Hyperpycnal Rivers and Prodeltaic Shelves in the Cretaceous Seaway of North America*

By
Janok P. Bhattacharya[1] and James A. MacEachern[2]

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[1]Robert E. Sheriff Professor of Sequence Stratigraphy, Geosciences Department, University of Houston, Houston, Texas (jpbhattacharya@uh.edu)
[2]Department of Earth Sciences, Simon Fraser University, Burnaby, BC, Canada

Introduction

Despite many sedimentological textbooks assuming that the bulk of marine "shelf" mud is deposited by gradual fallout from suspension in quiet water, work on modern active muddy shelves such as Papua New Guinea and the Amazon Shelf show that mud is principally supplied from river plumes that may be hyperpycnal or hypopycnal. Storms and waves may also be critical in allowing fluid mud to continue to move geostrophically along the shelf, forming low-angle prodelta clinoforms. Despite the many corroborating modern examples, these concepts have not been widely applied to the interpretation of ancient sedimentary systems, such as the Cretaceous Western Interior Seaway of North America. Comparison of the paleohydraulics of many Cretaceous trunk river systems with those of modern hyperpycnal-prone rivers suggests that these systems frequently went hyperpycnal.

Example: Cretaceous Siliciclastics, Alberta

Associated flood deposits show extremely high sedimentation rates of up to 1 m per year. High sedimentation rates are indicated by an abundance of normally and inversely graded siltstone beds, climbing current ripples, and soft-sediment deformation features (Figures 1 and 2). Associated high physico-chemical stresses result in a paucity of infaunal burrowing, a general lack of structures of inferred suspension feeding organisms, and an abundance of fugichnia and equilibrichnia. Associated sandstones show Bouma successions, commonly with quasi-cyclic alternation of massive T_A division and horizontal-planar-parallel-laminated T_B-divisions, suggesting waxing-and waning flows. Graded siltstone-claystone beds locally record muddy (low-density) turbidites; where they are associated with syneresis cracks, they probably reflect freshet flood-induced emplacement, because the fresh-water laden sediment-gravity flow lies adjacent to the originally marine substrate. Such reductions in salinity are, however, short lived; the rapid return to fully marine conditions leads to the abrupt vertical juxtaposition of highly stressed, syneresis crack-bearing mudstones with bioturbated units containing structures recording the activities of organisms deemed intolerant of physico-chemical stresses (e.g., *Zoophycos*, *Phycosiphon*, *Asterosoma*, and *Scolicia*).

Rapidly emplaced fluid muds *via* hyperpycnal processes lead to organisms moving through the unit, imparting vague disruptions in delicate laminae. Such "sediment-swimming" organisms leave biogenic structures most easily detected where they cross the interface between beds of differing lithology; such disruptions are regarded as “mantle and swirl” structures. Where mudstones are more massive and laminae are not present, the fabric may appear unburrowed. In the case of thick fluid muds, this may, indeed, be the case, though sediment-swimming annelids may leave a subtle record. In the case of some shelf mudstones, however, the apparent lack of bioturbation is almost certainly a taphonomic control, wherein bioturbation is masked by a lack of lithologic contrast. Such units commonly display very high proportions of benthic foraminifera, indicating a thriving benthic community. Careful analysis of laminated black shales, commonly deemed to be anoxic and devoid of life, likewise shows the presence of burrows. With increasing silt content, the presence of bioturbation is generally readily apparent in such settings.

In hyperpycnal-prone prodeltaic settings, the biomass is generally reduced, so that trace fossil suites are impoverished. Where delicate laminae are preserved intact, sediment-swimming annelids were probably absent. Bioturbation, which is typically isolated, records deeper tier structures (e.g., *Chondrites*, *Thalassinoides*, bivalve equilibrium-adjustment structures, *Piscichnus*, and *Diplocraterion*) that have penetrated into the unit after its burial and semi-compaction. Surface grazing of hyperpycnal muds is rarely apparent; these units are rapidly emplaced, typically are composed of debris of terrestrial origin, and generally lack food resources compatible with the marine community. As a result, virtually all beds associated with hyperpycnal emplacement display low bioturbation intensities, highly sporadic distributions of burrowing, “top-down” penetrations, and abundant fugichnial and equilibrichnial behaviours.

In more wave-influenced deltaic successions, hummocky cross-stratification (HCS) beds and aggradational oscillation ripples draped with largely unburrowed, carbonaceous mud beds suggest a close (genetic) linkage between storms and hyperpycnal river discharge. Hyperpycnal conditions are probably easily met in relatively small wave- and storm-influenced deltas, where precipitation concomitant with the storm event results in significant increases in river discharge. Successive storm events also serve to rework previous flood deposits, leading to successions of hyperpycnal flood emplacement, mudstone beds, and HCS.

Mudstones associated with hypopycnal conditions, by contrast, show significantly higher abundances and diversities of ichnofauna. In such settings, mud flocculation from buoyant mud plumes creates a regime wherein mudstone deposition rates are more uniform (less episodic) and generally slower than in their hyperpycnal counterparts. Such mudstones tend to be more thoroughly burrowed, show shallow-tier (e.g., *Phycosiphon*, *Planolites*, and *Teichichnus*) as well as deep-tier structures (e.g., *Rosselia*, *Cylindrichnus*, *Ophiomorpha*, *Thalassinoides*, *Chondrites*, and *Zoophycos*), and display wider ranges of organism ethology, though dominated by deposit-feeding and grazing behaviors. Sediment-swimming organisms are probably less abundant in hypopycnal-dominated systems, although they may be present where thicker fluid mud beds are emplaced due to rapid mixing of storm-/flood-related buoyant mud plumes with basinal waters, heightening the rate of clay flocculation. In contrast to the non-deltaic offshore zones, however, even these suites remain impoverished, dominated by facies-crossing ichnological elements, and a paucity of suspension-feeding/filter-feeding organisms due to greater than optimal water turbidity.

On the shelf, deltaic overprint (acting as the principal source of sediment) is readily apparent. Shelf settings that experience *neither* hypopycnal nor hyperpycnal processes are characterized by heightened carbonate production and an increase in nektonic calcareous microfauna. Bioturbation intensities tend to be high, with unstressed, fully marine ichnological suites showing complex overprint of successive tiers. By contrast, shale-dominated “shelf” mudstones display a strong prodeltaic overprint, are characterized by impoverished micro-fauna, limited mainly to arenaceous benthic foraminifera, and show sediment-swimming structures, sporadic bioturbation, and lower trace fossil diversities.

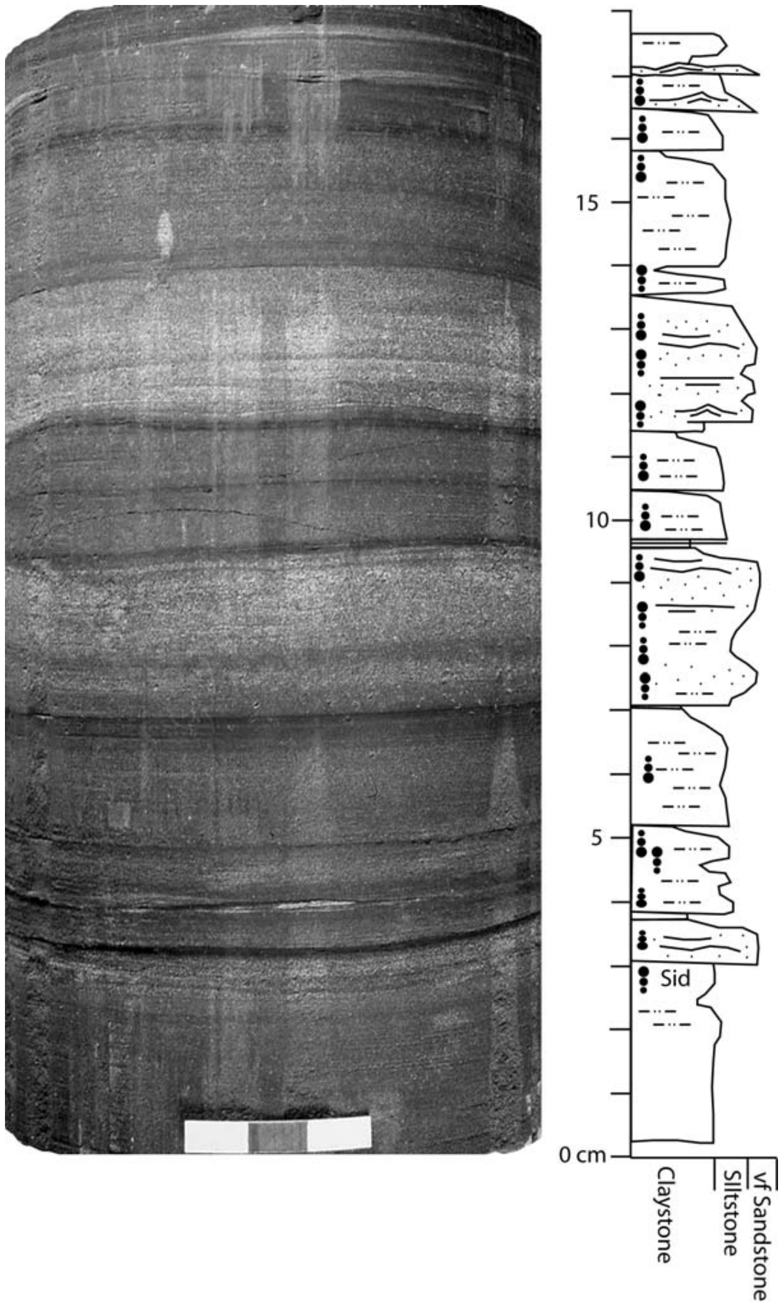

Figure 1. Core photo of prodelta hyperpycnites from the Cretaceous Dunvegan Formation, Alberta, Canada, showing normal and inverse grading and a lack of burrowing.

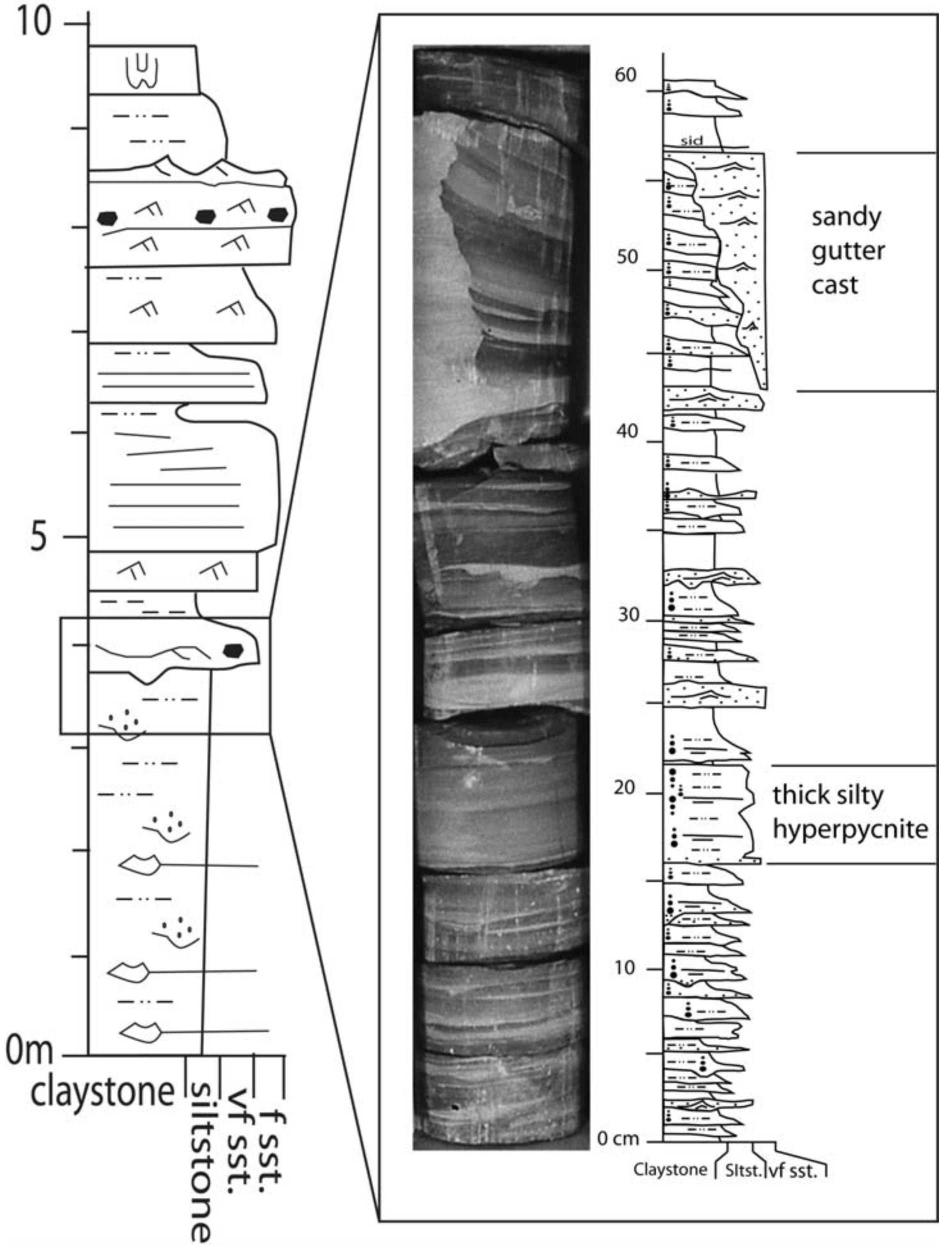

Figure 2. Photos and descriptions of a 10 m thick, storm-wave-influenced prograding, river-flood-dominated delta facies succession. Photo inset highlights abundant normal and inverse graded beds, differential compaction around hummocky-filled gutter cast and shows the general lack of burrowing. Cretaceous Dunvegan Fomation, Allomember E, Alberta, Canada.