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Documenting Fine-Sediment Import and Export for Two Contrasting Mesotidal Flats

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LONG-TERM GOALS

The general goal of this project is to examine the seabed, quantitatively document the fluxes of fine sediment (over different time scales), and thereby validate localized measurements and numerical models of sediment transport.

OBJECTIVES

The specific objectives are to:

a) document changes in bed elevation (deposition, erosion) on time scales intrinsic to the driving forces; e.g., tidal and wind-driven currents, local waves, river discharge, and interannual variability;

b) measure net accumulation rates over decades at many sites to calculate fine-sediment budgets for both Willapa and Skagit tidal systems;

c) examine sedimentation at sufficient locations to characterize spatial variability of grain size and its vertical stratification.

In addition, this grant was responsible for coordination of the Tidal Flats project.

APPROACH

The tidal-flat sedimentation in Willapa mud flats and Skagit sand flats has been contrasted, with a focus on understanding the import of mud to the Willapa flats and the export of mud from the Skagit flats. This has involved development of sediment budgets to document quantitatively the fate of muddy sediment, and also includes investigation about the variability of sedimentation over several time scales. Because UW is located near the Willapa and Skagit tidal flats, we helped provide logistical support to colleagues traveling long distances to work in these areas. We have acted as the primary contact for the federal, state and county regulatory agencies. As coordinator for the Tidal Flats DRI, I helped organize a special issue of Continental Shelf Research (to be final in FY11).

WORK COMPLETED

During FY11, research results were synthesized into three publications for the Tidal Flats special issue of Continental Shelf Research, entitled "*Hydrodynamics and Sedimentation on Mesotidal sand- and Mudflats*". Titles for those papers are:

Lessons learned from comparison of mesotidal sand- and mudflats; Nittrouer, Raubenheimer, and Wheatcroft

Seasonal transfer and net accumulation of fine sediment on a muddy tidal flat: Willapa Bay, Washington; Boldt, Nittrouer, and Ogston

Export and retention of fluvial sediment on the Skagit River tidal flats, Washington State; Webster, Ogston, and Nittrouer

RESULTS

Willapa flats

Tidal flats act as natural laboratories in which fundamental sediment-transport processes can be directly related to resulting seabed deposits. These environments represent important repositories for terrestrial particles (including organic carbon) entering marine dispersal systems. Along the coast of the US Pacific Northwest, tides, waves, currents, and storms create year-round energetic environments that evolve on myriad time scales, from semi-diurnal to interannual. In southern Willapa Bay, WA, an extensive tidal flat is accreting away from the mouth of any major local fluvial source. During winter, freshwater input and suspended-sediment concentrations are one-to-two orders of magnitude greater than in summer, and wind- and wave-generated shear stresses prevent sediment from accumulating on the tidal flat. Temporary deposits form as a drape across secondary channels off Bear River (Fig. 1).

Sedimentary structures from these deposits reveal 15-30 cm of physically stratified sediment underlain by a discrete, 2-8-cm-thick layer of shell hash. The presence of relatively uniform excess ^{210}Pb activities in the sediment above the shell-hash, and only supported activities below indicate recent deposition of the surficial sediment. During summer, average bed shear stresses are not significantly lower, but the presence of eel grass and microphytobenthos on the seabed could act to decrease effective bottom shear stresses and increase the threshold of sediment resuspension, respectively. Progressively through the summer, tidal currents and wind waves remove the temporary channel deposits and expose a buried shell-hash layer, and the concurrent seabed changes allow the tidal flats to trap this remobilized sediment. Accumulation rates determined by ^{210}Pb analysis for cores collected on the tidal flats show mean accretion at 1.4 mm/yr (Fig. 2). The mass of sediment stored in the temporary channel drapes during winter is sufficient to account for annual tidal-flat accumulation in the vicinity of these channels. This suggests a mechanism by which sediment temporarily stored in winter channel deposits is subsequently reworked before and during summer, and transferred onto the tidal flats. The accumulation rate on the flats approximately matches local sea-level rise, which implies this system accretes over longer time scales in equilibrium with the space provided. The preservation of laminated deposits (65-90 cm thick) buried 155-230 cm beneath the modern surface suggests that the past accommodation space was greater than at present. Coseismic subsidence during Cascadia earthquakes represents a possible mechanism by which vertical space is created.

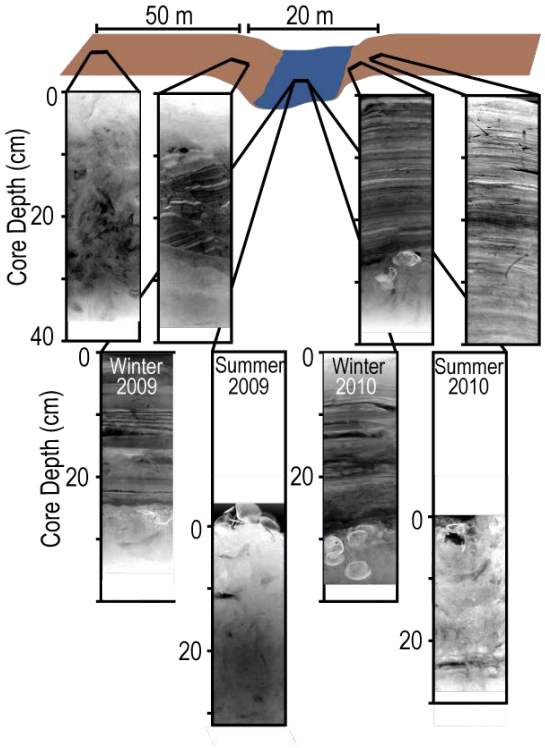

Figure 1. – A transect of cores collected across D Channel. The cores from the banks and flats (upper tier) were collected in July 2009, and show (from left to right) mottled sediment away from channels, and laminated sediment (occasionally with slump features) on the banks. The cores from the thalweg (lower tier) show the seasonal evolution of the channel deposits.

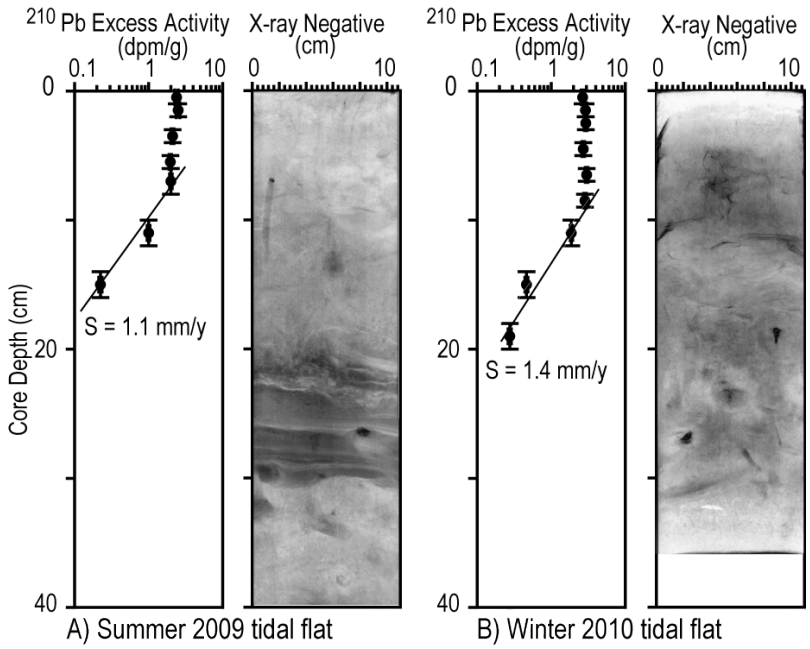

Figure 2. – Sediment cores collected away from channels exhibit steady ^{210}Pb accumulation rates with a mean of 1.4 mm/y (n=12, SD 0.3), below a surface-mixed layer from bioturbation. Most of the flat cores lack physical sedimentary structures, as seen in x-radiograph negatives.

Skagit flats

River input to the Skagit tidal flats creates a broad estuary only a few meters deep with reversing currents and ample sediment supply. Rivers supply much fine-grained material to the sea, but the Skagit River tidal flats are expansive and mostly sandy (Fig. 3). Therefore, a mechanism must be efficiently exporting mud off the flat. This study evaluates the sediment-transport processes, short-term deposition and long-term burial across the intertidal flat. Within the braided tidal-channel system, strong river discharge and tidal currents act to deliver, rework and rapidly export mud to the seaward edge of the flat. To investigate the sediment-transport mechanisms, water-column and seabed observations were collected seasonally under varying river discharge. Mud was found to be scarce on the seabed of the flat, and its presence varied temporally (found following high river discharge) and spatially (found near distributary channels and on the seaward flat edge). The seabed is reworked on various timescales: on a daily tidal timescale, both channel and flat seabeds are reworked to 1-2 cm; and over a decadal timescale, meandering channels act to rework the seabed to 1-2 m, making the limited mud deposits available for export. On ebbing tide, the water column is well mixed with moderate suspended-sediment concentrations, which are transported to the seaward flat edge, largely through the channels. A confined receiving basin combined with strong tidal currents act rapidly to export fine-grained material from the flat edge to deeper regions many kilometers away (Fig. 4). By pairing water-column observations with seabed sampling, this mechanistic understanding is obtained for a tidal system that exports most of it fine-grained sediment from the flat.

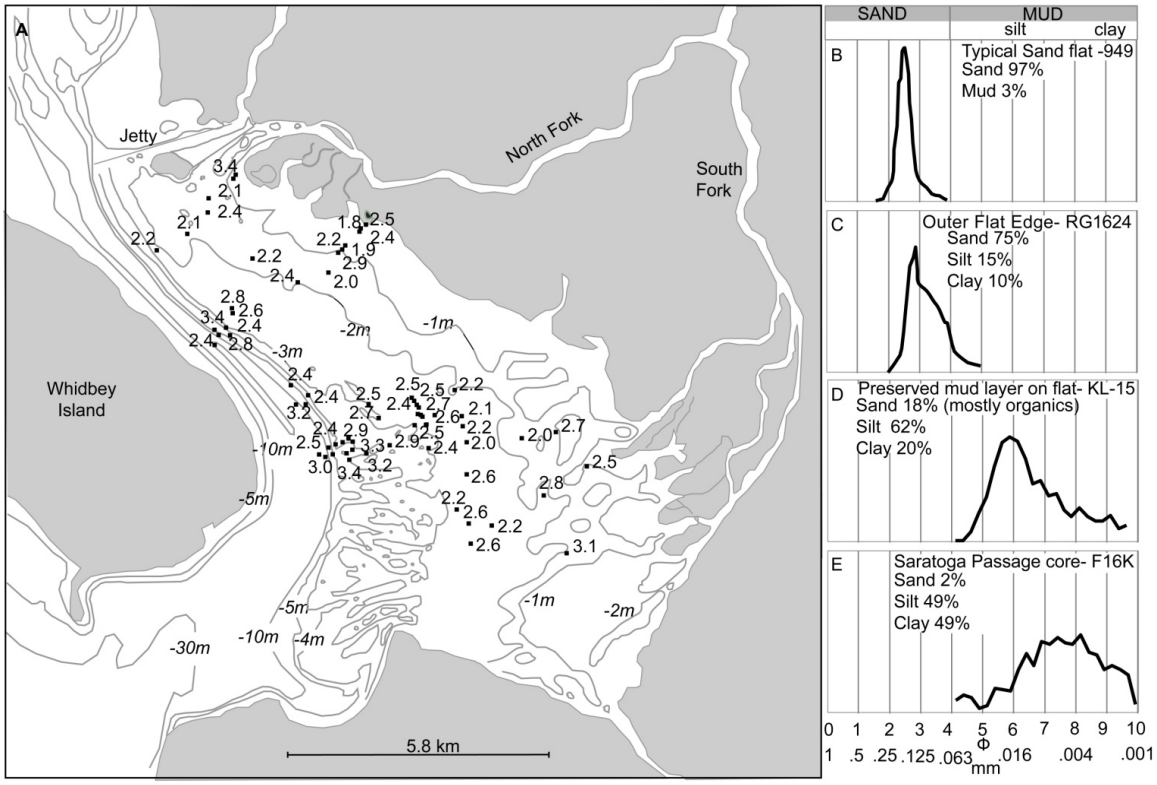

Figure 3. – A) Map showing variation in median grain-size on the Skagit flats (phi units). Also shown are examples of grain-size distributions from various points of the system: B) intertidal flats, C) outer edge of flat, D) preserved mud layer, and E) northern Saratoga Passage.

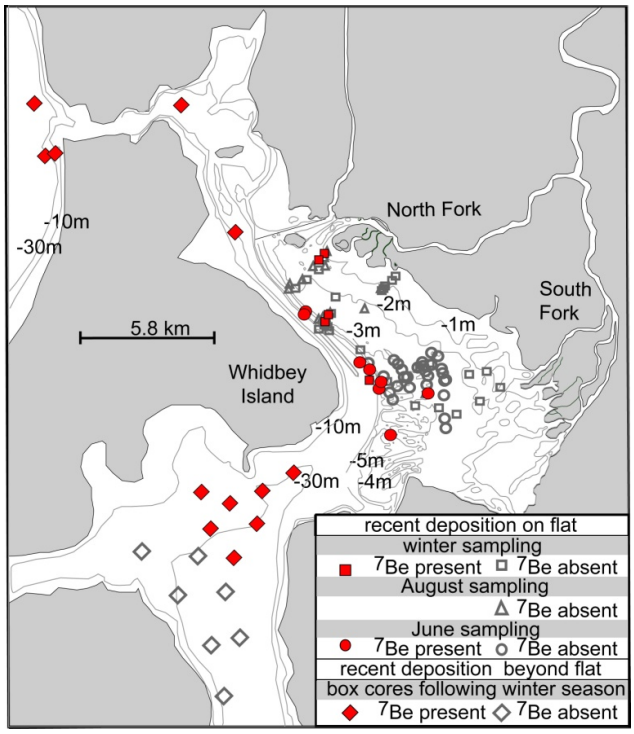

Figure 4. – Map indicating the presence or absence of ^{7}Be from sediment samples collected seasonally. Recent fine-grained sediment was observed on the outer flat and within channels during winter 2008 and spring 2009. No recent fine-grained sediment was observed in August. Following the winter storm season, ^{7}Be was found in northern Saratoga Passage and west of Deception Pass. This indicates that fine-grained sediment was rapidly distributed up to 13 km within several months.

TRANSITIONS

Other investigators in the Tidal Flats DRI are transferring the results from this effort into their projects. Those studying the seabed incorporate radiochemical and textural data to document the processes (e.g., physical reworking, bioturbation) impacting seabed characteristics. Researchers analyzing boundary-layer processes also utilize these data to understand bed erosion and deposition. Accumulation rates, sediment budgets, and grain-size data are key components to input parameters for numerical models.

RELATED PROJECTS

Related projects include studies of: the seabed by R. Wheatcroft and P. Wiberg; boundary-layer processes by A. Ogston, R. Geyer, P. Traykovski, and D. Ralston; suspended-sediment dynamics by P. Hill, B. Law and T. Milligan; seabed thermal processes by J. Thomson and C. Chickadel.

PUBLICATIONS

Written publications

Boldt, K.V., C.A. Nittrouer, and A.S. Ogston., in press, Seasonal transfer and net accumulation of fine sediment on a muddy tidal flat: Willapa Bay, Washington, *Continental Shelf. Research*.

Nittrouer, C.A., B. Raubenheimer, and R.A. Wheatcroft, in preparation, Lessons learned from comparison of mesotidal sand- and mudflats, *Continental Shelf Research.*

Webster, K.L., C.A. Nittrouer, and A.S. Ogston, in preparation. Fluvial sediment dispersal through an insular sea: modern sedimentation associated with the Skagit River delta, *Marine Geology.*

Webster, K.L., A.S. Ogston, and C.A. Nittrouer, in press. Export and retention of fine-grained sediment on the Skagit tidal flats – implications for the fate of fluvial particulate discharge, *Continental Shelf Research*.

Published abstracts

Boldt, K.V., C.A. Nittrouer, and A.S. Ogston, Seasonal sediment transfer and net accumulation on an accommodation-space-limited muddy tidal flat: Willapa Bay, Washington. AGU Meeting, San Francisco, CA. 13 Dec 2010.

Boldt, K.V., C.A. Nittrouer, and A.S. Ogston, Linking sediment transport to laminated seabed Deposits in a fine-grained tidal flat: Willapa Bay, WA. CERF 20th Biennial Conference, Portland, OR, USA, 1-5 Nov 2009.

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Nittrouer, C.A., K.M. Lee, K.V. Boldt, and A.S. Ogston, Tidal flats in S2S systematics: importers and exporters of fine sediment. AAPG Annual Convention, New Orleans, LA, 11-14 Apr 2010.

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Nowacki, D.J., A.S. Ogston, and C.A. Nittrouer, Water-surface elevation controls on sediment-transport dynamics in channel-flat environments of intertidal flats.

Ogston, A., K. Lee, K. Boldt, R. Hale, and C.A. Nittrouer, Tidal asymmetry of sediment transport dynamics on intertidal flats: two contrasting examples. CERF 20th Biennial Conference, Portland, OR, USA, 1-5 Nov 2009. Ocean Sciences Meeting, Portland, OR. 24 Feb 2010.