The Presence and Transport Processes of Bed Aggregates within the James River Estuary, Virginia

David Perkey, Research Physical Scientist, U.S. Army Corps of Engineers-Engineer Research and Development Center, Vicksburg, Mississippi, David.Perkey@usace.army.mil
Jarrell Smith, Civil Engineer, U.S. Army Corps of Engineers-Engineer Research and Development Center, Vicksburg, Mississippi, Jarrell.Smith@usace.army.mil
Kelsey Fall, Research Physical Scientist, U.S. Army Corps of Engineers-Engineer Research and Development Center, Vicksburg, Mississippi, Kelsey.A.Fall@usace.army.mil

Abstract

Aggregation can significantly impact the size and density of sediment particles, and thus alter the transport characteristics of sediments. Past scientific literature has shown that mud aggregates have frequently been observed in both the geologic record and modern depositional environments. For example, terms such as rip-up clasts (e.g. Knight 1999, Fujiwara et al., 2000; Benito et al., 2003; Bondevik et al., 2003; Donnelly, 2005; Goto et al., 2011), mud balls (e.g. Little 1982; Bachmann, 2014); and mud pebbles (e.g. Karcz, 1972; Durian et al., 2007) are commonly used to describe mud aggregates associated with high energy events such as floods, storms, and tsunamis. However, mud aggregates have also been observed and described in less energetic environments (e.g. Rust and Nanson 1989; Wright and Marriott 2007; Plint et al. 2012; Gastaldo 2013). Additionally, anthropogenic activities such as dredging have also been noted to produce aggregated clasts from the consolidated bed (e.g. Fettweis et al., 2009; Smith and Friedrichs, 2011). The above cited research has shown that these mud aggregates can be transported in both suspension and in bedload, and that transport of eroded bed aggregates over distances of kilometers might be possible in some conditions. Currently, relatively dense mud aggregates associated with cohesive sediment erosion are largely absent from numerical models used to predict sediment transport. Instead, transport models frequently rely on sediment properties obtained from the analysis of disaggregated bed samples. The results of these analyses may not best represent the physical state of material mobilized from cohesive beds. The USACE has recently developed the Flume Imaging Camera System (FICS) to be paired with the Sedflume erosion flume (McNeil et al. 1996) to allow for the imaging and size analysis of material immediately following mobilization from the sediment bed. The goal of this work is to present sediment data that documents the presence and erosion of mud aggregates in an environment where frequent dredging and efficient sediment management practices are a concern for the USACE, the James River Estuary.

The James River Estuary is located in southeastern Virginia and spans approximately 90 miles from Richmond, VA downstream to the mouth of the James River at the entrance to the Chesapeake Bay (Figure 1). Federally maintained navigation channels span this region, and it is estimated that 45-92% of the river sediments being brought down the James River are deposited within the estuary (Nichols, 1990). To maintain the federal channel, the USACE performs routine maintenance dredging. From 2015-2018 dredging projects have removed an average annual volume of 7.7×10^5 yd^3 of sediment from the channel at an average cost of approximately $5 million per year. In many locations throughout the estuary, these dredging projects place material in disposal areas adjacent to the navigation channel.

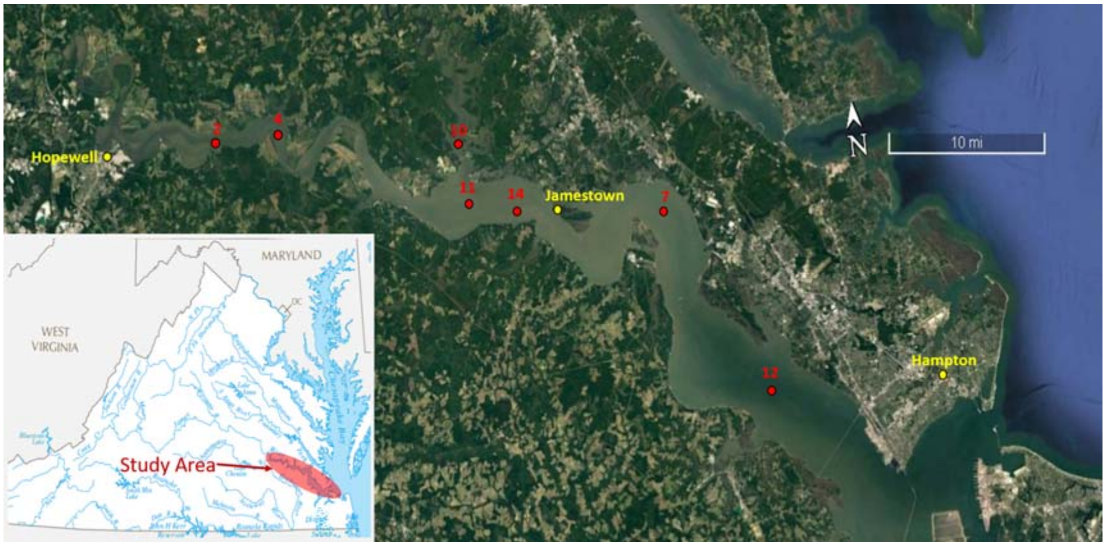

Figure 1. James River Estuary Study Site. Core locations indicated by red circles.

In November of 2017, erosion testing of sediment cores from the James River Estuary were performed as part of an ongoing Regional Sediment Management (RSM) study to evaluate the transport of placed dredged material within the estuary and improve the understanding of sediment transport patterns within the system (Figure 1). Of particular concern was the infilling of the navigation channel and if channel adjacent placement practices were impacting infill rates. The coupled FICS and Sedflume devices were utilized to evaluate the physical properties of eroded James River Estuary sediment cores. Laser Diffraction Particle Size Analysis (LDPSA) of disaggregated bed material samples collected from the upper 2 cm of the cores showed the estuary floor to be dominated by muddy sediment with median grain sizes that ranged from 13-172 μm (Figure 2). However, physical samples of eroded sediments collected from the flume outflow, along with corresponding FICS videos, indicated that the majority of the eroded sediment was in the form of larger aggregated particles (Figure 3). Analysis of FICS videos showed that median size based on particle count ranged from 200-270 μm, or roughly an order of magnitude greater than LDPSA median sizes of the disaggregated bed. FICS size distributions based on eroded volume produced median values that were frequently ~1 mm, or nearly two orders of magnitude greater than LDPSA medians of the disaggregated bed. Only the core surfaces with sand content >50% (Cores 2 & 10) produced median values that agreed within 1 order of magnitude, suggesting that larger bed aggregates are not commonly produced in sand dominant beds (Figure 2). Variation of median grain size values on this scale could significantly impact sediment transport processes and predictive model results.

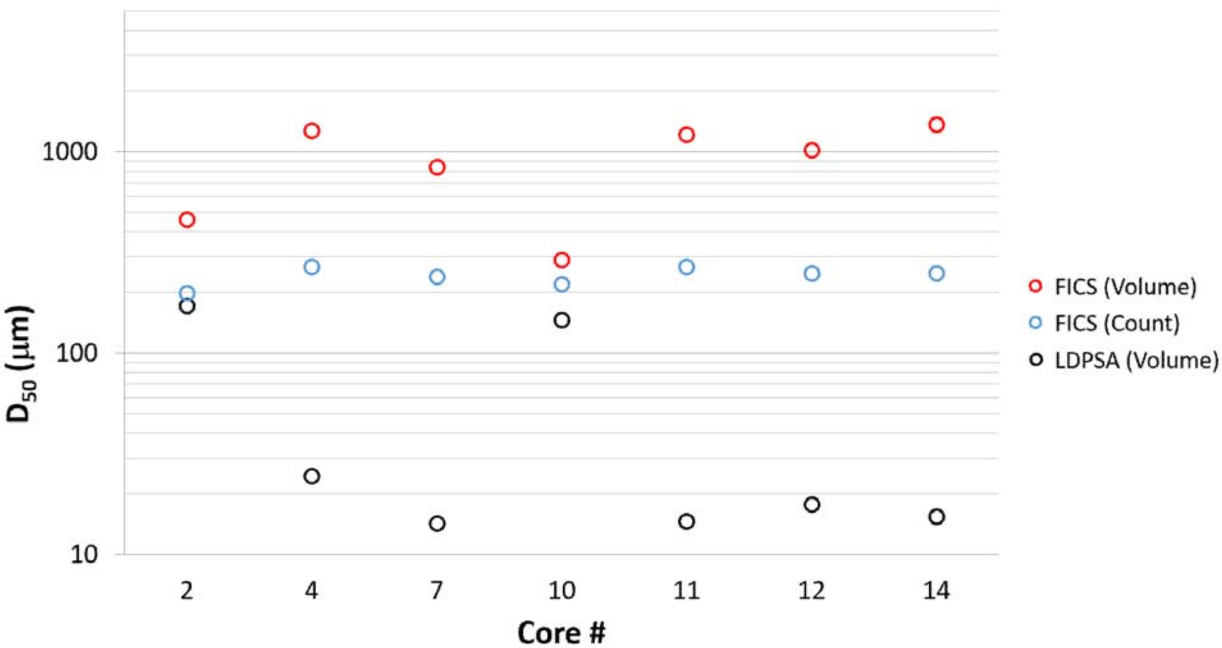

Figure 2. Plot of median grain sizes for sediments within the upper 2 cm of each core.

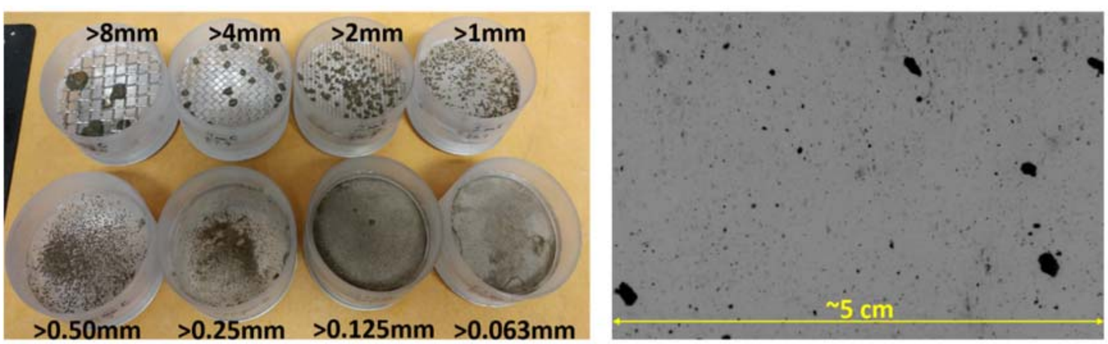

Figure 3. Sediment eroded from 0.7 cm depth of Core 14, retained on sieves (left) and imaged by FICS (right).

To illustrate potential impacts of aggregation on fine sediment transport within the James River Estuary, depth averaged velocity data obtained from the Coastal Hydrodynamics three-dimensional (CH3D) model were utilized to estimate theoretical transport thresholds and modes of sediment transport. The CH3D model has been utilized previously in numerous studies to simulate the hydrodynamics of the Chesapeake Bay system, including the James River (e.g. Johnson et al., 1993; Wang and Johnson, 2000; Cerco et al., 2002; Park et al., 2008; Cerco et al., 2013). In this simulation velocity data from the time period April 1-9, 2000 were utilized to simulate typical tidal flow conditions with maximum current speeds of ~50 cm/s.

Assuming that initial mobilization of the aggregated particles has already occurred, continued transport of these discrete clasts was then estimated by well-established relationships for transport and settling of sediment particles (Schiller and Naumann 1933; Shields 1936; VanRijn 1984). Figure 4 presents results of these simulations and shows that disaggregated mud particles with an assumed density of 2.65 g/cm3 were almost entirely maintained in suspension following initial mobilization. Conversely, larger aggregated mud particles with a density similar to a consolidated bed (1.5 g/cm3) were frequently transported in bedload or remained immobile on the bed following initial erosion. Further, durability testing of James River Estuary mud clasts revealed that following 20 minutes of tumbling within a modified Slake Durability device, 30-50% of the bed aggregate mass remained >250 μm. This suggests that mobilized bed aggregates are robust enough to survive bedload transport over distances of 100's of meters within the James River Estuary. Current dredge material management practices within the estuary frequently calls for the placement of dredged sediments in areas <1 km from the navigation channel. In environments such as these, the presence of bed aggregates could significantly impact management issues such as channel infilling rates and sustainable use of placement areas.

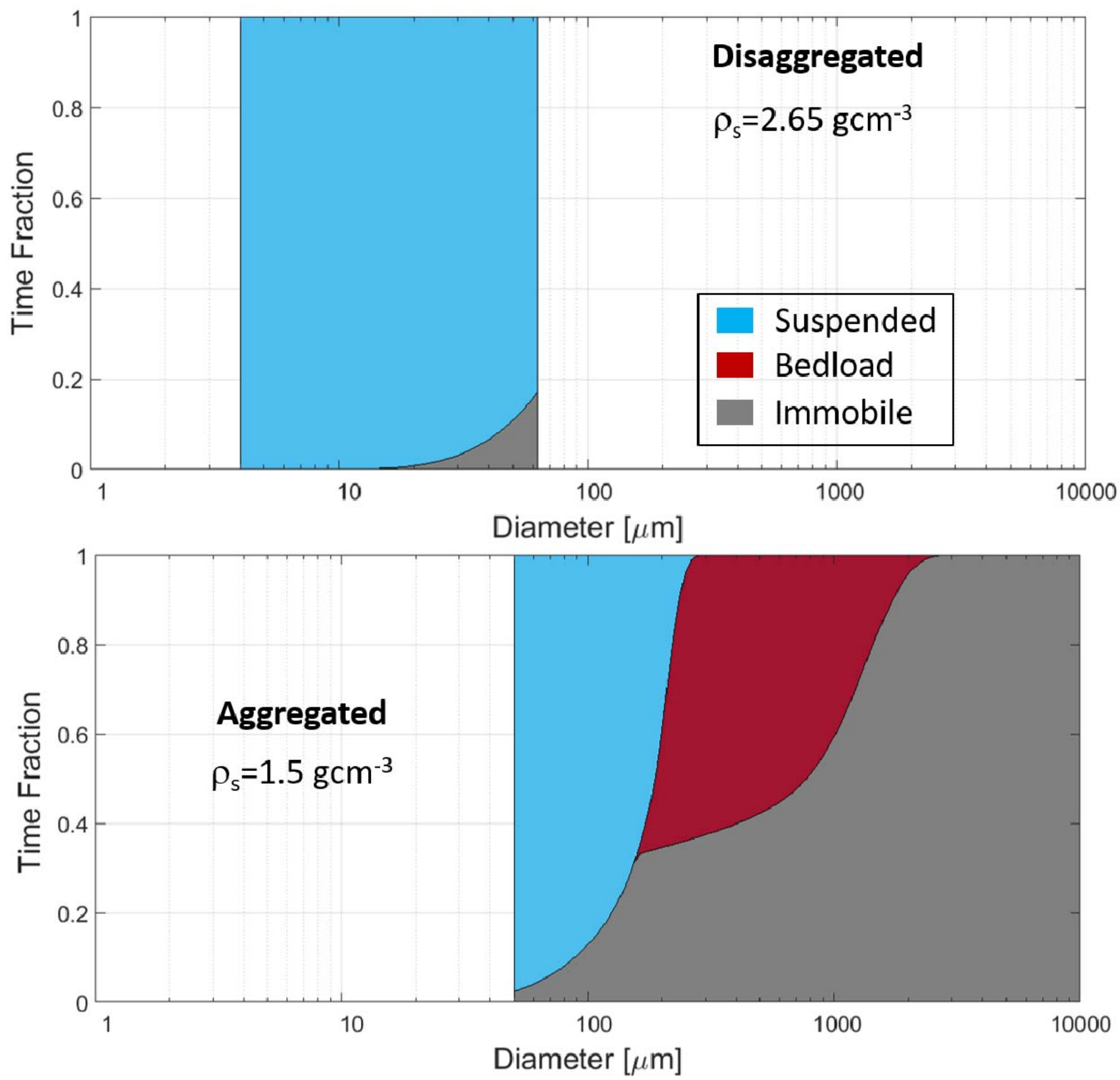

Figure 4. Estimated transport mode for mud sized primary mineral sediment (A) and aggregated mud (B) particles.

These resulting data showcase the potential importance of including aggregated bed clasts in the modeling of sediment transport in environments with cohesive sediment. Ongoing work is being conducted to incorporate the bed aggregate properties measured in this study into the USACE Long-term Fate of Dredge Material (LTFATE) sediment transport model. Model sensitivity testing is planned to evaluate the impact of aggregation state on the life cycle of dredge material mounds and disposal areas within the James River Estuary.

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