

MECHANICS OF MIXING IN SEDIMENT-LADEN PLUMES

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LONG TERM SCIENTIFIC GOAL

The long-term scientific goal is to develop sound theoretical models for submarine sediment movement that can be used to predict both the initiation, spatial development, and time duration of turbidity currents, as well as the characteristics of the sedimentary deposits that these flows generate in continental shelves and slopes.

OBJECTIVES

- To measure, using a variety of newly developed experimental techniques, both the temporal and three-dimensional spatial structure of a gravity current front generated using a specially-designed facility to arrest these fronts
- To understand the fluid mechanical processes that mix sediment-laden fluid with ambient water in large-scale turbidity currents
- To use this knowledge to construct simpler and more accurate models of large-scale turbidity currents and their sediment deposits

APPROACH

A facility was constructed capable of arresting gravity currents with the use of a conveyor belt. Various experimental techniques (e.g., high-speed conductivity probe; laser-induced fluorescence, LIF) were employed to measure the spatial and temporal structure of the velocity and excess density fields. Another existing facility, which is insulated, was used for non-isothermal gravity currents. A wide range of parameter space was explored to find the effect of double-diffusive effects on fixed-volume, sediment-laden surface gravity currents. Strength of convection was observed with simple laser diagnostics.

WORK COMPLETED

After running over one hundred experiments under an extremely wide variety of conditions, it is clear that Reynolds number effects are important not only in the bulk parameters of previous studies, but in the basic structure of the internal dynamics. A limit of this similarity appears around a Reynolds number of 500. It was also found, in the smaller lock-exchange tank, that warm surface turbidity currents can produce double-diffusive convection at levels not previously realized. This convection can enhance effective settling rates of sediment beyond those predicted by flocculation alone. Further, it appears the presence of a stable salinity gradient does not retard this process and can allow extremely strong convection to occur.

RESULTS

Front Processes

A Reynolds number criterion for mixing processes in a gravity current was found. Before

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this work, the criterion was attributed to another Reynolds number and the criterion was significantly smaller. The processes found, that were left out in earlier work, were secondary instabilities which help form the lobe-cleft structure in gravity current fronts. This instability also generates a series of alternating streamwise vortices in the gravity current body. These structures can be speculated to cause certain geological formations on continental margins (i.e., gullies on the continental slope).

Sedimentary Double-Diffusion

The data set generated from the double-diffusive experiments showed strong convection/sedimentation for a variety of plume situations, most of which were similar to conditions found by field researchers at the Eel River site. The experimental results can be broken into two broad categories: plumes with just a stabilizing temperature gradient (two component experiments) and plumes with both a stabilizing temperature and salinity gradient (three component experiments). Parameter dependence was essentially on the sediment concentration in the experiments, though a more generalized theory was formulated and collapsed the data obtained from other researchers (see Figure 1a). As can be seen in Figure 1b, the dependence on the dependent parameter changes with the addition of the salt. The addition of a salinity gradient to this problem has never been performed, either experimentally or theoretically, despite the applicability to the problem of river plumes. Most interesting, however, is that the strength of the sedimentation does not change considerably with the addition of salt. Added to these plots are the percentile values of the original Sternberg floc settling data set. It is speculated that the change in parameter dependence occurs because the underlying fluid mechanical process changes due to the salinity gradient. In a few experiments, the peculiar effects manifested themselves in fairly stable nepheloid layers. Work is ongoing to describe the particular fluid mechanical processes behind this unique and relevant behavior.

IMPACT/APPLICATIONS

The Reynolds number criterion will aid in the design of future experimental models. In addition, the processes found for the 'build-up' of similarity (i.e., the secondary instabilities) will aid in studies of the sediment patterns laid down by large turbidity currents. Most importantly, however, is the finding of the robust nature of double-diffusive convection/sedimentation. Sedimentation of the strengths observed herein has never been seen before. The fact that they occur in the presence (and even in the dominance) of a saline-stratified water column is of particular significance for relation to oceanic river plumes.

TRANSITIONS AND RELATED PROJECTS

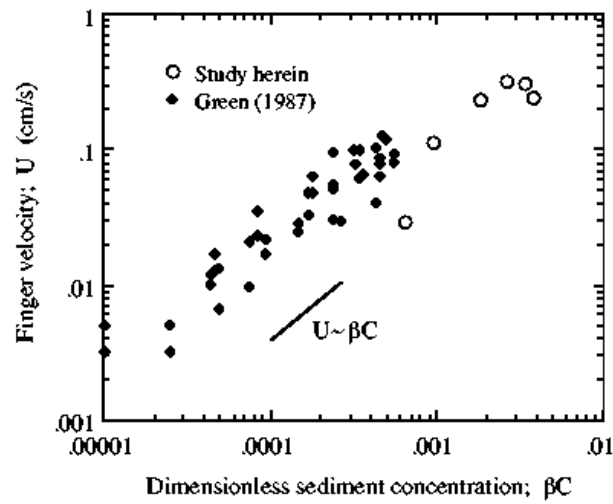
It is hoped that the work on the double-diffusive behavior, if it is verified with field data obtained from other researchers, will be integrated into the models of Rocky Geyer, James Syvitski and others. The model of Mark Morehead currently relies on a three-fold increase of the settling rate of the sediment to reproduce the deposit of the January 1995 flood. Though it is still matter of great debate, the inclusion of double-diffusive effects, possibly through a simple empirical relation illustrated in Figure 1, could help to resolve the anomalous settling flux. In terms of front processes, the Reynolds number criterion serves as a useful tool in the design of future turbidity current experiments both within the UIUC group and others (e.g., St. Anthony Falls).

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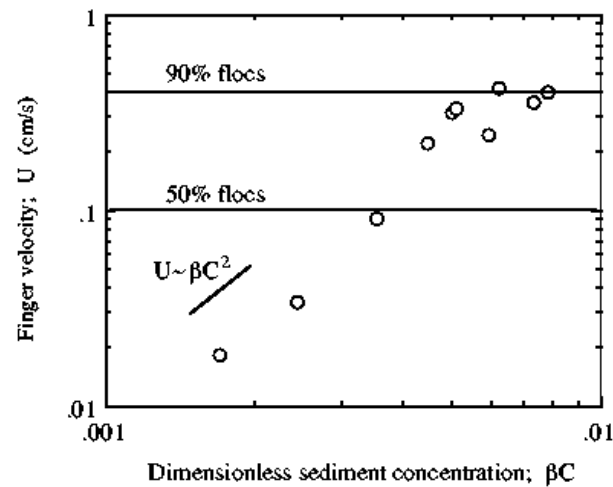
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A web page dedicated to this work can be found at: <http://www.students.uiuc.edu/~prson/research.html>



(a)



(b)

Figure 1 Comparison of finger velocities with dimensionless sediment concentration for (a) two component experiments with T. Green (1987). The importance of double diffusion to the settling of suspended material. *Sedimentology*, **34**, 319-331. Collapse of Green (1987) was performed with theory mentioned earlier. (b) Three component experiments are compared with the data set of Sternberg *et al* (1996). It should be noted that the upper limit of the data herein is an experimental artifact and a physical limit of the behavior studied.