# The Non-Conforming Sequence Stratigraphic Development of an Ancient Continent Margin Turbidite System, Neoproterozoic Windermere Supergroup, Western Canada

*Bill, R.W.C., Arnott and countless student researchers*

*Department of Earth and Environmental Sciences, University of Ottawa*

## Summary

Deep marine rocks of the Windermere Supergroup are composed mostly of siliciclastic sedimentary rocks intercalated with carbonate and mixed carbonate-siliciclastic intervals indicating episodes of elevated eustasy. Observations along a several 100 km-long depositional transect that stretches from upper slope canyons to deep basin floor deposits show a number of systematic changes, but only in the slope part of the transect. Further basinward, on the other hand, the basin floor stratigraphy shows no systematic temporal change in stratal architecture. This suggests that contrary to many popular stratigraphic models, the effects of eustatically controlled changes in sediment supply became attenuated and apparently completely filtered as flows descended the continental slope, ultimately resulting in a basin floor stratigraphy largely unaffected by upslope conditions but instead controlled primarily by local seabed topography.

## Introduction

Early sequence stratigraphic models were principally developed in the shallow marine sedimentary record where many of the important bounding surfaces that subdivide the stratigraphic column can often be readily identified (e.g. Van Wagoner et al. 1988; Catuneaunu, 2006). Over the past few decades researchers have been pushing landward into the non-marine and basinward into the deep-marine parts of the sedimentary record to investigate how these surfaces and associated stratigraphy become manifest. In the case of the deep marine is it generally assumed that it is the presence (highstand) or absence (lowstand) of the shelf (i.e. topset) that controls the makeup of the stratigraphic column further basinward (e.g. Posamentier et al., 1988). In general, it is hypothesized that when the shelf is flooded during transgressive and highstand conditions, siliciclastic sediment is sequestered in marginal marine settings and a general condition of sediment starvation prevails offshore with the sedimentary record being dominated by fine-grained lithologies deposited under low rates of sedimentation. Conversely, during lowstand and a much diminished shelf, sedimentation rate and sediment caliber are interpreted to generally increase and the accumulation of coarse clastic sediment to be displaced downward onto the basin floor. In part this model is based on geological intuition and also the interpretation of seismic images, where resolution may become an underappreciated consideration. Additionally, it is assumed, seemingly implicitly, that the stratigraphic response is independent of basin size or tectonic setting. Here these assumptions are tested.

## Example

Deep marine rocks of the Windermere Supergroup record a several km-thick sedimentary pile that accumulated along the prograding passive continental margin of Neoproterozoic Laurentia (ancestral North America) (Ross and Arnott, 2007). The succession comprises mostly siliciclastic sedimentary rocks intercalated with carbonate and mixed carbonate-siliciclastic intervals that range up to over 100 m in thickness. Unlike most examples in the ancient deep-marine sedimentary rock record, the distance from the shelf-slope break to the basin floor is measured in 100s of kilometers, and therefore is dimensionally consistent with modern and related hydrocarbon-bearing passive-margin turbidite systems.

In the Cariboo Mountains slope deposits form a ~2 km-thick succession dominated by thin-bedded turbidites that locally are intercalated with up to >100 m-thick by several km-wide erosional and leveed channel complexes. Channels exhibit two end member kinds of fill: aggradational and laterally accreting. Aggradationally-filled channels occur low in a depositional sequence, commonly overlying the sequence boundary (Fig. 1). Channels are incisionally bounded or bordered by well-developed depositional levees. Levee deposits show a consistent lateral thickening then thinning or monotonically thinning trend superimposed on a general fining of sand-rich strata. Channel-fill deposits show a consistent upward and in many cases lateral fining and thinning. In contrast, laterally-accreting channels occur higher in the depositional sequence and typically overlie aggradational channel complexes (Fig. 1). These channels are filled with obliquely-dipping lateral accretion deposits, or LADs, that are anomalously coarse grained and show negligible lateral or upward change in grain size, although bed thickness may decrease slightly. At the top of the channel fill, obliquely-dipping coarse-grained LADs exhibit a distinctive interfingering with thin-bedded turbidites, which are interpreted to be inner-bend levee deposits upon which the coarse-grained LADs onlapped. Associated with the development of laterally-accreting channels is the input of carbonate sediment, typically occurring as carbonate cemented sandstone and mudstone clasts. Additionally, evidence of mass wasting, in the form of thickly developed and areally extensive debrites, slump and slide deposits become an important component in the stratigraphy. Fragments within these strata, namely stromatolite and oolite fragments, in addition to abundant carbonate cemented sandstone and mudstone clasts, indicates the resedimentation of debris sourced from an upslope shallow-water carbonate platform under late transgressive, highstand and possibly also early falling stage conditions. Specifically, the rise of eustasy is interpreted to have not only initiated the development of a carbonate platform, and thereby the input of carbonate sediment, but more importantly changed the makeup of the siliciclastic sediment supply, principally in terms of its grain size and grain-size distribution. These modifications to the sediment supply altered the nature of basinward-flowing turbidity currents and caused them to become highly density stratified – the consequence being a major change in how momentum was distributed in the flow, and accordingly the preferential development of channels that filled by lateral rather than vertical accretion (Fig. 1).

Basin floor deposits are well developed throughout the Cariboo and western Rocky Mountains where they form a 2-4 km thick succession made up of intercalated decameter-thick “sheetlike” sandstone and mudstone layers. Sandstone layers are composed mostly of terminal splay deposits with lesser distributary channel complexes and rare feeder channels. Grain size of the sand is little different from that on the slope. Mudstone layers are dominated by thin-bedded, upper division turbidites intercalated with moderately coarser-grained, medium-bedded turbidites. Stratigraphic evidence of (flow) bypass has not been recognized. Unlike slope deposits, the various stratal elements that build up the basin floor stratigraphy, namely terminal splays/depositional lobes, distributary channels, feeder channels and inter-element thin-bedded turbidites show no systematic vertical (i.e. temporal) change in architecture (Fig. 1). This suggests that the effects of eustatically controlled changes in sediment supply became attenuated and apparently completely filtered as flows descended the continental slope, ultimately resulting in a basin floor stratigraphy largely unaffected by upslope conditions but instead controlled principally by local seabed topography. Notably also, phosphate-rich layers, some up to 25% $P_2O_5$, are common and often closely spaced through the basin floor and slope section. Typically, such horizons are interpreted to represent periods of sediment starvation (condensed section) related to highstand (e.g. Loutit et al., 1988). Here, on the other hand, these phosphate-rich horizons reflect episodes of elevated productivity most probably near the shelf-slope break, and therefore changes in oceanographic circulation patterns rather than eustasy.

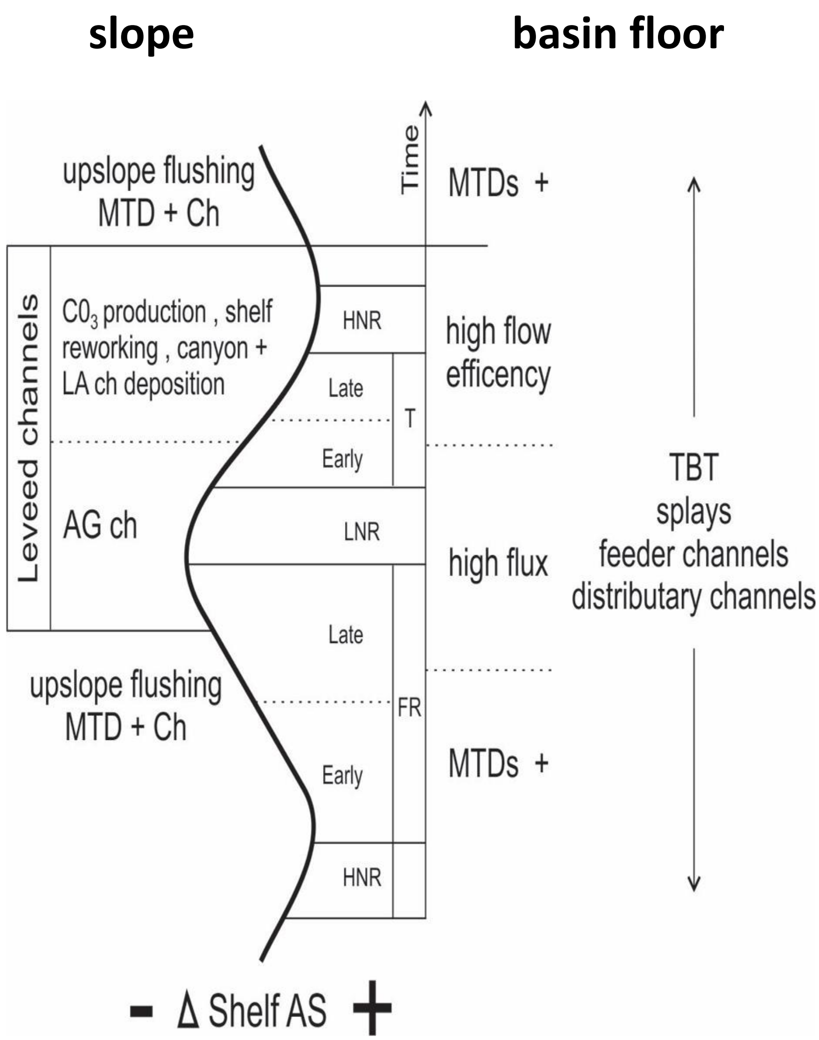


Figure 1. Schematic illustrating changes in the component architectural elements on the continental slope (left) and basin floor (right) as a function of changes in shelf accommodation caused by eustatic rise and fall. The sequence stratigraphic framework (for example HNR (highstand normal regression), Early FR (early forced regression) etc.) is from Catuneanu (2006).

## Conclusions

Popular sequence stratigraphic models for deep-marine turbidite systems imply that topset accommodation (i.e. the shelf) is the primary control on the lithological makeup, stratal architecture and temporal evolution of the accumulated sedimentary column (Jervey, 1988). However using carbonate-rich horizons as a proxy for episodes of elevated sea level, the stratigraphy of the deep-marine Windermere sedimentary pile suggests that in addition to changes in the volumetric flux and mean grain size of the sediment supply, it is the distribution of grain sizes within the sediment supply that controls the character of the sediment-transprting turbidity currents, which ultimately controls the stratigraphy. Specifically, the anomalous abundance of coarse sediment, which is an artifact of transgressive processes, causes turbidity currents to adopt a plug density structure that then modifies momentum distribution within the flow and interfacial shear, which together encourage long-distant transport sediment, including sand and gravel, into more distal depositional settings.

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