Biological pumps: from microrganisms to oceans

N.J. BUTTERFIELD[1]

[1]Department of Earth Sciences, University of Cambridge, Cambridge, UK CB2 3EQ (njb1005@cam.ac.uk)

Seawater is a relatively viscous medium, leaving most unicellular organisms trapped in a low Reynolds number (*Re*) and low Peclet number (*Pe*) world. Although flagellated unicells are capable of swimming through this system, it is only with collective multicellular behaviour that organisms are in a position to actively manipulate it. Even at micrometre scales, the effects of advective biological pumping dramatically enhance trans-membrane gas exchange, releasing organisms from 'the tyranny of diffusion.' The challenge of limited oxygen availability, for example, is readily met by taking on a multicellular habit.

Flagella- and cilia-based pumping acquires additional levels of advective advantage when combined with an internal piping/plumbing system, such as developed in benthic suspension feeding animals. These massively parallel biological pumps are capable of processing enormous volumes of water and generating high velocity (>*Re*) exhalent flows – while at the same time scrubbing out most suspended picoplankton and DOC. The immediate effect of such activity is pronounced aeration and clarification of the water column. By triggering a range of non-linear feedbacks, the evolution of such forms will have revolutionized the redox expression of mid-late Neoproterozoic shelf settings.

In the long run these cilia- and flagella-powered pumps were effectively replaced by more sophisticated muscle-based systems. Muscles (and associated sketal apparatus) allowed metazoans to occupy the pelagic realm where they mix and modify seawater on a truly global scale. Whether or not the turbulence they now add to the oceans is comparable to that of the winds and tides (Dewar et al. 2006), there is no question that they have 'engineered' fundamental shifts in its structure over evolutionary time. The 100-800 metre diunal vertical migration (DVM) of marine zooplankton, fish, whales, etc., for example, is the largest mass movement of biomass on the planet – a phenomenon that actively transports surface-derived primary productivity (and accompanying biological oxygen demand) to mesopelagic depths. Prior the evolution of swimming animals this particular biological pump simply didn't exist, while intermediate states can be recognized in the early Paleozoic and subsequent OAEs. To an important degree the modern oceans owe their ventilation to the evolution of progressively more sophisticated and powerful biological pumps.