Pleistocene Margin Stratigraphy, New Jersey vs. Northern California: A STRATAFORM Study of Contrasts

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LONG-TERM GOALS

The goal of STRATAFORM is to link short-term biological and physical processes affecting sedimentation ("event" stratigraphy" developed over hours to weeks) to the stratigraphic geometry and facies distribution of the upper ~100 m of continental margin sediments representing ~10^6 years of preserved record.

OBJECTIVES

Three groups of processes have been isolated for study by STRATAFORM investigators: 1) shelf sediment dynamics and the development of lithostratigraphy; 2) slope processes and their role in shaping geomorphology; and 3) stratigraphic sequence generation. Collecting high-resolution seismic reflection data as has been done is at the core of this third approach. All three are linked by the goal of determining how the morphology and facies patterns of the modern sea floor (revealed by multibeam bathymetry, backscatter data, and sampling of the shelf and slope) compare with the preserved geologic record observed in seismic images and sampled in the subsurface.

APPROACH

With funding from ONR and other sources, Lamont-Doherty assembled equipment to meet the STRATAFORM requirements of high-resolution reflection profiling. This included a generator-injector ("GI") airgun, towing harness, and shot control system, a 2000 psi diesel-powered compressor, a 48-channel 600-m narrow-gauge (solid, not oil-filled) analog streamer with depth-control birds, and a digital recording system capable of the moderately high sampling rates (0.5 msec) required for ~5m vertical resolution of sub-seafloor images. Existing profiles showed that a track spacing of 2 to 5 km on the New Jersey margin was sufficient to map the comparatively uniform stratigraphy of that passive margin; a 950 nm survey was completed on cruise Oc270 in July, 1995. Structural complexities off northern California, by contrast, required line spacing of 800 m and less; a 1200 nm grid on cruise W9605 was completed in July, 1996. Both seismic surveys were designed to: cover areas previously mapped with swath bathymetry and acoustic backscatter; tie to available seafloor samples; and duplicate several profiles of lower resolution (air gun) and higher resolution (Huntec) imaging. This "nested" data set allowed us to optimize the information provided by each acquisition system and provide a more complete understanding of processes shaping the geologic record along both continental margins.

WORK COMPLETED

All Oc270 seismic profiles have been processed and exchanged with colleagues at UTIG, and each group of investigators now has a complete set of stacked and migrated SEG-Y files. Both institutions are on their own to prepare these as displays on paper and/or on seismic workstations. At L-DEO we have reformatted these data and loaded 61 profiles onto disk for mapping with our Landmark 'SeisWorks' interpretation package. Ten sub-seafloor surfaces have been identified, traced, and correlated throughout this grid. Depth to and thickness between each of these surfaces has been calculated and mapped in meters. These features have been correlated to the results of ODP Leg 174A drillsites 1071, 1072, and 1073, and to the more recently acquired Marion-Dufresne II piston cores collected in June, 1999. Extensive core and downhole log measurements relevant to integration with the seismic data and to understanding the stratigraphic histories of these sites have been prepared to aid correlation between all data types. Intriguing relationships between seismic stratal geometries, log character, sediment composition, and chronostratigraphy have been revealed and reported at STRATAFORM and other national science meetings.

Unwanted noise is present in the W9605 data set from the northern California margin. We believe it originated in electronic crosstalk from the 'birds' that control the depth of the streamer. At L-DEO we evaluated various techniques designed to minimize or totally eliminate this noise before declaring that the data were processed to our satisfaction and available for distribution. After a considerable amount of time and effort searching for solutions, we concluded that due to the erratic, non-periodic nature of the noise there was no 'quick fix' that could be applied in an automatic fashion. We had great success in eliminating 95% of the noise with an exceedingly labor-intensive interactive trace editing scheme, but we concluded that the marginal improvement in data quality was not justified by the effort involved. We are on schedule to complete the processing of all W9605 data allotted to L-DEO on or near the last day of September, 2000. We intend to then make isopach and structural contour maps of key sub-seafloor reflectors traced in this data set, and coordinate this effort with colleagues at UTIG who are doing the same with their portion of the W9605 data set. Because only the Oc270 can thus far be tied to subseafloor samples, correlations to the rock record are currently restricted to the New Jersey margin.

RESULTS

Mapping seismic features along the New Jersey outer shelf and upper slope with the aid of a computer workstation provided several new insights relevant to STRATAFORM objectives. Two outstanding conclusions are described here (Fig. 1). The first is documenting the profound influence that pre-existing morphology exerts on the preservation and character of the continental slope. The study area was intentionally chosen to straddle two regions where the New Jersey slope is: a) deeply incised by submarine canyons, and b) devoid of significant evidence of erosion and/or sediment by-pass. The latter region is informally called the 'Hudson Apron' and has been examined in several studies in the past (Knebel, 1979; Twitchell et al., 1985; Milliman et al., 1990.) It had been assumed that spill-over from the adjacent Hudson Canyon or off-shelf dispersal has mantled this region with a thick layer of sediment during one or more Pleistocene lowstands of sea level. Mapping 10 surfaces within the Pleistocene section (using the Oc270 dataset reliably tied to the detailed chronology of ODP Site 1073) has shown that the truly critical element in the evolution of this physiography was a pre-existing structure (possibly a mid- to late-Cretaceous reef) beneath today's middle and lower slope. Whatever the feature, its effect was to preserve unusually gentle gradients in a 35-km wide corridor along the slope by allowing seaward-directed transport to bank sediments immediately landward of it. In other areas, locally steep slope gradients led to massive sediment failure that generated retrograde erosion that cut landward as far as the shelf break (Farre et al., 1983; Pratson et al., 1994; Mountain, 1996). Off-shelf sediment transport tended to focus in these indentations, and led to networks of submarine canyons that persisted from one sea-level oscillation to the next in such density that the modern slope is almost entirely cut by canyons or their tributaries. By contrast, the Hudson Apron region experienced a more uniform buildup from the time of reef burial to the present. Slope gradients prior to the Pleistocene were a gentle 1:35, steepened to a steady 1:25 in the middle Pleistocene, and have remained at that value to the present day. No amphitheater-like sediment scars have been detected in any of the Pleistocene sediments that comprise the Hudson Apron. Consequently, with no headward erosion cutting into the slope, the adjacent shelf edge has not been indented by massive failure events, and shelf-edge sediments have on occasion built out onto the slope with a steadily maintained gradient of 1:25. This has important consequences on the resulting geometry of stratal surfaces, and impacts our ability to read geologic history from their signature in reflection profiles as described in the following paragraph.

Oc270 profiles show for the first time that the Pleistocene section beneath the modern shelf can be divided into four unconformably-bounded units 100's of m thick. Up to a point, these units exactly fit the standard definition of depositional 'sequences' (Vail et al., 1977). That is, each is bounded above and below by reflector terminations that indicate various degrees of depositional hiatus or outright erosion. Furthermore, these surfaces of discontinuity can be traced seaward across an abrupt change in gradient (the 'clinoform breakpoint') separating modest shelf gradients from steeper slope gradients, and marking shorter and shorter breaks in accumulation history along the way. Presumably as sea level became progressively lower during times of Pleistocene glaciation, the New Jersey shelf narrowed and shoaled, and increasingly large volumes of terrestrial sediment spilled onto the slope. However, there is no evidence on the Hudson Apron that these lowstand sediments by-passed the slope as is generally assumed in standard applications of sequence stratigraphy. The Oc270 data demonstrate that given a slope of stable grade (in this case 1:25) that lacks locally steeper canyons or slump scars, 'lowstand sediments' can accumulate on the slope and become part of the preserved record. The standard model, bolstered by numerical calculations (Pitman and Golovchenko, 1983), predicts that during the time of most rapid sea-level fall the outer shelf is likely to be subaerially exposed, rivers will incise the shelf edge, and canyons will deliver sediment to a more distal submarine fan. Then, during a slowing of sea-level fall or certainly during the early stages of the following sea-level rise, sediment will once again accumulate on the slope by lapping onto the previous sequence with clear angular discordance, and will eventually return to settling on the shelf when water depths become sufficiently deep. In this manner, the 'sequence boundary' will: a) mark the time of most rapid sea level fall, b) correspond to an outershelf erosional surface, and c) lie beneath lowstand sediments on the adjacent slope. Thus far the Oc270 profiles across Hudson Apron tied to ODP Sites 1071, 1072, and 1073 shows that feature a) cannot be determined because of the long time that is missing in shelf sediments, feature b) is not confirmed because simple by-pass without actual erosion into the shelf explains these same observations, and that feature c) is most definitely wrong. Those surfaces on the Hudson Apron slope that correspond to shelf sequence boundaries were revealed at ODP Site 1073 to be 'condensed sections' that appear to have formed during times of sediment starvation. These events occurred during interglacial high stands when the shoreline was near its present location, and the shelf was deeply flooded and able to retain most of the terrestrial sediment that reached it. Hence, by marking times close to maximum high stand of sea level, the features thought to be the slope equivalents of sequence boundaries have an origin exactly opposite to what is assumed in the standard model.

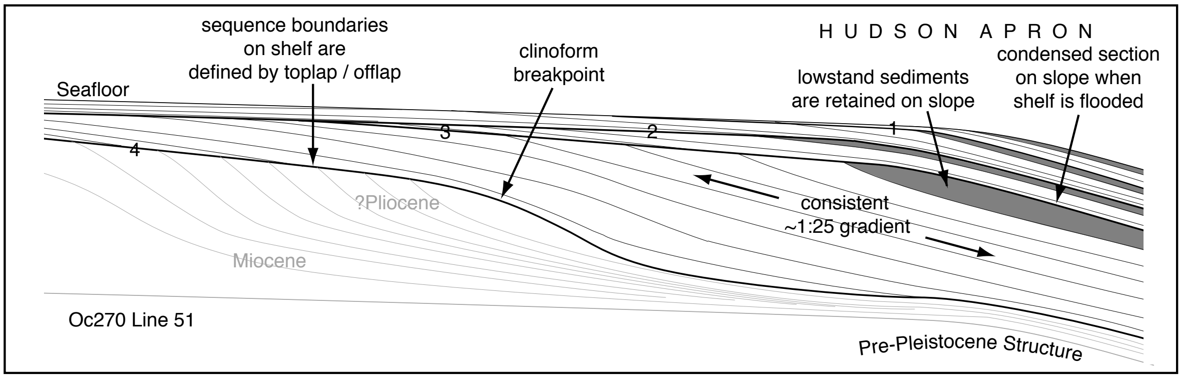

Fig. 1- Dip line 51 across the NJ shelf-slope transition showing 4 Pleistocene units separated by disconformable boundaries 1-4 on the shelf, and 4 condensed sections on the slope. A stable ~1:25 gradient minimizes sediment by-pass and retains lowstand sediments (gray fill) on the slope.

IMPACT / APPLICATIONS

These findings demonstrate that the slopes of passive margins can contain surprisingly complete geologic records that far surpass the integrity of the record on outer shelves. Submarine canyons, though abundant on many margins, are not a necessary physiographic element, and in fact, their absence (such as the Hudson Apron) provides more accurate understanding of the relationship between sea level change and evolution of the continental terrace. If continued work on these data bears out the early conclusions described above, we must be far more cautious in applying the standard depositional sequence model to the outer continental shelf where the seaward boundary is effectively a slope of limitless water depth and a basin floor plain at an infinite distance. The standard model was developed in sedimentary basins of much more modest dimensions and may be lead to surprising errors of interpretation if not carefully applied.

TRANSITIONS

Maps of sediment thickness and structural features off both New Jersey and northern California will be made available to all STRATAFORM investigators. We have matched these data to other acoustic records (HUNTEC, lower resolution airgun profiles, etc.) and have developed a coring strategy to ground-truth these data and address the primary STRATAFORM issue of how well the event-scale features of the seafloor are preserved in the geologic record.

RELATED PROJECTS

STRATAFORM investigators are in regular communication, pursuing parallel and complementary studies. Data will be exchanged between all investigators when complete. For example, M.Field and colleagues (USGS) have a similar project evaluating finer-scale histories of sediment geometries off Eel River using Huntec technology; J.Austin and colleagues (UTIG) are doing similar interpretations of HUNTEC data off New Jersey. The combination of Hi-Res MCS data along overlapping track lines on both margins will provide a unique and valuable assessment of sediment processes at a wide range of scales. M. Steckler

(L-DEO) and colleagues are modeling depositional geometries on both margins, and profiles developed in this project will provide them with valuable ground truth. We anticipate especially unique insights to be gained by incorporating the effects of Pleistocene ice loading on the New Jersey margin. J.Goff (UTIG) and colleagues have prepared a seabed backscatter map on both margins and will be examining correlations between their findings and sub-bottom facies and structure that our profiles reveal. James Syvitski (Colorado) and colleagues are examining factors that destabilize slope sediments, and the history of mass wasting revealed by our profiles will be a valuable long-term record.

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