How are Changes in Sediment Supply Manifest in an Ancient Deep-Marine Slope Channel System?

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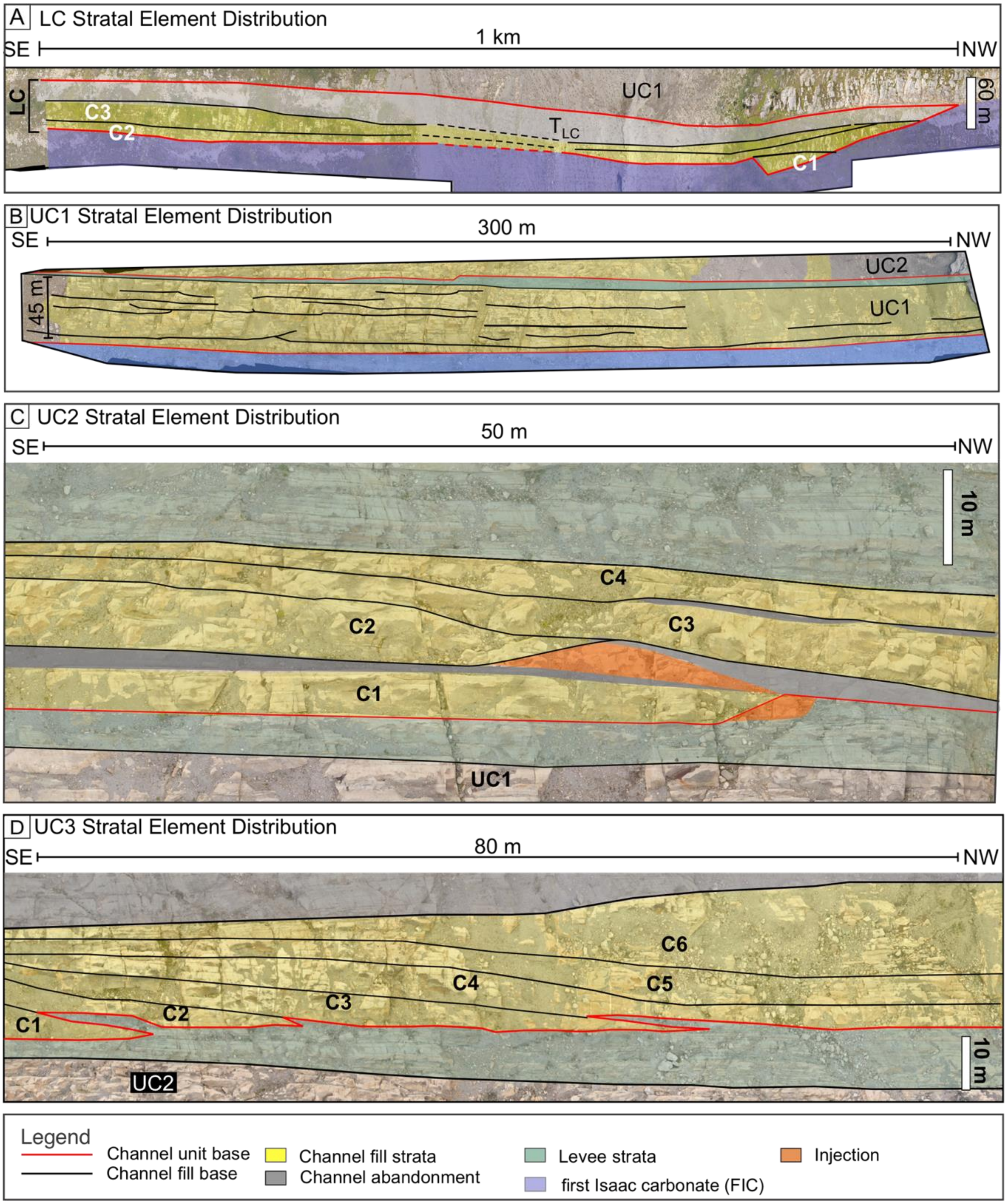
Introduction

Commonly reported from seismic, outcrop, and stratigraphic forward modelling studies is the systematic evolution of deep-marine slope channel systems from an initial stage of lateral migration of successive channels forming a composite sheet-like stratigraphic unit overlain by a succession of isolated, aggrading channels (Fig. 1). Presently, many models attribute the change to the equilibrium profile and systematic variations in sediment supply, specifically the sand-mud ratio, which in turn is related to positions of relative sea level (e.g., Posamentier and Walker, 2006; Arnott, 2010). For example, during lowered relative sea level, large sand-rich flows promote erosion on the slope, which then decreases the equilibrium profile and causes channel accommodation to be reduced, and as a consequence channels to be completely filled and the system to show little net aggradation. In contrast, during episodes of elevated relative sea level, and landward position of the shoreline, mud content increases and progressively raises the equilibrium profile (e.g. accommodation) and causes simultaneous aggradation of the channel floor and adjacent levees (Kneller, 2003; Samuel et al., 2003; McHargue et al., 2011). However, it is important to note that much of this evolutionary model is based on the interpretation of seismic profiles with at best sparse core control, and nor has it been rigorously tested in outcrop. At the Castle Creek study area (BC, Canada), a superbly exposed channel system of the Neoproterozoic Windermere Supergroup termed Isaac channel complex 1 (ICC1) crops out. ICC1 is 220 m-thick, exposed for 5 km along strike, and consists of four vertically-stacked channel units: lower channel unit (LC), and three upper channel units (UC1-UC3). ICC1 overlies a sequence boundary that separates an almost 200 m-thick mixed carbonate-siliciclastic succession, termed the first Isaac carbonate (FIC), from siliciclastic strata of ICC1, suggesting the cessation of carbonate production and the exclusive delivery of sediment from the continental hinterland. This, therefore, provides an ideal opportunity to investigate the influence of changes in sediment supply and relative sea level on the stratal architecture of a seismic-scale leveed slope channel complex.

Fig. 1 (next page). Drone photomosaics of the four channel units, lower channel unit (LC) and upper channel units UC1, UC2, and UC3 (A-D, respectively), that stack to form ICC1.


A LC Stratal Element Distribution
1 km
SE
NW
LC
C3
C2
UC1
T_LC
C1
60 m
B UC1 Stratal Element Distribution
300 m
SE
NW
45 m
UC2
UC1
C UC2 Stratal Element Distribution
50 m
SE
NW
10 m
C4
C2
C3
C1
UC1
D UC3 Stratal Element Distribution
80 m
SE
NW
C6
C4
C5
C3
C2
C1
10 m
UC2
Legend
Channel unit base
Channel fill base
Channel fill strata
Channel abandonment
Levee strata
first Isaac carbonate (FIC)
Injection

ICC1 Channel Fill Observations

Based on lithological, textural, and stratal trends, two styles of channel fills and stacking patterns are recognized – disorganized stack of aggradationally filled channels and organized stack of laterally-accreting channel fills. 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 60 m deep into strata of the FIC (Fig. 1A). Additionally, the lowermost channel fill in LC consists uniquely of quartz pebbles and carbonate-cement mudstone and sandstone clasts (Fig. 2A). UC1 and UC2 exhibit common cut and fill characteristics suggesting multiple erosively juxtaposed channel fills that are 4 - 12 m thick. UC1 is dominated by coarse-grained, graded, massive or cross-stratified sandstone with little upward or lateral changes in facies (Fig. 1B; Fig. 2B). UC2, on the other hand, comprises nested channel fills that are 5 - 8 m thick and composed of coarse-grained sandstone that progressively fine and thin upward and laterally (Fig. 1C; Fig 2C). Point counting in petrographic thin sections indicate that strata in LC, UC1, and UC2 are poorly sorted, although sorting does improve upward from LC to UC2 (Fig. 3A). Collectively, these textural and stratal trends suggest that channels of LC, UC1, and UC2 filled aggradationally (i.e. from the bottom up) by poorly-sorted, (vertically) density-stratified flows.

UC3, on the other hand, is up 30 m thick and comprises at least six laterally-accreting channel fills that populate a succession of flat-based, lateral-offset-stacked 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 (Fig. 1D). These deposits are interpreted to be lateral accretion deposits that formed on the inner bend of sinuous subaqueous channels. Channel fills are up to 10 m thick and typically filled with coarse-grained sandstone and conglomerate that show little upward or lateral change in grain size or bed thickness. Distinctively, strata consist of dispersed red-colored sandstone clasts cemented with a pervasive ferroan calcite cement (Fig. 2D). In comparison to the granulometric make-up of aggradationally-filled channels (LC, UC1 and UC2), strata in UC3 channels are distinctively better sorted (Fig. 3A). This caused the through-going flows to adopt a more uniform near-bed density-profile; specifically, a dense, coarse-grained basal layer of more or less uniform sediment concentration overlain abruptly by a much finer grained, lower density suspension (Tilston et al., 2015). In channel bends the coarse, moderately well-sorted sediment in the lower part of the flow developed a cross-flow density gradient that resembled the hydraulic pressure conditions in fluvial channel bends, which then promoted continuous lateral channel migration with deposition on the inner bend (point bar) and erosion on the outer bend (cutbank).

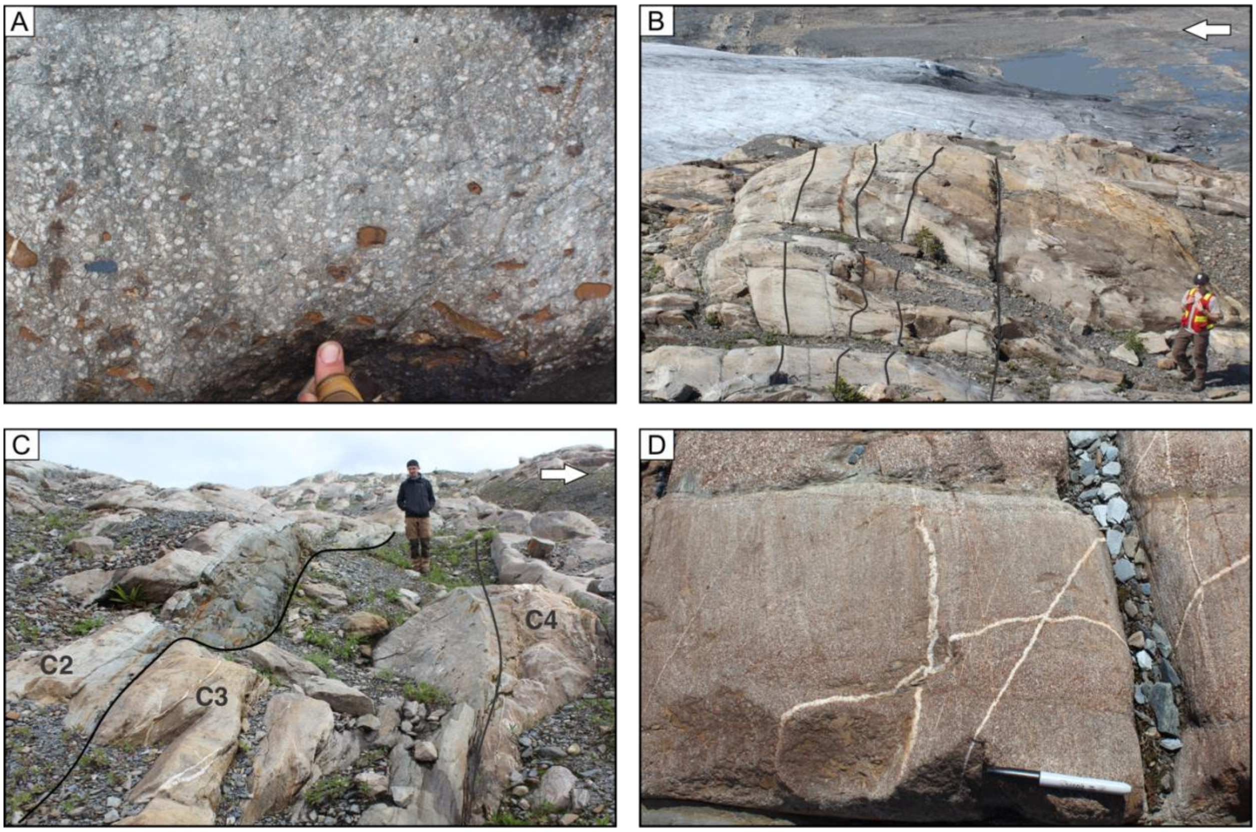


Fig. 2. Close-up field photos of the textural make up of strata in LC (A) and UC3 (D), and common channel filling patterns in UC1 (B) and UC2 (C). (A) Normally graded, quartz granule- and pebble-rich conglomerate with dispersed carbonate-cemented mudstone (weathered orange) and siliciclastic mudstone (grey) clasts. Note the sub-rounded to well-rounded pebbles in the lowermost channel fill of LC. (B) Erosionally-based channel fills of UC1 (black lines). Each channel fill comprises thick-bedded, coarse-grained, amalgamated sandstone with negligible change in facies vertically or laterally. (C) Channel fills C2-C4 of UC2 comprising decimeter-thick beds of coarse-grained, amalgamated sandstone that fine and thin upward, which in the case of C2 and C3 are overlain abruptly by thin-bedded, fine-grained, planar-laminated sandstone with a distinctive green colour indicating elevated chlorite content (most probably related to metamorphic alteration of detrital clay minerals). The lateral continuity of these finer-grained beds is < 50 m due to erosion at the base of younger channel fills. (D) Example of a normally graded, coarse-grained sandstone in UC3. Note the distinctive red-coloured hue of the sandstone that is the result of a pervasive ferroan calcite cement.

Sediment Supply and Shelf Conditions

The upward change from aggradational to laterally accreting channel is interpreted to be the stratigraphic manifestation of a fundamental change in the character of the turbidity currents that transited the Windermere continental slope, specifically the granulometric make up of the sediment that formed the currents. Sheetlike, composite bodies in the lower part of ICC1 composed of erosively juxtaposed aggradational channel fills were formed by continuously density-stratified flows reflecting a poorly-sorted, hinterland-dominated sediment supply. This succession is then overlain by laterally accreting, vertically aggrading channels, which here is interpreted to reflect a change to a better-sorted, shelf-modified sediment supply that formed turbidity currents with a two-part density structure, rather than the more typical assumption of differences in the sand: mud ratio (e.g., McHargue et al. 2011). Changes in sediment supply, and accordingly, stratal architecture and temporal evolution of slope channels in ICC1, are possibly tied to long-term (3rd order?) sea level changes, and attendant expansion and contraction of the continental shelf (width) where hinterland sediment was modified and coarse sediment, now considered relict and palimpsest, was retained (Fig. 3B). Superimposed on the long-term trend were shorter duration (4th / 5th order) changes that transported this coarse sediment to the shelf edge where it eventually became the principal sediment component in downslope flowing turbidity currents, which stratigraphically is manifest by the change from aggradational to laterally accreting channel fills.

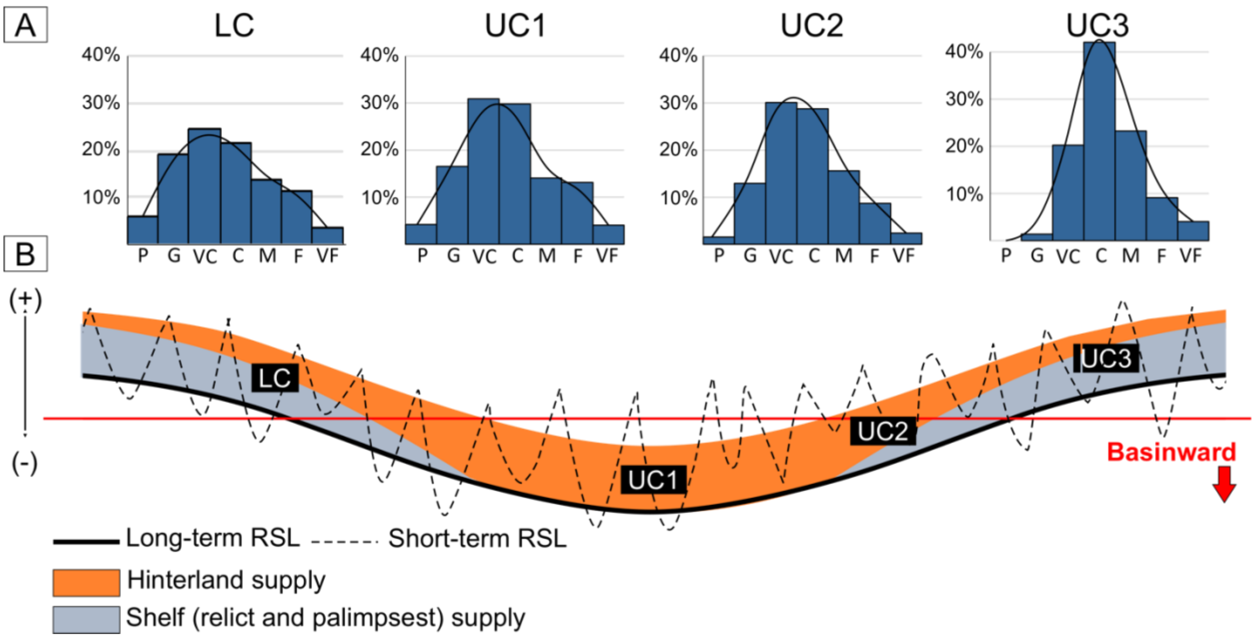


Fig. 3. (A) Histograms showing the combined frequency percent (%) grain size distribution in three samples from thick-bedded, coarse-grained sandstone in each of the four channel units. Note the progressive narrowing of the grain distribution stratigraphically upward from LC (poorly sorted) to UC3 (better sorted). (B) Short-duration, high-frequency 4th /5th order fluctuations of RSL (black dashed line) superimposed on the long-duration, low-frequency 3rd-order changes of relative sea level (solid black line) and position of deposition for each channel unit. Red line

indicates the shelf edge, which remains constant through time; the red arrow indicates the basinward direction. Note that although high frequency lowstands are the mechanism that transport coarse sediment to the shelf edge, it is the 3rd-order changes in RSL that controlled the comparative contribution and timing of hinterland (orange) versus shelf (grey) sediment to the shelf-edge. These changes, in turn, control the character of the flows that resediment that sediment down the continental slope, and ultimately, the lithological make up, stratigraphic architecture, and timing of the depositional record.

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