Modeling of Selected Continental Slope Processes

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LONG-TERM GOALS

My long-term goals are to improve our understanding of the physical evolution of continental slope morphology and stratigraphy, and enhance our ability to extract stratigraphic information from geophysical data.

OBJECTIVES

The objectives of this project are to:

(1) Characterize the effect of spatial variations in deposition and erosion on the fluid flow, pore pressures and thus the stability of continental slope sediments.

(2) Constrain the impact of individual turbidity currents and debris flows on seafloor evolution.

(3) Develop a technique for correlating stratigraphy complicated by spatial variations in sedimentation, erosion and post-depositional processes.

(4) Assess the fidelity to which various seismic sources image stratigraphy.

APPROACH

I am exploring the linkages between sedimentation/erosion, fluid flow, pore-pressure evolution and slope stability with M. Tice (Stanford) using numerical modeling. I am also using numerical modeling in collaboration with J. Imran (U. S. Caro.), G. Parker (U. Minn.) and J. Syvitski (U. Colo.) to simulate the dynamics of turbidity currents and debris flows and their respective roles in seafloor evolution. Correlation of any two series of down-core measurements of stratigraphy (e.g., lithology, physical properties or log response) is being done with D. Martinson (L-DEO) and is being automated on the basis of variations in measurement amplitude. And I am investigating the stratigraphic content of seismic reflection data with W. Gouveia (Mobil), C. Paola (U. Minn.) and D. Herrick (Duke) by simulating seismograms of experimental stratigraphy formed in a new laboratory basin at St. Anthony Falls Laboratory (Univ. Minn.).

WORK COMPLETED

During FY99 (working with those cited above), I developed a fully coupled 2D finite-element model of fluid flow and stress evolution in sedimented slopes; carried out a modeling comparison of turbidity-current and debris-flow dynamics (Pratson et al., 2000); and established a modeling approach for generating synthetic seismograms of experimental and/or numerically-modeled strata (Pratson and Gouveia, in review). Work on several of these projects has progressed during FY00. New accomplishments include:

(1) The numerics and accuracy of the 1D model of turbidity current dynamics have been validated (Pratson et al., in press). The validation was accomplished by successfully reproducing the results of both existing turbidity current models and the measured behavior of experimental turbidity currents.

(2) A 2D model has been developed of debris flow dynamics (Pratson et al., in press). The model is able to simulate not only the downslope movement of a debris flow but also its spreading in the alongslope direction (Fig. 1).

(3) Improvements have been made to the model developed to simulate physical properties for experimental strata so that synthetic seismograms can be generated of them (Herrick et al., 2000). The model now also computes bulk and shear moduli for clastic strata. As before, the approach can also be applied to computer-generated strata.

RESULTS

(1) The simulations of experimental turbidity currents made using the 1D turbidity current model further confirm that in order to accurately predict the morphologic and stratagraphic impacts of such events, a constraint must be placed on their erosive power. This is accomplished in the model by linking the frictional drag at the base of the flow to its turbulent kinetic energy as proposed by Parker et al. (1986). Inclusion of the Parker et al. (1986) formulation enables the model to reproduce the dynamics and deposits of sediment-laden depositional flows, but, interestingly, not purely saline flows. Its applicability to erosive flows has yet to be determined due to a lack of data.

(2) The 2D debris flow model remains to be validated and so its results remain preliminary. However, among the most significant of these is that the model predicts that the size and shape of a debris flow deposit is governed by the viscosity of the flow as well as its initial velocity and the seafloor gradient it passed over.

(3) Several approaches have been evaluated for deriving bulk and shear moduli beginning only from measurements of clay vs. sand content (Herrick et al., 2000). These include formulations for the bulk frame modulus that rely on empirical relationships (Marion et al., 1992) to purely theoretical constructs (Xu and White, 1995; Berryman, 1980a,b). Of these, the self-consistent method of Berryman (1980a,b) has yielded the most natural-looking results (Fig. 2). Its true validity is now being evaluated against industry well-log data.

IMPACT/APPLICATIONS

(1) The simulations of experimental flows using the 1D turbidity current model has pointed out the need for additional research into the linkage between frictional drag at the base of turbid flows, flow turbulent kinetic energy, and flow erosion of the seabed.

(2) The 2D debris flow model now allows for the simulation of the movement of debris flows over 3D bathymetric surfaces rather than 2D profiles. It is also an important first step in process-modeling of continental margin evolution in three dimensions.

(3) The enhanced sophistication in the modeling of physical properties for experimental/computer-generated strata permits the simulation of S-wave velocities as well as P-wave velocities (Fig. 2). Furthermore, the data can now be used in poro-elastic models of seismic wave propagation. This then opens the door for analyzing seismic wave attenuation in different strata and the effects of different pore matter, including gas.

TRANSITIONS

The 2D debris flow model has helped motivate a series of debris flow experiments planned for this upcoming fiscal year at the Univ. of Minnesota to explore the impact of initial and boundary conditions on flow dynamics and deposits. A consortium of oil companies is now providing supplementary funding for the physical property modeling and the modeling of synthetic seismic data, which the companies hope to apply in their own research.

RELATED PROJECTS

The regional scale studies of margin morphology and seafloor failures mentioned in last year's report have now been published (O'Grady et al., 2000) or are in press (McAdoo et al., in press). The work on the relation between the dynamics of internal waves and the gradients of the continental slopes continues (Cacchione et al., in 2000). A publication is being prepared for modeling results within the STRATAFORM study areas, and the analysis is now being extended to continental slopes along both sides of the North and South Atlantic.

REFERENCES

Berryman, J.G., 1980a. Long-wavelength propagation in composite elastic media I. Spherical inclusions: *Journal of the Acoustic Society of America*, v. 68, p. 1809-1819.

Berryman, J.G., 1980b. Long-wavelength propagation in composite elastic media II. Elipsoidal inclusions: *Journal of the Acoustic Society of America*, v. 68, p. 1820-1831.

Cacchione, D., Pratson, L., and Ogston, A., 2000 (abs.). Internal Tides, Sedimentation, and Seafloor Slopes: *AGU*, 2000 ASLO meeting, San Antonio, TX.

Herrick, D., Gouveia, W., and L.F. Pratson, 2000. Building a lithology-based elastic model from digitized photographs of stratigraphy: 2000 AAPG Annual Convention Program, v. 9, p. A67.

Marion, D., A. Nur, H. Yin, D. Han, 1992. Compressional velocity and porosity in sand-clay mixtures: *Geophysics*, v. 57, p. 554-563.

McAdoo, B., Pratson, L., and Orange, D., in press. Submarine landslide geomorphology, US Continental Slope: *Marine Geology*.

O'Grady, D., Syvitski, J., Pratson, L.F., and Sarg, J.F., 2000. Categorizing the morphologic variability of siliciclastic passive continental margins: *Geology*, v. 28, p. 207-210.

Parker, G., Y. Fukushima, and H.M. Pantin, 1986. Self-accelerating turbidity currents: *Journal of Fluid Mechanics*, v. 171, p. 145- 181.

Pratson, L.F., J. Imran, G. Parker, J. Syvitski and E. Hutton, 2000. Debris flows versus turbidity currents: a modeling comparison of their dynamics and deposits, in A.H. Bouma and G. Stone (eds), Fine Grained Turbidite Systems: *AAPG Memoir 72/SEG Special Publication No. 68*, p. 57-72.

Pratson, L., J. Buttles, J. Imran, G. Parker, P. Harff, H. Toniolo and J. Marr, in press. Numerical modeling of unconfined debris flows (abs): *Society of Engineering Science 37th Annual Technical Meeting*, Columbia, South Carolina.

Pratson, L.F., J. Imran, E. Hutton, G. Parker and J. Syvitski, in press. BANG1D: A one-dimensional Lagrangian model of subaqueous turbid clouds: *Computers & Geosciences*.

Pratson, L., and Gouveia, W., in review. Linking stratigraphic and seismic modeling: *AAPG Bulletin*.

Xu, S., and R.E. White, 1995. A new velocity model for clay-sand mixtures: *Geophysical Prospecting*, v. 43, p. 91-118.

FY00 PUBLICATIONS

Cacchione, D., Pratson, L., and Ogston, A., 2000 (abs.). Internal Tides, Sedimentation, and Seafloor Slopes: *AGU*, 2000 ASLO meeting, San Antonio, TX.

Herrick, D., Gouveia, W., and L.F. Pratson, 2000. Building a lithology-based elastic model from digitized photographs of stratigraphy: 2000 AAPG Annual Convention Program, v. 9, p. A67.

McAdoo, B., Pratson, L., and Orange, D., in press. Submarine landslide geomorphology, US Continental Slope: *Marine Geology*.

O'Grady, D., Syvitski, J., Pratson, L.F., and Sarg, J.F., 2000. Categorizing the morphologic variability of siliciclastic passive continental margins: *Geology*, v. 28, p. 207-210.

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Pratson, L., J. Buttles, J. Imran, G. Parker, P. Harff, H. Toniolo and J. Marr, in press. Numerical modeling of unconfined debris flows (abs): *Society of Engineering Science 37th Annual Technical Meeting*, Columbia, South Carolina.

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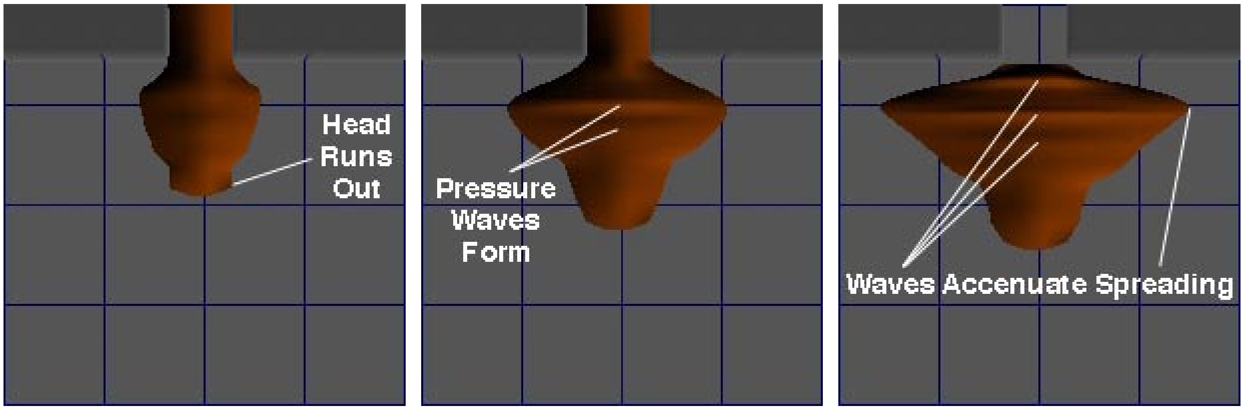

Figure 1. From left to right, three stages in the evolution of an unconfined debris flow as predicted by the 2D debris flow model. Flow begins with an initial velocity in a chute and then enters onto an open dipping plane.

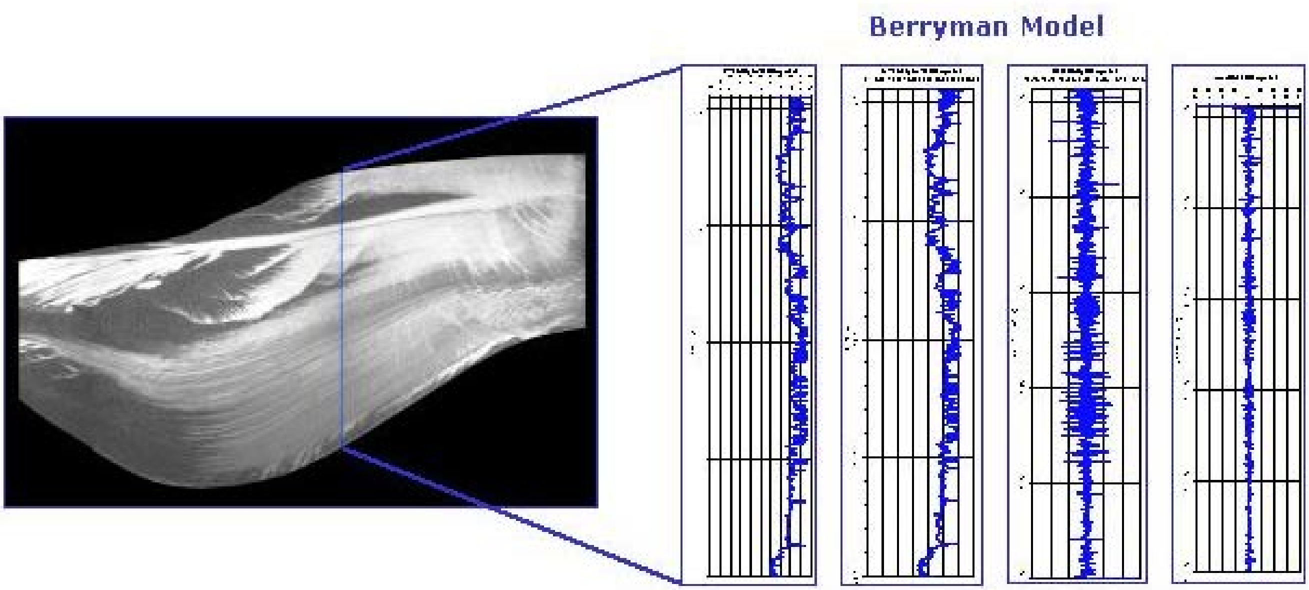

Figure 2. Synthetic data from left to right: P-wave velocity, S-wave velocity, reflectivity and seismic trace. Synthetic data are derived from a single column of gray scales in the digital image of experimental stratigraphy shown at left. Experimental stratigraphy was formed in the XES Basin prototype at the University of Minnesota.