

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 an interactive computer model of stratigraphic sequences at continental margins, and am applying these models 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 (L-DEO) on the interpretation and modeling of the New Jersey margin. I am collaborating with Don Swift and John Carey (Old Dominion University)

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and Chris Reed and Alan Niedoroda (Woodward-Clyde) in incorporating shelf sediment transport models and facies models into the stratigraphic model, and applying the model to the Eel River basin. I am working with Gary Parker and Chris Paola (University of Minnesota) for incorporating improved models of slope and fluvial processes. I am working with James Syvitski to coordinate our modeling efforts. I am coordinating with my co-chair, Jamie Austin (UTIG) to manage the stratigraphy project efforts.

WORK COMPLETED

The interactive stratigraphic modeling software, SEQUENCE, continues to be updated according to the requirements of the research. The 2¹/₂-D functionality to include affects of along-strike variations in the model has been improved. We have performed more sensitivity experiments to further investigate the model response. Plans for improved modeling of non-marine and slope processes and for incorporating facies into the model have been developed. Forward model runs are successfully simulating features observed at the New Jersey and Eel River margins.

Sequential backstripping and reconstruction of the paleobathymetry and geometry of the the New Jersey margin from the coastal plain to the mid-shelf had been completed (Steckler et al., 1999). This work has now been extended to the upper continental slope. This allowed reconstruction of the New Jersey margin from the Oligocene to the present.

Landmark seismic interpretation software has been installed in the multichannel seismic processing center and New Jersey seismic data has been loaded onto it. When the seismic interpretations are transferred to this system, it will enable the mapping of sequence geometies and examination of along-strike variability to proceed more easily.

RESULTS

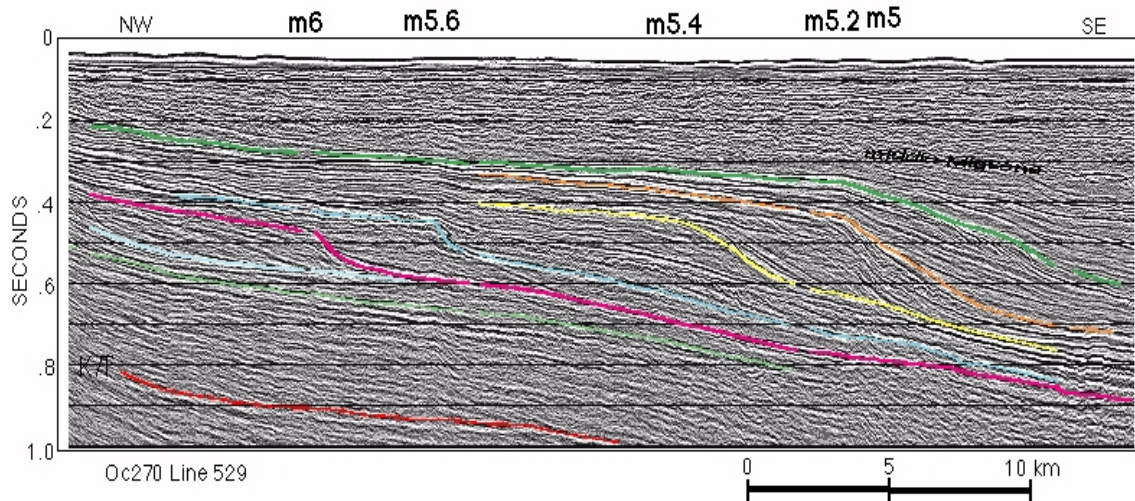
An expanded backstripping of the NJ margin has yielded an improved geologic history of the margin. In the Eocene, the NJ margin was a carbonate ramp dipping at ~1:300. The shelf edge lay at 5-600 m water depth. Enhanced terrigenous sediment supply starting in the Oligocene caused progradation of clinoforms across the margin creating a new shallower shelf. The clinoform rollovers represent a new shelf edge. The clinoform heights and slope increases as they prograde across the seaward-dipping ramp. This is in agreement with predictions of advection-diffusion models of clinoform formation. The reconstructions now image the progradation of the new shelf edge past the relict shelf edge. This appears to coincide with the initiation of greater mass flow deposits on the slope and rise.

The backstripping results show significant peaks in sediment supply that correlate with major climatic shifts as indicated by $\delta^{18}\text{O}$. These correspond to the onset of permanent Antarctic glaciation and the start of the large Northern Hemisphere glacial cycles. I interpret these sediment pulses to transient readjustments of the continental landscape to climatic shifts. These order of magnitudes increases in sediment supply allowed the preservation of higher frequency eustatic cycles at the margins. Similar pulses at other margins indicate that this may be a global phenomenon.

Numerical modeling of the preserved sequences on the New Jersey margin reveals the controls on sequence architecture. Simulations contrast the conditions and sequence architecture for early and late Miocene sequences. The numerical experiments were undertaken with initial conditions taken from the backstripping reconstructions. The early to middle Miocene sequences (Fig. 1) display sigmoidal

clinoforms that transition from progradational to aggradational. Well controls indicate that the shoreline lay ~50 km landward of the clinoform rollovers. The modeling fits the pattern with a sea-level cycle amplitude of 20 m, considerably smaller than previous estimates (Haq et al., 1988). Our new estimate is in accord with $\delta^{18}\text{O}$ and backstripping data (K. Miller, S. Pekar, pers. comm. 1999). The modeling results also showed clinoforms that steepened as they prograded into deeper water, consistent with observations and the backstripping.

A



B

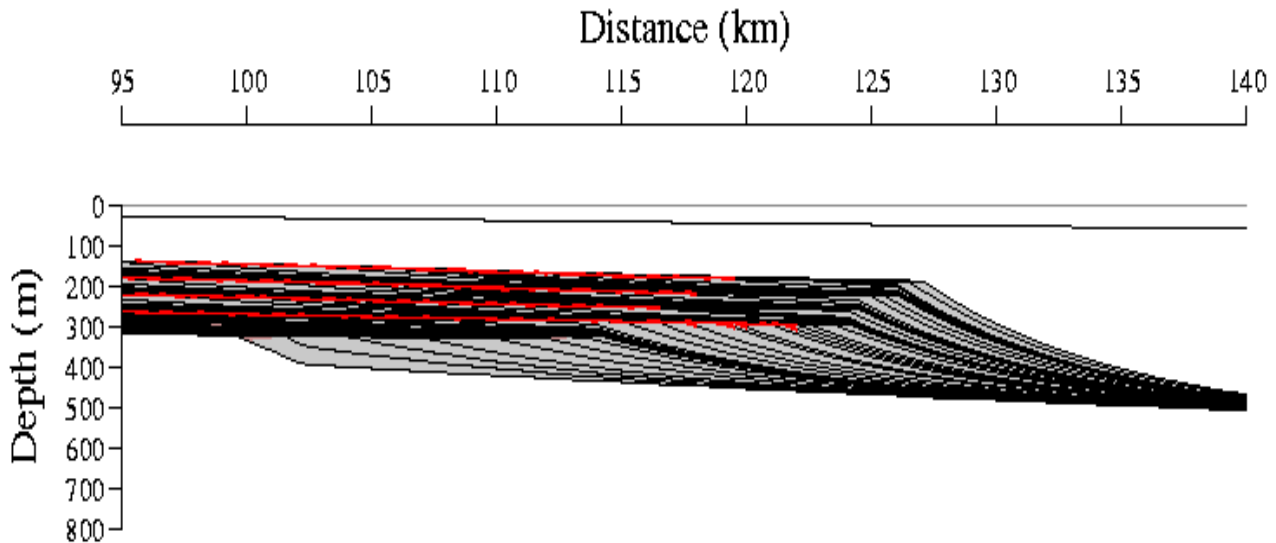


Figure 1. A) Section of seismic profile from New Jersey showing clinoforms of early Miocene age.

The sequence boundaries are colored and labeled at top of image over their rollover. The clinoforms represent the progradation of a new shallower continental shelf over an earlier ramp. The sequence of clinoforms shown exhibit a transition from progradation to aggradation, and an increase in height and foreset angle through time.

B) Model experiment using a 20-m amplitude sea level cycles 2 My in length. Timelines are in black with erosion surfaces highlighted in red. Results also show progradation to aggradation cycles with the clinoform height increasing from 40 to 150 m and the clinoform foresets steepening.

The shelf width is ~50 km and matches the paleoenvironment at the Island Beach well, 35 km landward of the profile.

The late Miocene-Pliocene sequences exhibit large, truncated oblique clinoforms. The simulations required large sea level fluctuations, on the order of 90 m. They predicted extensive transgressive deposits and the formation of oblique, truncated clinoforms during sea level fall. The shoreline position fluctuated widely. Erosion truncated much of these deposits, but limited shore and non-marine strata are preserved close to the clinoform rollover. All of these results are very similar to findings of recent ODP Leg 174A drilling (Austin et al.; 1998). The modeling and drilling results conflict with previous models for sequence development at passive margins.

Initial models of the Eel River shelf predict a complex pattern of erosion surfaces separating packages of regressive shorefaces interfingering with transgressive or minor lowstand to wedges near the shelf edge. These strata are covered by a relatively thick Holocene transgressive sheet. Earlier transgressive sheets were almost entirely eroded during subsequent sea level falls. The changing shape of the shelf profile during sea level fluctuations greatly influences preservation. The model can now take into account along-strike variations in tectonic subsidence and the alterations to the sediment loading they cause. This was required because of the short spacing between synclines and anticlines on the margin. This has enabled better match to the observations, particularly the shoreline position.

IMPACT/APPLICATIONS

The changes in continental margin morphology and sediment supply seen at New Jersey appear to be widespread and apply to numerous 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. The peaks in sediment supply at climatic transitions highlights the importance of transients in the landscape and stratigraphic response to external forcing. These findings will enable better prediction of the stratigraphy at other margins.

The numerical model has matured sufficiently to simulate observed sequences and derive realistic estimates of controlling parameters. The convergence of sea level amplitude estimates for the early Miocene from three different methods increases our confidence in these estimates. Differences between the early and late Miocene sequences are attributable to primarily to differences in the sea level history, sediment supply, and preexisting margin morphology.

Sequence stratigraphic models will have to be revised to deal with differences between sequence architecture as imaged by clinoform geometry and facies patterns as mapped by shoreface stacking patterns. Implications of the presence of sharp-based shorefaces for sequence interpretation need revision. In general, modeling and detailed field studies are raising questions about the simplifying assumptions that allowed sequence stratigraphic theory to initially develop.

TRANSITIONS

Software is being used at Old Dominion University and the University of Edinburgh/Imperial College for both STRATAFORM and other sequence stratigraphic investigations. The code has been installed at INSTAAR and the University of Minnesota. I will be distributing software more widely, such as to INFREMER. I will be using the software to model Jurassic Tank results.

RELATED PROJECTS

Reconstructions of West African margins using the sequential backstripping software show strong similarities with the NJ margin. In particular, peaks in sediment supply occur at the same times. Other margins around the world show similar prograding sequence architectures. I conclude that widespread changes in morphology and sediment supply at continental margins occurred during the Tertiary and they are related to global climatic change.

I have started to use the forward model to investigate the sequence architecture in rift basins. Initial experiments suggest that changes in sea level, rather than in sediment supply or tectonics are responsible for the fine-scale cyclicity in preserved strata.

I will be installing an initial set of continuous GPS stations in the Ganges-Brahmaputra Delta to monitor subsidence of the delta.

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