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Sediment transport in the San Francisco Bay Coastal System: An overview

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ABSTRACT

The papers in this special issue feature state-of-the-art approaches to understanding the physical processes related to sediment transport and geomorphology of complex coastal–estuarine systems. Here we focus on the San Francisco Bay Coastal System, extending from the lower San Joaquin–Sacramento Delta, through the Bay, and along the adjacent outer Pacific Coast. San Francisco Bay is an urbanized estuary that is impacted by numerous anthropogenic activities common to many large estuaries, including a mining legacy, channel dredging, aggregate mining, reservoirs, freshwater diversion, watershed modifications, urban run-off, ship traffic, exotic species introductions, land reclamation, and wetland restoration. The Golden Gate strait is the sole inlet connecting the Bay to the Pacific Ocean, and serves as the conduit for a tidal flow of ~8×10^9 m^3/day, in addition to the transport of mud, sand, biogenic material, nutrients, and pollutants. Despite this physical, biological and chemical connection, resource management and prior research have often treated the Delta, Bay and adjacent ocean as separate entities, compartmentalized by artificial geographic or political boundaries. The body of work herein presents a comprehensive analysis of system-wide behavior, extending a rich heritage of sediment transport research that dates back to the groundbreaking hydraulic mining-impact research of G.K. Gilbert in the early 20th century.

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1. Introduction

San Francisco Bay (Fig. 1) is the largest estuary on the U.S. West Coast, and the 2nd largest in the United States (Conomos et al., 1985); combined with the contiguous Sacramento–San Joaquin Delta (Fig. 2) it covers a total surface area of ~4100 km^2 and a watershed area of ~162,000 km^2. It contains several economically significant harbors ($20 billion worth of cargo annually) in one of the most developed regions of the United States, with a surrounding population of over seven million people. San Francisco Bay and the adjoining Delta are among the most human-altered estuaries and hydrologic systems, respectively, in the world (Knowles and Cayan, 2004). Major historical changes were driven by the extensive hydraulic mining influx of sediment in the late 19th century (e.g., Gilbert, 1917), massive alteration of the drainages entering San Francisco Bay in the 20th century (e.g., Wright and Schoellhamer, 2004), and the enormous amounts of sediment removed throughout the San Francisco Bay Coastal System from the early part of the 20th century to the present (e.g., Dallas and Barnard, 2011). The system is well-advanced along the timeline of human development common to many estuaries, i.e., disruption (mining, deforestation, agriculture, urbanization) in the watershed that increases load, followed by dams, water diversions, and river management that reduce variability and thus sediment supply, and now restoration of damaged habitats. The many alterations to the system have resulted in significant changes to the Bay floor, area beaches, Bay-fringing tidal marshes, and ecosystems, serving as an example for understanding the evolution of other estuaries. Coupled with strong anthropogenic signals, distinct and powerful natural processes make this region the ideal scientific laboratory for analyzing sediment transport processes, including strong seasonal variability between wet and dry seasons, well-defined flow pulses, strong interannual variability of freshwater inflow, well-defined estuarine boundaries, and strong seasonal variations in wind strength. In addition to the above, intense resource management has provided a critical mass of modern data and studies.

This special issue is a culmination of nearly 100 years of sediment transport research in the San Francisco Bay Coastal System. Here we present ~20 papers, representing the state-of-the-art in sediment transport research on many topics, ranging from tidal marsh sustainability, suspended sediment transport variations, bedform migration and evolution, behavior of the open coast littoral system, and fluvial inputs. The intention of this introductory paper is to describe prior research that forms the basis of our understanding of the fundamental processes that shape this complex coastal–estuarine system, and to clearly identify the data gaps that are addressed in this special issue.

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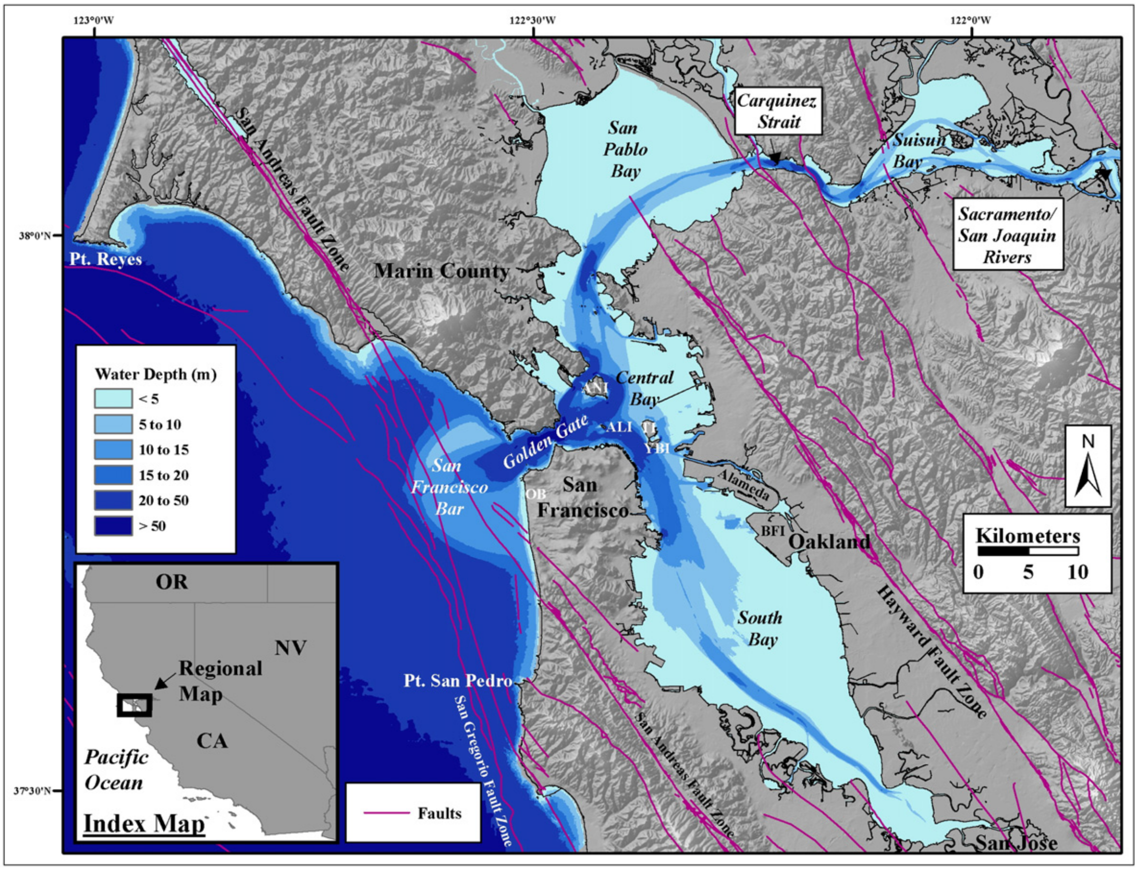

Fig. 1. The San Francisco Bay Coastal System, including major tributaries. Fault lines from U.S. Geological Survey (2006). (ALI = Alcatraz Island, ANI = Angel Island, BFI = Bay Farm Island, OB = Ocean Beach, TI = Treasure Island, YBI = Yerba Buena Island).

Despite the legacy of sediment transport research in the San Francisco Bay Coastal System, there are still some fundamental questions that remain unanswered, which this special issue addresses.

1) What are the primary sediment transport pathways, sources and sinks?
2) How has sediment delivery to the estuary changed over the course of the last century?
3) What is the net direction of sediment transport across the Golden Gate? Is the Bay a net importer or exporter of sand?
4) Is there a geochemical signature that can link sediment inside and outside the Bay?
5) What is the current trend of suspended sediment concentration in the Bay? What are the ramifications of this signal for marsh sustainability as sea level rises during the 21st century?
6) How will current trends in sediment transport dynamics and projected climate change affect the future morphological evolution of the San Francisco Bay Coastal System?
7) How do physical processes and topography control circulation and sediment transport patterns?
8) Can fine sediment transport and morphological evolution be effectively simulated with numerical models?

While this special issue will have direct implications for the regional management of the San Francisco Bay Coastal System, the techniques applied and physical processes analyzed throughout this special issue are on the cutting edge of sediment transport research, and add to the collective knowledge base and understanding of coastal–estuarine systems worldwide.

2. Historical geomorphology and sediment transport

2.1. Early history of San Francisco Bay

San Francisco Bay is situated in a tectonically active basin created from a structural trough that formed during the late Cenozoic (Lawson, 1894, 1914; Atwater et al., 1977; Atwater, 1979). It is bordered by the Hayward Fault Zone to the east and the San Andreas Fault Zone to the west (Fig. 1), which are both associated with the plate transform motion of the San Andreas Fault system (Parsons et al., 2002). The basin has been occupied by an estuary during interglacial periods, and was traversed by a fluvial system during glacial periods, with the current drainage configuration from the Central Valley established by ~0.4–0.6 Ma (Lawson, 1894, 1914; Atwater et al., 1977; Atwater, 1979; Sarna-Wojcicki et al., 1985; Harden, 1998; Lanphere et al., 2004). The open-coast shoreline was located approximately 32 km west of its present position during the Last Glacial Maximum (~18 ka), the current position of the continental shelf break. The basin was most recently flooded during the Early Holocene (Gilbert, 1917; Louderback, 1941, 1951), between 10 ka and 11 ka, as rising sea level inundated the Sacramento River channel that cuts through San Francisco Bay, through the Golden Gate straight, and across the continental shelf (Atwater et al., 1977). Schweikhardt et al. (2010) interpreted the oxygen isotopic composition of foraminifera in a sediment core taken from San Francisco Bay to indicate that the modern estuary was established by 7.7 ka, by 7.4 ka the estuary was highly stratified, and within another century a gradual decrease in water column stratification produced conditions that are similar to the modern, partially-mixed estuary. In the Delta, marshes began forming approximately 6.8 ka, which is likely

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