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Quantification of biogenic 3-D structures in marine sediments

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Abstract

Burrow and tube structures of marine infauna were quantified in sediments from cores obtained at 3 depths (75, 95 and 118 m) at 3 occasions over a 1-year period. The benthic communities at the two deeper stations were re-establishing subsequent to re-oxygenation after hypoxic conditions; the shallow station was a reference station unaffected by hypoxia. The benthic macrofauna was simultaneously quantified from sieved grab samples. The sediment cores were frozen and later sliced with a plane in horizontal layers. Biogenic structures in these sections were digitally analysed for numbers, area and volume. Number of tubes and burrows showed a general decline with depth in the sediment. The biogenic structures in the sediment at the reference station increased the sediment–water interface about 1.5 times compared to the surface area. The surface areas of burrows and tubes were 2 to 3 times larger at the reference station than at the deeper stations. The benthic fauna at the 95-m and 118-m stations showed a temporal increase in density and number of species. In contrast, development of biogenic surface areas in the sediment at these stations showed no significant temporal trend during the benthic faunal succession. Relic tubes of *Melinna cristata* were found throughout the sampling period at the 118-m station. The ecological importance of bioirrigation for biogeochemical processes is discussed.

Keywords: Benthos; Bioturbation; Burrow; Irrigation; Redox; Reworking; Tube

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1. Introduction

In sediments without bioturbating fauna mineralisation of organic material occurs in a vertically stratified reaction sequence characterised by an upper oxic layer, an underlying suboxic layer where nitrate, manganese (IV) and iron (III) are used as electron acceptors, and finally an anoxic layer where sulphate reduction and methanogenesis occur (Kristensen, 2000). Usually oxygen is restricted to the upper few millimetres of the sediment in coastal marine environments (Jørgensen and Revsbech, 1985). Presence of sediment-living infauna and their bioturbation alter this simplified picture (Rhoads, 1974). In order to survive within the sediment, most animals irrigate their tubes and burrows. By bioirrigation, oxic microniches are created in the otherwise anoxic sediment, resulting in a multi-dimensional diffusion pattern of oxidising agents and reduced compounds. This mix of

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redox conditions has been shown to stimulate oxic as well as suboxic and anoxic mineralisation of organic material (Aller, 1988; Aller and Aller, 1998). Animal tubes and burrows are generally kept oxygenated, at least intermittently, by the irrigation of animals. These biogenic structures can thus be viewed as extensions of the sediment–water interface increasing the amount of oxic and oxidised sediment as well as the oxic–anoxic interface. Tube and burrow walls may, however, not be similar to the surface sediment since chemical gradients usually are steeper in tube and burrow walls (Aller and Aller, 1998; Fenchel, 1996a). This is due to radial diffusion geometry (Aller, 1988), higher microbial activity in the mucus lined wall and intermittent irrigation patterns observed for many species (Foster-Smith, 1978; Kristensen et al., 1991). Steep chemical gradients in animal tube walls and consequently short distances for nitrate to diffuse into the anoxic zone is thought to be important mechanisms by which bioturbation stimulates denitrification rates (Jørgensen and Revsbech, 1985).

Despite the established understanding of burrows and tubes as micro-environments of chemical significance to sediment–water exchange processes, measurements of tubes and burrows and their extension in the field is limited. Hylleberg and Henriksen (1980) and Fenchel (1996a) have shown that populations of *Nereis virens*, *Nereis diversicolor* and *Corophium volutator* through their burrowing activity significantly increased the oxic conditions within the sediment. Similarly, Davey (1994) found that a natural population of *N. diversicolor* could increase the surface area within the sediment by about 300%.

The resin cast technique, pioneered by Shinn (1968), has been used by ecologists interested in architecture and scale of, e.g. crustacean burrows. Particularly burrows of large thallassinidean crustaceans have been investigated by this method (e.g. Astall et al., 1997), but also galleries of other animals such as the polychaete *N. diversicolor* have been visualized (Davey, 1994). Architecture of burrow systems has also been studied by X-radiography (Schaffner et al., 2001). Recently, computer-aided tomography (CT) has been used to image biogenic structures in the sediment (Perez et al., 1999). With CT it is possible to measure the space occupied by the biogenic structures in the sediment (Mermillod-Blondin et al., 2003).

The aim of this study was to assess the number, size and depth distribution of biogenic 3-D structures in sediments, and show how these change during benthic faunal succession following improved oxygen conditions after hypoxia. Organisation of benthic infaunal communities has been shown to change predictable and gradually along gradients of organic enrichment and oxygen deficiency (Pearson and Rosenberg, 1978). The model of benthic succession suggested that the vertical distribution of biogenic structures and the redoxcline increased towards reaching “mature” successional stages. This general temporal succession of infaunal vertical activity in the sediment was later demonstrated by using in situ sediment profile imagery (Rhoads and Germano, 1986; Nilsson and Rosenberg, 2000; Rosenberg et al., 2002), but the areas occupied by biogenic structures were not quantified.

This study was done on three stations with different depths (75, 95 and 118 m) in the Gullmarsfjord on the Swedish west coast (Fig. 1). Sediment cores from the stations were frozen, sectioned and digitally analysed.

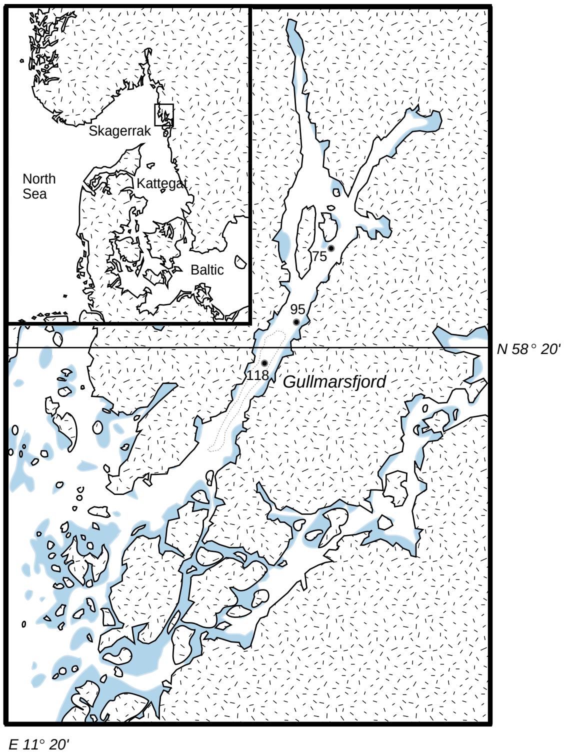

Fig. 1. Map of the 3 sampling stations with depths in the Gullmarsfjord, west Sweden.