Field Measurement of Bottom-Boundary-Layer And Sediment-Transport Processes in Support of the STRATAFORM Shelf Dynamics and Plume Studies

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LONG-TERM GOAL

The global objective of the Virginia Institute of Marine Science involvement in the *STRATAFORM* program is to improve understanding of the spatially and temporally varying mechanisms that suspend, transport, and deposit sediment on the continental shelf in the vicinity of the mouth of the Eel River specifically and generally on continental shelves that are accumulating fine sediment.

OBJECTIVES

Specific objectives of efforts to date have been: a) to characterize the spatial and temporal variability of bed roughness; b) to obtain estimates of time-varying bed stresses at two sites on two across-shelf transects of the mid shelf including one transect in close proximity to the Eel River plume source; c) to evaluate sediment resuspension and flux in response to observed stresses at multiple sites; d) to examine the effects of abundant under-consolidated fine sediment on bottom-boundary-layer processes; and e) to examine bottom-boundary-layer processes and transport mechanisms associated with sediment-laden flood plumes from Eel River. Over the past year (October 1997-October 1998) we have been focussing particularly on the role of easily-suspended mud in damping turbulence and favoring further mud deposition.

APPROACH

Our approach has involved field observations of bed micromorphology (roughness), benthic flow, bed stress, and suspended-sediment flux on the Northern California continental shelf north of the Eel River mouth. Over the late fall and winter of 1995 to 1996, we obtained regional measurements of bottom roughness at the *STRATAFORM* shelf sites via side-scan sonar surveys and made more detailed, localized measurements using plan-view and sediment-water interface-profiling cameras. We obtained data from two fully-instrumented bottom-boundary-layer tripods on the “S” line at depths of 60 m and 70 m, beginning on 5 January and continuing through the month of February 1996 during which time two high energy events occurred. The tripods were deployed on “G” line at depths of 30 m and 60 m over the period 21 November, 1996-27 January 1997, period that included a major flood event.

The two tripods deployed on the “S” line in January and February of 1996 were configured to collect benthic-boundary-layer profiles of velocity and suspended-sediment concentration. They supported arrays of electromagnetic current meter sensors within the near-bed log layer, pressure gage, optical

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backscatter (OBS) sensors for suspended sediment profiling. The two tripods deployed by VIMS on the "G" line in winter of 1996/1997 were similar in configuration to those used on the "S" line but also supported an Acoustic Doppler Velocimeter (ADV), and an upward looking acoustic-Doppler water column velocity profiler (ADP).

In FY 1998, we had no new field activity but concentrated on detailed analyses and syntheses. These activities fell into three categories: (1) completing and revising a manuscript on the results from the first year's field work (1995/96); (2) analyzing and interpreting tripod data from the second year's field work (1996/97); and (3) carrying out comparative analyses of data from the Eel River shelf and other sites that are actively accumulating fine sediment.

WORK COMPLETED

From the first deployment (Jan.-Feb. 1996), we retrieved roughly 2 months (at 8 bursts a day) of data. The analyses of this data set are now completed. We retrieved more than 2 months (at 6 bursts a day) of pressure, velocity, and suspended sediment data from the 65 m tripod on "G" line during the second deployment (Nov.1996-Jan.1997). Despite extensive attempts to recover the "G" 30 m tripod, this tripod remains buried beneath about 3m of sediment at the site of its original deployment. All of the data from both deployments are now available for use by other STRATAFORM investigators. The summary data are available on 3.5 diskettes and at the VIMS STRATAFORM website: http://www.vims.edu/physical/strataf/strataform.htm. The complete data sets including measurements within bursts are available on CD-ROM.

Data analyses, interpretations and reporting have taken place progressively over the period of the grant. Data reports (Wright et al., 1996; Hepworth et al., 1997) including data summaries on diskettes were prepared and distributed to interested STRATAFORM participants as soon as initial analyses and data quality assessments were completed. Some initial results from the first field experiment were reported in a special issue of *Oceanography* by Wiberg et al. (1996). A more detailed and substantive paper on the VIMS results is now in press awaiting publication in a special issue of *Marine Geology* (Wright et al., in press). Analyses of data from the G 65m tripod have been carried out in concert with analyses and comparisons of results from three other field environments that are accumulating fine sediment. These results have been embodied in a manuscript entitled "BOTTOM BOUNDARY LAYER PROCESSES ASSOCIATED WITH FINE SEDIMENT ACCUMULATION IN COASTAL SEAS AND BAYS" that will soon be submitted to *Continental Shelf Research*.

RESULTS

Analyses and interpretations from the first field experiment are reported in a manuscript now in press (Wright et al. in press) and those results are summarized as follows: Biogenic roughness with ~ 2 cm relief prevailed at both the 60 m and 70 m sites on "S" line in late 1995. Bottom-boundary-layer tripods were deployed on the 60 m and 70 m isobaths over the period 5 January to 7 March 1996 during which time two high-energy events occurred. Skin-friction shear stresses were subcritical under "average" conditions but appreciably exceeded the threshold for sediment suspension during storms. During those high-energy events, near-bed suspended sediment concentrations reached 2 g/l at 60 m (15 cm above bed) and 1g/l at 70 m (27 cm above bed) and suspended-sediment-induced stratification significantly affected bed stress estimates. At those times, increases in current shear were accompanied by increases in suspended-sediment-concentration gradients causing the gradient Richardson number within the log layer to remain near the critical value of ¼. This suggests suppression of turbulence by sediment induced stratification.

The abundance of under-consolidated fine sediment on the shelf to the north of the Eel River mouth presumably allows increases in stress to be accompanied by progressive increases in suspended-sediment concentration within the log layer to maintain the critical balance. This contrasts to situations where bed armoring limits the total amount of fine sediment in suspension. Applications of a wave-current boundary-layer model with stratification effects included reduces estimates of current friction velocities, u_{*c} by about 24% relative to results from fitting the von Karman-Prantdl equation without stratification. The model suggests that the total wave-current friction velocity, u_{*cw}, reached 3.0 cm/s at 70m and 3.5 cm/s at 60 m. Depth-integrated across-shelf suspended-sediment fluxes were offshore at the 60 m isobath and near zero to weakly onshore at the 70 m isobath during high-energy periods, implying flux convergence. This is consistent with the conclusions of other STRATAFORM investigators that rapid long-term accumulation of mud is occurring on the mid shelf. A general implication is that shelf settings that are rapidly accumulating fine sediment in the presence of frequent agitation by waves, as is the case on the mid shelf off the Eel River mouth, may favor continual production of stable stratification by sediment resuspension until an "equilibrium" is reached and further resuspension is inhibited.

From our analyses of the data from the second deployment, we observed a significant, but indirect contribution to bottom boundary layer processes to have been made by the Eel River flood plume. Bottom-boundary-layer velocity profiles and suspended sediment concentration profiles were measured with an instrumented tripod on the 65-m isobath on the northern California shelf off the mouth of the Eel river in connection with STRATAFORM during the winter of 1996-1997. The observations coincided with a storm that caused a major flood of the Eel River. Benthic flows measured at the "G65" site in the winter of 1996-1997 were slightly larger in magnitude than those observed at S60 the previous year. Near-bottom mean and orbital velocities exceeded 40 cm/s on several occasions. In addition, strong mean currents were occasionally observed in the absence of strong waves. A major flood of the Eel River that peaked on January 1, 1997 distinguished the 1996-1997 field period. The storm that caused the flood also caused high southwesterly winds, high waves (~4 m), and strong northward directed currents (~35 cm/s) which prevailed during the rising and peak stages of the event. During the latter half of the event, the currents shifted to the south and a high concentration event was observed at G65. This event contained fine sediment advected from the north and originally discharged during the flood. Wave agitation of the bed was strong during the first part of the high-turbidity event but weak thereafter. Distinctively different velocity and turbidity profiles prevailed during the "strong-wave" and "weak-wave" phases of the event.

Our comparative analyses utilized bottom-boundary-layer velocity profiles, bed stresses and suspended sediment concentration profiles that were measured with instrumented tripods in four contrasting shelf and semi-enclosed bay environments that are presently accumulating fine sediments. The sites were: the northern California shelf off the mouth of the Eel river; Eckernförde Bay, southern Baltic Sea; the York River estuary, lower Chesapeake Bay; and the Louisiana shelf to the west of the Mississippi River mouth. Bed micromorphology was often biogenic and generally smooth. Near-bed sediment concentration was attributable to local resuspension in the more energetic cases but was also influenced by the horizontal advection of near bottom turbid layers. The presence of density stratification caused simple fits of log profiles to velocity observations over the lowest meter to overestimate bottom stress.

Observed semi-log velocity profiles were (1) concave downward, (2) straight, or (3) concave upward depending on whether the density anomaly decreased with height above the bed (1) much more slowly than, (2) at roughly the same rate as, or (3) much more rapidly than z^{-1}. Stable stratification was attributable to a combination of locally resuspended sediment and thermohaline effects, with the former and latter dominating under high and low energy conditions, respectively. Near bed thermohaline stratification was observed to increase z_o, the elevation of the zero intercept of the logarithmic velocity profile. The effects of sediment-induced stratification were less clear. At all sites, the near-bed gradient Richardson number approached or exceeded the critical value of ¼ implying that turbulence was damped by stable stratification. Results point to the likelihood that stable near bed stratification, which is often associated with fine sediment accumulation plays an important role in accelerating accumulation by reducing near bed turbulence.

IMPACT/APPLICATION

Measurements of near-bottom processes at different depths on the shelf provide insights into the mechanisms responsible for along-shelf and across-shelf transport, the sources and nature of across-shelf variations in hydraulic roughness, and the causes and steepnesses of the across-shelf gradients in sediment flux that may contribute to sediment deposition. The results from the STRATAFORM site, when compared with other sites that are accumulating fine sediment, have yielded new generic insights concerning differences between bottom boundary layer processes in such environments and those that prevail on sandy shelves. Our results are being applied to develop modified models for transport of highly concentrated fine sediment over soft, easily eroded beds.

TRANSITIONS

Our data on bed stresses and resulting sediment resuspension have been made available to modelers and other *STRATAFORM* investigators and are being used to verify bottom boundary layer and sediment transport models. Investigators who have already incorporated our results into their work include Ogsten and Sternberg.

RELATED PROJECTS

1. Biological Mediation of Bottom Boundary Layer Processes and Sediment Transport in Estuaries. Office of Naval Research (Harbor Processes).
2. Suspension and cross-shelf transport of larvae. National Science Foundation (co-op).
3. Physical and biological mechanisms development and evolution of sedimentary structure. Naval Research Laboratory (Coastal Benthic Boundary Layer).

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PUBLICATIONS

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