Fluid Mud in Energetic Systems: FLUMES

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LONG-TERM GOALS

The goal of this research is to develop greater understanding of the dynamics of fluid mud and its role in the transport and deposition of sediment on the continental margin. In particular, we seek greater understanding of the processes that influence the formation and maintenance of fluid muds in energetic environments.

OBJECTIVES

The research is a process-based study that addresses three primary objectives:

- Determine controlling factors in the formation and destruction of fluid mud under a sheared flow

- Verify Richardson number dependence for suppression of turbulence and carrying capacity of a high-concentration suspension

- Evaluate effects of mixed grain size on high-concentration suspensions

APPROACH

To evaluate the controls on fluid-mud formation and the influence of sediment-induced stratification on flow, in situ measurements of vertical gradients of velocity, suspended-sediment concentration, and fluid density throughout the water column, including the fluid-mud layer are necessary. In addition to these parameters, the thickness of the fluid mud layer through accelerating and decelerating flows must be measured.

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The Peticodiac River located in the Upper Bay of Fundy was selected as the study site. The Peticodiac Estuary is a macro-tidal environment that has been modified by the construction of a causeway in the late 1960s. During construction, depositional rates downstream of the causeway were on the order of 1 cm day^{-1} resulting in a decrease in the cross-sectional area of up to 90% within one year of closure. Maximum tidal currents are now on the order 2 m s^{-1} and suspended-sediment concentrations regularly exceed 10 g l^{-1} and can reach 300 g l^{-1} (Curran et al., 2004). At slack tide, sediment settles rapidly forming fluid mud layers on the order of 1-2 m thick.

The Peticodiac River Estuary now provides an ideal natural lab where the formation and destruction of fluid mud can be studied under a sheared flow with a quasi-steady current and without the complicating effect of waves. Flow speeds can be varied by timing the experiments to coincide with the spring neap tidal cycle and by modifying the release of freshwater through the control structure. Measurements are carried out from a bridge that provides a solid framework for instrument deployment thus eliminating many of the challenges of shipboard operations in high-current environments. The Peticodiac has a distinct advantage over laboratory studies in terms of scale and avoids the practical issues of dealing with the quantities of mud required to create a fluid mud layer and maintaining flume equipment at these high concentrations of suspended sediment.

For water-column sampling in high flow conditions a streamlined underwater buoyancy (SUBS) package designed at the Bedford Institute of Oceanography was modified for use as an instrument profiler (fig. 1). Current shear is determined using two Marsh McBirney electromagnetic current meters mounted 60 cm apart on the front of the package. An Ocean Sensors CTD and an optical backscatterance sensor (OBS) are mounted through the front and side of the package respectively. A sample port is co-located with the OBS and connected to a series of pumps to provide suspended sediment for OBS calibration and grain size analysis. To determine the depth of the lutocline and continuously monitor flow velocities, a dual frequency Knudsen echo sounder and an RD Instruments ADCP are mounted on a surfboard tethered to the bridge next to the location of the profiling package. Instruments are deployed from specially designed davits mounted on the bridge deck. Measurements are made every 45-60 minutes over tidal cycles.

All work is being conducted collaboratively between Tim Milligan of the Bedford Institute of Oceanography (BIO) and Gail Kineke of Boston College (BC). Brent Law (BIO) and graduate student Kristy Heath (BC) provide technical support in the laboratory and field. Ms Heath is proceeding with data analysis for her Masters thesis.

WORK COMPLETED

Design and construction of the instrument package and davits was completed in May 2006. Two field experiments were carried out over two 1-week periods in June and August 2006. The June experiment was used to test equipment and observe high flow conditions. The August experiment coincided with a spring tide during a period of maximum seasonal sediment deposition in the Peticodiac.

Calibration of the OBS using the in situ sediment samples collected is complete. This calibration takes advantage of the non linear response of the OBS at concentrations greater than 5 g l^{-1} that was demonstrated for fluid mud on the Amazon Shelf (Kineke and Sternberg, 1995). The grain size analysis for the June suspended sediment samples is also complete.

Data analysis is ongoing. Preliminary results were presented at the International Sedimentological Conference, Fukuoka, Japan and further results will be presented at the AGU Fall meeting, December 2006.

RESULTS

In June, over 100 mm rain just prior to the experiment period meant that the mud in the estuary was displaced downstream. Gates at the control structure remained open except for a short period near high slack water. While suspended sediment concentrations exceeded 40 g l^{-1} the material in suspension consisted primarily of medium to coarse silt. Based on the salinities measured and the settling behaviour of the material observed in the grain size distributions, the system was unflocculated. No fluid mud was present during this time.

In August, fresh water discharge was greatly reduced. Sediment concentration reached 280 g l^{-1} and fluid mud was observed with the profiling package, dual frequency echo sounder and ADCP. Maximum current velocities at the surface were on the order of 1 m s^{-1} on both the flood and ebb tide. Fluid density, calculated as a function of salinity and temperature only, shows a well-mixed water column on the flood tide with lower density (lower salinity) water at the bottom. This density deficit was compensated for by the high concentrations of suspended sediment at the bottom (fig.2). At the end of the rising tide, current speed dropped and a lutocline formed, further increasing the density deficit (fig. 2). Velocity profiles during flooding currents showed strong but almost constant shear through the water column leading to strong mixing (fig. 3a). Velocity profiles during ebbing currents show uniform velocity in the upper water column and within the fluid mud, and strong shear at the lutocline (fig. 3b). .

IMPACT/APPLICATION

Our observations will help refine our understanding of formation and maintenance of fluid mud in sheared flows and to test threshold conditions for the suppression of turbulence and carrying capacity of turbulent flows (Trowbridge and Kineke, 1994). These criteria (e.g. critical Richardson number) have been used to ‘set’ a maximum concentration to drive a gravity flow. This approach has been used in the STRATAFORM and EuroSTRATAFORM projects to model the density underflow observed on the Eel Shelf (Friedrichs et al. 2000; Wright et al. 2001; Scully et al. 2002) and to predict gravity flows off the Po River (Friedrichs and Scully in press). These models assume a critical Richardson number of ¼ , but field observations of shear and density gradients in high concentrations have been limited before now.

RELATED PROJECTS

G. Kineke is a co-PI on a new ONR MURI project, “Mechanisms of Fluid-Mud Interactions Under Waves.” This project includes investigators from Johns Hopkins (Dalrymple, Shen), Woods Hole Oceanographic Institution (Trowbridge, Traykovski), MIT (Liu, Mei,Yue) and Memorial University (Bentley). The major objective of this study is to examine the various mechanisms of water wave dissipation over muds and field, laboratory, and theoretical approaches will be employed.

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Figure 1: Profiling package deployed in the Petitcodiac River to observe the behaviour of fluid mud in a sheared flow. Instruments mounted on the package include 1) D&A optical backscatterance sensor and sample port for pumped samples (see inset), 2) Ocean Sensors CTD and 3) Marsh McBirney electromagnetic current meters.

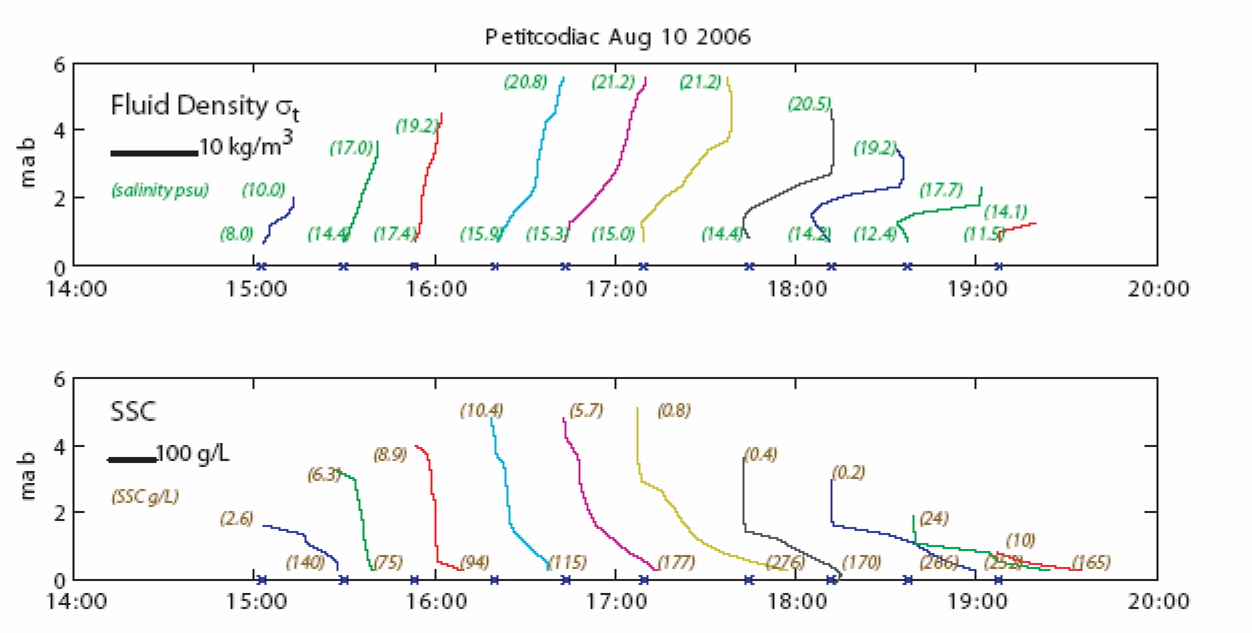

Figure 2: Water-column profiles of fluid density calculated from salinity and temperature, top panel, and suspended sediment concentration (SSC), bottom panel. Each profile is plotted over the range indicated by the scale bar. Surface and bottom salinity and suspended sediment concentration are indicated in parentheses. Cast times are indicated by x symbols on the x-axis. The decrease in fluid density with depth is mostly due to lower salinity water at the bottom, but the water column is stable due to the high concentration of suspended sediment.

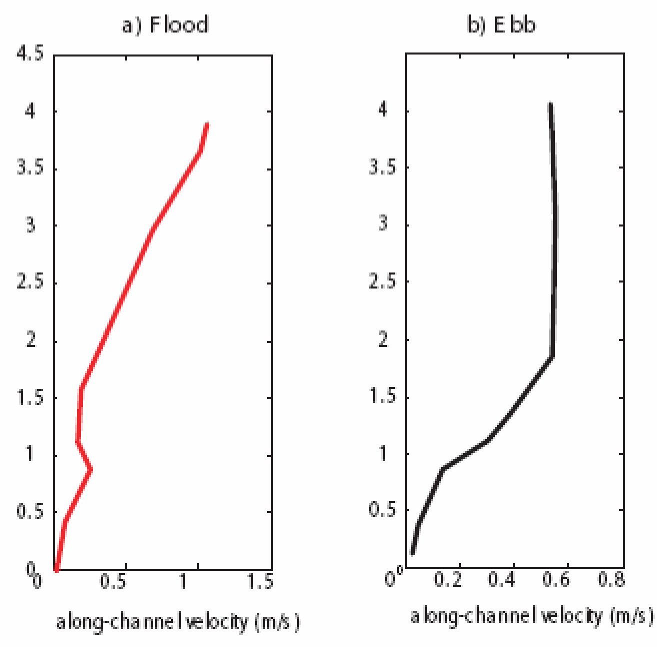

Figure 3. Velocity profiles during flood (a) and ebb (b) coinciding with profiles at 1555 and 1745 on Figure 2. The flood profile exhibits strong, nearly constant shear resulting in a mixed water column. The ebb profile is nearly uniform in the upper water column, above the fluid mud, and shows strong shear across the lutocline.