Estuarine, Coastal and Shelf Science 91 (2011) 333–339

Contents lists available at ScienceDirect

Estuarine, Coastal and Shelf Science

journal homepage: www.elsevier.com/locate/ecss

Short communication

The strength of biogenic sand reefs: Visco-elastic behaviour of cement secreted by the tube building polychaete *Sabellaria alveolata*, Linnaeus, 1767

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ARTICLE INFO

Article history:
Received 8 June 2010
Accepted 31 October 2010
Available online 6 November 2010

Keywords:
biogeomorphology
biogenic reef
Sabellaria alveolata
mechanical behaviour
visco-elasticity

ABSTRACT

Mechanical properties of the biomineralised cement from tube-building marine worms are poorly known. Secreted from an organ connected to the polychaetes specialised glands, the cement glues sand grains and calcareous shell fragments of a given size and, on a larger scale, ensures the resistance of the reef to waves. In this study, three kinds of mechanical tests were performed with worm tubes to establish the nature of the cement behaviour. Results obtained show that cement behaves like a visco-elastic material. This property allows the tubes to dissipate the mechanical energy from the waves to which they are subject and to reduce the mechanical stress transmitted inside the tubes to the polychaetes. Comparison of "fresh" and "dry" cements highlights that the visco-elastic behaviour of the cement is maintained after five years. The viscosity of the cement is therefore not related to moisture but to its chemical composition. More generally, these results offer a better understanding of the role of cement on worm reefs strength and their persistence in the geological record.

1. Introduction

Some marine annelids are known to build and to maintain massive sandy reefs which can cover several kilometres in length (Caline et al., 1988; Callaway et al., 2010). The family Sabellariidae aggregates several species of reef-building polychaetes which are present along all coastlines, except the Arctic. The sabellariid polychaete *Sabellaria alveolata* Linnaeus, 1767 forms large intertidal colonies at the north-western coasts of Europe, especially in the Bay of Mont-Saint-Michel (France) which hosts the greatest European worm-reef structures (Dubois et al., 2002; Godet et al., 2009; Noernberg et al., 2010). These annelid reefs are known to trap carbonate-rich sediments and to actively control the texture and the distribution of intertidal sediments (Kirtley and Tanner, 1968; Godet et al., 2008; Toupoint et al., 2008). The single tube of each individual is made from bioclastic sand of a given size and shape, gathered in the water column when the reef is submerged at high tide. The rigidity of the tube is acquired at low energetic cost because the bioclastic grains have the shape of small tiles and thus, a large surface area per unit of mass. The tubes constructed are joined together with a biomineralised cement which is produced by specialised glands, located in the thorax of the worm. The cement of sabellariid species such as *Phragmatopoma* spp. and *S. alveolata* consists of several protein substances such as glycine, serine and alanine (Waite et al., 1992; Zhao et al., 2005), and significant levels of phosphorus, calcium and magnesium (Gruet et al., 1987; Fournier et al., 2010). The matrix of the cement is pitted with spheroidal depressions and is shaped like a microporous foam (Stewart et al., 2004; Flammang and Lambert, 2008; Shao et al., 2009). Zhao et al. (2005) and Stevens et al. (2007) have demonstrated that the difference in pH between the secretory glands and seawater might explain the drying out reaction mechanism involving an initial rapid (30 s^{-1}) change in the nature of the bonding of divalent cations with the protein Pc3, and secondly a reaction characterized by a slower hardening of the cement. Earlier studies showed that the stability of the cement in *S. alveolata* tubes is achieved by internal quinone tanning (Gruet et al., 1987), but calcium or magnesium depletion can affect the structural and mechanical properties of the cement by lowering pull-out forces and tube compressive strength (Sun et al., 2007). Paradoxically at first sight, several studies have also underlined the fragility of the reefs built by these worms but, at the same time, their strength to withstand the hydrodynamic pressure (i.e. wave

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doi:10.1016/j.ecss.2010.10.036

energy dissipation) over long periods of time (Kirtley and Tanner, 1968; Caline et al., 1988; Main and Nelson, 1988). In the Bay of Mont-Saint-Michel, the amplitude of the swell only exceeds 2 m about ten days a year with a maximum of 3.5 m; 50% of the record reveal that the amplitude remains under 0.5 m with a period between 7 and 11 s^{-1}. Occasionally, lapping waves, which are caused by winds stronger than 12.5 m s^{-1}, are superimposed on the north-west swells (Caline et al., 1988). The aim of this paper is to study the mechanical properties of the biogenic cement in order to understand its role in the resistance of individual tubes of *S. alveolata* to physical pressure, a questioning that has been performed on other species of reef-building worm (e.g. *Lanice conchilega*: Callaway et al., 2010). This study is the first step towards the characterization of the resistance of reefs to breaking waves, especially in the context of global change with increasing wave energy at coasts (Allan and Komar, 2000; Goldenberg et al., 2001). Three different mechanical tests have been used to distinguish the behaviour of tubes when some compressive constraints are applied. The first test intends to establish the mechanism of failure of the tube submitted to a compression loading. The second one was used to define the nature of the mechanical behaviour of the cement. The last one aims to compare the nature of the mechanical behaviour of fresh and old cements, and more particularly their viscosity.

2. Experimental set-up

2.1. Materials and sample geometries

Three box cores were extracted in 2010 from the reef with a 15-cm side corer (225 cm^{-2}) to a depth of 20 cm, corresponding to the layer where *Sabellaria alveolata* lives. Blocks of tubes of were collected in the main worm reef (ca 150 ha) located in the central part of the bay of Mont-Saint-Michel and stored in plastic bags (Fig. 1). All collected tubes were constructed by adult worms but it was not possible to determine the age of individuals. The higher parts of the tubes were carefully and individually separated from the block with scalpel in the laboratory. The top of the tubes was selected as this part of the tube is the most recently built. Replicates were stored for both mechanical tests and grain-size analysis. For grain-size analysis of each of the samples, segments of tubes were washed carefully with distilled water and following decanting during 48 h. Sediments were then dried at 60 °C for 24 h and were then sieved through AFNOR standard sieves (meshes of 2.5, 2, 1.6, 1.25, 1, 0.8, 0.63, 0.50, 0.40, 0.315, 0.25, 0.20, 0.16, 0.125, 0.100 mm, 80, 63, 50, 40 and <40 μm). Each size fraction was weighed and the associated results expressed as percentages of the total sample weight. Sedimentary parameters were determined by performing grain-size analysis on raw data through the Gradistats v.4.1.

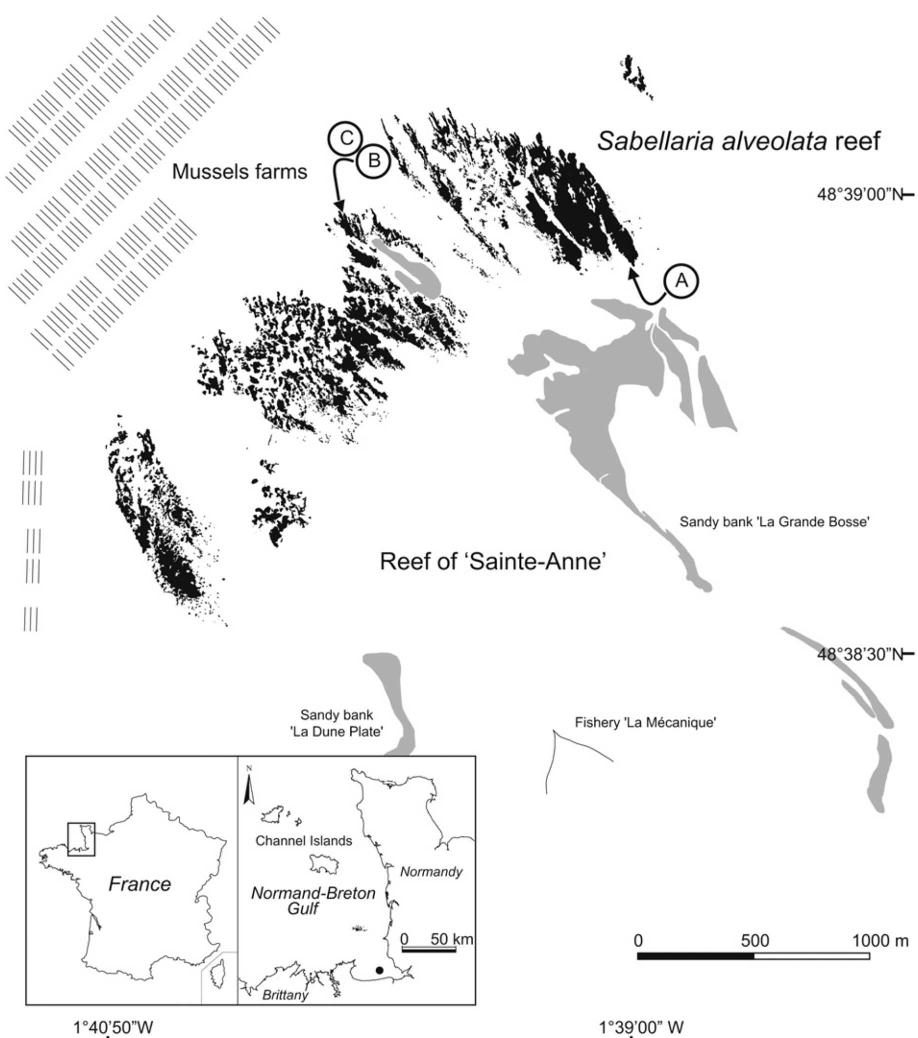

Fig. 1. Location of the study area (Mont-Saint-Michel Bay, France) and location of the sampling area (Reef of 'Sainte-Anne') and samples A, B and C.