

Recognition of Diagnostic Acoustic Signatures in Shelf and Slope Deposits: The STRATAFORM California Site

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Award#: N00014-97F0022

LONG-TERM GOAL

One of the major goals of the STRATAFORM Project is to gain a better understanding of how strata form and how they combine to form characteristic stratigraphic sequences, such as drapes, aprons, wedges, sigmoids, and other characteristic geometries. An essential part of this understanding is the analysis and interpretation of surface features and deposits in the upper 50 m of the shelf and slope to provide information on the mechanism of sediment transport and deposition. Interpreting the signatures of various processes in surface and near-surface deposits provides a critical link between knowledge gained from measuring physical processes that are dominant over time spans from the duration of a single event to several years, and those inferred from seismic-reflection data that may represent 10^2 to 10^4 years. Towards these ends, we have been testing some of the concepts of sequence stratigraphy.

OBJECTIVES

Our objectives are to identify the types of sediment signatures that occur in high-resolution seismic-reflection and sidescan-sonar records from the California continental margin, correlate them with the causative process (flood sedimentation, turbidity flow, slow hemipelagic drape, slope currents, etc.) that formed the deposits, and identify the relative abundance and significance of slope- and shelf- sediment signatures. These signatures can then be correlated with results from other STRATAFORM investigations and major patterns can be related to fluctuating sediment sources, sea levels, and climate.

Report Documentation Page

*Form Approved
OMB No. 0704-0188*

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1. REPORT DATE 1998	2. REPORT TYPE	3. DATES COVERED 00-00-1998 to 00-00-1998			
4. TITLE AND SUBTITLE Recognition of Diagnostic Acoustic Signatures in Shelf and Slope Deposits: The STRATAFORM California Site		5a. CONTRACT NUMBER			
		5b. GRANT NUMBER			
		5c. PROGRAM ELEMENT NUMBER			
6. AUTHOR(S)		5d. PROJECT NUMBER			
		5e. TASK NUMBER			
		5f. WORK UNIT NUMBER			
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) U.S. Geological Survey, 345 Middlefield Rd, Menlo Park, CA, 94025		8. PERFORMING ORGANIZATION REPORT NUMBER			
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)		10. SPONSOR/MONITOR'S ACRONYM(S)			
		11. SPONSOR/MONITOR'S REPORT NUMBER(S)			
12. DISTRIBUTION/AVAILABILITY STATEMENT Approved for public release; distribution unlimited					
13. SUPPLEMENTARY NOTES See also ADM002252.					
14. ABSTRACT					
15. SUBJECT TERMS					
16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT unclassified	b. ABSTRACT unclassified	c. THIS PAGE unclassified	Same as Report (SAR)	5	

Our specific objectives for FY1998 included the following:

- Complete and publish our initial studies of continuity, extent, vertical history, and overall significance of gullies on the slope.
- Complete and publish our initial studies of the timing, instability mechanisms, and sedimentary processes that formed the Humboldt Slide Zone.
- Analyze high-resolution seismic-reflection records to map sediment sequences on the shallow shelf and interpret the styles of sedimentation and the amount of sediment deposited during the last transgression and present-day highstand of sealevel.
- Initiate studies to define the nature and style of sediment deposition and deformation in the vicinity of a large, active anticline on the outer shelf.
- Present findings at an international meeting in Sicily and at national meetings and workshops on slope gully systems, slope sediment-gravity deposits, reflector geometry, and inferred sediment processes, including mass failure, gully formation, turbidity flows, and aggradation and progradation of the shelf-slope sediment sequences.

Sediment is deposited on shelves and slopes in distinctive packages or sequences that bear similarities at many sites around the world. The exact processes that form these sequences are not well understood. The STRATAFORM project seeks to integrate studies of sediment transport with observations of sediment deposition and with computer models to develop a better understanding of how sediment sequences originate on continental margins.

Our study contributes as an integral part of STRATAFORM, specifically the investigation of small-scale topography on the shelf and slope. We have employed high-resolution seismic-reflection data and sidescan sonar to document the presence and distinctive characteristics of marine sediment-gravity deposits and record the diagnostic geometric patterns of shallow subsurface strata on the shelf and slope.

WORK COMPLETED

We identified key scientific issues from analyses of high-resolution acoustic profiles and sidescan data from two major research cruises using the Hunttec DTS System and a Datasonics SIS-1000. Our research focus has been directed toward the following science topics, all of them key to addressing the over-arching goals of the project and the STRATAFORM Program:

1. The role of channels in slope evolution: how they transport and distribute sediment across the slope and onto the plateau?
2. Detailed analyses of the Humboldt Slide Zone: what is the dominant style of sediment mass-transport (slide vs. flow)?
3. Stratigraphy of the inner shelf: separation of units above the transgressive surface of erosion into transgressive and high-stand components, and mapping the loci of deposition and total volumes and over-all rates of sedimentation.
4. Mapping of surface pock marks and subsurface gas: how the two are related in distribution and genesis.

5. Tectonic deformation of shelf and slope strata: uplift on an upper slope anticline has resulted in large waves of near-surface sedimentary strata, but the causative processes need to be delineated.

RESULTS

Shelf and Slope Sedimentation Since the Last Lowstand of Sea Level

This past year we sought to explore the tenet that sediment accumulates on the shelf and slope in predictable patterns, and that these patterns are controlled by water depth, sediment sources, and the diagnostic styles of transport and deposition. Sedimentation on a tectonically active continental margin such as the STRATAFORM site off northern California should display a sediment pattern that reflects the strong interplay between sediment delivery and concurrent tectonic deformation. The STRATAFORM study is located in the Eel River Basin offshore of northern California, a forearc basin that has received large sediment volumes since the early Pliocene. The prolific coastal drainage basins (the Smith, Klamath, Mad, and especially, Eel Rivers) that lie along the uplifting and high rainfall coastal regions contribute large volumes of sediment annually to the shoreline and shelf. The Eel River alone contributes on the order of 15×10^6 tons of sediment annually to the basin; combined totals are likely twice that amount.

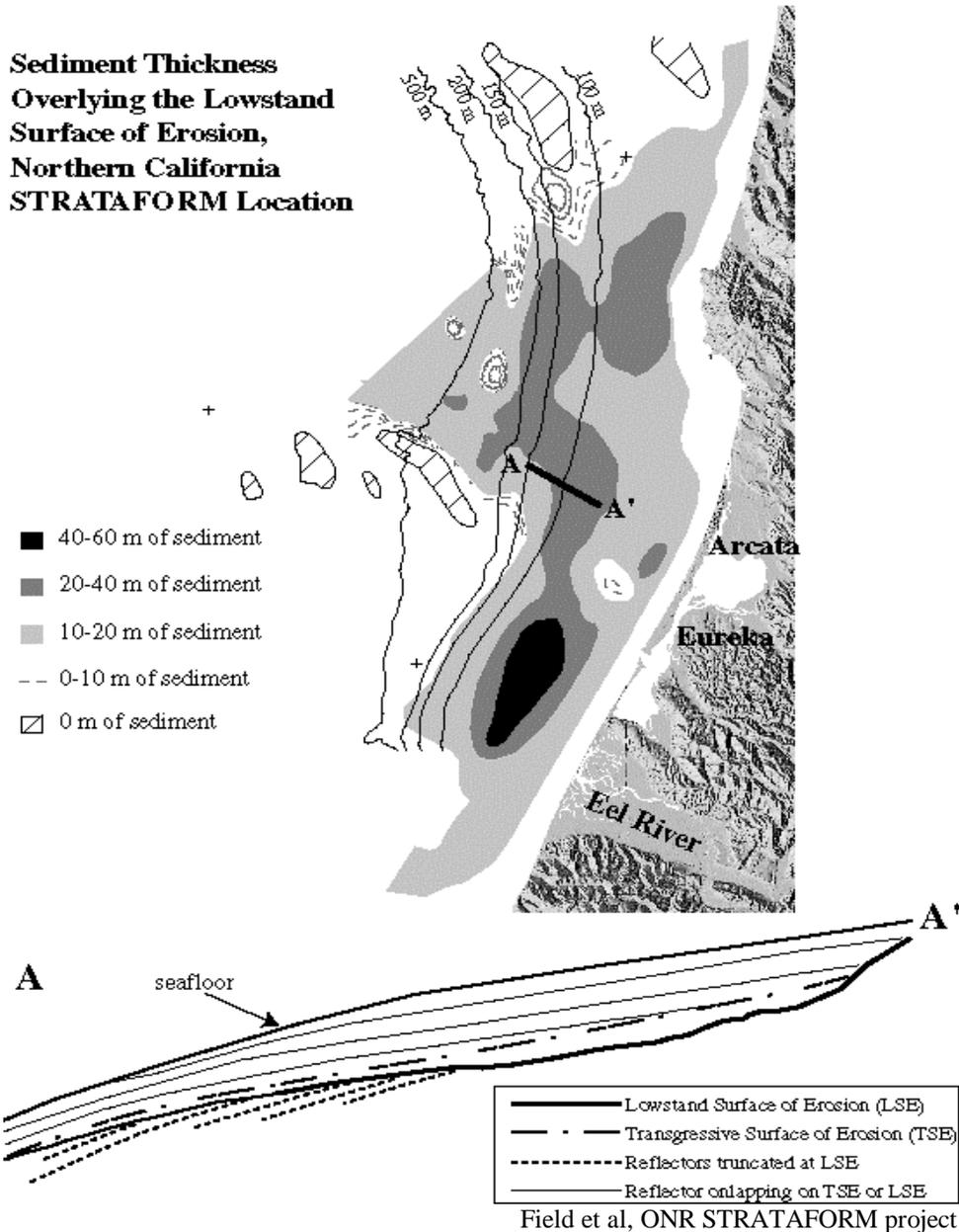
Our analysis indicates that these delivery systems were active during the most recent rise in sea level and that thick terrigenous flood deposits accumulated seaward of the transgressing shoreline. Two major surfaces in the shallow subsurface of the Eel shelf and slope are identifiable on high-resolution seismic-reflection records obtained with a Huntect DTS system. The lowstand surface of erosion (LSE) and its correlative conformity on the slope lie 10 to 20 m below the seafloor throughout much of the area. The transgressive surface of erosion (TSE) is locally separated from the LSE by several meters of coastal deposits, but over much of the area differences between the two surfaces can not be resolved (< 1 m). Deposits overlying the LSE/TSE are onlapping, laterally continuous beds with a typical aggregate thickness of 10 to 20 m. This transgressive unit is capped by a modern deposit of early highstand flood deposits that is one to several m thick.

Although the rates of sediment accumulation at the decade/century scale are well known in this region, the long-term sedimentation rates are less well defined. A few ^{14}C dates from wood and shell material indicate rates of sediment accumulation in the upper 3 m to be 30 cm/ky. The entire transgressive packet (~15 m thick) has accumulated at an approximate rate of 100 cm/ky, suggesting sediment yields were higher or trapping mechanisms more efficient during the transgression.

A key control on sediment trapping is accommodation space, and the Eel shelf is an excellent location to observe the effect of local changes in accommodation space. Sediment thickness varies as much *along* margin as it does *across* margin, a result of tectonic creation/removal of accommodation space. The pronounced thickness (30 to 50 m) of transgressive deposits offshore of Arcata correlates with a subsiding syncline. Other sediment loci overlie structural lows in the LSE/TSE, indicating structural control of accommodation space and, ultimately, sediment thickness. Sediment thickness on the shelf reaches minimal values of 0 to 10 m where it overlies structural highs along faults and uplifting anticlines.

IMPACT/APPLICATIONS

Our findings are significant to sequence stratigraphic models in two ways. First, the presence of relatively thick transgressive deposits adjacent to small coastal drainage basins indicates that sequence stratigraphic concepts operate differently on the narrow, high-relief, high-sediment load areas characteristic of Pacific-style margins where base levels rapidly adjust to sea level shifts. Changes in base level seem to be quickly accommodated, although sedimentation remains more-or-less continuous, with only subtle changes associated with shifts in sea level. This contrasts with many passive margin examples where all but the largest streams readjusted to rising base levels during transgression by infilling fluvial valleys, resulting in greatly reduced discharge onto the shelf. Thus, the transgressive tract appears to be relatively thick and dominated by shelf deposition, in contrast to the coastal-plain sequences where transgressive facies are relatively rare or dominated by estuarine deposits.



The second finding is that accommodation space varies along margins as well as across margins. On margins affected by local or regional tectonics, the processes of uplift and downwarp locally create and destroy space as rapidly as do shifts in sea level. Fold axes on the northern California shelf and slope strike normal to sub-parallel to the coastline, thus continuing uplift and downwarp along these axes destroys and creates accommodation space, respectively. The result is a shelf-slope depositional unit that is discontinuous and of variable thickness.

TRANSITIONS

Our results are being used directly by other ONR investigators in the STRATFORM Project to calibrate numerical models of sequence stratigraphy, compare analyses of short-term rates of sediment accumulation, analyze geologic structures and fluid escape features, and interpret the shallow part of MCS profiles.

RELATED PROJECTS

1. We are working with J. Syvitski (U Colorado) and also D. Swift (Old Dominion U.) and M. Steckler (Lamont Doherty Earth Obs.) to provide a time-bounded sediment sequence for their computer simulations of the Eel River continental margin.
2. Sediment accumulation rates measured by C. Nittrouer (U. Washington) and C. Alexander (Skidaway Inst.Ocean) are being compared with our maps of sediment sequences to extrapolate ages of seismic units.
3. Analysis of deep structure and stratigraphy in the Eel River basin is being studied by C. Fulthorpe and J.Austen (U. Texas) and D. Orange (UC Santa Cruz); we are working with them to use both the high resolution Hunttec data with the high resolution MCS data to provide an integrated interpretation.

PUBLICATIONS

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