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Biogenic effects on cohesive sediment erodibility resulting from recurring seasonal hypoxia on the Louisiana shelf

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ABSTRACT

Sediment erodibility was measured during summer 2010 at four sites off the Louisiana coast that experienced differing exposures to seasonal hypoxia. Stations were sampled along the 30-m isobath, and the sediments at all four sites were cohesive in nature. The largest difference in erodibility occurred between the site that had experienced hypoxia greater than 75% of the time and the site that had experienced hypoxia less than 25% of the time. Erodibility was higher at the sites with a history of seasonal hypoxia and lowest at the normoxic (< 25%) site. Laboratory measurements of lower sediment shear strength from cores were consistent with on-site measurements of higher erodibility from the sites that experienced seasonal hypoxia. The macrobenthos collected at the sites reflected the effects of hypoxia, with a more diverse assemblage occupying the normoxic site and less diverse assemblages occupying the sites exposed to hypoxia at greater frequencies. Although macrobenthic community analysis indicated that the assemblages at the four sites were similar, significant differences in the species abundance, feeding types, and bioturbation modes of the fauna were documented. Of particular importance to sediment erodibility may be the ratio of the concentrations of fauna known to be responsible for sediment dilation to the fauna known to be responsible for sediment compaction. Highly erodible and low shear strength sediments had a dilator/compactor ratio of 23 dilators to every one compactor; the less erodible and higher shear strength sediments had dilator/compactor ratios of 2.0–5.0. Ratios of dilators to compactors appeared to be consistent in macrofaunal censuses conducted previously at the same sites.

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1. Introduction

The erodibility of cohesive sediments, although of great interest due to their ubiquity in marine environments, is poorly understood in terms of the fundamental processes controlling transport and deposition (Harris and Wiberg, 1997; Dickhudt et al., 2009). Erodibility, which quantifies eroded mass as a function of bed stress, can be enhanced or reduced by both physical and biological aspects of the seafloor environment. Laboratory and field studies have demonstrated the role of sediment properties such as particle size distribution, bulk density, and shear strength in determining the threshold for erosion or the erosion rate (Grabowski et al., 2011; Dickhudt et al., 2011). Furthermore, the literature is replete with evidence that macrobenthic fauna in high abundance can influence the geological properties that affect the erodibility of cohesive sediments, especially at the sediment-water interface (e.g., Rhoads and Young, 1970; Myers, 1977; Meadows and Tait, 1989; Gerino, 1990; Jones and Jago, 1993; Rowden et al., 1998; Murray et al., 2002). Biogenic processes of biodeposition, advective/diffusive mixing, bioresuspension, enhanced interface roughness, adhesion of particles by extracellular polymeric substances, or formation of dense mats of tubiculous fauna can either enhance or hinder erosive forces (Blanchard et al., 1997; Graf and Rosenberg, 1997; Reise, 2002; Winterwerp and van Kesteren, 2004; Le Hir et al., 2007).

Benthic fauna can affect bed erodibility by altering the sediment surface or the structure and composition of the sediment (Pinn and Robertson, 1998; Grabowski et al., 2011). Typically, macrobenthos increase the height of the boundary layer above the sediment–water interface through the construction of numerous tubes projecting from the sediment or the production of relatively recalcitrant fecal mounds and coils that increase seafloor roughness (Wright et al., 1997). Feeding and egestion by deposit feeders repackage the sediment in ways that may promote or hinder erodibility, depending on the nature of the fecal castings. For

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instance, dense carpets of the amphipod *Corophium* can increase the critical stress velocity of the seabed through strengthening the cohesiveness of the sediment with fine particles scavenged from the overlying water (Myers, 1977; Pender et al., 1994). The size, density, and binding material of fecal pellets can affect the potential resuspension of the egested sediment (Nowell et al., 1981). The movement of macrobenthic fauna within and on the sediment can change the structure of the sediment fabric. Plowing through cohesive sediments increases the water content and dilates the sediment structure (Murray et al., 2002; Roast et al., 2004; Sgro et al., 2005). In addition to disrupting the sediment surface through movement and feeding, fauna such as tellinid bivalves may egest the consumed sediment in slurries, which significantly dilates surficial sediment and promotes erodibility (Willows et al., 1998; Kanaya et al., 2005). However, burrowing fauna can create denser accumulations of sediment by subsurface egestion of ingested surface sediment (Myers, 1977; Smith et al., 1986) or compression of burrow-wall sediment (Fernandes et al., 2006). Systematic harvesting of surface "fluff" and repackaging as subsurface fecal accumulation by surface deposit feeders, increasing sediment dewatering through burrow networks, and consolidating loose sediment into denser burrow walls can result in a net compaction of sediment over time that would reduce erodibility (Pender et al., 1994; Murray et al., 2002).

The formation of seasonal hypoxia (defined as <2 mg O_2 L^{-1}) in the northern Gulf of Mexico affects macrobenthic communities with declines in species richness, abundance, and biomass (Rabalais et al., 2001; Baustian and Rabalais, 2009). Hypoxia also affects the bioturbation activities of benthic infauna, through behavioral effects such as decreased movement and feeding and decreased burrowing depth (Tyson and Pearson, 1991; Díaz et al., 1992; Weissberger et al., 2009). With the modification of bioturbation behavior and the change in community structure by benthic macrofaunal assemblages come important consequences for sediment properties (Mazik and Elliott, 2000). Selective mortality and altered behavior of macrofauna as a result of hypoxic stress can change the natural balance between the competing diagenetic processes of sediment dilation and compaction normally determined by macrofaunal activities (Meadows and Tait, 1989; Jones and Jago, 1993; Rowden et al., 1998).

The influence of hypoxia on benthic fauna closely follows the Pearson–Rosenberg organic gradient model (Pearson and Rosenberg, 1978), which defines patterns of abundance and biomass of equilibrium and pioneering faunal species that occur along a gradient of increasing organic matter. According to the model, as eutrophication proceeds with an increased uptake of oxygen by heterotrophic activity, the environment shifts from a more aerobic to a more anaerobic one. Well oxygenated areas typically have abundant, diverse benthic communities that include larger, deeper burrowing fauna dominated by infaunal deposit-feeders. A normoxic environment involving intensive bioturbation should be characterized by a rough sediment–water interface covered with feeding pits and fecal or excavation mounds that might serve to expand the thickness of the benthic boundary layer, thus protecting the surface sediment from erosion. The diverse assemblage promoted by the normoxic environment allows a diversity of feeding types and bioturbation modes to flourish. A hypoxic environment should be characterized by sediment mixing restricted to surficial depths as a consequence of fewer, smaller fauna consisting of fewer species that represent a more limited range of burrowing/feeding activities (Pearson, 2001).

The goal of this work was to determine the variations in seafloor erodibility in cohesive sediment over an environmental gradient of hypoxic stress on the macrobenthic community and develop insights into the sedimentological properties and biological processes that influence these variations.

2. Methods

2.1. Study area and choice of sampling sites

The presence of hypoxic zones on the shelf off Louisiana reoccurs seasonally, with the spatial and temporal extent of the hypoxia varying from year to year (Rabalais et al., 2007). This means that some areas are exposed to hypoxia for different time periods, and this creates a natural exposure gradient in which hypoxic conditions can affect benthic communities and sediment properties. Four sites were chosen using historical bottom-water oxygen concentration data from mid-summer shelf-wide surveys (Rabalais et al., 2002; Baustian et al., 2011) from the Louisiana Universities Marine Consortium (LUMCON). Each site had a different frequency of hypoxia occurrence ($<25\%$, $\geq 25\%$, $\geq 50\%$, and $\geq 75\%$ for the 23 years between 1985 and 2008). To avoid anomalies in benthic communities due to variation in sediment types and shallow areas subject to intense, episodic sediment reworking, all sites were located close to the 30-m depth contour (Fig. 1). The site designations H7, E4, D5, and A6 are derived from

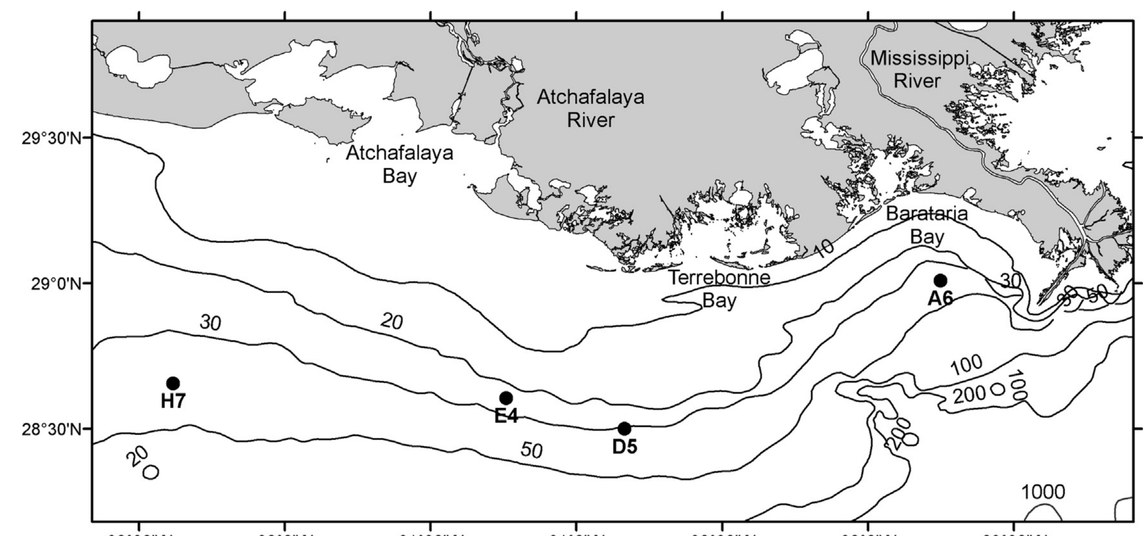

Fig. 1. Location of the four sites on the Louisiana shelf. Depth contours in meters.