Floc Dynamics, Sediment Flux, and Facies Generation on the Continental Shelf

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LONG-TERM GOALS

The goals of this research are to develop greater understanding of the links between floc dynamics and the generation of sedimentary facies on the continental shelf. In particular, we seek greater understanding of the dynamics underlying the sand-mud transition through investigation of how flocculation affects the transport and deposition of fine-grained sediments.

SCIENTIFIC OBJECTIVES

The proposed research has three original objectives.

- Use STRATAFORM data on floc size and disaggregated inorganic grain size (DIGS) to develop mechanistic understanding of the rates at which suspended sediment is lost from the Eel River plume.

- Extend models of floc breakup to include the mechanism proposed to produce abrupt reductions in floc size at a threshold shear (Hill et al., 2001).

- Develop, test, and implement models for quantitative process-based interpretation of disaggregated inorganic grain size in suspension and in the seabed.

We also initiated EuroSTRATAFORM work under an expansion of this award. The objectives of this work are to characterize the degree of flocculation of sediment suspended in the Po River plume and to link observed packaging to sediment sorting in the seabed.

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14. ABSTRACT
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APPROACH

Bulk sediment removal rates from the Eel River plume were monitored over four winters (1997-2000) with a helicopter-based sampling program. During floods of the Eel, an instrument package comprising a CTD, floc camera, two depth-actuated Niskin bottles, and a bottom-triggered syringe sampler was lowered through the water column on a grid of stations on the Eel River shelf. The contents of the Niskin bottles and the syringe sampler were filtered and weighed. Size analysis of the disaggregated inorganic sediment in the samples was carried out with a Coulter Multisizer IIe (Milligan and Kranck, 1991). Size analysis of images from the floc camera was performed with Image Pro Plus software. Size distributions were described with the equivalent circular diameter of the median particle area (Milligan, 1996, Hill et al., 2000).

Effective settling velocity is the bulk mean settling velocity required to explain observed clearance rates from a plume assuming first-order removal kinetics. A regression of the logarithm of concentration on alongshelf distance yields a line with slope $-w_e/(hu)$, where w_e is effective settling velocity, h is sampling depth in the plume, and u is plume velocity. With knowledge of plume velocity gleaned from current meter observations, one can convert the slope of the regression equation to an effective settling velocity. This type of analysis was performed on total sediment concentration and concentrations in individual size classes (Hill et al., 2000; Curran et al, submitted).

Seabed disaggregated inorganic size distributions were characterized for several slabs samples collected from box cores and x-rayed by Rob Wheatcroft. Size distributions were measured with the Coulter Multisizer IIe. Subsamples were closely spaced (mm-cm) throughout the cores. Sampling was more closely spaced in regions of interest on the x-rays.

To understand the size distributions in suspension and in the seabed we have been experimenting with a simple model. The model assumes that particles can exist either as single grains or as flocs. It also assumes that flocs can be characterized adequately with a single mean bulk settling velocity, the magnitude of which depends on whether shear is above or below a specified threshold for floc breakup. Finally, the model assumes that flocculation occurs only between flocs and single grains, not between single grains. This latter, potentially restrictive assumption, is required in order to make it possible to track a range of disaggregated particle size classes in suspension and in the seabed.

To assess the ability of the model described above to simulate sedimentation and sorting, we are conducting experiments in an invertible settling column (Milligan and Hill, 1998). Four different concentrations of sediment were "tipped" for three different periods, yielding twelve combinations of sediment concentration and tipping time. The goal of these treatments was to produce 12 different flocculation states in suspension. Short tipping time and low concentration yield a relatively unflocculated suspension. Long tipping time and high concentration yield a flocculated suspension. After tipping stopped, sediment was allowed to sink out. Suspended mass, DIGS, floc size, and floc size versus settling velocity were all monitored over a two-hour period. We plan to compare and contrast estimates of floc fraction based on model parameters produced by analysis of the evolution of DIGS with those based on direct observations of flocs.

In October 2000 the Po River experienced a 50-year return interval flood. In December 2000 a coring expedition mounted by Chuck Nittrouer, Andera Ogston, and Rob Wheatcroft revealed a thick flood deposit in the Adriatic Sea near the mouth of the Po. Studies of the emplacement, reworking, and

preservation of the Po River flood deposit are central to the new EuroSTRATAFORM program being funded by ONR. Our tasks in this new program are to investigate emplacement by making water column observations similar to our Eel River observations during periods of high discharge on the Po and to characterize and interpret DIGS in the seabed. Methods are similar to methods used in the Eel.

All work is being conducted collaboratively between Paul Hill of Dalhousie University and 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

One manuscript was accepted for publication in *Continental Shelf Research*. It interprets the loss rates of component grain sizes from suspension in a laboratory flume in the context of our simple model of particle aggregation/disaggregation. Another manuscript was submitted to *Continental Shelf Research*. It describes our new hypothesis regarding sediment resupply to the Eel River plume from the nearshore.

Kristian Curran completed his second year of work as a student on the STRATAFORM project. He took a lead role in data analysis, and he has applied 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 completed the experimental phase of the settling column experiment that will assess the efficacy of the parameterization for predicting DIGS evolution in suspension.

Jason Fox completed his first year of work as a student, with his focus on the Po dispersal system. He took a lead role in data collection during our June 2000 cruise to the Po delta. Over four hundred floc images and numerous suspended sediment samples were gathered on a grid of stations overlying the 2000 flood deposit. Over 750 sub-samples of x-rayed slabs gathered by Rob Wheatcroft, Chuck Nittrouer, and Andrea Ogston during cruises in November and January were collected for size analysis. To date, image analysis of the floc photos is complete, and suspended particulate masses have been calculated.

Ongoing collaboration with Pat Wiberg has led to advances in the parameterization of particle size in bottom boundary layers. 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 and across- and along-shelf position. The observation that effective settling velocity is signficantly less than estimated settling

velocities for flocs in the plume led us to conclude that the suspension in the plume was only partially flocculated (Hill et al., 2000).

During the past year MSc student Kristian Curran evaluated our hypothesis of a partially flocculated Eel plume by examining size-specific loss rates of various component grain size classes, by estimating the degree of floc packaging in the plume, and by assessing alongshelf patterns in floc size and concentration. Our hypothesis predicted that floc concentration should fall dramatically in the alongshelf direction and that the effective settling velocites of the smallest component grains should equal the estimated floc settling velocity multiplied by the fraction of the total suspension packaged as flocs, which we had estimated as 0.75 based on observed clearance rates. The data did not match these predictions. Floc concentration did not drop as rapidly as expected alongshelf, floc fractions were generally high and did not vary alongshelf, and the removal rates of the smallest component grains were lower than expected. A variety of other hypotheses was assessed, and we now propose that alongshelf loss rates of sediment are low because of resupply of sediment to the plume from the energetic nearshore (Curran et al, submitted).

Disaggregated inorganic grain size in the Eel River plume closely matches the DIGS in the central portions of the 1995 and 1997 flood deposits. At the bottoms and tops of the flood deposits, however, bottom sediments are better sorted than plume sediments. Reassessment of some old laboratory data on sedimentation in stirred beakers suggests that lack of sorting arises when suspensions are highly flocculated, which happens when concentration is high and/or turbulent stresses on flocs are low. Therefore, the better sorted lower portions of the flood deposits may have been deposited at the beginnings of their respective events, when seabed stresses were high, yet sediment concentrations had not yet built up. The central layers of the flood deposits deposited under conditions of high concentration. The upper portions deposited after suspended sediment concentrations had been depleted by sedimentation.

A collaboration with Dr. Alfredo Boldrin of the Instituto di Biologia del Mare, Consiglio Nazionale delle Ricerche in Venice was developed during the fieldwork carried out in June 2001. Initial assessment of data from the Po River plume in June indicates that sediment is lost rapidly from the plume in the form of flocs. This collaboration will be expanded with a joint cruise in the Po Delta region during the proposed October field program.

IMPACT/APPLICATION

Observations are helping to refine understanding of modes of delivery of flood sediment to the Eel River Shelf. These observations suggest that resupply of sediment from the surf zone to the plume slows the alongshelf loss of sediment significantly. 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 deposits by Pat Wiberg's group (Christiansen et al., 2000) and to interpretation of inherent optical properties of the bottom boundary layer by Paul Hill and Emmanuel Boss.

Controls on floc size in tidal rivers in South Carolina has been investigated in collaboration with Gail Kineke (Boston College) and Clark Alexander (Skidaway Institute of Oceanography) (Milligan et al, 2001).

RELATED PROJECTS

Control of floc size by turbulent kinetic energy was 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. Collaborator is Emmanuel Boss (OSU).

Floc size versus settling velocity relationships and their dependence on fluid stress are being investigated with support from the Natural Sciences and Engineering Research Council in Canada.

REFERENCES

Christiansen T, Wiberg P.L., Milligan T.G. (2000). Flow and sediment transport on a tidal salt marsh surface. *Estuarine Coastal and Shelf Science,* **50:** 315-331.

Hill, P. S., G. Voulgaris, and J. H. Trowbridge (2001). Controls on floc size in a continental shelf bottom boundary layer. *Journal of Geophysical Research,* **106:** 9543-9549.

Milligan, T.G., 1996, In-situ particle (floc) size measurements with the Benthos 373 plankton silhouette camera. *Journal of Sea Research,* **36**: 93-100.

Milligan, T.G., G.C. Kineke, A.C. Blake, C.R. Alexander and P.S. Hill, 2001. Flocculation and sedimentation in the ACE Basin, South Carolina. *Estuaries,* **24(5):** 734-744.

Milligan, T.G. and K. Kranck, 1991. Electro-resistance particle size analysers, in Theory, Methods and Applications of Particle Size Analysis. Syvitski, J. P. (ed.), Cambridge University Press, New York: 109-118.

PUBLICATIONS

Curran, K. J., Hill, P. S., and Milligan, T. G. Accepted June 2001. The role of particle aggregation on size-dependent deposition of drill mud. *Continental Shelf Research.*

Curran, K. J., Hill, P. S., and Milligan, T. G. Submitted July 2001. Fine-grained suspended sediment dynamics in the Eel River flood plume. *Continental Shelf Research.*

Hill, P. S., T. G. Milligan, and W. R. Geyer (2000). Controls on effective settling velocity in the Eel River flood plume, *Continental Shelf Research,* **20(16):** 2095-2111.

Geyer, W. R., P. S. Hill, T. G. Milligan, and P. Traykovski (2000). The structure of the Eel River plume during floods. *Continental Shelf Research,* **20(16):** 2067-2093.