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Influence of history and environment on the sediment dynamics of intertidal flats

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ABSTRACT

Morphological trends of three distinct intertidal environments in South San Francisco Bay were investigated using a combination of measurement and modeling tools. Because of the inherent relationship between the physical environment and the sediment properties, the sediment properties provide a good indicator of morphologic trends. A significant finding of this study is that surface sediment erodibility increases as the energy level in the environment increases. Conversely subsurface sediment erodibility shows a strong relationship to the long-term history of the site. The combination of the measured sediment properties, the history of deposition and erosion, and simple modeling of the physical environment illustrate the interaction of these properties such that an understanding of intertidal flat behavior is developed.

1. Introduction

Intertidal flats provide important, and sometimes critical, habitats for benthic communities, fish, birds, and mammals in San Francisco Bay. Additionally, intertidal flats can act as reservoirs for sediment bound contaminants from both historic and ongoing sources. The dual role of intertidal flats in critical habitat and as a potential reservoir for contamination may cause unacceptable ecosystem and human health risks. Development of a deeper understanding of the processes governing the morphology and character of the intertidal flats is critical for effective restoration of habitat and reduction of potential ecosystem and human health risks.

The stability and equilibrium of intertidal flats are influenced by a wide range of physical and biological factors (Friedrichs and Perry, 2001). Consequently, a large body of scientific literature has been devoted to both the physical and biological factors that affect intertidal flat morphology. Physically, intertidal flats are typically comprised of cohesive sediment mixtures in coastal and estuarine environments. The lack of a comprehensive understanding of the processes controlling the erosion, transport, and subsequent deposition of cohesive sediment provides a significant stumbling block to our ability to quantitatively predict the behavior of systems dominated by cohesive sediment (Whitehouse et al., 2000; Ziegler, 2002; Winterwerp and Kesteren, 2004; Lick, 2009). Several researchers have approached the problem from a morphologic perspective to gain a better understanding of the overall dynamics of intertidal flats (Aubrey and Friedrichs, 1996; Dyer et al., 2000; Roberts et al., 2000; Friedrichs and Perry, 2001; Wood and Widdows, 2002).

One of the more useful conceptual models of the physical processes acting on intertidal flats posited by many researchers (Aubrey and Friedrichs, 1996; Dyer et al., 2000; Kirby, 2000) is the balance of physical forcing and sediment supply. Generally in the presence of adequate sediment supply and tidal action an intertidal flat will act as a sediment accumulator. The idealized morphology resulting from these processes is a convex profile. Alternatively, if an intertidal flat is exposed to higher energy, such as waves, or an inadequate sediment supply the flat may become erosional. In these cases a concave profile results. Fig. 1 conceptually illustrates the morphologic trends on an idealized intertidal mudflat.

Biological effects can also work over time to significantly increase or decrease the overall stability of an intertidal flat. Benthic diatoms have been demonstrated to increase the strength of intertidal flat sediment (e.g., Paterson, 1989). On the other hand, macrozoobenthos have been demonstrated to decrease the strength of intertidal flat sediment. Consequently, seasonal changes in biota could have long-term effects on intertidal flat stability (Graf and Rosenberg, 1997; de Brouwer et al., 2000; Wood and Widdows, 2002; Andersen et al., 2010).

The general trend is that as an accreting intertidal flat becomes more "full" of sediment due to accumulation or "reduced" due to erosion, the energy and sediment supply will come into balance. The balance is many times followed by longer-term shoreline accretion or erosion.

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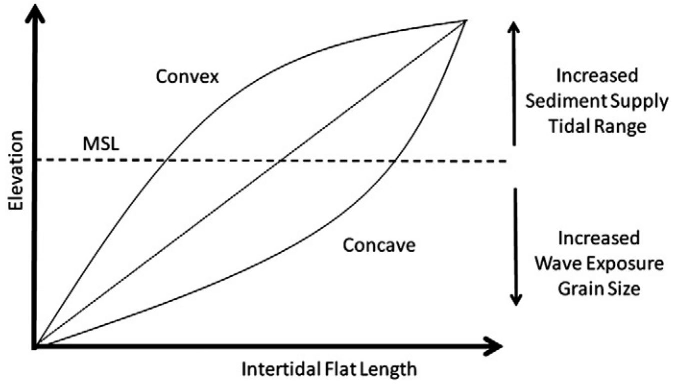

Fig. 1. Conceptual diagram of an intertidal flat cross-section in response to changing physical conditions.

Many researchers have shown these trends in analytic and numerical models as well as field validation (Southgate, 1989; Aubrey and Friedrichs, 1996; Roberts et al., 2000; Fan et al., 2006). Other physical processes that are more difficult to characterize also have effects on the sediment transport trends on intertidal flats. Longer-term climatic or anthropogenically-induced variations in sediment supply can upset the physical balance presented above. Water level variations can also change the energy experienced on an intertidal flat. Sea-level rise can reduce the tidal and wave energy on an intertidal flat resulting in accumulation that may keep up with sea-level rise (Meade, 1969; Kirwan et al., 2010).

The overall complexity of intertidal flats and their importance in coastal and estuarine systems has warranted further analysis of their long-term behavior. In general, sediment responds relatively rapidly, not on geologic scales, to changes in the physical and biological environment. The physical characteristics of the sediment in conjunction with a general system understanding can often guide a solid description of the sediment dynamics. With this description in hand, a plan for more quantitative sampling for environmental remediation and restoration efforts can be effectively designed where necessary. This study outlines the merging of long-term morphologic data, measurements of sediment erosion properties using Sedflume, and characteristics of the physical environment to develop an understanding of intertidal flats in three distinct environments in South San Francisco Bay, California.

2. Physical setting

South San Francisco Bay is a relatively shallow sub-estuary in the San Francisco Estuary with an average depth of approximately 3 m and a surface area of about 400 km^2 (Fig. 2) (Foxgrover et al., 2004). The bathymetry of South San Francisco Bay is simple with a single main channel flanked by broad shallows and intertidal flats (Fig. 3). The channel narrows from about 1 km in the north to several hundred meters in the south. The channel also shoals from north to south from approximately 25 m to 5 m depth.

Water movement in South San Francisco Bay is driven by tides, winds, and freshwater flow from seasonal streams. Conomos and Peterson (1977) presented an early summary of the general water properties, circulation, and tidal flows in San Francisco Bay. More recent discussions about hydrodynamic conditions in South San Francisco Bay can be found in Cheng et al. (1993) and Walters et al. (1985). During the summer, persistent northerly to northwesterly winds occur, with little to no rainfall. Wind driven waves resulting from these persistent winds play a strong role in intertidal sediment transport (Lacy et al., 1996). During the winter, frequent storms (cyclonic low-pressure atmospheric systems) transit the region and cause strong, gusty southerly to southeasterly winds. These storms often bring substantial rainfall to local land areas with subsequent runoff into the bay (Conomos et al., 1985). Local streams and small creeks that enter South San Francisco Bay discharge varying amounts

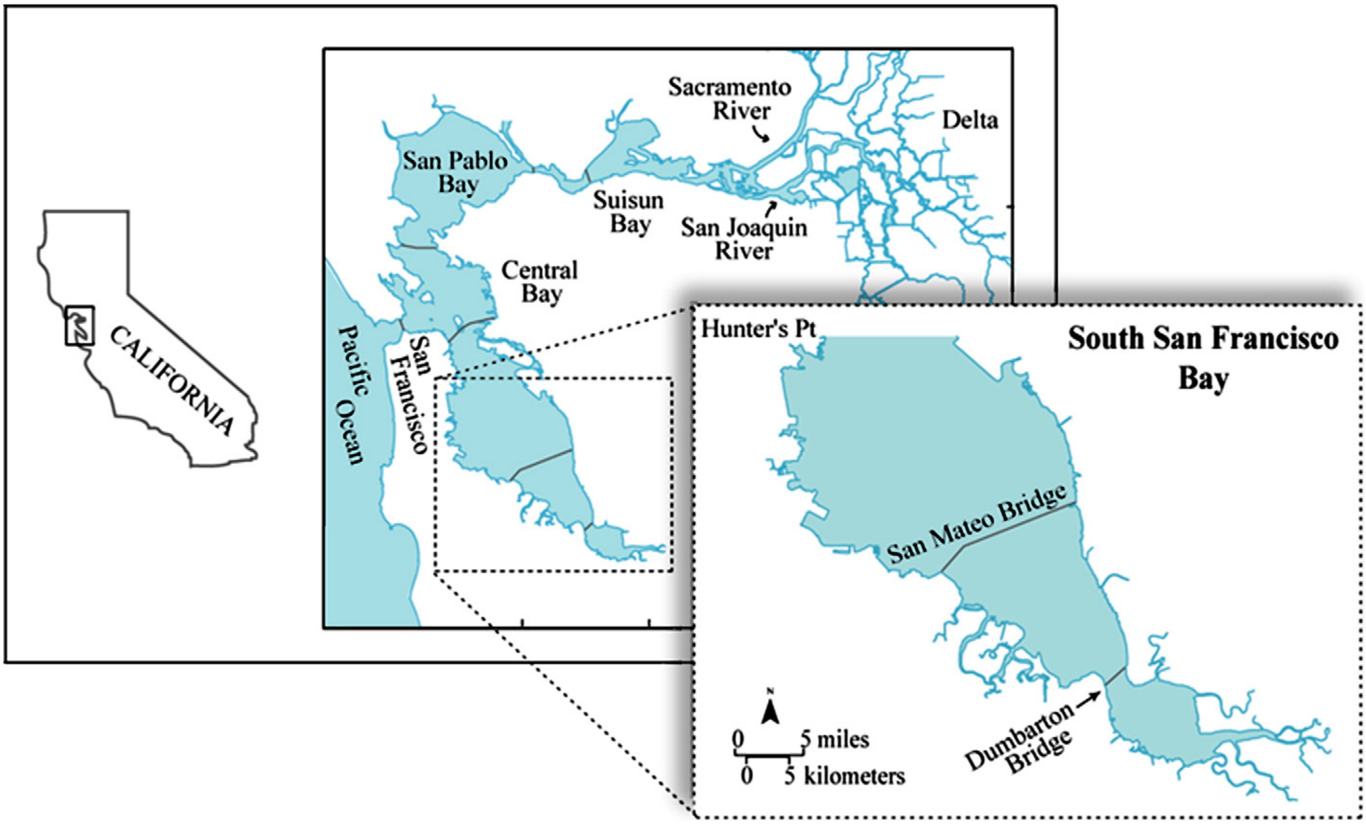

Fig. 2. South San Francisco Bay location map.