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Planar stratification: Flat as a pancake and not a ripple in sight

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Summary

Planar stratification is ubiquitous in fine-grained sedimentary systems, particularly in modern and ancient shallow- and deep-marine settings, and is a common component in economically important deposits like the Horn River Group, Bakken and Montney formations. Here we describe the micro-textural attributes of planar-laminated mudrocks in the shallow-marine Upper Cretaceous Puskwaskau Formation and the deep-marine Neoproterozoic Windemere Supergroup. In both successions, planar laminae consist of sub-millimeter-scale alternations of sharply bounded silt- and clay-rich layers, in which the clay-rich layers are composed of poorly-sorted fine-grained sediment, and the silt-rich layers are moderately- to well-sorted, and comparatively coarser grained. We interpret the origin of these plane-parallel-laminated layers to be the result of rhythmic changes in near-bed sediment concentration and its effect on horizontal (flow) stratification in these time-averaged steady currents. Ultimately, these conditions caused deposition to fluctuate between competence- and capacity-driven deposition, which in turn controlled the textural characteristics of the deposit.

Era	Neoproterozoic		Mesozoic
Period	Cryo.	Ediacaran	Cretaceous
Stratigraphic Hierarchy	Windermere Supergroup		Smoky Group
	Kaza Group	Isaac Formation	Puskwaskau Formation
Depositional Setting	Basin Floor	Slope	Epicontinental Shelf
Tectonic Setting	Passive Margin		Foreland Basin

Table 1 – A comparison of the geological characteristics of the Windermere Supergroup in the southern Canadian Cordillera with the Puskwaskau Formation in north-central Alberta.

Results

Upper Cretaceous Puskwaskau Formation

Mudstone beds are ~ 2 to 50 mm thick and consist of three stratal divisions, which in a complete and idealized succession, include, from base to top: low-angle cross-lamination, planar-lamination, and a structureless clay-aggregate-rich layer. The base is typically sharp and erosive, although undulatory contacts with load casts and flame structures are observed. Low-angle cross-laminae consist of well-sorted, medium to coarse silt-size quartz, feldspar, muscovite, and intraclastic aggregates. Parallel-laminae consist of sub-millimeter-thick alternations of sharply-bounded silt- and clay-rich layers (Fig. 1A). Silt-rich layers are moderately- to well-sorted and consist mostly of detrital silicate minerals and silt-size intraclastic aggregates, whereas clay-rich laminae are poorly- to moderately-sorted and composed of clay aggregates, fine to coarse silt, and dispersed organic matter (Fig. 1B). The uppermost division consists of a clay-aggregate-rich layer with dispersed silt grains. Commonly, the idealized tripartite succession is incomplete, and beds consist of parallel-laminated mudstone in which laminae thin and the bed becomes more clay-rich upward.

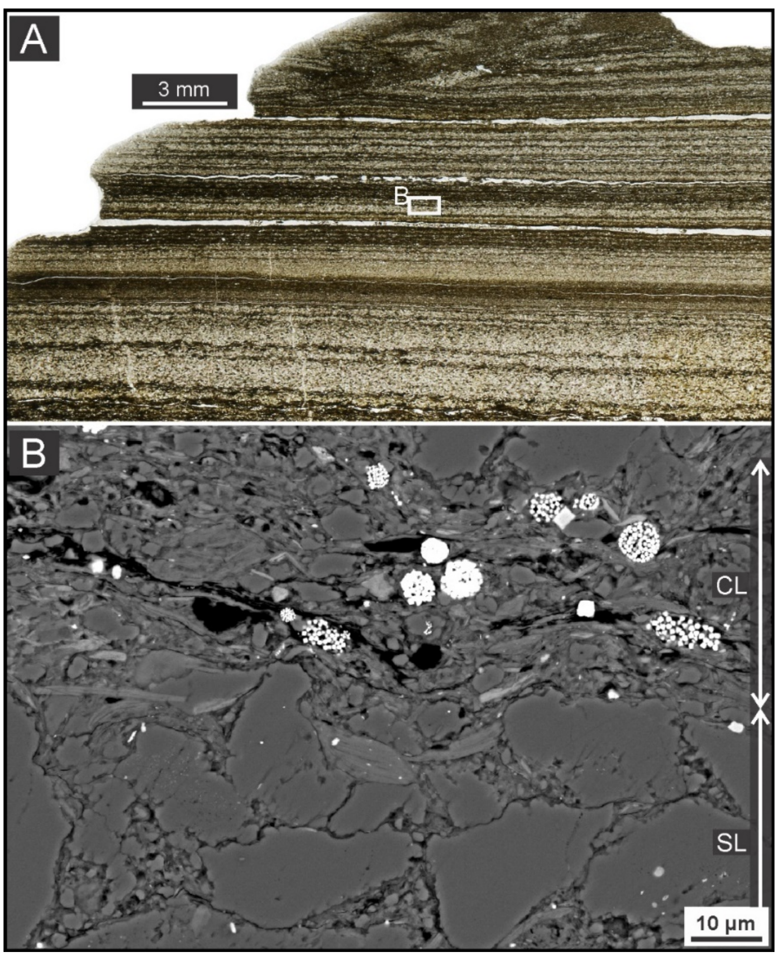

Figure 1 – A) High-resolution thin section scan of a parallel-laminated mudstone, Upper Cretaceous Puskwaskau Formation. B) Backscattered electron micrograph showing the sharp contact between a silt-rich (SL) and an overlying clay-rich (CL) layer. Note the moderately- to well-sorted texture of the silt-rich layer that is composed mostly of silicate minerals and intraclastic aggregates. In contrast, clay layers are comparatively more poorly-sorted and composed of abundant clay aggregates, dispersed silt-size detrital grains, organic matter, and framboidal pyrite (bright spots).

Neoproterozoic Windermere Supergroup

Mudstone beds are ~ 1 to 40 mm thick and most commonly comprise a two-part idealized succession made up of a parallel-laminated basal layer overlain sharply by a structureless mudstone (Fig. 2A). Bed bases are typically sharp and planar, although undulatory contacts are observed. Parallel laminae are sub-millimeter thick and consist of alternating, sharply bounded silt- and clay-rich layers (Fig. 2B). Silt-rich laminae consist of moderately- to well-sorted fine to coarse silt-size quartz, muscovite, and chlorite. In contrast, clay-rich laminae are mineralogically similar but are comparatively more poorly-sorted with a greater abundance of clay minerals. The structureless mudstone cap is composed of clay minerals and dispersed quartz silt. Significantly, both the parallel-laminated and structureless mudstone divisions can be traced in outcrop for 10s of meters along depositional strike with negligible change in thickness.

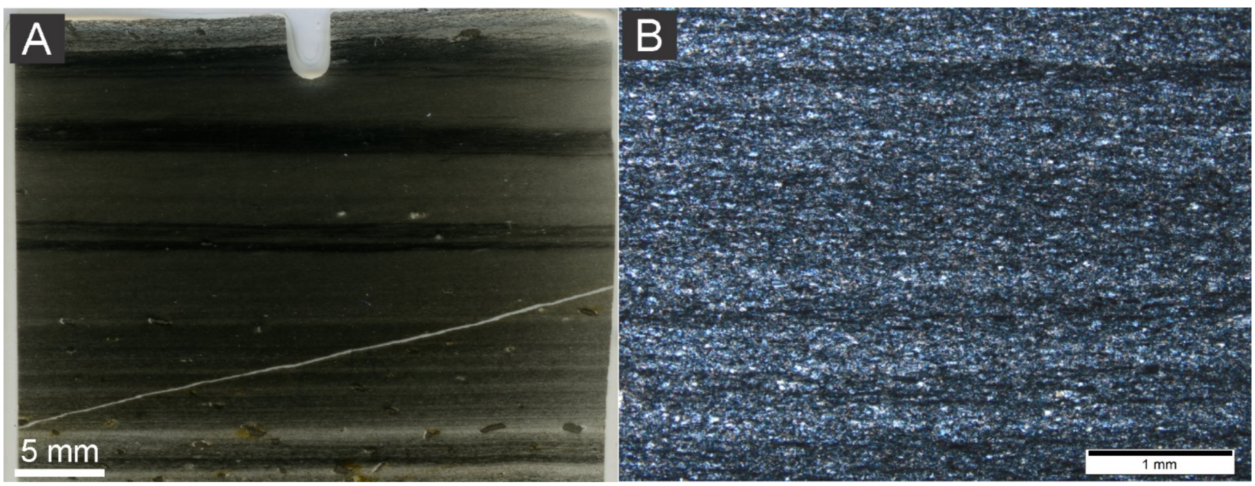

Figure 2 – A) High-resolution thin section scan, Neoproterozoic Windermere Supergroup. Beds typically comprise two parts: a sharp-based, planar-stratified mudstone overlain sharply by a structureless mudstone. B) Cross-polarized photomicrograph illustrating the repetitive banding of silt-rich (bright bands) and clay-rich (dark bands) layers.

Discussion

As described above, fine-grained strata in both the deep- and shallow-marine sediment records are commonly dominated by a distinctive alternation of poorly sorted, and better sorted, comparatively coarser-grained, plane-parallel layers. Following the experimental work of Schieber and others (2007, 2009a, 2009b, 2011) these strata are commonly interpreted to be deposited by downflow-migrating current ripples (e.g., Birgenheier and Moore 2018). Based on that interpretation, the millimetric to sub-millimetric vertical variations in texture are thought to be a consequence of sorting processes on the leeside of migrating ripples whereas the plane-parallel nature of the interstratified layers is related to post-depositional compaction of a fine-grained sediment pile. However, it is important to note that the experiments of Schieber and others, in addition to Baas and Best (2002) and Baas et al. (2009), were conducting using an open channel flow, not unlike that in a river (e.g., Plint 2019). However, transport of fine-grained sediment, generally very fine sand and finer, below storm-weather wave base in shallow-marine settings is thought to be related to sediment-gravity-driven processes. Termed wave-enhanced sediment-gravity flows by Macquaker et al. (2010), these currents were interpreted to be the product of wave-assisted sediment resuspension followed by gravity driven transport, and therein similar to better known turbidity currents in the deep sea. Irrespective of paleogeographic location, sediment-gravity flows, unlike fluid-gravity flows, for example rivers, owe their existence to suspended sediment that creates the requisite excess density, and therein the motive force for movement. Sediment-gravity flows differ in many important respects to fluid-gravity flows. Firstly, being driven by the excess density afforded by suspended sediment, even dilute sediment-gravity flows are significantly denser, especially in the stratigraphically important lower part of the current, compared to their fluid-gravity counterparts. Additionally, turbulence damping mechanisms like particle suspension and flow stratification are virtually absent in fluid-gravity flows. As a consequence, correlation of features in the mud-rich part of the shallow-marine (and deep-marine) sedimentary record with those in rivers is equivocal (Arnott, 2012; Tilston et al., 2015). Notably also, the isopachous nature of the stratification over horizontal scales of at least several tens of meters superimposed on a consistent upward fining and thinning of laminae is difficult to reconcile with a current ripple origin, even accepting the effects of post-depositional compaction.

Here it is argued that the ubiquitous plane-parallel stratification observed in both shallow- and deep-marine fine-grained strata is associated with deposition on a planar bed surface lacking the ability to initiate the development of angular bed forms like ripples (see also Tilston et al. 2015). Instead, stratification, in the form of alternating well-sorted, coarse and more poorly-sorted, finer layers, is interpreted to be the result of rhythmic changes in near-bed sediment concentration caused by longitudinal flow stratification and its effect on patterns of near-bed particle settling and transport. Variations in flow stratification relates to horizontal differences in flow velocity, which under time-averaged flow conditions (although superimposed on long-term flow waning) necessitates variations in particle concentration – specifically, lower velocity regions are more dense than higher velocity regions. The passage of these alternating regions over the bed results in a rhythmic alternation of fluid shear and suspension potential in the near-bed region, and ultimately in a flow near (sediment) saturation, the rhythmic alternation of competence- and capacity-driven deposition. With the passage of a faster, lower density region of the flow coarser particles were able to preferentially settle and be mobilized along bed, ultimately building up the few-particle-thick well-sorted layer. With the ensuing passage of a low velocity, high density region, capacity-driven deposition emplaced a layer of poorly-sorted sediment that quite likely resembles the granulometric make-up of the general sediment load in the near-bed region of the parent flow. Significantly, this mechanism requires rhythmic variations in flow conditions, which recently has been increasingly recognized in natural sediment-driven gravity flows (e.g. Kostachuck et al., 2018).

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