Turbidity Currents, Bedforms, and Gullies

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Award Number: N00014-93-1-0044

LONG-TERM GOAL

Our main goal is the development of physically-based models for submarine sediment movement that can be used to predict the initiation, spatial development, and time duration of mud flows and turbidity currents. Of particular interest are the characteristics of the sedimentary deposits generated by density underflows, mainly their capability to develop bed forms and gullies by means of sediment erosion and deposition and their role in the formation of strata in continental margins.

OBJECTIVES

This study pursues the analytical and experimental investigation of large-scale bedforms similar to those observed in various submarine settings, and thought to be created by unconfined turbidity currents and related dense underflows in continental slopes and rises. Two types of large bedforms are the main focus of this work. First, slope gullies, which are parallel, evenly-spaced, downslope-trending channels with typical relieves of the order of 1-5 m and separations ranging from 100 to 500m, found in most continental slopes around the world. Second, large-scale sediment waves (wavelengths 500-5000 m) surveyed in continental rises, on levees of deep-sea channels, and on the flanks of submarine canyons and submarine fans, which appear as upslope-migrating bedforms in the vast majority of observed cases.

APPROACH

The effect of suspended sediments on the mechanics of dilute turbidity currents was investigated by obtaining perturbation solutions for the variables involved in the problem, and using layer-averaged, one dimensional equations for turbidity currents (Parker et al., 1986). The presence of a conservative component in these currents ensures the existence of an equilibrium condition that can be used as the base solution in the regular perturbation analysis of the equations of motion. The analytical solutions indicate that the presence of suspended sediments could trigger a self-acceleration process, analogous to the one found by Parker et al. (1986) for the case of purely non-conservative turbidity currents. The perturbation solutions can also be used to further analyze the problem of bedform development, when additional relationships for bed evolution are introduced. However, the generalization of these results requires more research along these lines, since the downstream changing base flow, characteristic of every dense underflow, poses a problem that remains unsolved.

WORK COMPLETED

Linear stability analysis was performed for two cases, namely the purely-conservative (saline) density current with bedload transport, and for a two-component, dilute turbidity current with both bedload and suspended sediments, using a four-equation model, and a three-equation model, respectively. The aim here was to investigate whether these flows are capable of developing long-wavelength bedforms different modes of sediment transport in dense underflows might determine the main geometric characteristics of their associated bedforms. Successfully, a four-equation model for a supercritical saline density current that transports sediments as bedload predicts a range of wavelengths for which perturbations along the bed will grow and, possibly, develop long upstream-migrating antidunes. Similarly, a three-equation model for a two-component, dilute supercritical turbidity current with bedload and suspended sediments predicts that perturbations on the sea bed will become unstable to the action of these flows as well, and for which maximum growth rates are confined to small wave numbers. Comparison of maximum growth rate curves for the above mentioned cases, as function of Richardson number, show that turbidity currents tend to form longer waves than those associated with conservative density currents with bedload transport only (see Figure 1).

RESULTS

Series of preliminary experiments involving both saline density currents (conservative) and turbidity currents (non-conservative) were conducted in the MARGINS tank using a variety of conditions for the currents and initial beds, in order to investigate the formation of long sediment waves and longitudinal features similar to slope gullies. Preliminary results have shown that the action of successive saline density currents and turbidity currents formed their own characteristic long-wavelength bed waves. Migration directions have not been determined experimentally yet. For the cases in which governing parameters (i.e. driving force, slope, water discharge, etc.) for both type of currents were essentially the same, those preliminary results confirmed that, at least at first, turbidity currents tend to produce bedforms that are longer than those caused by the passage of conservative saline density currents, for which only bedload transport was assumed to be relevant. Small downstream-migrating ripples were commonly observed features, left by almost all currents.

Even though a wide range of experimental conditions were explored, longitudinal features resembling slope gullies have yet to be clearly observed in the laboratory. However, it should be mentioned that for a case in which a slope break with a gentle, curved transition was introduced in the channel, ripples tended to fold up at certain consistently fixed locations, forming downslope-trending lines where the small bedforms did not develop presumably due to local changes in the erosion-deposition process. These observations are encouraging and more experimental work along these lines will be pursued.

IMPACT/APPLICATION

Our results have important implications for the recognition of morphological features in the field. The laboratory experiments have clearly shown the capability of turbidity currents for producing longitudinal small-scale bedforms such as ripples as well as long-wavelength antidunes. Our understanding of the mechanics of bedforms in continental margins until now has been very limited (Field et al., 1999) and we hope that our findings will facilitate both the interpretation of the geologic record as well as the design and placement of submarine structures on stable sediment deposits.

TRANSITIONS

The STRATAFORM program will integrate field observations, laboratory experiments, and numerical modeling. Knowledge about the nature and dynamics of bedforms is crucial to the successful application of hydrodynamic models of turbidity currents, debris and mud flows in the submarine environment as well as for the interpretation of the geologic record. Turbidity currents could also play an important role in the scour around and burial of objects such as pipelines and mines.

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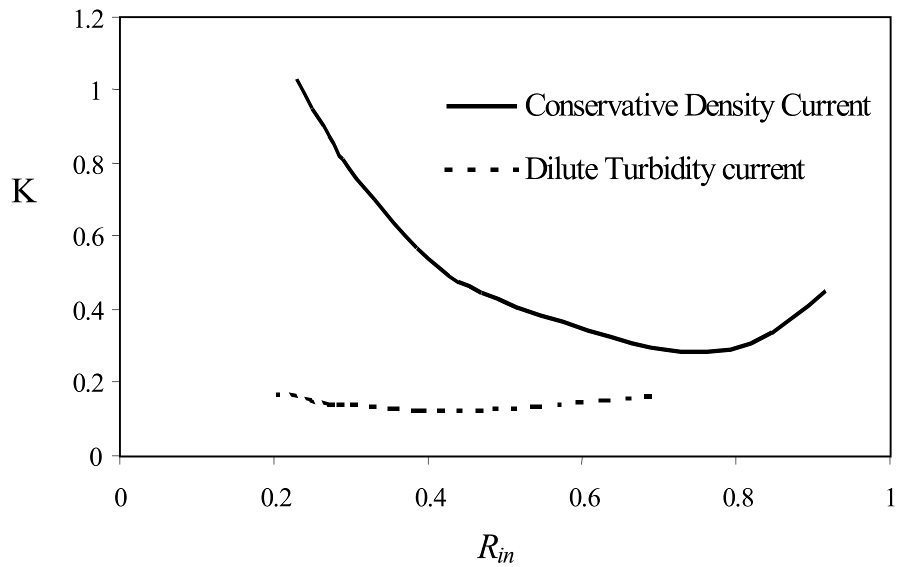

Figure 1. Maximum growth-rate curves (linear stability analysis) for: conservative density currents with bedload transport (four-equation model), and two-component, dilute turbidity currents with bedload and suspended sediment (three-equation model). Here, R_{in} is a 'bulk' Richardson number of the base (normal) flow, and $K = 2\pi H_i / \lambda$ is a dimensionless wave number, where H_i is the thickness of the normal flow at origin, and λ is the perturbation wavelength.