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

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Award #: N00014-02-1-0032
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 a setting with 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 have been 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 goal was to image strata at a scale (vertical resolution ~5 m) intermediate between those of the existing very-high-resolution (500-3500 Hz) Huntec deep-towed boomer seismic profiles and commercial MCS data, fulfilling the STRATAFORM goal of providing "nested" seismic coverage (several Huntec and commercial lines were duplicated). The seismic grid consists of 84 lines (~2200 km). A profile spacing of 800 m was maintained, where possible, in both dip and strike directions, to provide the 3-D stratigraphic perspective mandated by STRATAFORM. Data processing was shared by UTIG and L-DEO. The data are the focus of the Ph.D. research of University of Texas graduate student R.L. Burger (supervised by Fulthorpe and Austin).

WORK COMPLETED

UTIG processed all of its 42 lines to the stage of post-stack migration. We also received all 42 processed profiles from L-DEO. Interpretation of the shelf has been completed; two papers summarize this work (Burger et al., 2001; Burger et al., 2002). A third paper covers work on the upper continental slope (Burger et al., submitted).

RESULTS

Unconformities beneath the continental shelf fall into two distinct categories: 1) continuous "regional" high-amplitude surfaces, interpreted as transgressive ravinements, and 2) irregular unconformities of more limited lateral extents, with deep channel incisions and hummocky seismic facies, and generally immediately overlain and truncated by the regional surfaces. The incisions are interpreted as lowstand fluvial channels. By evaluating stratal relationships, sequence geometries, and seismic facies, 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. This model predicts that most preserved sediments are highstand marine silts and muds, transported and deposited by longshore-directed waves and currents. Preserved lowstand fluvial sediments are probably 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.

An important result has been to distinguish the effects of tectonism versus glacioeustacy on shelf sequence development. Glacioeustatic control is indicated by similarities between frequencies of regional unconformity formation and oxygen-isotope cyclicity over the past ~1.0 m.y. (Fig. 1). However, tectonically-influenced changes in accommodation space also affect 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 glacioeustacy 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., 2002). 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.

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. Timing is constrained by correlating two prominent mapped unconformities with other offshore seismic and onshore geological studies in this basin (Burger et al., 2002; Gulick et al., 2002; McCrory, 1995, 1996, 2000). The resulting tectonic and depositional history for the shelf has resulted in the following 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 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 (LSFZ) 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.

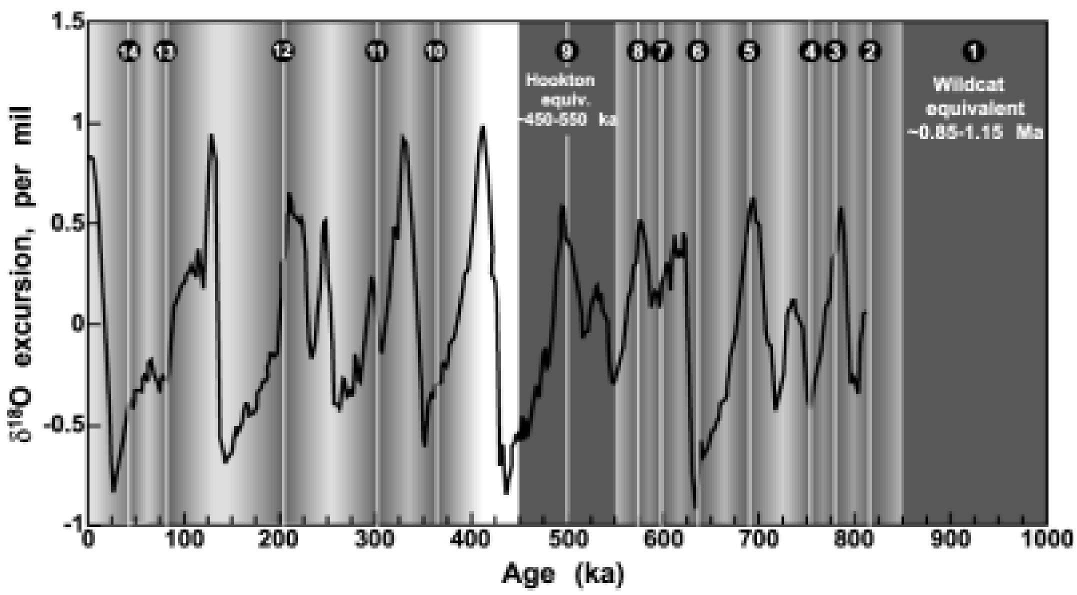

Figure 1 – Stacked $\delta^{18}O$ curve derived from fourteen different benthic records globally (Mederios et al., 2000). Vertical lines show estimated ages of Eel River Basin seismic unconformities; shading represents uncertainty in our age estimates. Solid gray areas represent estimated hiatus durations 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-domimated 100 kyr cycles during that interval. The apparent correspondence between $\delta^{18}O$ cyclicity and unconformity formation both before and after the orbitally-dominated transition implies that glacioeustacy controls formation of these surfaces, at least in part.

On the upper slope, seafloor morphology and seismic profiles define two regions with contrasting sequence stratigraphies (Burger et al., submitted):

1) *Humboldt Slide*. Seismic profiles record the sudden initiation of deformation beneath the Humboldt Slide, another potential effect of MTJ encroachment. The influence of eustasy within the slide is revealed by multiple, deformed, stacked, high- and low-amplitude sequence couplets (Fig. 2). These are inferred to be highstand vs. falling stage/transgressive sediments deposited during late Pleistocene–Recent ~100 k.y. glacioeustatic cycles. Lowstand sediments bypass through Eel Canyon.

2) *Northern slope*. The absence of mass wasting features indicates that MTJ-related seismicity does not yet affect the contrasting gullied slope north of the LSFZ. Here, vertically stacked gullies are inactive during highstands, such as the present. They are incised and undergo headward erosion between falling stage and early transgression, when both shoreface erosion and fluvial sediment sources are proximal to the upper slope.

The along-strike contrast in preserved upper-slope sequence morphologies therefore reflects both regional tectonic forcing and changing proximity to local shelf sediment sources controlled by sea-level fluctuations.

IMPACT/APPLICATIONS

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) allow development of models that 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). Such cores will provide ground truth for nested MCS and shallow-penetration Huntec profiles.

RELATED PROJECTS

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

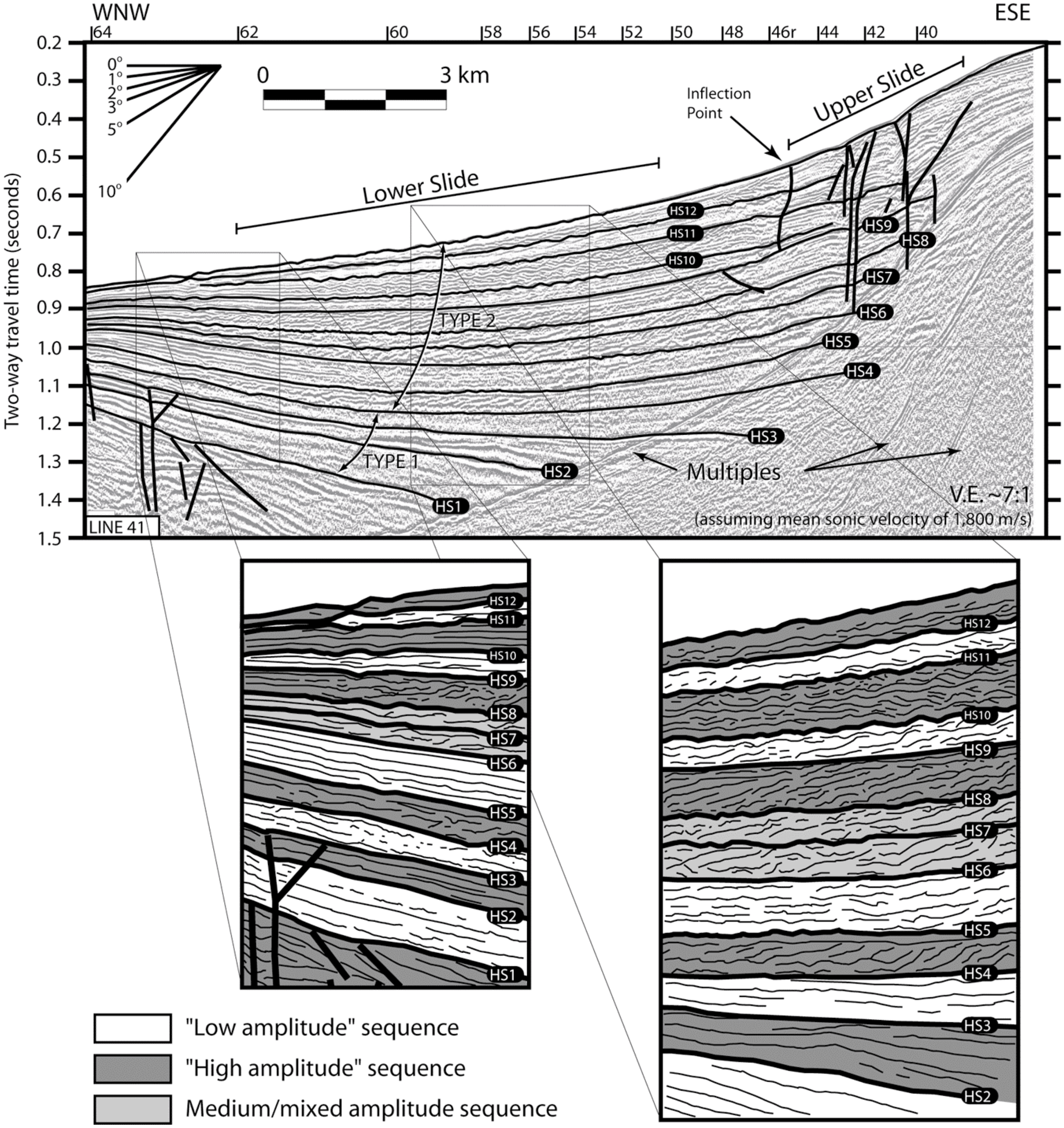

Figure 2. Dip seismic profile 41 showing sequences mapped through the axis of the Humboldt Slide (HS). Bold, steeply dipping lines represent faults. True dips are indicated at upper left. Inset figures from middle of the "lower slide" (right) and near the toe of the slide (left) indicate high-, low-, and mixed-amplitude sequences, as well as internal sequence geometries.

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