The Many Faces of Submarine Erosion: Theory Meets Reality in Selection of Sequence Boundaries

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Sequence stratigraphic application has emphasized the recognition and use of subaerial (fluvial entrenchment) or shallow marine/shoreface (regressive ravinement) surfaces as critical boundaries for defining sequences. These surfaces are objectively or conceptually associated with times of onset, maximum rate, and/or lowest position of relative sea level fall. However, a growing array of examples display stratigraphies in which demonstrable subaerial or ravinement surfaces correlative to fall events are poorly preserved or entirely lacking, BUT in which "relatively conformable, genetically related successions of strata bounded by unconformities or their correlative conformities" can be defined by use of various combinations of transgressive ravinement, marine deflation, and marine starvation surfaces. Three examples illustrate such successions.

1) ***Late Quaternary Rhone delta and adjacent Gulf of Lion shelf***. Offshore seismic traverses of the Pleistocene delta system display stacked progradational mid to outer shelf sediment wedges bounded below by low-relief erosional surfaces. As all but the youngest wedge is undated, older wedges cannot be objectively correlated to the well-defined Wisconsin glacioeustatic sea level curve. Thus, these wedges may be interpreted as (1) high-frequency sequences, in which transgressive ravinement has removed virtually all of the delta plain and channel-fill deposits of the shelf-margin deltas, creating composite surfaces, (2) high-frequency sequences in which regressive ravinement has augmented transgressive ravinement in truncating shelf-margin delta wedges, or (3) parasequences that record intermittent transgressive erosion during long-term Wisconsin sea-level fall. All the surfaces, except the late Holocene transgressive ravinement surface, converge toward and appear to truncate a single subaerial Pleistocene surface that extends beneath the present delta. In the absence of dating and consequent reference to known sea level history, choice among the three interpretations remains subjective. Along strike, seismic traverses from the western Gulf of Lion, marginal to the Quaternary delta system, paint a more diverse picture. Here, mid-shelf to shelf-margin wedges contain both low and high-angle clinoforms and are bounded by prominently erosional low-relief to rugose erosion surfaces. Channel-form scours, potentially recording subaerial exposure, are few, local, and of multiple types and origins. However, prominently mounded, strike-elongate, sand-rich buildups punctuate the depositional record. This stratal architecture records deposition in shore-zone and shelf systems where sediment transport was primarily along strike and unconfined. The regionally mapped surfaces that create the allostratigraphic framework clearly reflect erosion by marine processes in both their morphology and facies context. Widespread preservation of mounded marine sediment bodies and of clinoform toe sets above the subjacent erosion surfaces argues against a major role for regressive ravinement. Rather, broad, scoop-shaped scours and strike orientation of the sediment bodies and bounding scour morphologies argue for shelf deflation as the major erosional process.

2) ***Late Quaternary New Jersey continental shelf***. High-resolution imagery and dating relative to known Wisconsin sea level history substantially revises our understanding of this popular analog for traditional sequence stratigraphic models. During early to middle Wisconsin a glacial outwash plain covered the inner shelf. Simultaneously, a marine unconformity, "R", formed across the sediment-starved middle and outer shelf. A muddy outer shelf marine wedge expanded across "R" at ca 35 kA. During the brief glacial maximum at ca. 22 kA, a dendritic channel network scoured this wedge, creating a surface that has gone unrecognized until the newest generation of ultra-high-resolution data revealed its presence. A transgressive ravinement surfaces caps and commonly truncates the "channels" surface. The ravinement surface is, in turn, cut by and amalgamated with a widespread network of shelf scours, recording active Holocene marine deflation and shelf ridge construction. The modern seascape bears little imprint of underlying Wisconsin sediments and stratigraphy. The composite transgressive ravinement/shelf deflation surface forms the most prominent and regionally continuous surface developed within the succession. The long-recognized "R" surface has been widely misinterpreted as a subaerial sequence boundary, as has the modern Delaware Sea Valley, which records a catastrophic post-glacial lake outflow event. In short, marine surfaces and marine facies dominate late Quaternary New Jersey shelf stratigraphy.

3) ***Miocene Utsira Sandstone, North Sea Basin***. The Utsira extends 350 km from the southern Norwegian Shelf, along the axis of the Viking Trough, and into the northernmost Central Trough. It is a distinct sand-rich unit that is typically 100 to 300 m thick and laps out along the east and west margins of the basin. The Utsira Sandstone forms the core of a regional seismic and stratigraphic sequence that is bounded above and below by prominent

unconformities and extends from the southern North Sea Basin to the west Norwegian Shelf. The unconformities are variously recognized by a chronostratigraphic gap, abrupt gamma-ray log base-line change, concentration of glauconite, and truncation of underlying seismic reflections. The upper boundary is a regional seismic downlap surface. The Utsira sequence can be sub-regionally divided into as many as four seismic sequences by similar surfaces. Utsira sands are highly glauconitic and fossiliferous shelf facies that record an 8 my episode of deposition in a constricted strait, 100 to 300 m deep, between Norway and the British Isles. Bounding and internal surfaces reflect, in their morphology, facies context and lag composition, extended periods of marine starvation, bypass, and/or erosion. Deposition of the Utsira sequence followed a uniquely light δO^{18} excursion at 15-16 Ma, placing the sequence-bounding unconformity at a time of minimal Antarctic ice cap volume and highest global sea level. The total sequence incorporates 1.5 European "major transgressive-regressive cycles" of Hardenbol et al (1998), beginning with early Middle Miocene maximum transgression. Both the upper and lower bounding surfaces correspond to high-amplitude transgressions on their T-R facies cycle chart. Thus, one or perhaps both sequence-bounding surfaces formed at times of high global and/or regional relative sea level.

The stratigraphic record contains numerous examples where depositional origin, preservation, and/or data availability conspire to create and preserve marine or marine-dominated basin fills. In such settings, terrestrial facies and surfaces are absent, local, poorly preserved, and/or inaccessible. None-the-less, functional, reproducible, and chronostratigraphic "… genetically related successions of strata bounded by unconformities or their correlative conformities…" can be defined, correlated, mapped, dated, and interpreted through the use of regional marine erosion surfaces. These surfaces may not and need not correspond to a relative fall of sea level.