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Effects of vegetation and fecal pellets on the erodibility of cohesive sediments: Ganghwa tidal flat, west coast of Korea

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ABSTRACT

Although the Korean tidal flats in the Yellow Sea have been highlighted as a typical macrotidal system, so far, there have been no measurements of the sediment erodibility and critical shear stress for erosion (τ_{ce}). Using the Gust erosion microcosm system, a series of field experiments has been conducted in the Ganghwa tidal flat to investigate quantitatively the effects of biogenic materials on the erodibility of intertidal cohesive sediments. Four representative sediment cores with different surficial conditions were analyzed to estimate the τ_{ce} and eroded mass. Results show that τ_{ce} of the "free" sediment bed not covered by any biogenic material on the Ganghwa tidal flat was in the range of 0.1–0.2 Pa, whereas the sediment bed partially covered by vegetation (*Phragmites communis*) or fecal pellets had enhanced τ_{ce} up to 0.45–0.6 Pa. The physical presence of vegetation or fecal pellets contributed to protection of the sediment bed by blocking the turbulent energy. An inverse relationship between the organic matter included in the eroded mass and the applied shear stress was observed. This suggests that the organic matter enriched in a near-bed fluff layer is highly erodible, and the organic matter within the underlying sediment layer becomes depleted and less erodible with depth. Our study underlines the role of biogenic material in stabilizing the benthic sediment bed in the intertidal zone.

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1. Introduction

Erosion from the sediment bed directly influences the turbidity in the water column (Winterwerp and van Kesteren, 2004). Turbidity results from suspended sediments such as sand, silt or clay, and sometimes mixtures of inorganic and organic matters (OM) such as algae, plankton and decaying materials. In particular, resuspension of OM may enhance the level of biochemical oxygen demand in coastal environments (Wainright and Hopkinson, 1997). When bottom sediments with pollutants are resuspended to the upper water column, water quality can deteriorate significantly.

The cohesive sediment bed can be eroded when the applied bed shear stress (τ_b) exceeds a critical value, i.e., the critical shear stress for erosion (τ_{ce}) (Sanford and Halka, 1993; Winterwerp and van Kesteren, 2004; Ha and Maa, 2009). Erodibility of the sediment bed is determined by competition between external hydrodynamic forces (e.g., τ_b induced by currents and waves) and internal resisting forces within the sediment bed (e.g., inter-particle attractive forces) (Grabowski et al., 2011). At present, τ_{ce} is best measured using an *in-situ* erosion measuring device, since conditions might be changed during delivery to the laboratory.

In the intertidal zone, various biogenic materials above and below the sediment-water interface are repeatedly exposed and buried by the tidal cycles. They influence bed stability, namely how easily and quickly the bottom sediments can be eroded by external forces induced by currents and waves (Widdows et al., 2000; Widdows and Brinsley, 2002). For instance, the physical presence of vegetation contributes to absorbing hydrodynamic energy, trapping suspended sediment, and improving water clarity (Winterwerp and van Kesteren, 2004; Mudd et al., 2010; Townend et al., 2011). The pelletization of sediment may alter the physiochemical properties and its transport processes by changing the particle size distribution (Nowell et al., 1981). Although the Ganghwa tidal flat is known as a typical macrotidal system, most previous studies have been focused on understanding the biochemical processes (e.g., Koo et al., 2007; Hyun et al., 2009) and the geomorphologic changes and evolution (e.g., Choi and Jo, 2015; Baek et al., 2016; Choi and Kim, 2016). So far, there have been no measurements of τ_{ce} and erodibility, which are the important parameters needed to understand sediment transport over tidal cycles and predict water quality in the water column.

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In this study, using the Gust erosion microcosm system (GEMS; Gust and Mueller, 1997), a series of field experiments has been conducted to measure τ_{ce} and eroded mass from bed sediments with different surficial conditions. The primary objective is to investigate the effects of vegetation and fecal pellets on the erodibility of cohesive sediments in the intertidal flat. Erosion data measured in this study could be used to understand benthic sediment behavior in the intertidal zone well developed in the Yellow Sea, and to improve prediction capability of sediment transport models.

2. Study area

Erosion experiments were conducted in the Ganghwa tidal flat off the west coast of Korea (Fig. 1). As a macrotidal system, the mean and maximum tidal ranges are about 5.9 and 10.2 m, respectively (KMA, 1998). The total area of the Ganghwa tidal flat is about 105 km^2 (Lee et al., 2011). The study area is surrounded by three distributary channels: (1) Yeomha channel in the east; (2) Seokmo channel in the west; and (3) Jangbong channel in the south (Fig. 1). Tidal currents, which are predominantly oriented in NE-SW direction, are about 0.8 m s^{-1} during neap tides and about 1.5 m s^{-1} during spring tides (Choi and Kim, 2016). Winds are characterized by the regional monsoon with strong north-northwesterly winds in winter (mean: 2.7 m s^{-1}) and relatively mild south-southeasterly winds in summer (mean: 2.0 m s^{-1}) (Kim, 2006). Waves are relatively strong during the winter storm season. Wave energy is strongly dissipated due to the existence of extensive sand shoals with shallow depth (Choi and Kim, 2016).

Most sediments in the Ganghwa tidal flat are associated with sediment supply from the Han River during the summer flooding season. Their transport is mainly controlled by tides and estuarine circulations (Lee et al., 2013). The surface sediment is classified into sand, muddy sand, sandy mud, and mud facies (Kim, 2006). A previous investigation of surface sediment distribution described three distinct regions: (1) mud flat in the upper-intertidal zone; (2) mixed flat in the middle-intertidal zone; and (3) sand flat in the lower-intertidal zone (Baek et al., 2016). Halophytes are mainly distributed in the uppermost part of the mud flat.

3. Materials and methods

3.1. Measurement of erodibility

Measurement of erodibility was started within 2 h after collecting a sediment core to minimize the dewatering and consolidation processes. Sediment erodibility was measured using the GEMS originally designed by Gust and Mueller (1997). A schematic illustration and photos of the GEMS and related equipment are given in Fig. 2. The system comprises a control notebook computer, turbidimeter (Hach, 2100AN), pump controller, rotating motor, erosion head, spinning disk, and erosion chamber. The surface sediment was eroded from the core top by applying τ_b via a magnetically-coupled erosion head. The distance between the spinning disk and the core top was set to 10 cm before starting the experiment. τ_b was sequentially increased from 0.01 to 0.6 Pa in seven pre-determined steps (0.01, 0.05, 0.1, 0.2, 0.3, 0.45, and 0.6 Pa). Each step of τ_b was maintained during 20 min, and the step duration was manually adjusted, if needed, depending on the changes in suspended sediment concentration (SSC). Determining erodibility by interpretation of the experiment data, the most important thing was to define τ_{ce}, by establishing "when" the sediment bed starts to be eroded by the applied τ_b. When an abrupt increase of SSC (higher than a critical level of 1.5 mg l^{-1}) was first observed, and continued to increase for the succeeding steps with higher τ_b, the range between the first two successive τ_b's that caused the noticeable increase of SSC was defined as the initial τ_{ce}. Instead of using the average of such successive τ_b's suggested by Maa and Kim (2002), a certain range of τ_b was provided, which serves well for identifying the τ_{ce}.

The suspended sediment was passed through the turbidimeter, and then collected in sample bottles. The collected water samples were vacuum filtered through pre-weighed glass fiber filters (GF/F) (pore size: 0.7 μm). The residues on the filters were oven dried and reweighed to quantify the eroded mass and SSC. The nephelometric turbidity unit (NTU) measured by the turbidimeter was converted to actual SSC (in mg l^{-1}) using a calibration with linear regression ($r^2 = 0.75$, not shown). The dried sediment was then combusted at 550 °C for 3 h in a muffle furnace, and the loss in weight was used to

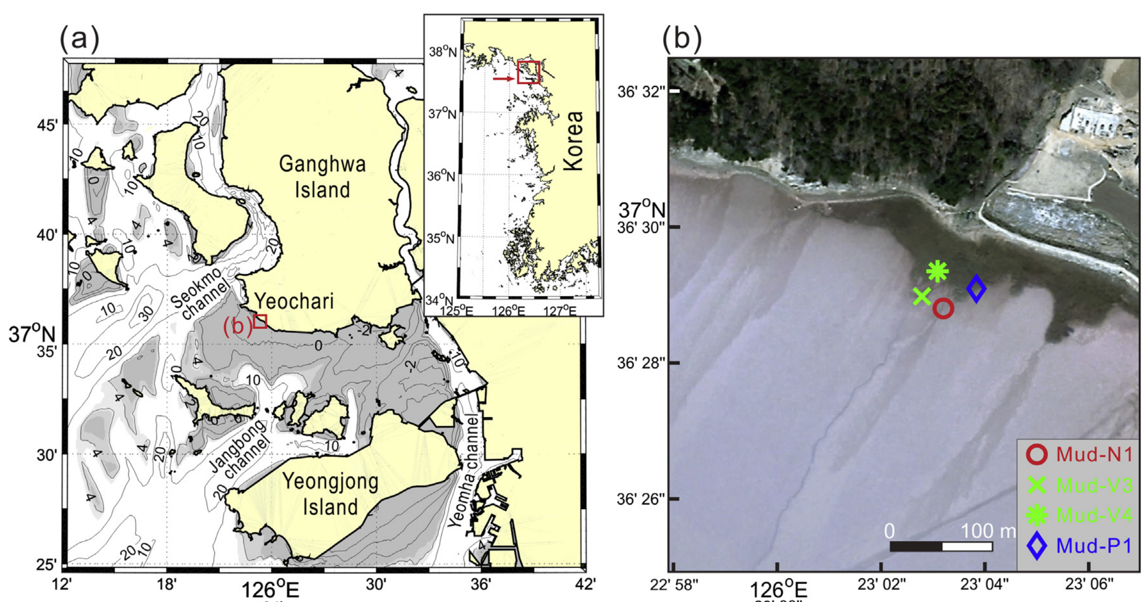

Fig. 1. (a) Map of study area, Ganghwa tidal flat. Thin black lines are isobaths. The grey area near the land represents the intertidal zone. (b) Satellite image showing the collection sites of sediment cores (image source: http://maps.naver.com).

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