

Sedimentary Processes and Stratigraphic Responses in a Tectonically Driven Basin: Northern California Continental Shelf and Upper Slope

Craig S. Fulthorpe and James A. Austin, Jr.

University of Texas, Institute for Geophysics, 4412 Spicewood Springs Road, Bldg. 600
Austin, TX 78759-8500

Phone: (512) 471-0459; Fax: (512) 471-8844 Phone: (512) 471-0450; Fax: (512) 471-8844
Email: craig@utigig.utexas.edu Email: jamie@utigig.utexas.edu

Award #: N00014-96-1-0359
<http://www.ig.utexas.edu/>

LONG-TERM GOALS

This project is a component of ONR's STRATAFORM program, the goal of which has been to link short-term (i.e., acting over hours to weeks) biological and physical processes affecting sedimentation ("event stratigraphy") to the sequence stratigraphy and facies architecture of the preserved record. STRATAFORM consisted of three interrelated projects whose goals are to study: 1) shelf sediment dynamics and the development of lithostratigraphy, 2) slope geological processes and resultant geomorphology, and 3) stratigraphic sequences resulting from shelf and slope sedimentation. High-resolution multichannel seismic (MCS) data collection, described below, was part of the third project, but the data also form part of a multi-faceted approach that ties all three projects together.

OBJECTIVES

Specific objectives include: 1) origins of sequence stratigraphic architecture in an environment characterized by high rates of sediment supply and active tectonism, 2) tracking the history of northward sediment dispersal from the Eel River and identifying sediment transport pathways that existed during sea-level lowstands, 3) morphologies and evolution of slope canyons, and 4) history of the Humboldt Slide.

APPROACH

STRATAFORM participants are documenting the stratigraphy of the continental shelf and slope of the Eel River Basin, northern California margin, at a variety of spatial scales (lateral and vertical) and in three dimensions (3-D). The key to this entire effort has been the collection of "nested" geophysical and geological data, through use of a variety of tools whose individual temporal and spatial scales overlap to form a wide-ranging continuum of measurements. High-resolution 2-D MCS profiles were collected from the outer shelf to slope, in the offshore portion of the Eel River Basin, jointly by the University of Texas Institute for Geophysics (UTIG; P.I.s Fulthorpe and Austin) and Lamont-Doherty Earth Observatory (L-DEO; P.I. G.S. Mountain) in July - August 1996. The seismic system, developed and owned by L-DEO, included a 48-channel I.T.I. streamer and 45/45 cu. in. G.I. air gun. A backup Geco streamer was used for part of the survey. The survey was designed to image stratal geometries at a scale intermediate between those of the existing very-high-resolution (500-3500 Hz) Hunttec deep-towed seismic profiles and commercial MCS data, fulfilling the STRATAFORM goal of providing "nested" seismic coverage (several Hunttec and commercial lines were duplicated). The seismic grid consists of 84 lines (~2200 km). Line spacings vary, but a spacing of 800 m was maintained, where

Report Documentation Page

Form Approved
OMB No. 0704-0188

Public reporting burden for the collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington VA 22202-4302. Respondents should be aware that notwithstanding any other provision of law, no person shall be subject to a penalty for failing to comply with a collection of information if it does not display a currently valid OMB control number.

1. REPORT DATE 30 SEP 2001	2. REPORT TYPE	3. DATES COVERED 00-00-2001 to 00-00-2001		
4. TITLE AND SUBTITLE Sedimentary Processes and Stratigraphic Responses in a Tectonically Driven Basin: Northern California Continental Shelf and Upper Slope		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) University of Texas, Institute for Geophysics,,4412 Spicewood Springs Road, Bldg. 600,Austin,,TX,78759		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				
14. ABSTRACT This project is a component of ONR's STRATAFORM program, the goal of which has been to link short-term (i.e., acting over hours to weeks) biological and physical processes affecting sedimentation ("event stratigraphy") to the sequence stratigraphy and facies architecture of the preserved record. STRATAFORM consisted of three interrelated projects whose goals are to study: 1) shelf sediment dynamics and the development of lithostratigraphy, 2) slope geological processes and resultant geomorphology, and 3) stratigraphic sequences resulting from shelf and slope sedimentation. High-resolution multichannel seismic (MCS) data collection, described below, was part of the third project, but the data also form part of a multi-faceted approach that ties all three projects together.				
15. SUBJECT TERMS				
16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	
a REPORT unclassified	b ABSTRACT unclassified	c THIS PAGE unclassified	Same as Report (SAR)	18. NUMBER OF PAGES 7
				19a. NAME OF RESPONSIBLE PERSON

possible, in both dip and strike directions. Such dense coverage was necessary to provide the 3-D stratigraphic perspective mandated by STRATAFORM. Vertical resolution is ~5 m. Data processing was shared by UTIG and L-DEO. The data are the continuing focus of the Ph.D. research of University of Texas graduate student R.L. Burger (supervised by Fulthorpe and Austin).

WORK COMPLETED

UTIG has processed all of its 42 lines to the stage of post-stack migration. We have also received all 42 processed profiles from L-DEO. Interpretation of the shelf has been completed, and two papers summarize this work (Burger et al., 2001; Burger et al., submitted). Current interpretations are focused on the upper continental slope area, with particular emphasis on the Humboldt Slide.

RESULTS

We have mapped unconformities and defined seismic sequences across the entire continental shelf part of the MCS grid. Unconformities fall into two distinct categories: 1) continuous "regional" high-amplitude surfaces, interpreted as transgressive ravinements, and 2) irregular unconformities with more limited lateral extents, characterized by deep channel incisions, hummocky seismic facies, and generally immediately overlain and truncated by the regional surfaces. These unconformities are interpreted as lowstand fluvial incisions. By evaluating stratal relationships, geometries of sequences, and seismic facies associated with the mapped sequences, and comparing them with similar studies from other high-energy margins (e.g. Barnes, 1995; Abbot, 1998), we have constructed a predictive sequence stratigraphic model for sediment deposition and preservation on the Eel River shelf (Fig. 1). This model predicts that the majority of preserved sediments are highstand marine silts and muds, transported and deposited by longshore-directed waves and currents. Preserved lowstand fluvial sediments are likely limited to isolated channel fills, and transgressive sediments are predicted to consist of a thin, coarse veneer of sand/gravel or shell hash directly overlying the transgressive ravinements.

In addition to defining the sequence stratigraphic model, another important result has been to distinguish the effects of tectonism and glacioeustasy in controlling sequence development on this margin. Glacioeustatic control is indicated by the similarities between the frequencies of regional unconformity formation and oxygen isotope cyclicity over the past ~1.0 m.y. (Fig. 2). However, tectonically-influenced changes in accommodation space impact sediment accumulation and the preservation of stratigraphic sequences. The most dramatic example is the sharp decrease in shelf sediment preservation rates after ~500 ka, apparently coincident with uplift caused by the northward-migrating Mendocino Triple Junction (MTJ). Although glacioeustasy appears to have the strongest influence on sequence preservation, multiple stacked channels at the southern end of the grid (Burger et al., 2001) differ markedly from the sequence morphology over the remainder of the shelf (Burger et al., submitted). The southern end of the basin experiences the greatest amount of uplift; stratigraphy in this area demonstrates how local tectonic effects can supersede eustatically-controlled stratigraphic architecture predicted by the model described above (Fig. 1).

Using the seismic profiles and isochron/sediment preservation maps, we have reconstructed a sequence of deformational and depositional events for the Eel shelf over the past ~1.0 m.y. We have also incorporated available timing constraints (Burger et al., submitted), which were obtained by correlating two prominent mapped unconformities with other offshore seismic and onshore studies in this basin (Gulick et al., in press; McCrory, 1995, 1996, 2000). The resulting tectonic and depositional history for the shelf has resulted in several observations:

- 1) Broad folding associated with Gorda-North America convergence progressively ended from south to north, possibly reflecting the first influence of MTJ migration on Eel River Basin sequences.
- 2) MTJ-related uplift since ~500 ka has induced repeated episodes of channel incision at the southern end of the MCS grid, formed the Table Bluff Anticline, and may have initiated formation of Eel Canyon (Burger et al., 2001).
- 3) The southern end of the basin is undergoing transpressional deformation, as evidenced by uplift of the Table Bluff Anticline and significant right-lateral offset across that structure.
- 4) Anticlinal folding in the Little Salmon Fault Zone ended on the shelf ~700 ka, but has been active more recently on the slope. Faulting has continued in this area, although strike-slip motion is likely dominant offshore, in contrast to dip-slip dominance onshore (Carver, 1987; Carver, 1992; Carver and Burke, 1988).
- 5) Sediment inputs to the shelf have shifted over the past ~1.0 m.y., with a previously dominant source near the northern end of the grid becoming progressively less important, and a southern source (likely the Eel River) appearing ~750 ka and becoming increasingly dominant since that time.

IMPACT/APPLICATION

The MCS data: 1) fill the gap in seismic resolution and depth of penetration between existing data sets to provide fully "nested" coverage, 2) link outer shelf and upper slope stratigraphic regimes, and 3) should allow development of models that will determine the transfer functions between modern sedimentary processes and stratigraphic preservation.

TRANSITIONS

The MCS data have been used to select sites for long (up to 150 m) cores (STRATAFORM Deep Coring Workshop, October 1998). These cores will provide ground truth for nested MCS and shallow-penetration Hunttec (deep-towed boomer) profiles.

RELATED PROJECTS

We have provided profiles to M. Field and G. Spinelli (USGS), for integration with Hunttec profiles, and D. Orange and J. Yun (University of California, Santa Cruz), to augment their analyses of deep-penetration commercial MCS profiles. We expect interactions with stratigraphic modelers D. Swift (Old Dominion University) and M. Steckler (L-DEO) to increase as our interpretations become more complete.

REFERENCES

- Abbot, S.T., 1998, Transgressive systems tracts and onlap shellbeds from mid-Pleistocene sequences, Wanganui Basin, New Zealand. *Journal of Sedimentary Research* 68 (2), 253-268.
- Barnes, P.M., 1995, High-frequency sequences deposited during Quaternary sea-level cycles on a deforming continental shelf, north Canterbury, New Zealand. *Sedimentary Geology* 97: 131-156.

- Carver, G.A., 1987, Late Cenozoic tectonics of the Eel River Basin region, coastal northern California. In: H. Schymiczek and R. Suchland (Editors), *Tectonics, sedimentation, and evolution of the Eel River and other coastal basins of northern California*. San Joaquin Geological Society: 61-72.
- Carver, G.A., 1992, Late Cenozoic tectonics of coastal northern California. In: Carver, G.A. and Aalto, K.R. (eds.), *Field guide to the late Cenozoic subduction, tectonics, and sedimentation of northern coastal California*. Pacific Section, American Association of Petroleum Geologists GB-71, 1-11.
- Carver, G.A., and Burke, R.M., 1988, Trenching investigations of northwestern California faults, Humboldt Bay region. Unpublished U.S. Geological Survey NEHRP Final Report, 53 pp.
- Gulick, S.P., Meltzer, A.M., and Clarke, S.H., Jr., In press, Effect of the northward migrating Mendocino Triple Junction on the Eel River forearc basin, California: part 1, stratigraphic development. *Geological Society of America Bulletin*.
- McCrary, P.A., 1995, Evolution of a trench-slope basin within the Cascadia subduction margin: the Neogene Humboldt Basin, California, *Sedimentology*, v. 43, p. 223-247.
- McCrary, P.A., 1996, Evaluation of fault hazards, northern coastal California, US Department of the Interior, US Geological Survey Open File Report 96-656.
- McCrary, P.A., 2000, Upper plate contraction in the vicinity of the Mendocino Triple Junction: implications for partitioning of strain. *Tectonics*, 19 (6): 1144-1160.
- Mederios, B.P., Karner, D.B., Muller, R.A., and Levine, J., 2000, The global ice volume record as viewed through a benthic $\delta^{18}\text{O}$ stack. *Eos, Transactions, American Geophysical Union* (suppl.), 81 (48): F597.

PUBLICATIONS

- Burger, R.L., Fulthorpe, C.S., Austin, J.A., Jr. and Gulick, S.P.S., submitted, Lower Pleistocene to Present structural deformation and sequence stratigraphy of the continental shelf, offshore Eel River Basin, northern California, *Marine Geology*.
- Burger, R.L., Fulthorpe, C.S., and Austin, J.A., Jr., 2001, Late Pleistocene channel incisions in the southern Eel River Basin, northern California. Implications for tectonic vs. eustatic influences on shelf sedimentation patterns. *Marine Geology*, 177 (3-4), 317-330.
- Burger, R.L., Fulthorpe, C.S., and Austin, J.A., Jr., 2001, Pleistocene sequence development on a tectonically active margin: the offshore Eel River Basin, northern California. American Geophysical Union, Chapman Conference on the Formation of Sedimentary Strata on Continental Margins, Ponce, PR, June, 2001.
- Burger, R.L., Fulthorpe, C.S., Austin, J.A., Jr., and Gulick, S.P.S., 2000, Mid-Pleistocene to present structural deformation and sedimentation patterns in the offshore Eel River Basin, northern California. *Eos, Transactions, American Geophysical Union* (suppl.), 81 (48): F649.
- Burger, R.L., Fulthorpe, C.S., Austin, J.A., Jr., and Mountain, G.S., 1999, Neogene-Quaternary channel incision on the northern California shelf: Implications for pronounced shifts in highstand vs. lowstand drainage in the southern Eel River Basin, *Eos, Transactions American Geophysical Union* (suppl.), 80: F560.
- Fulthorpe, C.S., Mountain, G.S., Austin, J.A., Jr., Buhl, P., Diebold, J., Goff, J.A., Schuur, C.L. and

Yun, J., 1996, STRATAFORM high-resolution MCS survey, Eel River Basin, northern California margin: shelf/slope stratigraphy and processes, *Eos, Transactions, American Geophysical Union* (suppl.), 77 (46): F330.

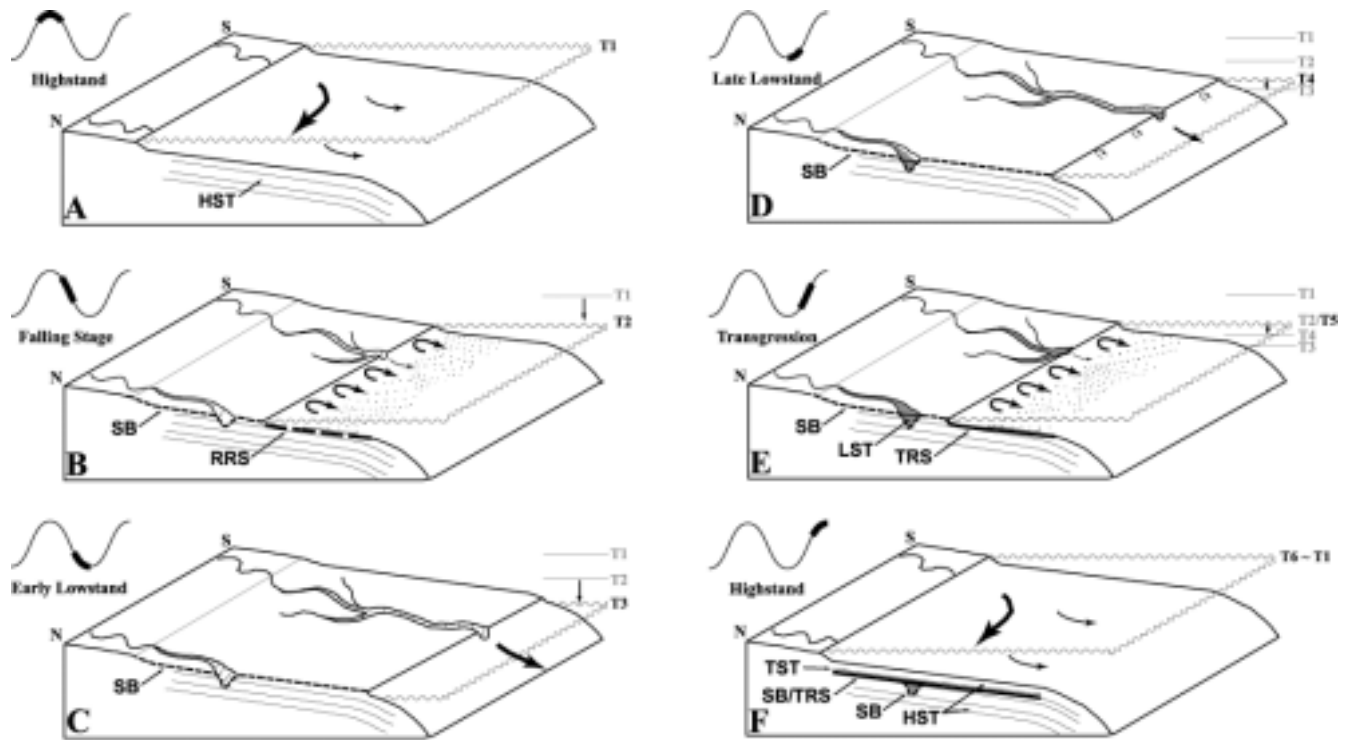


Figure 1 – Proposed sequence stratigraphic model for the Eel shelf. [A) Highstand – longshore-directed, shallow marine sediment transport and deposition dominates, as at Present. B) Falling stage –shelf is progressively exposed, and a regressive ravinement forms by shoreface erosion as it crosses the shelf. The exposed shelf represents the lowstand sequence boundary. C) Early lowstand – sea level falls below the shelf edge; sediments bypass shelf through fluvial channels. D) Late lowstand - fluvial gradients decrease, initiating channel infilling seaward; shoreface erosion of the shelf resumes. E) Transgression - shelf channels are progressively infilled seaward to landward; vigorous erosion forms a prominent transgressive ravinement as the shoreface crosses the shelf. Lowstand sediments and the sequence boundary are eroded in all but deeply incised areas. F) Highstand - longshore deposition of sediments over the entire shelf resumes. Over most of the shelf, highstand deposits immediately overlie highstand sediments from the previous sequence. SB = sequence boundary; RRS = regressive ravinement surface; TRS = transgressive ravinement surface; SB/TRS = composite surface; HST = highstand systems tract; LST = lowstand systems tract; TST = transgressive systems tract.]

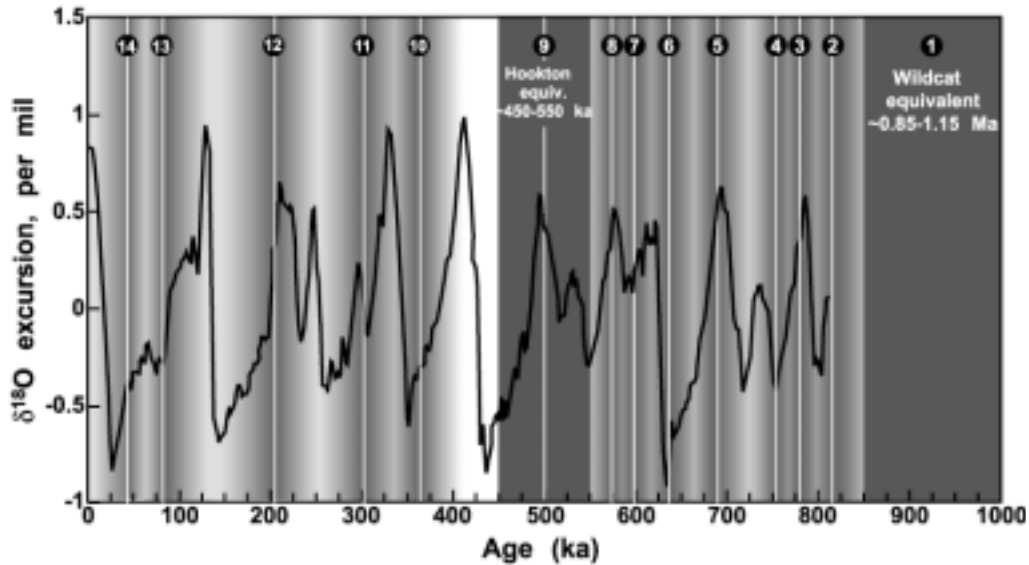


Figure 2 – Stacked $\delta^{15}O$ curve derived from fourteen different benthic records globally (Medeiros et al., 2000). [Vertical lines show estimated ages of Eel River Basin seismic unconformities; shading represents uncertainty in our age estimates. Solid gray areas represent estimated hiatus durations of the "Hookton" and "Wildcat" equivalents (Surfaces 1 and 9). Note the increased frequency of unconformity formation prior to ~550 ka, mimicking the obliquity-dominated 41 kyr glacioeustatic cycles during that same interval. After the Hookton Datum hiatus, the frequency of unconformity formation decreases, and coincides with the eccentricity-dominated 100 kyr cycles during that interval. The apparent correspondence between $\delta^{15}O$ cyclicity and unconformity formation both before and after the orbitally-dominated transition implies that glacioeustacy controls formation of these surfaces, at least in part.]