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Sometimes Planar, Sometimes Irregular: a Bipartite Bed Interface Conundrum.

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Introduction

Deep-marine strata consisting of a clean sandstone separated from an overlying muddier, mud clast-rich, poorly sorted layer by a planar or irregular interface, have been variously termed linked debrites (Haughton et al. 2003), co-genetic debrite-turbidite beds (Talling et al. 2004), hybrid event beds (Haughton et al. 2009), transitional flow deposits (Kane and Ponten 2012) and bipartite beds (Angus et al. 2019). In all cases, deposition of these two superimposed layers is interpreted to be genetically related but explained by very different physical mechanisms including: hybrid flows consisting of at least two discrete and mechanistically different parts, namely a turbidite overlain by debrite (Haughton et al. 2009), longitudinal flow transformation (Kane and Ponten 2012), vertical stratification effects and turbulence suppression in a high-concentration suspension (Talling 2013; Kane et al. 2017), and particle settling in a negligibly sheared mixed mud-sand suspension (Angus et al. 2019). In part, these differences can be attributed to the interpretation of the contact that separates the two distinctively different lithologies. In basin-floor rocks of the Ordovician Cloridorme Formation, Quebec, Canada, the contact is planar, irregular, or a combination of the two, and therein provides an excellent opportunity to investigate the origin of these strata.

Observations

Bipartite beds are composed of two sharply bounded parts – a lower sand-rich part overlain sharply by a planar- or irregular-based muddier upper part. Across the interface the grain-size distribution decreases slightly, but the matrix (detrital clay and silt) content increases by a few tens of percent. In the Cloridorme, 57% of the bipartite beds show an exclusively planar interface, whereas the remaining 43% of the bipartite beds show a lateral alternation of planar and irregular. The irregular interface is characterized by cm-scale synforms and antiforms with local overhangs and injections of sand from the sand-rich basal part into the overlying muddy part. Furthermore, the alternation between irregular and planar occurs on horizontal scales that range from dm to several meters.

Bipartite beds are part of a 100s m-long systematic proximal to distal depositional transect consisting of thick-bedded matrix-poor sandstone to medium- to thick-bedded muddy sandstone to medium-bedded bipartite bed and then thin- to medium-bedded sandy mudstone. Within the bipartite bed interval of the transect, the overall bed thickness changes little as the downflow thinning of the basal sand-rich part is compensated by the thickening of the upper mud-rich part. This trend remains consistent in terms of lithological and dimensional characteristics whether the bipartite bed interface is planar, irregular, or a combination of the two (Figure 1).

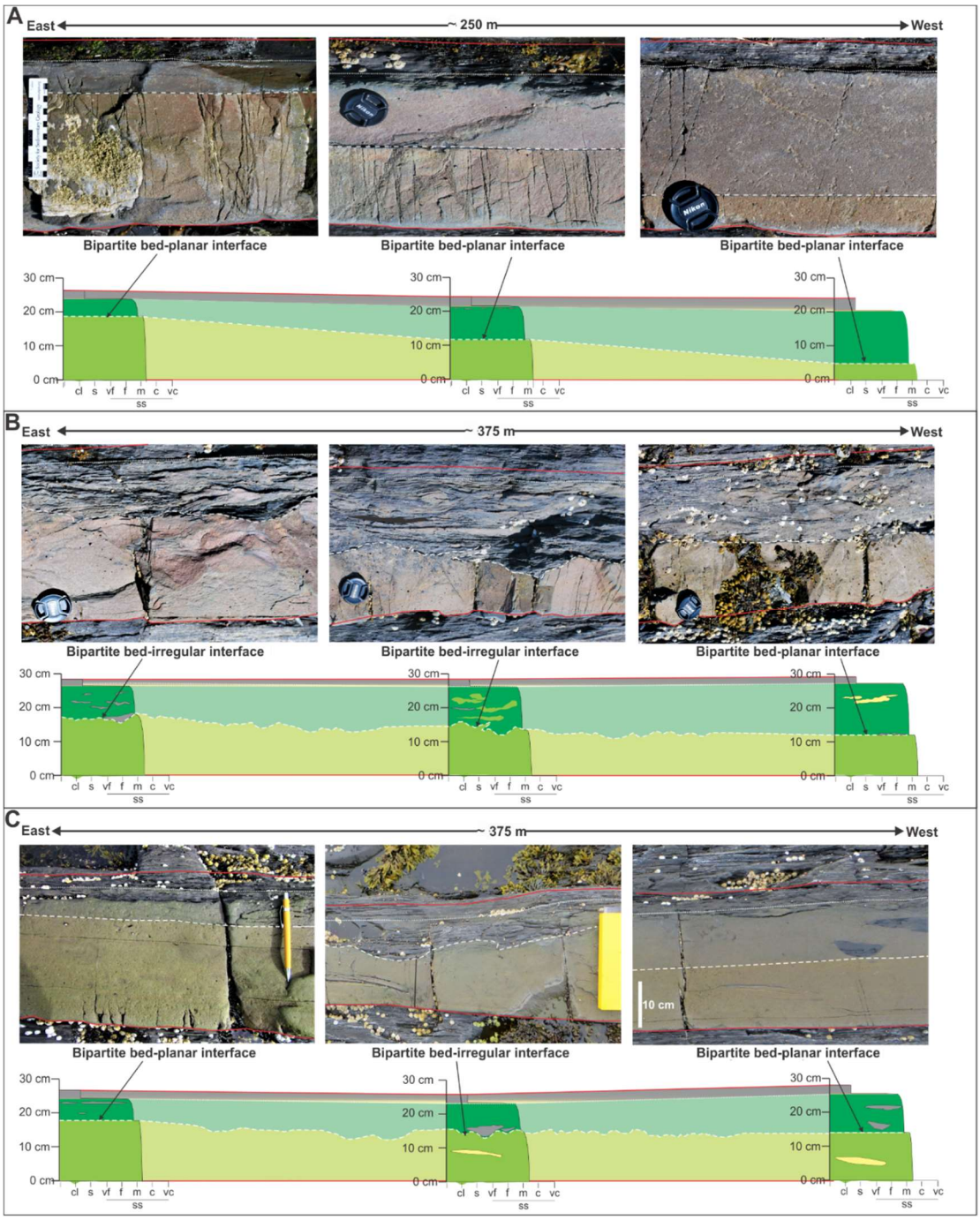

Figure 1: A) Outcrop photos and accompanying stratigraphic log of a bipartite bed with a planar interface separating sand-rich (below) from mud-rich (above) strata along the length of the transect, and (B, C) an alternation of planar and irregular morphologies. Note the consistent downflow (westward) thinning of the basal sandy part and compensatory thickening of the upper muddy part in all three beds.

Interpretations

In the Cloridorme mud-rich strata typically underlie sand-rich basin-floor terminal splays and are interpreted to be the initial deposits following initiation of the local transport system caused by an upflow avulsion. Avulsion formed a wall jet that locally scoured the mud-rich interchannel area and charged the flow with fine-grained sediment, namely very fine sand to clay, in addition to low-density mud clasts. The local incorporation of easily suspended fine-grained sediment resulted in the rapid conversion of turbulent kinetic energy (TKE) into potential energy for particle support. This dramatic loss of TKE caused the sediment suspension to collapse forming a negligibly sheared suspension that deposited a systematic along-flow depositional continuum consisting of matrix-poor sandstone to muddy sandstone to bipartite bed and then sandy mudstone over a distance of 100s meters (Figure 2, time-1). Deposition occurred in the same direction as the avulsed flow and represents a mouth bar that marks the downflow terminus of the flow.

More specifically, the bipartite bed portion of the continuum is the result of the settling of coarse sediment and concomitant upward flux of more slowly settling, finer-grained particles into the upper part of the suspension. With the exhaustion of settling particles, and accordingly the termination of the sand-rich lower layer, the mud-rich upper part of the flow continues to move, but only for a few decameters beyond the sand-rich pinch-out, forming a sharp planar contact that separates the two parts of the bed. An irregular interface, on the other hand, is interpreted to be a consequence of post-depositional deformation caused by variations in water saturation and pore fluid pressure in the lower sand-rich part of a bipartite bed (Figure 2. time-2). These conditions set up local Rayleigh-Taylor instabilities between the more dense, less permeable, mud-rich upper part and sandy, less dense basal part that leads to gravity-driven deformation of the previously planar interface (Figure 2, time-2), rather than a later flow of different kind or different turbulence characteristics.

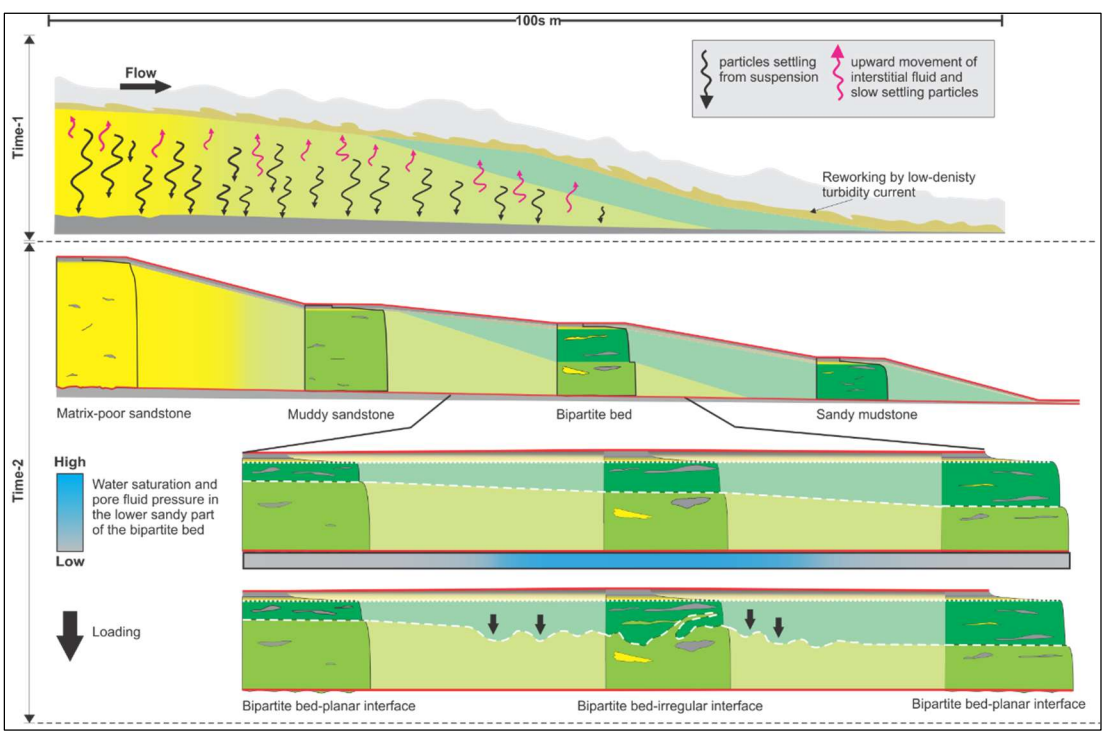

Figure 2: Schematic showing the post-depositional development of an irregular bipartite bed interface. Time-1 shows deposition of the lithofacies continuum from matrix-poor sandstone to muddy sandstone to bipartite bed and then to sandy mudstone. Note that the interface in the bipartite part of the continuum is planar. Sometime later (time-2) locally elevated water saturation and pore fluid pressure in the sand-rich basal part of the bipartite bed caused the planar interface to be deformed as localized areas of the overlying mud-rich layer sank, augmented locally by the upward injection of sand into the mud-rich upper layer.

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