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ScienceDirect
Estuarine, Coastal and Shelf Science 75 (2007) 317–326
ESTUARINE COASTAL AND SHELF SCIENCE
www.elsevier.com/locate/ecss

Effect of physical variables on particle critical erosion shear stress: Hydrostatic pressure, slope and changes in water density

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Received 12 April 2006; accepted 30 April 2007
Available online 13 July 2007

Abstract

In recent years, the importance of organo-mineral aggregates (OMAs) in the transport of organic material from the continental shelf to the deep ocean floor has been recognized. Attempts to model the transport of these OMAs rely on measurements of several physical parameters, such as the critical erosion shear stress. However, due to technical constraints, such measurements are not done in situ, making it difficult to assess the impact of environmental parameters on the measurements made, and their accuracy in representing the study site. Changes in hydrostatic pressure, slope angle and water density potentially can affect the critical erosion shear stress of OMAs. Using new methodologies, we found no measurable effect of hydrostatic pressure variation on the OMAs' resuspension behavior. Changes in slope angle resulted in the decrease of $u*_{cri}$ up to 35%. The $u*_{cri}$ decreased by 9% with an exchange with denser water, and it increased by 6% with an exchange with lighter water. These changes were temporary, and after a 3-h stabilization the $u*_{cri}$ returned to the original value. We will discuss the future applications of these results on modeling of particle transport.

Keywords: organo-mineral aggregates; transport; hydrostatic pressure; slope angle; water density changes; submarine canyons; Iberian Margin

1. Introduction

Continental margins comprise 15% of the total ocean area and account for 25% of the total ocean primary production. A considerable part of this production is removed from the surface through coagulation processes and sedimentation of aggregates (Alldredge and Silver, 1988; Simon et al., 2002; Thomsen, 2004). These aggregates have been shown to be the most important components of the organic matter flux to the deep-sea (Turley, 2000), and appear to be hotspots of heterotrophic activity in the water column, being an important carbon source for free-living bacteria throughout their descent (Kiørboe et al., 2001). The larger fraction of it is remineralized in the first 100 m below the sea-surface. After settling to the bottom, almost all of the remaining carbon is recycled, but a part of this organic matter becomes too refractory to be remineralized, and thus is buried in ocean sediments, sequestering carbon (Siegenthaler and Sarmiento, 1993; Hedges et al., 2001).

Nevertheless, some processes may influence the amount of organic matter that reaches the seafloor. Hydrostatic pressure inhibits the bacterial community of sinking aggregates, which may be a pathway for the sedimentation of less-degraded aggregates to the seabed (Turley, 1993, 2000). Also the reshaping of the aggregates within the benthic boundary layer by aggregation and disaggregation processes (Ransom et al., 1998; Thomsen, 1999), modifying them into what we call organo-mineral aggregates (OMAs). This may further delay the degradation of organic matter, since the sorption of organic matter to the larger amount of lithogenic material in these aggregates may provide some degree of protection against microbial activity (Hedges and Keil, 1999).

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doi:10.1016/j.ecss.2007.04.035

Once settled on the seafloor, OMAs are more easily remobilized into the benthic boundary layer than the sediment surface beneath, and are easily transported (Thomsen and Gust, 2000).

Submarine canyons are a natural trap for particles deposited on the shelf. They are also areas of potentially fast net transport to supply the lower slope with labile material (Thomsen et al., 2002).

To determine precisely the transport of aggregates it is necessary to have accurate measurements of their characteristics. The critical friction velocity ($u*_{cri}$) presents the most problems when trying to obtain representative measurements. Determination of $u*_{cri}$ for both OMAs and underlying sediment is in most cases performed onboard, in samples recovered from sediment cores. These measurements do not take into account several factors that might influence the measurements. We singled out for study three of these factors.

1.1. Hydrostatic pressure

As a rule of thumb, hydrostatic pressure increases 1 bar for each 10 m water depth. All previous measurements of $u*_{cri}$ have been made without taking into account sample decompression from in situ pressure. This is mainly due to the technical difficulties in maintaining and/or simulating such pressures while doing such measurements. The hydrostatic pressure can have an effect on resuspension, if structures are present within the porous OMAs that can be compressed and decompressed, thus altering the overall density of the OMAs. The first hypothesis of this work is that variations in hydrostatic pressure affect the resuspension behavior of the OMAs.

1.2. Slope angle

At the shelf break, the gently sloping shelf gives way to the steeper slope with average slope angles of 4–8°. The margins are disrupted by channel systems and submarine canyons that are more irregular shaped than the margins themselves. These channels and canyons have in general extensive areas with steeper slope angles than the remaining margin. Modern technology in seafloor mapping allows detailed analysis of slope angles at continental margins. Data show that extended areas with slope angles of >10° are common for continental margins.

So far measurements on particle behavior of samples from these areas have all been done horizontally without taking into account the steepness of the particular spot from where the samples were taken. The second hypothesis of this work is that increasing slope angles decreases the $u*_{cri}$ of the OMAs.

1.3. Density change

At continental margins seabed density changes in the overlying water occur periodically. This occurs when a different water mass advances over an area due to the influence of tides. This affects vast areas, both on the slope and inside submarine canyons. Since measurements of $u*_{cri}$ are discrete, models that use them do not take into account this periodic water density change. The third hypothesis of this work is that density changes of bottom water during tidal cycles influence the resuspension behavior of OMAs.

2. Methods

2.1. Sample collection

Samples were collected during the Eurostrataform cruise PE218 to the Portuguese west continental margin (Fig. 1). The samples were collected in the Setúbal Canyon, which is located in an area of complex topography and coastal configuration.

We selected the sample from Station 22 for the experiment based on the effect of hydrostatic pressure variation on resuspension. This station is located at a depth of 1463 m, being ideal for the protocol designed.

For the experiment on the effect of slope angle variation on resuspension we selected the sample from Station 21. This station is located in the head of the Setúbal Canyon.

For the experiment on the of density variation on resuspension we selected the sample from Station 16. This station is located in the head of the Setúbal Canyon at a depth of 430 m, which roughly corresponds with the interface between the Mediterranean Outflow Water and the North East Atlantic Deep Water (PE218 cruise report).

Cores were taken with an MUC 8+4 multicorer (Octopus GmbH), which utilizes an array of four 10 cm diameter and eight 6 cm diameter coring tubes. Individual 10 cm sediment cores were stored under in situ temperatures. Critical friction velocity ($u*_{cri}$) was determined onboard using an erosion chamber with controlled bottom stress (Thomsen and Gust, 2000), to the surface sediments in the sediment core. The $u*_{cri}$ was increased in small steps of 0.1 cm s^{-1}, until $u*_{cri}$ was attained and the OMAs resuspended.

The resuspended OMAs were collected in a polycarbonate chamber in the recirculation circuit (Fig. 2), and stored at 4 °C in PET bottles, for subsequent transport to the laboratory. A sub-sample was concentrated onto precombusted Whatman GF/F glass filters. The dry weight was subsequently determined. Based on the weight of the collected particles and the area of the core we estimated the resuspendable particle concentration per area. This is the amount of material that can be resuspended as aggregates. Subsequently the filters were analyzed with a Euro-EA Elemental analyzer (Hekatech) standardized with acetanilide. We measured the percentages of organic carbon and organic nitrogen (Ehrhardt and Koeve, 1999). This measurement was used with the estimated values of resuspendable particle concentration to calculate particulate organic carbon (POC), and particulate organic nitrogen (PON).

In the laboratory, the OMAs of different stations were used for the different experiments, as described above.