Deep-sea slope channels – if commonly sinuous, why only uncommonly laterally accreting?

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The Question

Continental fluvial channels commonly exhibit a sinuous planform with systematic lateral channel migration. This sets up the well-known pattern of continuous lateral accretion of individual channels related to erosion along the outer bend (cutbank) and deposition of lateral-accretion deposits on the inner bend (point bar) (e.g., Van de Lageweg et al. 2014). Deep-sea channels, whether in the modern or imaged in subsurface horizontal seismic slices, exhibit a similar sinuous planform (e.g., Posamentier and Kolla 2003), and therefore it would seem reasonable to expect that the stratigraphic record of these channels and their fill would also be similar. However, based on observations in the ancient sedimentary record, evidence of continuous lateral channel migration and associated lateral-accretion deposition is uncommon. More typically, ancient deep-sea channels show a bottom to top, or similarly, aggradational or cut-and-fill style of fill marked by the well-documented pattern of upward-fining and -thinning of more or less horizontal strata (e.g., Schwarz and Arnott, 2007; Macauley and Hubbard 2013) (Fig. 1A). Nevertheless, although uncommon, deep-sea channels with well-developed lateral accretion deposits are observed in the ancient sedimentary record (e.g. Arnott 2007; Dykstra and Kneller 2009) (Fig. 1B), which then raises the question as to what seemingly uncommon sedimentological conditions give rise to this style of channel migration.

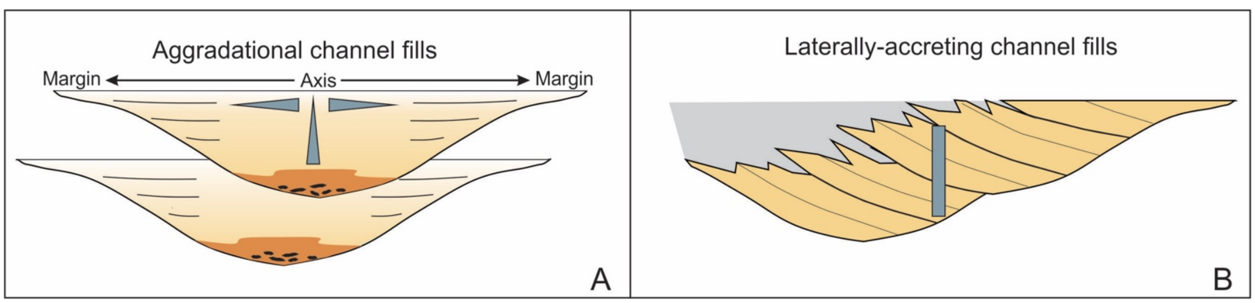

Fig. 1 End-member deep-sea channel fill types; grey polygons indicate grain size profile.

The Observations

Deep-water rocks of the Neoproterozoic Windermere Supergroup (WSG) are well exposed throughout the southern Canadian Cordillera of western Canada. Idealistically the succession consists of a few-km-thick rift succession overlain by a 5-7 km- several-km-thick, upward-shoaling post-rift succession consisting of basin-floor to continental-shelf deposits related to the progradation of the Laurentian margin into the thermally subsiding proto–Pacific Ocean (Ross and Arnott, 2007) (Fig. 2B). The continental slope part of that succession consists of sand-rich strata typically bordered by thin, finer and more mud-rich strata. Sand-rich strata range up to ~ 200 m thick and are interpreted to be the fill of slope channel complexes bounded by their genetically related but fine-grained levee deposits, in addition to common intercalated mass wasting (i.e. slump–slides) and debris flow deposits. Laterally accreting channels with well-developed lateral-accretion deposits (LADs) typically occur at the top of these channel complexes and exhibit a suite of characteristics that easily differentiates from the more common aggradationally-filled channels (Fig. 2). Channel bases are flat and horizontal with a common terrace-step morphology created by the lateral-offset-stacking with punctuated aggradation of successive channel fills. On one side of the channel fill coarse-grained channel deposits end abruptly against a steeply inclined contact with fine-grained, thin-bedded turbidites, whereas on the opposite side coarse-grained channel strata are inclined (~ 7–12^{o}; maximum 20^{o}) toward the channel base, and obliquely upward interfinger with fine-grained, thin-bedded turbidites interpreted to be inner-bend levees onto which sand-rich channel-filling strata onlap. Unlike aggradationally-filled channels that become finer grained and more thinly bedded upward, laterally accreting channel fills show negligible upward or lateral change in grain size, which distinctively is composed of moderately well-sorted, upper coarse to very coarse sandstone. Additionally, dispersed granule-size clasts composed of carbonate-cemented coarse sand grains are common.

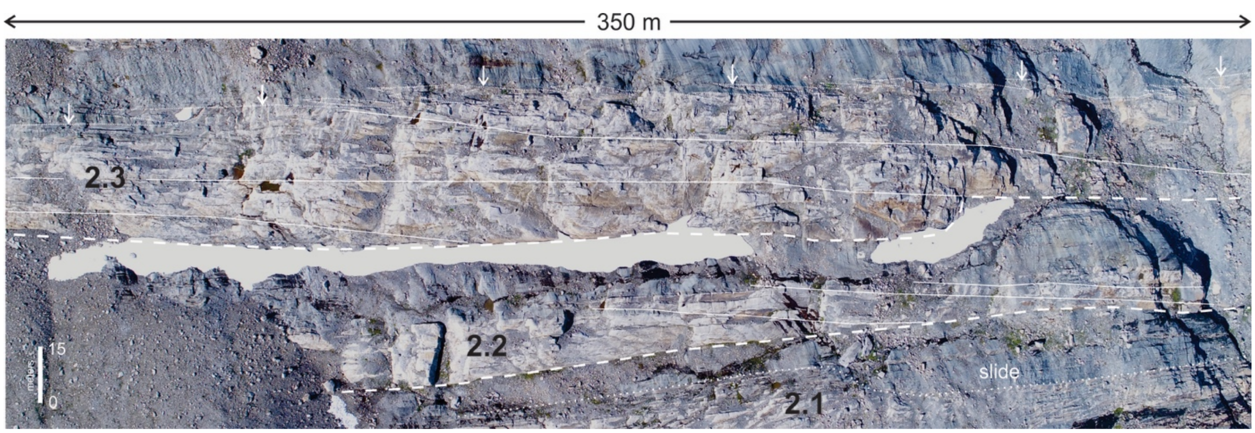

Fig. 2. Drone aerial photograph of part of Isaac channel complex 2. Note that strata are vertically dipping. Solid white lines demarcate surfaces that dip at ~ 7–12^{o} to the basal contact and mark out the continuous lateral (toward right) migration of successive channels that make up channel units 2.2 and 2.3. Note also the flat basal surface (white dashed line) in both channel units, which on the right in 2.3 steps abruptly upward, the step coinciding with the base of the third channel in a succession of (four) laterally-offset-stacked, aggrading channels. Channel aggradation is also indicated by the upward (toward right) trajectory of the top of 2.3 (indicated by vertical white arrows). The dashed white line at the top of 2.3 traces the upper surface of coarse channel fill strata where they onlap and end against fine-grained inner-bend levee deposits.

The Solution

As river flow rounds a channel bend, turbulence diffusion, in addition to a more effective secondary circulation driven by centrifugal acceleration, develops to relax the cross-flow momentum gradient. This, in turn, leads to deposition on the inner bend, termed the point bar, and erosion on the outer bend (cutbank), resulting in the continuous lateral migration of the channel. In the subaqueous realm *sediment*-gravity flows, specifically turbidity currents, replace fluid-gravity flows as the principal sediment transport mechanism. Being a kind of density current, particle-driven turbidity currents are capable of creating a cross-flow density gradient, which in order to promote continuous riverine-like lateral accretion would appear to be necessarily directed toward the inner bend. Here it is argued that near-bed river-like circulation and related depositional patterns are restricted to coarse-grained turbidity currents composed of two parts: coarse basal layer with a negligible density gradient, overlain sharply by a finer, lower-density layer. This requires an impoverished supply of particles with intermediate settling velocity, which otherwise would form an intervening layer between the coarse basal and fine upper parts of the flow, and therefore cause the flow to be continuously stratified. Although this grain size distribution may be representative of the hinterland sediment supply, it is more likely that it represents a modification of a polydispersed hinterland sediment supply along the transport system between the source and the deep-marine sink. Here it is argued that extraction of the intermediate grain sizes is the result of continental-shelf processes during transgression that modified the granulometric make-up of the sediment being supplied to the shelf edge, and in turn, the character of basinward-flowing turbidity currents. More specifically, it resulted in a two-part suspension whose density and velocity structure, and therefore momentum structure, resembles that in rivers (Fig. 3). Additionally, because of their weight, coarse particles in the lower part of the flow would be negligibly uplifted along the outer bank as they round a channel bend, resulting in negligible overspill and increased sediment concentration along the outer bank. This creates an inward-directed density gradient that exceeds the outward-directed centrifugal component in the near-bed region and caused flow to be directed toward the inner bank, forming a river-like secondary circulation with lateral-accretion deposits formed by the continuous lateral migration of single deep-marine channels.

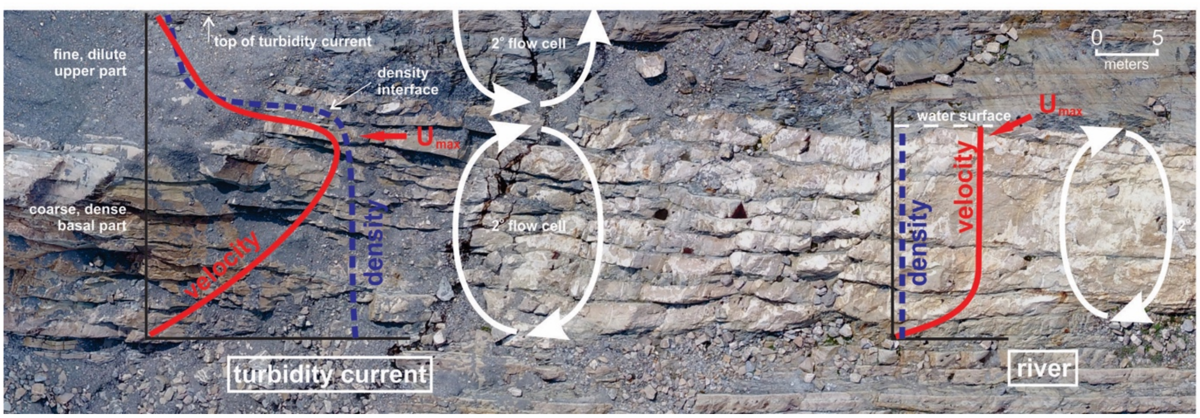

Fig. 3. Summary model for the origin of laterally accreting deep-water channels (river profile shown for reference); note well-developed lateral-accretion surfaces in the background photo.

Acknowledgements
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