Evolution of Particle Size in Turbid Discharge Plumes

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LONG-TERM GOALS

The goals of this research are to develop greater understanding of the fate of fine sediment delivered to the continental shelf by the Eel River during floods and to refine methods for interpreting quantitatively the environmental record stored in grain size distributions of fine sediments on the shelf.

SCIENTIFIC OBJECTIVES

The proposed research has three objectives.

- Develop and test energy-based parameterization of floc settling velocity.
- Monitor patterns of post-event, cross-shelf transport of flood sediment in the bottom boundary layer (BBL).
- Refine and test models for quantitative process-based interpretation of disaggregated inorganic grain size (DIGS) in suspension and in the seabed.

APPROACH

The field effort employs a rapid response strategy, in which preset streamflow levels in the Eel River elicit a mobilization of people and gear. Within 24 hours of a ``trigger," an instrument package comprising a CTD, optical backscatter sensor, silhouette floc camera (SFC), and 2 depth-actuated Niskin bottles is ready to be deployed from a Coast Guard helicopter. In 1999 two additional samplers were added to the instrument package: a bottom-actuated syringe for collecting samples of suspension within the bottom boundary layer and a bottom-actuated micro-grab sampler for collecting samples of surficial sediment. The instrument package is lowered on a wire into the water on a grid of 9-12 stations in the Eel River plume. Stations extend from just seaward of the surf zone to 40 meters water depth. Stations are occupied during the flood and for several days afterward, allowing examination of the post-flood distribution of suspended sediment on the shelf.

Analysis of DIGS focuses on process-based parameterization of fine-sediment grain size distributions. The parameterization of grain size distributions in the seabed divides a deposit into floc-delivered and single-grain delivered fractions. These distinctions are more valuable from a dynamic standpoint than typical sand-silt-clay ratios because they relate directly to mode of transport. This parameterization is being applied to closely spaced samples of x-radiographed slabs from box cores taken by Rob Wheatcroft on the Eel shelf. The parameterization of suspended sediment grain size distributions also divides a suspension into flocs or single grains. The proportion of sediment mass in flocs is determined by the relative magnitudes of aggregation and disaggregation rates. Because aggregation is a reaction that is second order in concentration while disaggregation is first order, high sediment concentrations beget large floc fractions.

The validity of the assumptions underlying the proposed parameterization of flocculated suspensions is untested. The key assumptions are that particles either reside within flocs or as single grains, that aggregation only occurs through interaction of flocs and single grains and not by single grain-single grain interactions, and that floc sinking can be characterized by a single mean floc settling velocity. We will examine these assumptions with a settling column study being designed by Masters student Kristian Curran. In the settling-column Kristian will measure directly floc size, floc settling velocity, and floc fraction, and through application of our new parameterization, he also will estimate these variables based on the observed evolution of DIGS in the column. Disagreement between estimated and observed floc fraction and floc settling velocity will expose any shortcomings of the proposed parameterization and its underlying assumptions.

All work is being conducted collaboratively with Tim Milligan of Bedford Institute of Oceanography. Milligan takes primary responsibility for equipment design, data acquisition, and particle size analysis. Hill takes primary responsibility for modeling, data analysis, and communication of results.

WORK COMPLETED

In winter 2000 particle size distributions were monitored during and after one flood event on 2 helicopter missions. We also characterized the "background" water column properties by deploying the instrument package on a non-flood mission. Water samples have been analyzed for suspended particulate mass, and disaggregated grain size distributions have been generated with a Coulter Multisizer. Also, we continue to characterize disaggregated size distributions for a variety of cores on the Eel shelf.

Two manuscripts were accepted for publication in a *Continental Shelf Research* special volume on event sedimentation on the continental shelf. The first (Hill *et al.*) explores the role of flocculation in determining clearance rate of sediment from the Eel River plume during the 1997 and 1998 flood seasons. The second (Geyer *et al.)* examines the controls on plume structure and sediment fate.

Kristian Curran completed his first year of work as a student on the STRATAFORM project. He took a lead role in data collection, and he is applying the parameterization of sediment partitioning in suspension to the interpretation of the evolution of DIGS in the Eel plume and in a flume study that he conducted as a work-term student in our laboratories. Kristian has also initiated design of the settling column experiment that will assess the efficacy of the parameterization for predicting DIGS evolution in suspension.

Ongoing collaboration with Pat Wiberg has led to advances in the parameterization of particle size in bottom boundary layers. Pat has found that our simple model of aggregation and disaggregation is useful for predicting spatial patterns of DIGS in the seabed in a salt marsh. She has devoted some attention to the effect of several different breakup parameterizations on predicted spatial patterns of DIGS.

RESULTS

Bulk effective settling velocities required to explain sinking losses from the Eel River flood plume off the coast of northern California are of order 0.1 mm s^{-1} for five different helicopter-based sampling surveys conducted in January and February 1998. These effective settling velocities exceed those expected by single-grain sinking by a factor of two and implicate flocculation as an important mechanism for speeding the removal of sediment from the Eel River plume. The relative constancy of effective clearance rates despite widely varying winds, waves, and currents is consistent with photographs in the plume that show little variability in floc size with day, depth, or across- and along-shelf position. These observations of floc size contrast with those made in winter 1997 during the exceptionally large New Year's flood. During that event, increases of floc size with depth are evident. In 1997, higher sediment concentrations associated with the significantly larger discharge allowed flocs to grow substantially as they sank through the plume, whereas in 1998 low concentrations precluded significant increases in floc size with depth. These observations do not support the hypothesis that concentration controls maximal floc size; rather they indicate that the time required to form large flocs scales inversely with concentration. Using a published relationship between floc size and settling velocity for the Eel shelf suggests that approximately three fourths of the sediment in the plume was packaged as flocs during the 1998 floods. These data provide unique quantification of the role of flocculation in determining clearance rates from riverine discharge plumes, thus advancing efforts to develop a process-based understanding of flood deposits on continental shelves.

Disaggregated inorganic grain size in the Eel River plume at the G-line matches closely the DIGS in the flood deposit in 1997. All of the material is poorly sorted and less than 30 μm diameter. Samples collected near the bed beneath the plume, however, are better sorted and coarser, as is expected for resuspended bottom sediment. Because plume sediment is delivered to the bottom boundary layer in relatively shallow water and then transferred to the flood deposit at 70 m water depth by bottom boundary layer processes (Geyer *et al.,* 2000), an outstanding question is how transfer from the plume to the flood deposit is effected without incorporation of resuspended, inner shelf coarse silts and sands.

In a laboratory flume, size-specific clearance rates suggest that sediment deposits primarily within small “microflocs” that sink at fractions of a millimeter per second. The dominance of microflocs over large, fast-sinking macroflocs is expected given the highly turbulent environment within the flume and its impeller-driven flow-return section. To reconcile observed size-specific clearance rates with our new parameterization requires that some fraction of deposited sediment is resuspended. This result was also found by Pat Wiberg when she applied the parameterization to interpretation of DIGS in a salt marsh.

IMPACT/APPLICATION

Observations are helping to refine understanding of modes of delivery of flood sediment to the Eel River Shelf. These observations will allow quantitative constraint of aggregation time scales that has been lacking in the past. The generalized parameterization of particle aggregation and disaggregation rates will ease incorporation of these important processes into models of fine sediment transport.

TRANSITIONS

Parameterization of fine sediment size distributions is being applied to interpretation of salt marsh deposits by Pat Wiberg and to interpretation of inherent optical properties of the bottom boundary layer by Paul Hill and Emmanuel Boss.

RELATED PROJECTS

Similar observations of in situ and disaggregated grain size were made with ONR support in a turbid discharge plume in Yakutat Bay, Alaska. Collaborators are James Syvitski (U. Colorado), Ellen Cowan (Appalachian St. U.) and Ross Powell (N. Illinois U.).

Control of floc size by turbulent kinetic energy is being investigated under the aegis of ONR's Coastal Mixing and Optics program. The proposed parameterization of aggregation and disaggregation is being applied successfully to the interpretation of optical measurements gathered at the Coastal Mixing and Optics site by Oregon State University researchers. Collaborators are Emmanuel Boss (OSU), Peter Traykovski (WHOI), George Voulgaris (University of South Carolina), and John Trowbridge (WHOI).

Controls on floc size in tidal rivers in South Carolina are being investigated by Milligan in collaboration with Gail Kineke (Boston College) and Clark Alexander (SKIO). Hill is assisting with data analysis and interpretation.

PUBLICATIONS

Hill, P. S., T. G. Milligan, and W. R. Geyer (in press). Controls on effective settling velocity in the Eel River flood plume, *Continental Shelf Research*.

Geyer, W. R., P. S. Hill, T. G. Milligan, and P. Traykovski (in press). The structure of the Eel River plume during floods. *Continental Shelf Research.*

Gonzalez, E. A. and P. S. Hill (1999). An investigation of Bremer et al.'s aggregation time. *Colloid and Surfaces A: Physicochemical and Engineering Aspects*, **155:** 113--116.

Gonzalez, E. A. and P. S. Hill (1998). A method for estimating the flocculation time of monodispersed sediment suspensions. *Deep-Sea Research I*, **54:** 1931-1954.