Forward Modeling of Stratigraphic Sequences at Continental Margins

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LONG TERM GOALS

The goal of the Stratigraphy project of the STRATAFORM program is *to understand the creation of the preserved stratigraphic record on continental shelves and slopes as the product of physical processes acting with spatial and temporal heterogeneities.* I am using numerical models to provide insight into the formation and preservation of stratigraphic sequences at margins. My goal is to obtain a quantitative understanding of the interactions of environmental parameters and their influence on stratal architecture and facies distribution. I wish to be able decipher the stratigraphy on margins to read the geologic record of the past and predict future stratigraphy.

OBJECTIVES

I wish to understand how sea level and other factors control the formation of the stratigraphic record at margins. The stratigraphy at margins is packaged into unconformity-bound sequences whose form and lithology record the active processes at the margin. The influences of individual processes that create these sequences are only partly understood. My aim is to quantitatively determine the system response of margins to different forcing functions sufficiently to be able to both predict stratigraphy and invert observed sequence architecture for geologic history.

APPROACH

I am using numerical models as a tool to provide insight into the formation and preservation of stratigraphic sequences at continental margins. In conjunction with others, I have constructed, and am continuing to improve, an interactive computer model of stratigraphic sequences at continental margins. I am applying the model to the STRATAFORM field areas. The work is proceeding along three lines:

(1) Development of 2-D models focused on combining parameterizations of the dynamic sedimentologic and morphologic processes that control sediment deposition and erosion within a framework that accounts for geologic processes that effect accommodation .

(2) Numerical experimentation with the model to determine the stratigraphic consequences of the processes and parameter interactions. Examination of margin data to calibrate the model. Application of the model to the sequences in the field areas.

(3) Analysis of the geologic record sedimentary and geomorphologic processes in NJ and CA. A particular focus is backstripping to reconstruct the margin development. The modeling of the two margins provides constraints for unraveling the control of sequence development.

In this work I am collaborating with Greg Mountain on the interpretation and modeling of the New Jersey and northern California margins. I have been collaborating with most of the STRATAFORM modelers and others (Steckler et al, 2001) to incorporate and improve sediment transport models from the coastal plain to the continental rise. I am working with James Syvitski to coordinate our modeling efforts. I am coordinating with my co-chair, Jamie Austin to manage the stratigraphy project efforts.

WORK COMPLETED

The interactive stratigraphic modeling software, SEQUENCE4, underwent a significant upgrade. At the June 2000 Modeler's meeting, we designed a system for implementing a fully dynamic set of algorithms to represent long-term sediment transport, deposition and erosion. A moving-boundary formulation (Swenson et al.., 2001) with four units (coastal plain, shelf, upper slope and lower slope/rise) was chosen as the framework for the model (Fig. 1). The positions of the boundaries and morphology of the margin all vary dynamically.

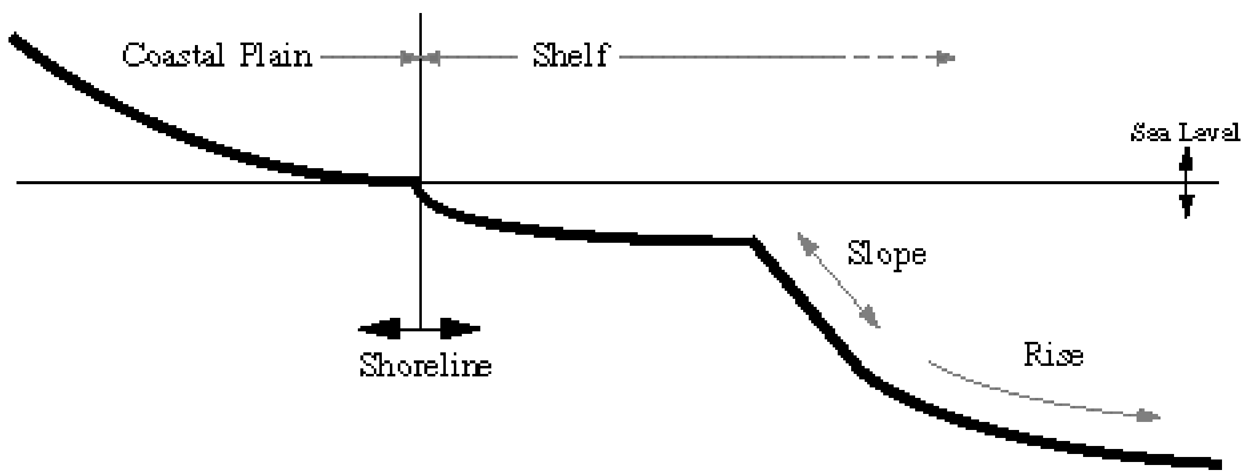

Figure 2. Conceptual diagram showing the components of the sediment transport/deposition modules in SEQUENCE4. The models includes coastal plain, shelf, slope and rise regimes. The boundary between the nonmarine coastal plain and marine shelf deposition is a moving boundary that tracks the shoreline. Shelf deposition tails off as water depth increases. Gravitational slope processes are invoked where profile meets threshold criteria. These sediments are transported seaward and deposited on the rise as turbidites. Multiple invocations of slope and rise algorithms are possible where clinoforms produce multiple breaks in slope on the profile.

In order to develop the detailed implementation scheme for the component parts, a group of the STRATAFORM Modelers who are involved in the development of *SEQUENCE* met at Lamont for two days in February. I have replaced the geometric module for coastal plain sedimentation by one that uses a diffusion-based algorithm. The coastal plain is based on the Paola et al (1992) diffusion model. The shelf transport is a nonlinear diffusion scheme based on the Niedoroda et al. (1995) behavioristic model. This has enabled improved estimation of shoreline positions during model runs, particular the response to changes in sediment supply. Slope failure has been incorporated using a critical slope threshold (Pratson pers. comm.); failed sediments are transported to the rise and deposited using a simplified turbidite model (Parker et al., 1986). The current version is for a single grain size. Over the next year, in addition to modifying components of the model and improving the interface, the biggest upgrade will be development of the multiple grain-size version and incorporation of facies. Calibration, testing and application of the model will also be a major part of next years work.

We have performed sensitivity experiments to investigate the response of this new model. The models predictions differ in several significant aspects from standard sequence stratigraphic models (e.g., Posamentier et al, 1988). I have applied it to a data sets from the Ganges-Brahmaputra delta (Goodbred et al., in press), the Eel River basin (Steckler et al., 2001). The New Jersey margin has not yet been modeled in detail with the new version, but runs with input parameters similar to New Jersey margin conditions exhibit tantalizing similarities in several aspects of sequence geometry.

RESULTS

The numerical model and standard sequence model (Vail, 1987; Posamentier et al., 1988; Van Wagoner, 1990) contain significant differences as well as some similarities. In both models the shoreline roughly follows sea level. However, clinoform front, or depositional shelf edge in the numerical model can develop significant lags of leads from the sea level curve. The clinoform front slope also increases and decreases during a sea level cycle which has implications for slope failure. If one breaks down the model into systems tracts (Fig. 2), considerable difference from the standard model appear. In the standard model, the sequence boundary (SB) occurs mid-way through the relative sea level fall. The SB is best picked as the top of the subaerial unconfromity over the prograding shorefaces, down the front of one of the last shorefaces and across the regressive marine erosion surface and generally occurs near the sea level lowstand. This and all surfaces in the model are time transgressive. Also, preserved coastal plain develops during the TST, whereas it forms in the HST in the standard model.

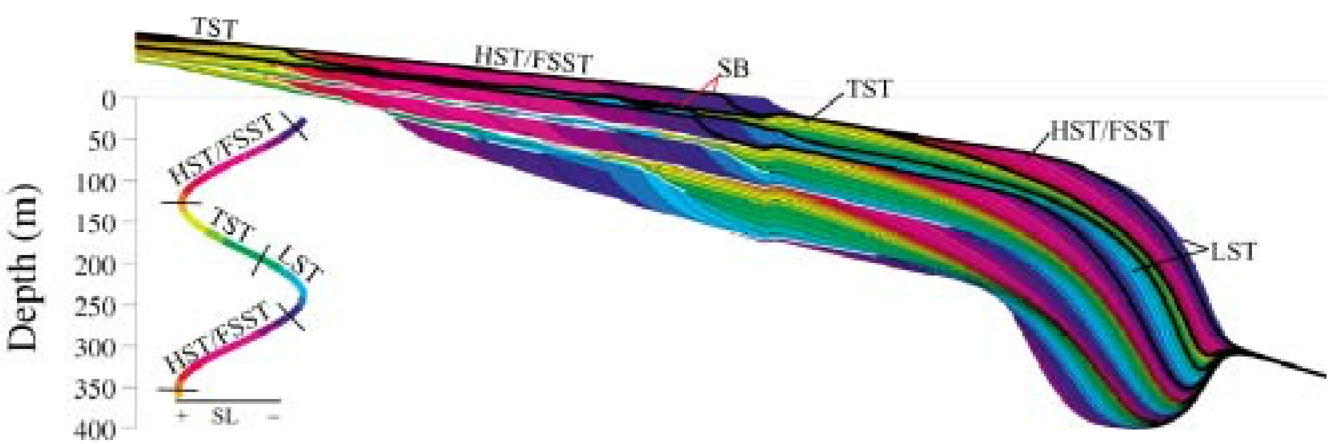

Figure 2. Cross section produced by the model showing the interpreted systems tracts. The layers are colored by position on the sinusoidal sea level curve used as input with hot colors for highstands and cools colors for lowstands. Timelines are drawn in black. Bold lines show the major bounding surfaces. Labels on section and sea level curves indicate the sediment packages as follows: HST/LSST – Highstand Systems Tract/Falling Stage Systems Tract, LST – Lowstand Systems Tract, TST- Transgressive Systems Tract, SB – Sequence Boundary.

While the numerical results show these and other differences from predictions, it exhibits many feature observed in seismic data. Below the sequence boundaries, the shelf strata (Figure 2) show a pattern of sigmoid to oblique clinoforms that is very similar to Pleistocene strata on the New Jersey margin. The model yields prograding sigmoid deposits that formed during the transgressive systems tract (TST). This type of deepening upwards facies in prograding clinoform deposits was one of the surprises of the Leg 174A drilling (Austin et al., 1997).

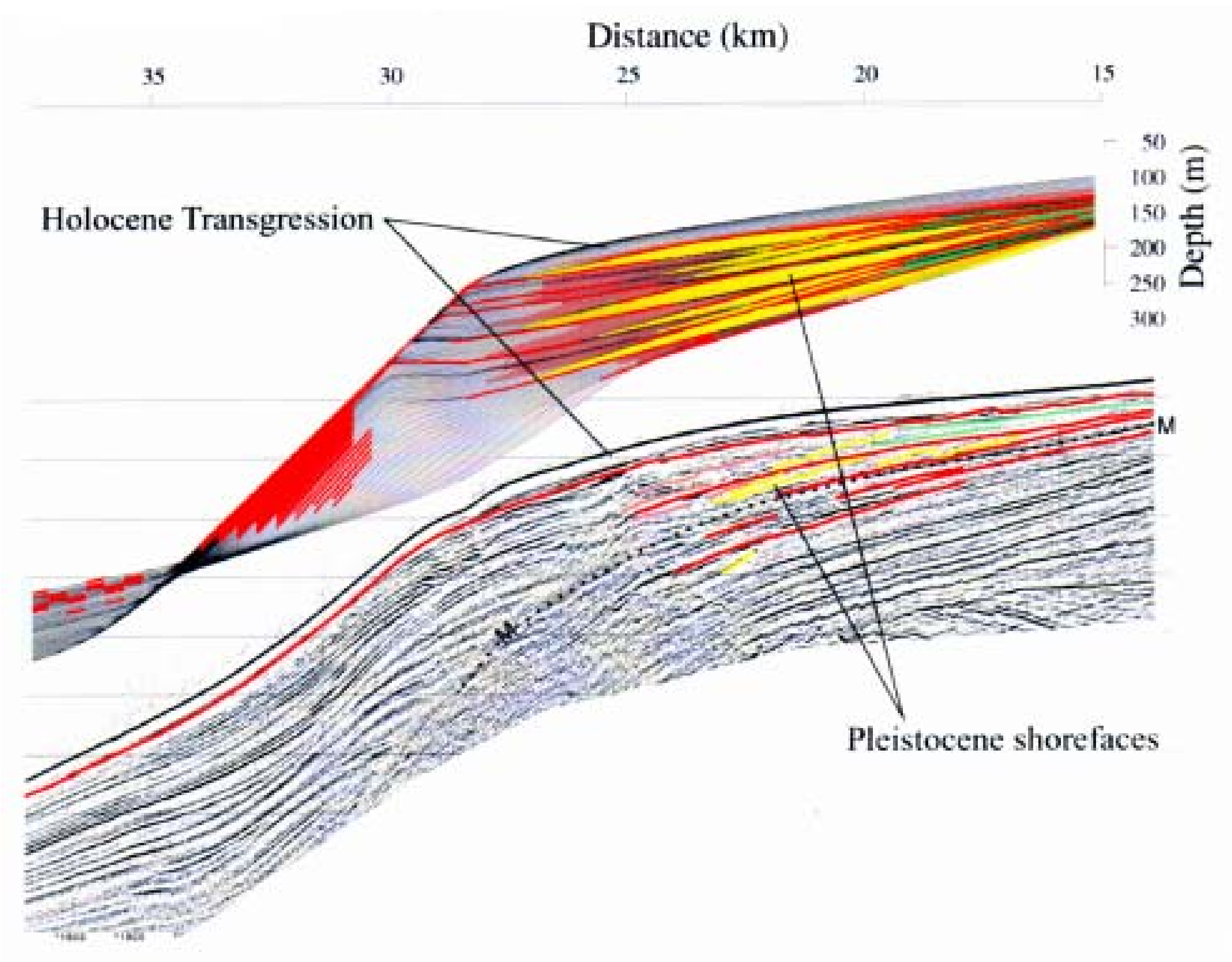

Figure 3. Comparison of model simulation to seismic line from the Eel River basin. The model on the top shows fanning progradational packages formed during the multistage sea level fall covered by a Holocene drape. Time lines are every 1000y. Strata are colored green-nonmarine, yellow-shoreface, maroon-shelf and gray-slope/rise. Unconformities are heavy red lines. Below, is Wecoma line 83, which exhibits a similar pattern of reflectors. These have been marked in colors corresponding to the model.

Figure 3 shows the results of a preliminary simulation of the stratigraphy of the STRATAFORM field arrea in the Eel River basin. The simulation was run using the relatively steep dips of this margin, rapid subsidence, high sediment supply and a sea level curve for the last 125ka. The complex mutlistage sea level fall from Stage 5 (125 ka) to Stage 2 (18 Ka) produces a series of progradational packages. Considerable erosion leaves a very incomplete section with numerous erosion surfaces. The large sea level rise since the last glacial maximum has covered the entire section with a smooth marine trangressive drape. Below is a section of a seismic line through the Freshwater that appears to resolve some patterns consistent with the model predictions. The section shows a series of strong slightly fanning reflectors on the shelf, topped by the relatively transparent Holocene transgressive drape. Within these packages are series of more steeply dipping reflectors that I interpret to correspond to the prograding shorefaces and other more steeply dipping interfaces in the model.

In modeling with the geometric version of SEQUENCE has been used for long-term modeling for the New Jersey margin (Steckler et al., 1998, 1999, 2000). This version has been very successful at capturing major features of the sequences imaged on the New Jersey margin. I found that differences in preexisting topography and sea level amplitude can explain the contrasting sequence architectures of the Early Miocene and Plio-Pleistocene sequences in New Jersey. A paper about these results is in preparation. Further modeling using the new version of SEQUENCE is planned.

A comparison of backstripping results for the NJ margin with the West African margin and other margins around the world indicate that there is a widespread pattern indicating that margin morphology has evolved with global climate since the Eocene (~40 Ma). Numerous margin were carbonate ramps with a deep (5-600 m) shelf edge and little terrigenous sediment input in the late Eocene. Since the Oligocene, increased sediment supply has transformed them to modern margins with shelf breaks at ~100 m. A paper discussing these results and their implications for terrestrial erosion rates, shelf processes and water masses and climate is about to be submitted (Steckler and Lavier, to be submitted).

IMPACT/APPLICATIONS

The new version of SEQUENCE is able to realistically deal with changes in sediment supply and slope failure during model runs. The response of the shoreline to changing conditions (e.g., sea level, tectonics, sediment supply) no longer is proscribed, but determined by the coupling between the transport processes for the land and the sea. This holds great promise for more accurate prediction of the long-term morphodynamic response of margins to environmental change and more accurate predictions of stratigraphy. The model is already providing new predictions that correspond to features previously observed on sesimic and in outcrop.

The changes in continental margin morphology and sediment supply seen at New Jersey appear to be widespread and apply to other margins. They are hypothesized as being related to the climatic changes of the Cenozoic. I conclude that widespread changes in morphology and sediment supply at margins during the Tertiary are related to global climate. These findings will enable better prediction of the stratigraphy at other margins.

TRANSITIONS

Software is being used/installed at several other universities for both STRATAFORM, other sequence stratigraphic investigations, and for teaching sequence stratigraphy.

RELATED PROJECTS

Reconstructions of West African margins using the sequential backstripping (Lavier et al., 2001) show strong similarities with the NJ margin. Other margins around the world show similar prograding sequence architectures. Widespread changes in morphology and sediment supply at continental margins occurred during the Tertiary and they are related to global climatic change.

I used the latest version of SEQUENCE to model the stratigraphy of the Ganges-Brahmaputra Delta. This largest delta in the world differs from most others because large temporal changes in sediment supply halted the Holocene transgression during the rapid sea level rise and started progradation of the delta (Goodbred et al., in press).

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PATENTS

None.