Modeling Sedimentary Deposits on the Continental Margin

Donald J. P. Swift
Department of Oceanography, Old Dominion University, Norfolk, VA, 23908
Ph. (757) 683-4937; Fax (757) 683-5303; dswift@odu.edu

Alan W. Niedoroda
URS Corp, 3676 Hartsfield Rd, Tallahassee, Florida U.S.A.
Ph. (850) 574-3197; Fax (850) 576-367632303; Alan_Niedoroda@urscorp.com
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Christopher W. Reed
URS Corp, 3676 Hartsfield Rd, Tallahassee, Florida U.S.A.
Ph. (850) 574-3197; Fax (850) 576-367632303; chris_reed@urscorp.com

LONG TERM GOAL

The long-term goal of our research group is to construct mathematical descriptions of the processes that form sedimentary deposits at all spatial scales on continental margins, from storm beds to the deposits of 100,000 yr sea level cycles, and to conduct numerical experiments leading to the prediction of the sedimentary fabric (structure and stratification pattern) of the resulting deposits.

OBJECTIVES

A first objective is to investigate the fabric (pattern) of seabed stratification on continental margins at small time and space scales (1 cm-50 cm depth into the seabed; 1 hr-3 yr sedimentary record). To this end, we are testing the hypothesis that on muddy shelves such as the northern California shelf, Holocene event stratigraphy consists of the deposits of high-concentration storm regimes associated with river floods, alternating with deposits of low-concentration storm regimes, in which river flooding does not occur.

At intermediate spatial scales (1 -20 m depth into the seabed; 1-1,000 yrs), we are testing a second hypothesis. The hypothesis states that facies assemblages are stacked on, or are capped by, erosional bounding surfaces (source diastems,) in patterns reflecting fluid power gradients in the parent dispersal system; and that these patterns are responses to progressive sorting and stratal condensation mechanisms.

At large time and space scales (1 -1,000 m depth into the seabed; 100-2.5 million yrs) we are testing a third hypothesis. The hypothesis states that that depositional sequences can be explained in terms of shifts in the equilibrium configuration of shelf surface in response to changes in sea level, the rate and character of sediment input, and the hydrodynamic climate.

A final objective is upscaling; forming connections between models so that information produced by simulations at small spatial scales can serve as input to models at larger spatial scales,

APPROACH

We are testing the short-term sedimentation ("flood" bed) hypothesis by simulating event beds from time series of bottom velocity and concentration measurements, and by comparing them with observations (box cores, piston cores, and seismic records). Two algorithms have been developed. EVENT I describes the transport of sediment as dilute, near bottom suspensions (low concentration regime). EVENT II describes the transport of sediment as fluid mud flows on the sea floor (high concentration regime; Fan et al., 2001; in press). The EVENT algorithms are driven by time series of wind-driven current velocity, wave orbital velocity and tidal current velocity. The storm bed hypothesis is being tested by simulation of the stratigraphy formed during the winter of 1996 on the Eel margin as revealed in box cores, piston cores slow cores and seismic records. A second deterministic model for sediment transport. (SLICE) describes fluid circulation and sediment transport on continental margins in response to waves, wind-driven currents and tides, using the wind *field* as input SLICE is being developed by Chris Reed and Alan Niedoroda at URS Corp in Tallahassee.

We are testing the hypothesis for intermediate scale sedimentation (facies assemblage hypothesis) by linking deterministic algorithms for boundary layer sedimentation (EVENT I, Event II) with a probabilistic algorithm for stratal succession. (FACIES; Zhang et al., 1997, 2000; Fan et al., 2001).

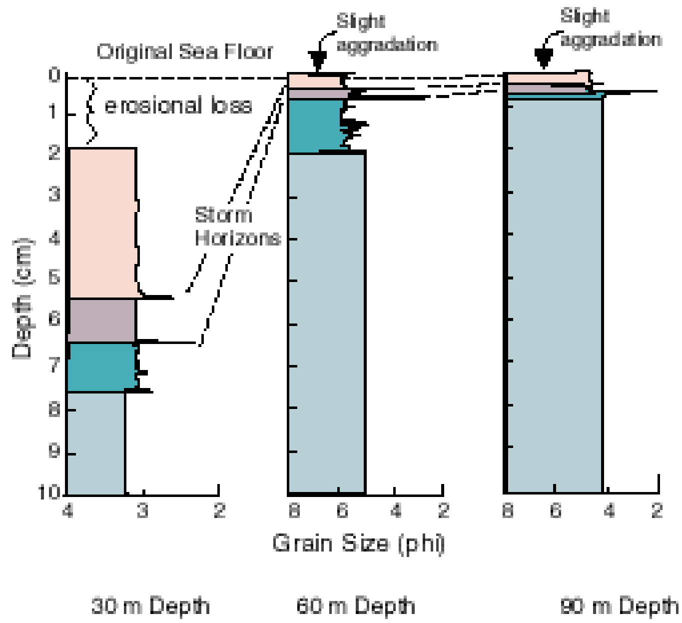

Fig. 1. Simulation by EVENT I of virtual cores through stratigraphy deposited on the Eel Sector of the northern California Continental shelf during January and February 1996.

In order to test the hypothesis for long -term sedimentation (equilibrium margin hypothesis) We have combined the morphodynamical model for continental margin evolution developed by URS Corp (1995) with Mike Steckler's (1993) geodynamical model, leading to a combined stratigraphic model (SEQUENCE). Steps are being taken to embed FACIES in SEQUENCE so that facies characteristics can be assigned to the spaces between the bounding surfaces in SEQUENCE simulations

WORK COMPLETED

Working codes now exist for Event I, EVENT II, SLICE, FACIES, and SEQUENCE. Simulations from these models compare favorably with stratigraphic observations from the northern California shelf.

In addition, an early version of SEQUENCE has been modified to examine the continental in two horizontal dimensions as well as the vertical. This model (CST for Coastal Systems tract model) includes representation of the shoreline in the long shore direction, and littoral transport processes. River sediment loads can be represented and the shoreline response to river loads, external loads (upstream or downstream boundary), sea level, and climate change is simulated for 10 to1000 year periods.

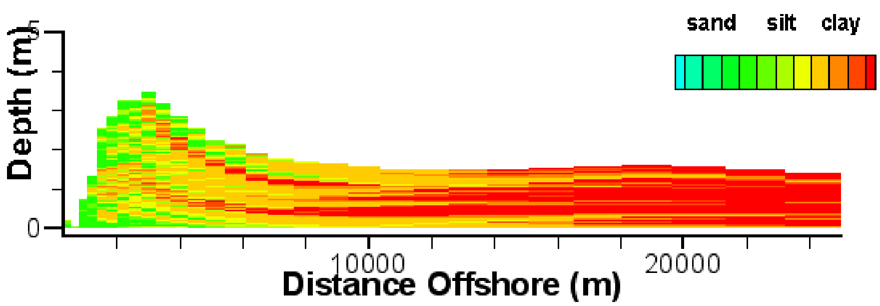

Fig. 2. Simulation by SLICE showing 500 years of sedimentation on the Eel Sector of the Northern California shelf.

RESULTS

Simulations using EVENT I (Fig. 1) and EVENT II and SLICE (Fig. 2) show that short lived, coast-hugging, surface flood plumes, forming over the inner shelf of northern California during winter storms, leave behind them slowly consolidating, high-concentration, near-bottom suspensions (fluid mud). If the flood is accompanied by elevated wave heights, or if it is followed by elevated wave heights before the mud consolidates, then offshore transport of the fluid mud occurs, as it respond to its own excess density. Later spring and summer resuspension episodes are less likely to involve significant flood discharge, and wave resuspension of sea floor sediment during these events results in more dilute suspensions (low concentration regime). These more dilutes suspensions do not form fluid muds, but are passively borne seaward and alongshelf by wind driven currents. The resulting storm beds (Fig. 1) are thin and sand rich, partly as a consequence of *in situ* winnowing, and partly as a consequence of advection of sand from the further inshore (Fan et al., in press).

A simulation of 400 years of sedimentation on the Eel Shelf has been prepared, using the FACIES algorithm (Fig. 3). In the simulation, flood bed properties are computed by EVENT II, and storm bed properties (properties of beds due to waves only) are computed by EVENT II. In the simulation, 400 floods and 800 storms have occurred. Variation in storm and flood intensity is modulated by Gumbel distributions (extreme event distributions) of wave height and flood discharge, selected from the extreme event distributions by a Monte Carlo method. In the simulation, “flood” beds, deposited by fluid muds, dominate the section. A transition from the Interbedded Sand and Mud Facies to the Laminated (Bioturbated) Mud Facies is apparent. Bedding is much more continuous in the latter. Storm beds consist of sand in Interbedded Sand and Mud Facies, but as the pass into the Laminated (Bioturbated) Mud Facies they have become more fine-grained than the associated flood beds.

A simulation of the deposits of the last glacial sea level oscillation (the last 125 thousand years) on the eel sector of the northern California shelf depict a complex assemblage of high-frequency sequences, similar to those seen on Seismic records collected (Fig. 4)

IMPACT AND APPLICATIONS

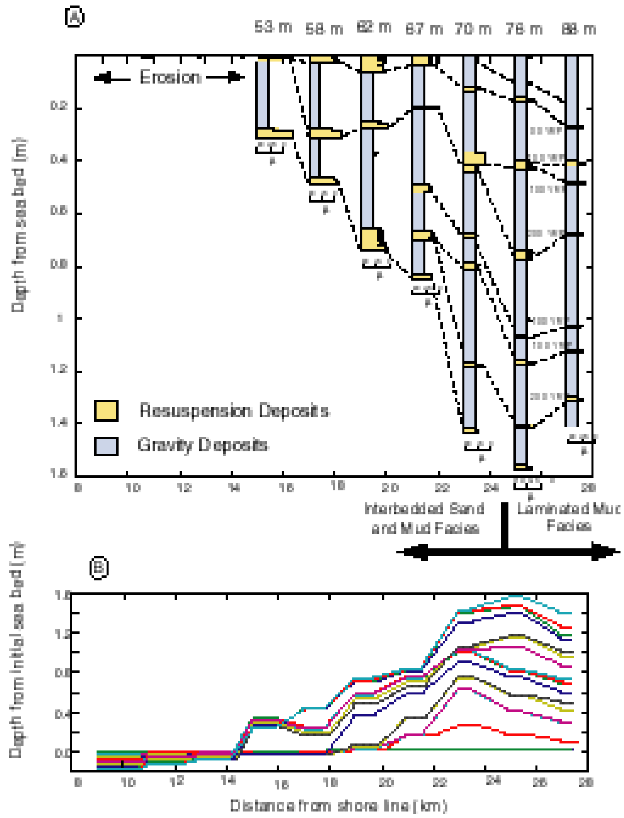

Fig. 3. Synthetic event stratigraphy simulated by FACIES with return periods in years (YRP) noted. The boundary between the Interbedded Sand and Mud Facies and the Laminated Mud Facies is indicated. A: virtual cores. B: 20-year time lines.

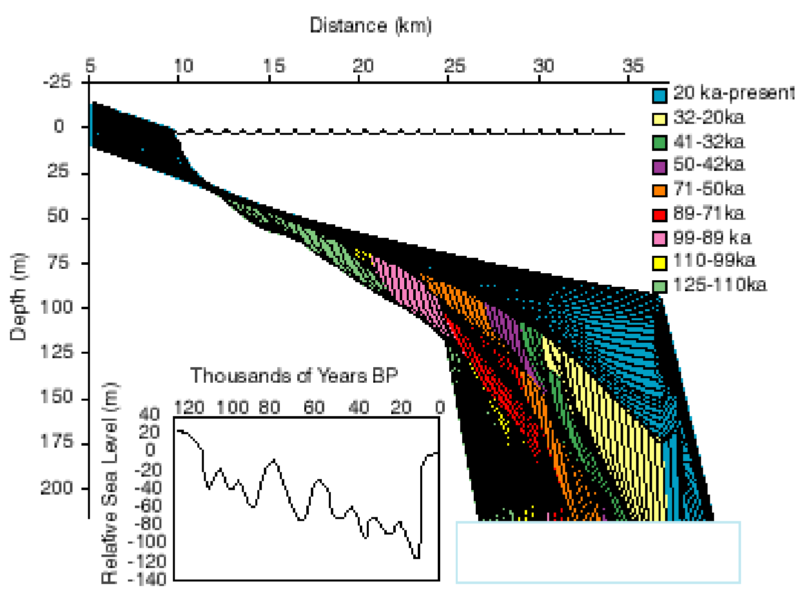

Fig. 4. Simulation by SEQUENCE of the deposits the latest glacial sea level oscillation on the Eel Sector of the northern California shelf.

EVENT I and EVENT I are being modified to predict the geotechnical and acoustic properties of first meter of the sea floor. FACIES will then predict the geotechnical and acoustic properties of first 10 meters of the sea floor. SEQUENCE will predict seafloor structure at depths up to several kilometers, for foundation studies and petroleum exploration.

TRANSITIONS

Results from long-term SLICE simulations are being analyzed to determine diffusion characteristics o of sediment transport needed as input to SEQUENCE. We are the most "downstream" component of STRATAFORM in the sense that we use the results of other STRATAFORM groups as constraining data. The process is linear however, but has feedbacks; our modeling results have lead to changes in the approach of our observationist colleagues (Mike Field's seismic work, the U.S. geological Survey, Menlo Park, and Neal Driscoll's seismic work at Scripps Institute of Oceanography).

We can, however, contribute directly to other STRATAFORM modeling groups. The SLICE model has been configured for combination with SEDFLUX (Syvitski et al., 1997), in order to provide predictions of shelf sedimentation and sediment transport to the slope region Chris Reed and Alan Niedoroda are coordinating with staff from INSTAAR to complete the integration process. Also, the SLICE model is being used to deduce parameters for use in the SEQUENCXE model (Steckler, 1999).

The larger oceanographic community outside of STRATAFORM are also consumers of our products. We are presently exchanging code with Peter Cowell, University of Sidney, Australia, and other members of the PACE group (Predicting Aggregate Coastal Evolution) funded by the European Economic Community.

REFERENCES AND PUBLICATIONS

Carey, J. S., D. J. P. Swift, M. Steckler, C. W. Reed and A. W. Niedoroda, 1999. High-resolution sequence Stratigraphy modeling: effects of sedimentation processes. P. 151-164, in *Numerical Experiments in Stratigraphy: Recent Advances in stratigraphic and sedimentologic Computer Simulations*. Soc. Econ., Paleon. Mineral. Spec. Publ. 62, 362 pp.

Cowell, P.J., M. J. Stive, A. W. Niedoroda, M. Buisman, P.S. Roy, P.L. DeBoer, D.J. P. Swift, M. Capobianco, and H. J. DeFriend. in revision. The Coastal tract: aggregated modeling of Low Order Coastal Change, Journal of Coastal Research.

Fan, F., D. J. P. Swift , P. Traykovski, S. Bentley, A. W. Niedoroda , and C. W. Reed. In revision. Dynamics of Cross-Shelf Sediment Transport, Northern California Shelf: Role of High and Low Concentration Suspensions in the Formation of "Flood" Beds. Marine Geology.

Fan, F., D. J. P. Swift , and S. B. Parsons, In press: Transgressive stratigraphy on the Northern California Margin: Observations Versus simulations by the FACIES Model. Proceedings, 2001 Annual Conference of the international Association for Mathmatical geology, Cancun, Mexico, Sept 6-12, 2001

Goff, J. A., D. J. P.. Swift, C. L. Schuur, L. A. Mayer and J. Hughes-Clarke, 1999. High Resolution Sonar Investigation of a Sand Ridge, Dune, and Ribbon Morphology in the Offshore environment of the New Jersey Margin. Marine Geology, v. 161. P. 307-337

Goff, J., , Wheatcroft, R.A., Lee, H., Drake, D., Swift, D.J.P., and Fan, S., in preparation. Spatial variability of shelf sediments in the STRATFORM natural laboratory, Northern California. Marine Geology.

Niedoroda, A.W., Reed, C.W., Swift, D.J.P., Arato, A. and K. Hoyanagi, 1995. Modeling shore-normal large-scale coastal evolution. Marine Geology, v. 126, p. 181-199.

Parsons , B. S., D. J. P. Swift, **and K. Williams,** in Preparation. Facies and Facies Assemblages (Depositional Systems) in Shallow Marine Settings. Part II: Quaternary Dispersal Systems and Depositional Systems in Chesapeake Bay Mouth: A Uniformitarian case study. J. Sed Research.

Reed, C.W., A. W. Niedoroda and D.J. P., Swift, 1999. Sediment entrainment and transport limited by bed load armoring. Marine Geology., v. 154, p.143-155

Reed, C.W., A. W. Niedoroda, D. J. P. Swift, Y. Zhang, J. Carey, and M.S. Steckler,1997. Coastal Evolution: Modeling fabric and form at successive spatial scales. 1997 Coastal Dynamics congress, University of Plymouth, Plymouth, U.K. p. 604-613

Steckler, M.S, Swift, D.J.P., Syvitski, J.P., Goff, J.A. and Niedoroda, A.W., 1996, Modeling the sedimentology and stratigraphy of continental margins, Oceanography, v. 9, p183-188

Swift, D. J. P. B. S. Parsons, A. Foyle, and G. F. Oertel, in revision. Between Beds and Sequences: Stratigraphic Organization at Intermediate Scales in the Quaternary of the Virginia Coast, USA. Sedimentology.

Syvitski, J., L. Pratson. P.L. De Boer, M. Garcia, M. Steckler., H. Lee, M. Perlmutter, G. Parker, P. Wiberg, and D. Swift, 1997. Earthworks: a large scale and complex numerical model to understand the flux and deposition of sediment over various time scales. in Pawlowsky-Glahn, Proceedings of the Third Annual Conference of the international Association of mathematical Geologists. International Center for Numerical Methods, Universitat Politechnica de Catalunya, 08034, Barcelona, Spain.

Zhang, Y., D.J. P. Swift,. C. R. Reed, A. Wm. Niedoroda and S. Fan, In Press. Two-dimensional numerical modeling of storm beds for sedimentary facies simulation. Marine Geology.

Zhang, Y., Swift, D. J. P., Niedoroda, A. W., Reid, C. W., and Thorne, J. A., 1997. Simulation of sedimentary facies on the northern California Shelf: implications for an analytical theory of facies differentiation. *Geology* v. 27, p. 635-638.