Ripples and Deep-Sea Levees – together, forever

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Summary

Subaqueous levees are positive topographic elements that bound channels in deep-marine turbidite systems. One of the most distinctive attributes of both modern and ancient deep-marine levees is the ubiquitous occurrence of current ripple cross-stratified sand (stone) (Fig. 1). Puzzlingly then is the comparative rarity of this structure in the adjacent channel deposits, where at a minimum one would expect it to form during the latter low-energy stages of most/all sediment transport events, assuming at least moderate preservation.

Current ripples, or simply ripples are low-energy unidirectional, angular bed forms. Like dunes, ripples become initiated from a bed-surface defect that alters the spatial distribution of sediment transport and deposition on the bed surface, which in turn allows for defect amplification and ultimately bed-form growth. The inception of the defect is ultimately controlled by conditions in the very near-bed region. Specifically, a rapid upward decay of density (i.e. sediment concentration) is needed to spatially organize local bed-load transport rates that generate the initial bed defects, which are the precursors to angular bed-form development. This density stratification condition tends to occur when fluid shear is relatively low compared to particle settling velocity, and apparently coincides with flow conditions commonly developed over levees. Here, the flows feeding the levees are decoupled from the channelized flow through a variety of overbanking processes and are characterized by three important qualities that promote near-bed density stratification: 1) they are relatively fine and dilute, thereby containing less kinetic energy, which allows particles to easily settle; 2) they are sourced from the lower velocity (upper) regions of the channelized current; and 3) they are unconfined, and therefore prone to accelerated potential energy loss. The first two conditions indicate that overbank currents lack much of the suspension potential contained in the channelized flow, which becomes further exacerbated by lateral flow spreading due to the absence of confinement. Collectively these three conditions all promote the development of a rapidly upward-decaying density profile over levees, and in turn the preferential development of low-energy current ripples compared to their channelized counterparts.

Results, Observations, Conclusions

Levees are formed of sediment that spills out of the adjacent channel, and in the case of deep-marine levees the source of that sediment is throughgoing, channel-bound turbidity currents. In these currents the motive force is provided by a bottom-hugging sediment suspension that is most highly concentrated in its lower part and decreases upward – grain size typically decreasing upward too. Being a density current flow speed is controlled by bed slope and the strength of the density contrast between the current and the ambient seawater. Density contrast is controlled by sediment concentration, which therefore is greatest in the basal part of the current and it is here that the current is most strongly propelled. As flows overspill the channel it is mostly the upper, more dilute part of the current that is involved. Upon existing the channel the more dilute upper part of the flow is no longer sustained by the lower, more dense part, in addition to becoming unconfined and as a result expanding. Collectively these result in a rapid collapse of the flow and the immediate settling of suspended sediment particles. Being in a sufficiently dilute and fully sheared flow, particles, in this case composed mostly quartz, and therefore of equal density, settle according to their grain size. This results in the rapid build up of the fastest settling (i.e. coarsest) particles in the lower part of the flow overlain by a suspension of rapidly diminishing density. Sediment being moved as bed load, then, is moulded into bed forms dependent on flow speed. The ubiquity of ripple cross-stratification in subaqueous levee deposits would suggest that when sediment begins to accumulate on levees the flows are very commonly slow-moving suspensions, and the bed surface is hydraulically smooth. Additionally, the fallout of sediment into the lower part of the flow and then onto the bed, which if exceeding the volumetric transport flux of bed-load sediment, would cause the bed forms (i.e. ripples) to climb – a commonly reported characteristic of levee deposits. At the same time, but in the adjacent channel, the comparative absence of angular bed forms, whether they be ripples or dunes, would suggest that flow conditions, even during the low-energy tail end of most transport events, maintained a more plug-like density profile, which caused the bed surface to remain nominally flat and net deposition to build up a planar stratified deposit (typically above an earlier deposited structureless graded sandstone) until the end of the sedimentation event and suspension deposition of a fine-grained drape.

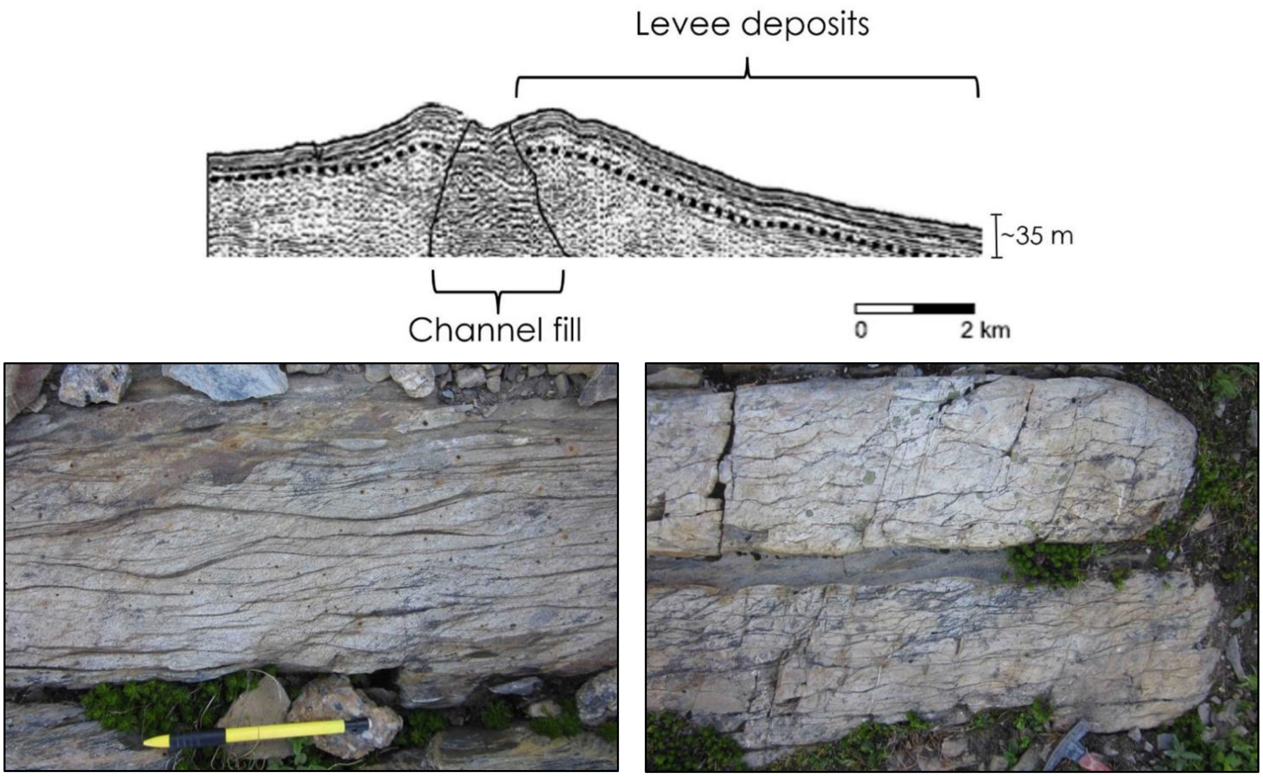

Fig. 1. Seismic image illustrating the gull-wing geometry of a modern Amazon deep-marine leveed channel (modified from Skene, 1998). Photos show medium-bedded, multi-set, ripple cross-stratified upper fine/lower medium-grained sandstone in levee deposits of the Neoproterozoic Windermere Supergroup.

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References

Skene, K.I. 1998 Architecture of submarine-channel levees: Ph.D. thesis, Dalhousie University, 365 p.