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Does One Model Fit All? Exploring Factors that Influence the Stratigraphic Evolution of a Deep-Water Channel-Levee Complex System.

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Introduction

Advances in technology, namely 3D reflection seismic and bathymetric surveys, have produced a collection of images of the deep ocean seafloor and subsurface. One of the most distinctive features are submarine channels, which extend for hundreds to thousands of kilometers down the continental slope. Like their subaerial counterparts in modern systems, namely rivers, slope channels are responsible for transporting large volumes of sediment, pollutants and nutrients from the continent into deeper water, in addition to hosting significant hydrocarbon reservoirs (Posamentier and Kolla, 2003; Mayall et al., 2006). Despite their importance, their inaccessibility in modern systems (due to water depth) has resulted in a poorly developed understanding of their internal stratigraphy, in addition to their spatial and temporal evolution. To help bridge this gap, deep-marine channel deposits preserved in the ancient sedimentary record provide valuable insight into formative sedimentary process, stratal architectures and channel evolution that shape deep-sea channels. While commonly sinuous, many channels possess an internal architecture suggesting that they filled aggradationally (e.g Camacho et al., 2002; Navarro et al., 2007; Macauley and Hubbard, 2013) and less commonly as laterally migrating channels with well-defined lateral accretion deposits (e.g Abreau, 2003; Arnott, 2007). Moreover, based on seismic images, it is generally thought that channels exhibit a highly organized temporal evolution from laterally migrating channels with negligible aggradation to aggradation with limited accretion ("hockey-stick" model; Figure 1) (Peakall et al., 2000; Sylvester et al. 2011; Jobe et al, 2016) – a model that has not been rigorously tested in outcrop.

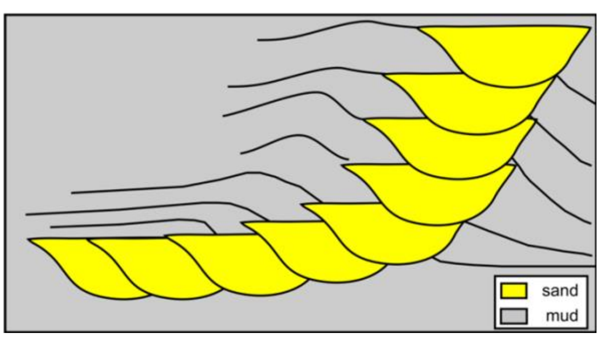

Figure 1. Hockey-stick model illustrating submarine channel evolution from an early phase of lateral migration of successive channels followed by a phase of aggradation with negligible lateral migration (from Jobe et al., 2016)

At the Castle Creek study area (British Columbia, Canada) a superbly exposed, thickly developed and areally expansive leveed-channel complex in the Windermere turbidite system, here termed Isaac channel complex 1, or simply ICC1, crops out. Detailed documentation of the lithological composition and stratigraphic relationships of inter- and intra- channel fills allows for a comprehensive examination of the complex history of erosion and deposition in a leveed slope-channel system, and therein the opportunity to test the hockey stick model. ICC1 overlies a sequence boundary that separates mixed carbonate-siliciclastic strata (first Isaac Formation; FIC) from siliciclastic strata of ICC1 and represents the reintegration of sediment delivery from the hinterland (Cochrane, 2019). ICC1 is 220 m-thick and exposed over 5 km along strike, which makes it comparable in scale to channel-belts observed in seismic and modern bathymetric datasets. ICC1 consists of two vertically-stacked complexes termed LC and UC, the latter being subdivided into three channel units (UC1-3).

ICC1 Channel Complexes Architectural Characteristics

Siliciclastic strata of LC comprise three nested channel fills, each about 10-15 m thick and composed of amalgamated, thick-bedded, very coarse-grained sandstone and conglomerate in their axis that then fine and thin upward and laterally. Strata of LC are confined to the southeast part of the study area where they onlap an erosional surface incised at least 30 m deep into older FIC strata. The top of LC is mantled by a laterally continuous, thin-bedded, fine-grained succession of upper division turbidites interpreted to indicate an abandonment of the local transport system (Figure. 2A). UC, in contrast, is 95 m thick and crops out across the entire study area. UC1 and UC2 are, respectively, 50 m and 25 m thick, bounded on their margins by fine-grained deposits and exhibit common cut and fill features suggesting multiple erosively juxtaposed channel fills. UC1 is dominated by coarse-grained, graded, massive and cross-stratified sandstone with little upward or lateral change in facies (Figure. 2B). UC2, on the other hand, comprises nested channel fills that are ~10 m thick and composed of coarse-grained sandstone that progressively fine and thin upward and laterally (Figure. 2C). In turn, UC3 is up 30 m thick (Figure. 2D) and comprises at least six channel fills that are up to 10 m thick, filled with coarse-grained sandstone and conglomerate that shows little upward change in grain size or bed thickness, and exhibits well developed lateral-accretion surfaces and deposits. Also, individual laterally-accreting channel fills in UC3 show a lateral-offset-stacking of successive flat based channels that on one side erosionally onlap thin-bedded, finer-grained turbidites and on the other interfinger obliquely upward with thin-bedded, finer-grained turbidites.

ICC1 System Evolution

ICC1 was initiated by highly efficient, erosive flows that transited topographic lows on the surface of the FIC. As flow efficiency and momentum diminished, each channel in LC was filled by vertically density-stratified flows with a high-density axial part, which deposited

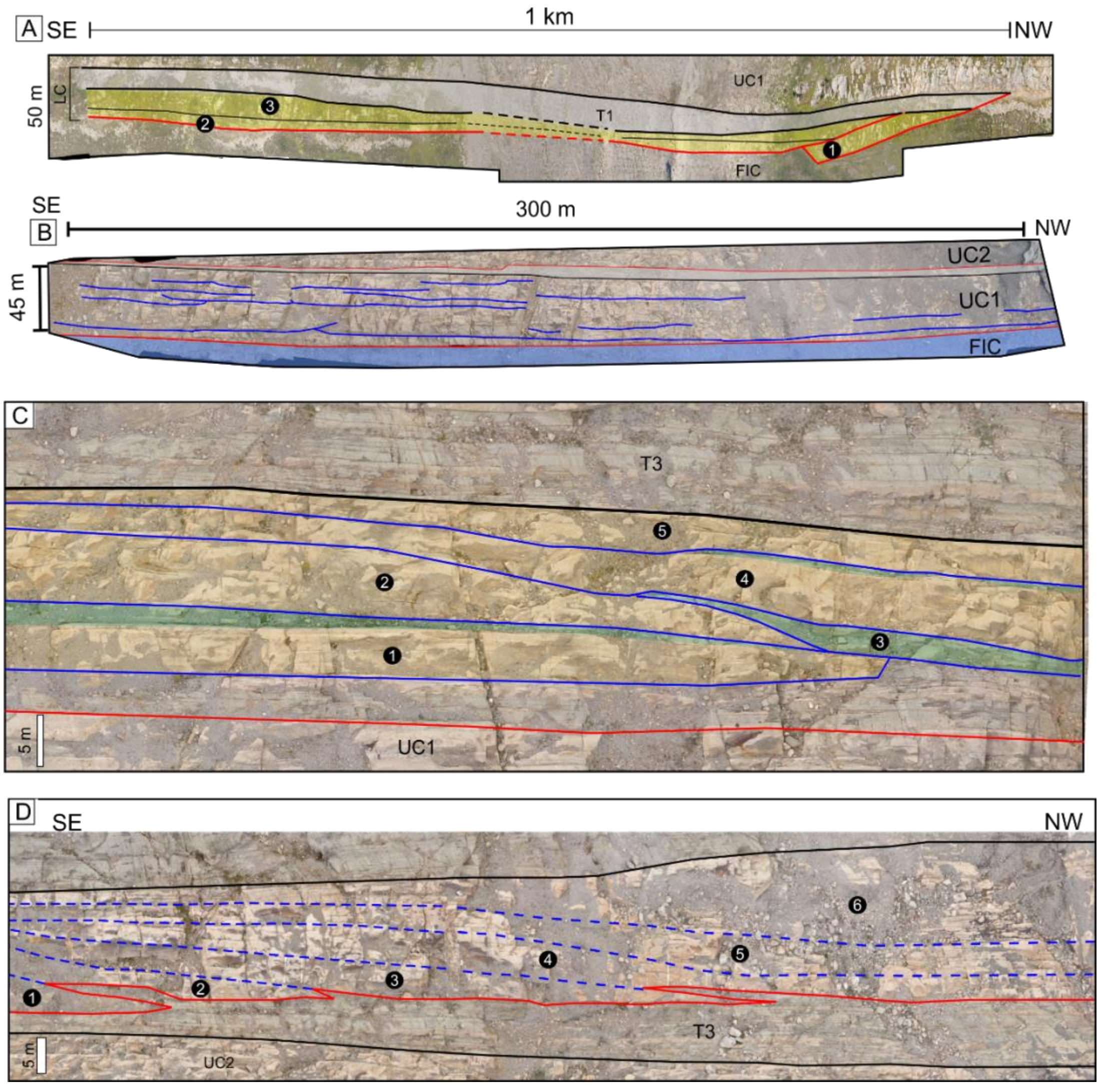

Figure 2. Drone photomosaic of the LC (A) and the UC channel units (B-D). (A) LC comprises three channel fills that are confined to the southeast region of the study area and onlap a deeply incised surface eroded into the FIC. Each channel fill is up to 15 m thick and fines and thins upward and laterally. LC is sharply overlain by a thick succession of thin-bedded, fine-grained turbidites (T1). (B) UC1 in the south region of the study area. Here, UC1 sharply overlies the FIC and is an up to 45 m-thick succession of almost 100% amalgamated sandstone. (C) UC2 comprises several laterally and vertically juxtaposed channel fills. (D) UC3 comprises at least six laterally accreting channel fills. Note that the base of each channel fill (blue lines) is inclined to the base of UC3 (red line), which is subparallel to regional bedding.

amalgamated, coarse-grained sandstone, and low-density, lower energy margins that deposited finer and thinner-bedded strata. Following abandonment of the LC system, and once transport conditions on the slope became re-established and stabilized, UC1 was developed. Erosionally based channels filled aggradationally and also completely with coarse-grained sandstone in their axial part. Subtle variations in local seafloor topography related to spatial differences in post-depositional compaction caused younger channels to preferentially cannibalize and erode in areas of slightly lower topography underlain by finer, thinner strata that accumulated on the margins of older channel fills (e.g. McHargue et. al, 2011). Over time, the amalgamation of individual channel fills formed the sandstone-rich but spatially disorganized amalgamation of channel fills that make up UC1. Unlike UC1, UC2 channel fills commonly fine and thin upward, which is related to an increase in aggradation rate that subsequently allows for better preservation of the upper and lateral margins of individual channel fills. Nevertheless, like UC1, UC2 channel relief was insufficient and unable to confine succeeding flows and as a result also exhibit a disorganized channel stacking pattern . In contrast, UC3 channels show significant aggradation and little upward or lateral change in grain size or bed thickness, in addition to well-developed lateral accretion surfaces and the systematic lateral-offset-stacking pattern of successive channels. These latter stratal characteristics suggest a change from a disorganized to a highly organized pattern of channel evolution, which most likely can be attributed to changes in the character of the sediment transporting flows, and in particular their density profile. Flows are interpreted to have been poorly density stratified with a basal, coarse-grained layer of more or less uniform sediment concentration overlain abruptly by a much finer grained, density-stratified suspension (Tilston et al., 2015). The density structure in the part of the flow closely resembles the plug-like density profile observed in open channel flows (i.e. rivers), which then caused the lower, depositionally important part of the flow to operate much like a river where lateral channel accretion is a common phenomenon (i.e. point bars).

Conclusions

Isaac Channel Complex Set 1 of the Windermere turbidite system (British Columbia, Canada) comprises two vertically-stacked channel complexes. Channel fills in the lower complex and the lower and middle channel units of the upper complex (UC1 and UC2, respectively) consist of a disorganized stack of discrete, aggradationally-filled channels that exhibit negligible lateral migration of individual channels. In contrast, UC3, which crops out at the top of the succession, consists of a systematic (i.e. organized) lateral-offset-stack of aggrading, laterally-accreting channels. Collectively, these observations are inconsistent with the pattern predicted by the hockey-stick model and illustrate the need for a better understanding of the spatial and temporal sedimentary variables that control channel and associated levee sedimentation.

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