# Abstract

## Sequence Stratigraphic Models - Latitudinally Derived Differences

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Sequence stratigraphy has proven to be an extremely powerful tool for analyzing and interpreting the rock record. Decades of outcrop, subsurface, flume & modern analog studies have elucidated how significant surfaces form, and the grouping of genetically related strata between the surfaces. The capabilities of this methodology in predicting the nature of strata likely to be encountered beyond the extent of available data are a key component, especially in frontier exploration. Unfortunately, for a variety of reasons, the studies from which sequence stratigraphy was developed are overwhelmingly based on low to mid latitude depositional settings and their characteristics, introducing both a bias and limitation to the methodology for higher latitude applications. Many low-mid latitude sedimentary processes are either diminished or absent in high latitude settings; conversely, important processes that impact deposition at high latitudes are either diminished or non-existent at low latitudes. This process variability manifests as changes to both the timing and type of deposits and/or significant surfaces at different latitudes.

Comparisons of depositional units from high latitude, ice influenced systems to low latitude systems show a phase shift in the expected arrangement of sands vs shales. High latitude systems in an icehouse world, where eustatic changes are driven by glacial-interglacial cycles, tend to be closer to the primary source of change (ice sheets). For this reason, the response to change of high latitude systems reflect both the primary control (ice sheet growth & decay) as well as the derivative control (eustasy), whereas low latitude systems are responding dominantly to the derivative control. Mid-latitude systems may appear to be more akin to high or low latitude systems dependent on their paleogeographic location.

The general model for sequence development in a lower latitude setting is:

1. HST – Deltaic and shoreface systems first aggrade & then prograde across the shelf. With a significant eustatic fall, fluvial systems extend and/or incise across the exposed shelf & may create a series of prograding delta lobes ending with a shelf margin delta. In deepwater settings, the early HST may be reflected in a condensed section, upon which mass transport complexes & fan units progressively build.

2. SB –The initial sequence stratigraphic models explicity stated the maximum extent of the sequence boundary is reached at the end of the HST, matching the most rapid rates of eustatic fall. This surface extends from the fluvial system, across the shelf & upper slope to its correlative conformity in the deep basin. Although it is now understood that the development of the SB is strongly time

transgressive, a single surface marking the transition between the HST & LST is still used in developing a basin's sequence stratigraphic framework.

3. LST – During the LST shelf margin deltas feed sand to the deepwater creating robust submarine channels & fans. The most basinward evolution of the submarine system is likely at this time. In the case in which headward erosion directly connects slope canyons with fluvial channels of shelf margin deltas, direct conduits to the basin floor system provide the highest amount of sand to the deepwater. Thus, this systems tract typically contains most deepwater reservoirs of interest.

4. TST – In the TST, the shelf & submarine systems progressively disconnect as the fluvial-deltaic system backsteps from the shelf edge. Flooding/abandonment surfaces progressively extend further landward. The upper portion of the underlying shoreline & deltaic systems may be eroded by the transgressive revinement surface. In the deepwater, channel systems may fill with mud as the submarine systems shut down. Condensed sections form during non-deposition, while deposition of fine-grained sediments and organic materials can accumulate source, seal, and unconventional reservoir facies.

5. MFS - At the most landward position of the shoreline the maximum flooding surface forms. This surface, and the underlying TST is the most likely to contain source and seal facies.

In high latitude settings, the following pattern develops in response to the same glacio-eustatic drive:

1. HST – Shoreline & deltaic systems start to prograde across the shelf. As the ice sheets grow however, the drainage areas are increasingly covered by ice, thereby diminishing the drainage area and the potential sediment supply delivered to the fluvial systems. If the ice sheets grow near or onto the shelf, the ice overburden isostatically drives the land surface down, resulting in flooding of the shelf. As the HST progresses, the delivery basin will increasingly be covered in sea ice. As the sea ice becomes hard fast ice, sediment delivery to the deepwater is blocked. Under these conditions, sediment delivery to the deep basin is progressively reduced and a condensed section begins to form.

2. SB – over most of the shelf and deepwater areas, the period of sequence boundary formation in these systems is manifest as a condensed section.

3. LST – During the LST, minimal amounts of sediment are delivered to the deepwater. The water column, being capped by sea ice, is likely to become stratified, continuing the condensed section development. This fine-grained unit may not have an elevated TOC as upwelling and sea surface production is also impacted by the sea ice. However, this interval could make a good regional seal.

4. TST – This period is characterized by the melting and retreat of ice sheets. In front of the ice sheets enormous outwash systems develop. During the early TST these systems transport large volumes of sediment & water from underneath the melting ice sheets. As the ice sheets recede, the land begins to isostatically rebound causing fluvial systems to incise as they experience a base level fall along

with increased sediment load. This period contains the highest sediment supply of all the systems tracts, which makes it the most likely period for sand delivery to the deepwater. As the TST progresses, the sea ice melt in the receiving basin triggers large algal blooms as trapped nutrients are released and the degree of sunlight penetrating into the water column is improved. These algal blooms provide organic carbon to the basin sediments and may induce oxygen minima. This results in increased potential for source rock development. In this case, even though the processes differ, the optimal timing for source rock development in both low & high latitude systems is the late TST.

5. MFS – As the ice sheets retreat, fluvial drainage areas increase. The landscape will also undergo increased colonization by plants, which results in increased chemical weathering and an associated increase in fine-grained clay material in the sediment load of the system.

It is not the point of this paper to suggest conventional seismic stratigraphy cannot be used in high latitude settings. Rather, we contend that conventional seismic/sequence stratigraphy can be performed in high latitude icehouse systems, but the correlation of sequence in low latitudes to those in high latitudes requires understanding the variance that proximity to ice sheets imparts on the rock record. The resultant systems tract characteristics will not suitably correlate with an age equivalent low latitude system due to this phase shift. Exploration in high latitude settings also requires the understanding that the early TST, rather than the LST, contains most of the conventional reservoir targets.