The Role of Fluid Mud in Sediment Transport Processes Along a Muddy Coast

Gail C. Kineke
Dept of Geology and Geophysics
Boston College
Chestnut Hill, MA 02167
phone: 617-552-3655 fax: 617-552-2462 email:kinekeg@bc.edu

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LONG-TERM GOALS

The long-term goals of this study are to evaluate the role of fluid mud in sediment transport processes along muddy coastlines. This requires an understanding of the formation and dynamic behavior of fluid muds, as well as the effects on attenuation of surface waves as they approach the shoreline.

OBJECTIVES

The motivation for this study comes from the acknowledgement that work done on sandy beaches is not directly transferable to muddy coasts, and the role of fluid mud is critical to large-scale beach changes on muddy coasts. This study addresses the following objectives:

1. to examine the formation of fluid mud on the inner shelf as the result of a) trapping due to convergence of bottom flows and enhanced settling at a salinity front, or b) a resuspension process due to surface wave activity;
2. to test the concept of a critical bearing capacity for a flow, based on results of Trowbridge and Kineke (1994); and
3. to document the attenuation of wave energy over an inner shelf with fluid muds and relate that to areas of shoreline accretion and erosion.

APPROACH

The study area is the shallow shelf (< 20 m water depth) from Atchafalaya Bay to ~ 100 km west along the western Louisiana coast. Spatial surveys consisting of a series of shore normal transects have been repeated during different river discharge conditions to define the thickness and extent of fluid muds in relation to water properties (extent of freshwater plume and nearshore mudstream). An instrumented profiling tripod capable of measuring flow and fluid characteristics (Sternberg, et al., 1991) and a second, hand-deployable profiler (CTD plus optical backscatterance sensor) for shallow water work have been used. The tripod is extremely effective in environments with fluid mud because it is able to sample very close to the seabed (approximately 10 cm), and it can measure very high concentrations of suspended sediment (up to 330 g l^{-1}, Kineke and Sternberg, 1992). The profiling tripod has been used for spatial surveys (shore normal

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transects throughout the study area), as well as for tidal time series at salinity fronts while the ship is at anchor. The hand-deployable profiler is used off a small boat in water shallower than approximately 5 m. In addition, the small boat is equipped with a dual high frequency echo sounder and differential GPS for mapping thickness and extent of nearshore fluid muds.

Anchor station time series have been done using the profiling tripod to determine temporal variability and transport on tidal time scales. Simultaneous measurements have been made with pressure sensors to document wave attenuation across the shelf.

A new instrumented staff is being constructed to measure flow and fluid characteristics and to document vertical changes in differential pressure, and thus changes in fluid density, from within the mud bed to ~1.5 m above the bed. This will document changes in fluid mud thickness with passage of gravity waves, as well as the appearance of fluid mud due to settling.

The surveys and anchor station measurements are being analyzed to evaluate (1) the influence of river discharge and frontal processes on fluid mud formation and (2) to test the concept of a bearing capacity for a given flow. The pressure sensor array and instrumented differential pressure staff will be used for time-series measurements to evaluate (1) the role of surface gravity waves in fluid mud formation and (2) the effects of the presence of fluid mud on surface gravity wave attenuation.

WORK COMPLETED

The project has been underway for two years and five months. Three cruises have been completed aboard the R/V Pelican: October 1997-low river discharge, March 1998-rising river discharge, high wind activity, and April 1998-high river discharge, diminishing wind activity.

Data collected on these cruises include hydrographic/suspended sediment surveys of 45 stations along seven shore normal transects, time series measurements of 12-26 hours, shallow water surveys with the dual frequency echosounder and CTD profiler, and coastal characterization. Wave sensors have been deployed in shallow water for documentation of surface gravity waves for the duration of the experiment. The heavy fishing activity in the study area has inhibited efforts at long term deployments. A prototype differential pressure staff is currently under construction and should be ready for deployment during the next cruise scheduled for March 1999.

RESULTS

Analyses are presently underway, but preliminary results comparing the suspended sediment and freshwater distributions over the shallow shelf during a range of conditions demonstrate several things.

1) High concentration suspensions, or fluid mud, have consistently been observed in the Atchafalaya channel in the region of maximum along-channel salinity gradient,

regardless of river discharge. This implies the fluid muds form as a result of a flow convergence at the salinity front which is well downstream from where one might expect a turbidity maximum. This location is extremely difficult to perform extended time series because of the narrow channel and heavy ship traffic.

2) While there are significant differences in the amount of freshwater observed on the shallow shelf from cruise to cruise (season to season), the suspended sediment concentrations are highly variable in space and time and the biggest influence appears to be the wind (and wave) conditions. Field observations in March 1998 documented the passage of a cold front with accompanying strong winds causing dramatic changes of the suspended sediment concentration field. Figure 1 with an extended caption shows the evolving sediment, salinity, temperature and density field through this event. Fluid mud formed through rapid settling of elevated suspended sediments through the water column following the period of strong winds. While waves were likely responsible for the resuspension of sediments providing the source for fluid muds; we did not observe evidence of fluidization of the seabed due to surface waves. Determining the mechanism for fluid mud formation through rapid settling or seabed fluidization is one of the main objectives of this project.
3) Radioisotope measurements of sediment accumulation and mixing rates (Mead Allison, TAMU) from boxcores closest to shore are consistent with suspended sediment observations that imply rapid deposition nearshore during high discharge, and reworking and subsequent transport through the remainder of the year.

IMPACT/APPLICATIONS

A tremendous amount of research on coastal processes and sediment transport has occurred on sandy beaches; however, muddy coasts are quite common worldwide, especially close to large rivers, and have received relatively little attention by comparison. Wave attenuation is of primary significance for mitigation of shoreline erosion and coastal flooding, and wave attenuation on a muddy coast is directly linked to the characteristics and consolidation state of the muddy substrate, unlike sandy shorelines. In the presence of fluid muds, waves will progressively attenuate as they travel landward, resulting in decreasing boundary shear stresses close to shore, the opposite of what occurs on sandy coasts. Thus, the processes important on sandy beaches are not directly transferable to muddy coasts. The amount of field research done on wave/muddy coast interactions is severely lacking, although a great deal of effort has been done in laboratory flumes and theoretical studies. The proposed field study will provide essential observations for evaluation of the role of fluid muds in sediment transport and our ability to model the effects of wave-mud interaction.

TRANSITIONS

See Related Projects below.

RELATED PROJECTS

Sediment Trapping and Transport in Estuaries, Southeastern US, National Science Foundation CAREER Development Program, Kineke PI. This project began in

September 1997 and will study sediment transport and trapping mechanisms in three estuaries in the southeastern United States. Sediment transport experiments in each of these estuaries in South Carolina and Georgia have revealed the presence of fluid muds, previously not observed, in localized areas surrounded by sandy bottom sediments. The trapping mechanisms for each estuary might be different in the details, but the presence of these high concentration suspensions in estuaries of rivers with low source sediment concentrations implies effective trapping mechanisms in regions of horizontal salinity gradients or changing particle characteristics. The formation of these dense suspensions has important implications for the mixing and trapping of nutrients and particle exchanges from the freshwater zones of the river to/from the salt marsh and to/from the coastal ocean. Understanding the dynamics of sediment trapping, fluid mud formation, and the influence on the transporting flow is of fundamental interest to me, and is directly related to the work proposed here.

Dr. Brent McKee (Tulane University) has ongoing research in the Gulf of Mexico and the Mississippi and Atchafalaya estuaries (state and federal funding). Dr. McKee, a radioisotope geochemist, has made extensive measurements dealing with short and long term accumulation rates on the shallow shelf, which will serve as a guide for areas of fluid mud formation. Further, we have agreed to coordinate our field plans as much as possible, with his experiments providing an opportunity for us to accomplish surveys during other times of the year, and my being able to supply fluid mud samples to Dr. McKee.

Collaboration with Dr. Miguel Goñi, an organic geochemist (University of South Carolina), began in March 1997. Dr. Goñi and his students have participated in all of our research cruises and collected bottom sediments for organic content and composition analyses. He has recently been funded by the National Science Foundation to investigate the terrigenous inputs of organic matter to sediments from deeper locations in the Gulf of Mexico (including the outer shelf, continental shelf and abyssal plain). We have coordinated our field efforts to make efficient use of ship time, we are sharing results, and I am serving on the committees of one of his students. This allows an exciting interdisciplinary component to the ongoing study by analyzing the fate of terrestrial organic matter in marine sediments.

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Figure 1. Transects of suspended sediment concentration (top panel), salinity (second panel), temperature (third panel) and sigma-t (bottom panel) on the inner shelf west of the Atchafalaya over a 19-hour period (Column 1: 3/8/98 1500; Colum 2: 3/9/98 0300; Colmumn 3: 3/9/98 1000). Over a period of ~ 6 hours, temperatures dropped 10°C and sustained wind speeds during that time were over 15 m s^{-1}. During the period of increasing winds, the water column of the shallow shelf changed from stratified in salinity, density, and suspended sediment concentration (first column) to well mixed and vertically homogeneous with respect to all three properties (second column, approximately 12 hours later). Suspended sediment concentrations were approximately 1.4 g l^{-1} throughout the water column in depths of ~ 5 m. Within two hours of the wind speed weakening, suspended sediments settled rapidly forming a high concentration suspension with maximum measured concentration of 25 g l^{-1} at 20 cm above the bed (third column).