutes kept the pH at a low value so that the flux of hydrogen ions reversed. Hydrogen ions now diffused from their source in the sediment across the TS deposit into the overlying seawater. 2. Because the TS deposit increased the diffusive distance between source and sink of hydrogen ions, the pH of the deposit-underlying coastal sediment remained below its value in undisturbed sediment (Fig. 4). That is, the deposit impeded the transport of hydrogen ions and thus increased their subsurface concentration maximum. Trials with O_2 sensor foils impressively demonstrated the dynamic nature of the sediment pore water redox chemistry. We observed how settling TS particles disturbed the diffusive boundary layer between coastal sediment and flume seawater. This disturbance briefly increased the O_2 penetration but the build-up of the surface deposit then gradually shifted the O_2 concentration gradient upwards into the deposit (Fig. 2). Finally, we showed, for the first time, that deposition of an only 0.5 mm TS layer stopped the irrigation of a polychaete burrow. The oxygenation of the burrow void and the surrounding sediment rapidly decreased until the polychaete re-established flow through the burrow. A subsequent deposition of a approx. 2 mm layer left the burrow anoxic for at least one hour, the maximum time measured.

Conclusion

The ability of polychaetes and other macrofauna to maintain a subsurface solute exchange will certainly have limits that future experiments with the VisiSens™ system may explore to better understand thresholds in the response of coastal benthic ecosystems to stress. Such understanding will be indispensible in predicting the functioning of future coastal ocean.