Shelf and Slope Sediment Transport in STRATAFORM

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LONG-TERM GOALS

The overall long-term goal of STRATAFORM is to advance our understanding of the development and modification of stratigraphic sequences on continental shelves and slopes. An essential part of this understanding comes from direct measurements of the response of bottom and suspended sediment to oceanic forcing in the study areas. In this project our specific long-term goal is to understand the variability of the sediment response at the seafloor to bottom stresses caused by physical oceanographic forcing. This work is accomplished through statistical and dynamical analyses of available field measurements of wave and current flows, sediment resuspension and concentration, and bottom sediment distributions.

In this specific project we focus on understanding sediment dynamics of the shelf and slope off the Eel River, California. Our goals are to evaluate the role of internal waves, surface waves, tides, quasi-steady shelf and slope currents in causing sediment resuspension and transport in this region.

OBJECTIVES

- Evaluate the role of internal waves and tides in transporting sediment on the shelf and slope in the STRATAFORM study regions.
- Determine the variability in the magnitude and directions of bottom stresses caused by currents and surface waves in the STRATAFORM field area off northern California.
- Estimate time-dependent sediment transport at specific shelf sites in collaboration with other investigators.
- Develop statistical information and relationships on the response of the bottom sediment to the bottom stresses using measurements from various locations on the shelf.
- Examine the intense transport events in the bottom-boundary layer measurements to determine the significance of thin, near-bed, high concentration layers (e.g., fluid mud) in transport volumes.

APPROACH

The linearized formulation for internal wave characteristics is used to estimate relationships between characteristic directions and bottom slopes. These relationships are then discussed in terms of their importance for sediment distributions and patterns on the outer shelf and upper slope in the STRATAFORM study regions.

We have gathered recent and historical CTD data to estimate the vertical density profiles (and Brunt Vaisala frequencies) in the Eel River offshore region. These density profiles are then used to compute the characteristics or energy rays for the internal tides and other internal waves. By comparing the slopes of the characteristics with the bottom gradients in the study area, we develop estimates of areas where internal tides and other internal waves might affect the bottom and suspended sediment distributions. We are also using the temperature and current meter measurements obtained at the long-term mooring (over 4 years of continuous data) in 450 m water depth on the upper slope to examine the internal wave dynamics.

This internal wave work is being done in close collaboration with other STRATAFORM investigators: Dr. Lincoln Pratson (Duke University), Dr. Andrea Ogston and Dr. Richard Sternberg (U. of Washington), and Dr. Charles Nittrouer and his students (U. of Washington). Dr. Cacchione has also collaborated with Dr. Erica McPhee, recent Ph.D. at U. of Washington, on the role of internal waves in causing oceanic mixing and nepheloid layer generation.

A secondary part of this project has been to analyze with Dr. Ogston and Dr. Sternberg long-term sediment transport rates and mechanisms in the study region (Ogston, et al., 2000). We have collaborated on evaluating the role of fluid mud generation and transport on the overall transport scheme for the Eel River shelf. Instrumented bottom tripods that have been deployed at many sites on the Eel river shelf during the five-year field program of STRATAFORM have been used in this analysis. This work has produced estimates of sediment flux and bottom stresses over long time periods at various shelf locations.

WORK COMPLETED

- We have presented our results dealing with the effects on sediment movement by internal tides and other internal waves at several professional society meetings and other symposia. We have collected the historical and recent CTD data and computed vertical profiles of density and Brunt Vaisala frequency for the STRATAFORM regions, and calculated characteristic gradients. We have also computed and displayed (GIS maps) bathymetric gradients for both STRATAFORM study areas.

- We have completed a draft manuscript that presents our results on sediment effects caused by internal tides on the continental slope. This paper will be submitted for publication.

- In collaboration with other STRATAFORM investigators we have completed and submitted a manuscript on sediment transport in dense, thin bottom layers on the Eel River shelf (Dr. A. Ogston was the principal author).

RESULTS

During this past year we have made progress in our analysis of the role that internal tides and other internal waves have had on sediment movement and distributions in the STRATAFORM study areas off northern California and New Jersey. Our focus has been on the continental slopes in these regions where the bottom gradients appear to be similar to the slopes of the internal M2 tidal characteristics.

The principal investigator in this project has reported on this geometric relationship previously, and has discussed its potential importance in slope sediment processes (e.g., Cacchione and Drake, 1986).

Using available CTD and detailed bathymetric data we have calculated the slopes of internal wave characteristics and the gradients of the seafloor in the STRATAFORM study areas. The results indicate that over large sections of both regions internal M2 tides are critical or near-critical (within 10% of critical). Here critical is defined as equivalence of the two gradients (i.e., the ratio of the slope of the internal tidal characteristic and the bottom slope is unity). An interesting result of this analysis is that the zones of criticality vary significantly in different seasons off New Jersey, whereas little seasonal variability is found off northern California. This difference is controlled by the nature of the density profiles: off New Jersey the historical profiles in the water column between about 100 and 1000 m have significant changes in temperature and salinity from winter to summer, whereas off northern California the variability in the historical profiles is much less.

We have also completed preliminary work on estimating bottom shear velocities on the slope for near-critical and critical internal waves. These results indicate that these shear velocity values are high enough to inhibit deposition of fine sediment on the upper slope, and at times, high enough to resuspend bed particles in the coarse silt-fine sand size range. If these results hold up under our continuing analysis, we will have found an important mechanism to explain in part the “slope of the slope.” That is, we will have shown that turbulent bottom shear caused by the interaction of the internal tide with the seabed is an effective and important mechanism for controlling sedimentation on the continental slope. These shears might control the rate at which the slope progrades throughout long time periods, effectively maintaining an equilibrium bottom gradient (in balance with the energy and turbulent shear associated with the internal semi-diurnal tide).

IMPACT/APPLICATIONS

If our analysis bears up under closer scrutiny and continuing analysis, we will have uncovered an important geological process that has not received wide application in morphological and sedimentological models of the floor of continental margins. The slow deposition of fine particulate matter onto the surface of the continental slope might be in large part controlled by the nature of the turbulent shears associated with this process. During periods when the internal tidal motions are highest, which varies considerably over the year as determined by our analysis of the STRATAFORM current and temperature data off California, turbulent shears may reach values large enough to prevent deposition of fine sediment (clay and silt sized particles), and may even cause local resuspension of bottom sediment.

This work has applications for modeling of formation of sediment units on continental slopes. It may also have implications for sedimentation on certain continental shelves where turbulent shears from surface waves and other currents are relatively low (as compared with internal wave effects). Also, in a related project we have found that internal tidal currents and shears are large along the island slopes of Hawaii (Cacchione, et al., 2000). This result suggest that internal waves interacting with slopes along islands, seamounts, and guyots might also be important for sediment processes in these regions. For example, Cacchione, et al. (1988) proposed that sediment ripples on top of Horizon Guyot in about 1500 m water depth were formed and actively moved by internal tidal currents.

RELATED PROJECTS

This project is closely related to those STRATAFORM projects investigating morphology and surface sedimentation on the upper slopes and outer continental shelves. The work on internal tides and sediment movement is related to projects led L. Pratson (Duke University), R. Sternberg, C. Nittrouer, and A. Ogston (all three at University of Washington), J. Syvitski (INSTAR, University of Colorado), and G. Parker (University of Minnesota).

The work on sediment resuspension and transport by waves, currents and other processes that includes analysis of bottom tripod data is directly undertaken in collaboration with P. Wiberg (University of Virginia), L.D. Wright and C. Friedrichs (VIMS), and R. Sternberg and A. Ogston (U. of Washington).

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