[PS]Prodelta Hyperpycnites: Facies, Processes and Reservoir Significance - Examples from the Lower Cretaceous of Russia*

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Abstract

Current depositional models enhance the importance of delta front sandstones as the main clastic reservoir related to marine littoral deltas. In contrast, prodelta deposits are considered poor or non-reservoir deposits composing a narrow fringe of fine-grained sediments mainly accumulated by fallout from the buoyant plume (hypopycnal flow). Controversially, growing evidences show that most prodeltas are characterized by low gradient and extensive clastic wedges composed of fine-grained sediments. These deposits can extend for hundreds of kilometers from the coast, and are mostly composed of meter to decameter thick coarsening and thickening upward successions of fine-grained heterolites (sand-silt couplets). This basinward extension is possible because the seasonal occurrence at river mouth of sustained muddy hyperpycnal flows during floods, allowing the transfer of a huge volume of clastic sediments farther offshore. According to their direct linkage with fluvial discharges, muddy prodelta hyperpycnites often content abundant phytodetritus, which enhances their potential as unconventional resources of oil and gas. Fine-grained heterolites are often characterized by abundant clean sandstones forming thin levels interbedded with shales. These last characteristics together with their wide areal extension could result in important conventional clastic reservoirs especially in shallow oilfields. Early Cretaceous (Aptian) Karabashskiy Oil & Gas discovery in western Siberia provides an example of the importance of prodelta hyperpycnites as a large conventional reservoir. Main reservoirs are shallow marine fine-grained heterolithics deposits of the Leushinskaya and Vikulovo formations, interpreted as prodelta hyperpycnites. Trace fossils are locally abundant, with an association considered typical of prodelta settings. Individual beds are internally graded and centimeter to decimeter thick. Sedimentary structures include HCS, planar lamination, climbing ripples, wave bedding, lenticular bedding and lofting rhythmites. Most beds are disposed over a basal erosional surface and display internal evidences of multiple waxing-waning cycles related to velocity fluctuating muddy hyperpycnal flows. These deposits are stacked forming cycles of different hierarchical orders, probably reflecting seasonal and periodic changes in the associated deltaic activity.

Prodelta hyperpycnites: facies, processes and reservoir significance.

Examples from the Lower Cretaceous of Russia

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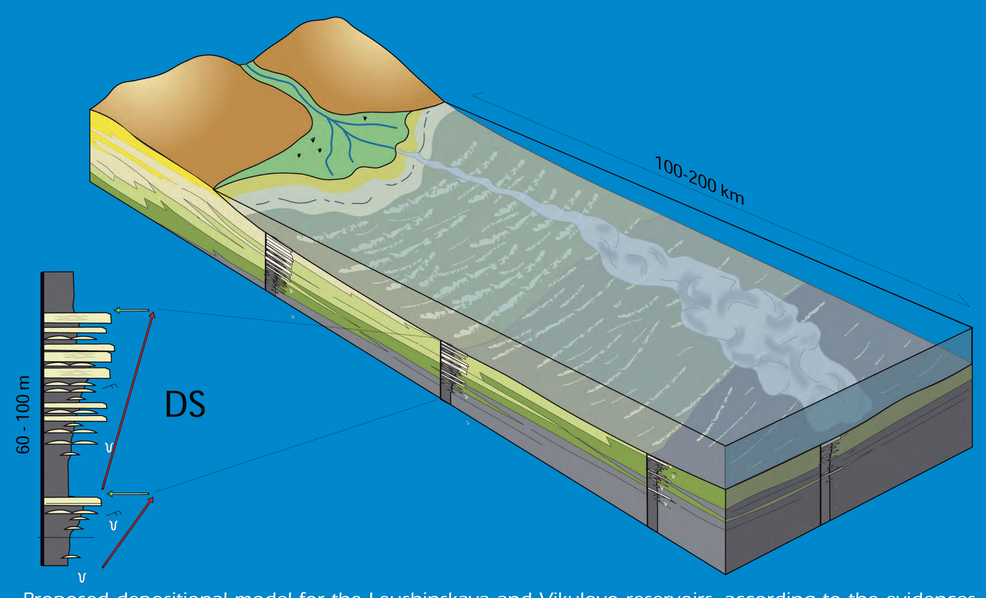
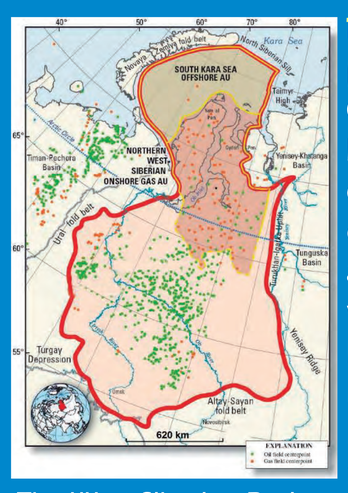
1. Introduction

Current depositional models enhance the importance of delta front sandstones as the main clastic reservoir related to marine littoral deltas. In contrast prodelta deposits are considered poor or non-reservoir deposits composing a narrow fringe of fine grained sediments mainly accumulated by fallout from the buoyant plume (hypopycnal flow). Controversially, growing evidences show that most prodeltas are characterized by low gradient and extensive clastic wedges composed of fine grained sediments. These deposits can extend for hundreds of kilometers from the coast, and are mostly composed of meter to decameter thick coarsening and thickening upward successions of fine grained heterolites (sand-silt couplets). This basinward extension is possible because the seasonal occurrence at river mouth of sustained muddy hyperpycnal flows during floods, allowing the transfer of a huge volume of clastic sediments farther offshore. According to their direct linkage with fluvial discharges, muddy prodelta hyperpycnites often content abundant phytodetritus, which enhances their potential as unconventional resources of oil and gas. Fine grained heterolites are often characterized by abundant clean sandstones forming thin levels interbedded with shales. These last characteristics together with their wide areal extension could result in important conventional clastic reservoirs especially in shallow oilfields.



Proposed depositional model for the Leushinskaya and Vikulovo reservoirs, according to the evidences provided by sedimentology, facies analysis and biostratigraphy. Depositional sequences (DS) conform prograding coarsening and thickening upward successions up to 100 meters thick, bounded by regional flooding surfaces.

2. Example from the Karabashkyi oil field

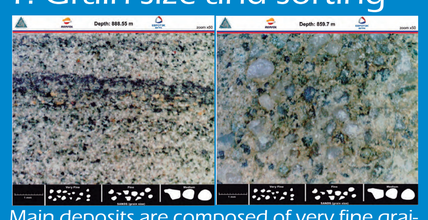


The West Siberian Basin.

Early Cretaceous (Aptian) Karabashskiy Oil & Gas discovery in the West Siberian Basin provides an example of the importance of prodelta hyperpycnites as a large conventional reservoir. Main reservoirs are shallow marine fine-grained heterolithics deposits of the Leushinskaya and Vikulovo formations, interpreted as prodelta hyperpycnites.

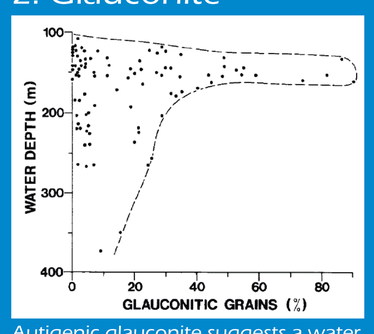
3. Key points for understanding the sedimentological model

1. Grain size and sorting



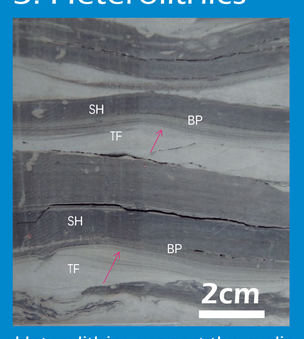
Main deposits are composed of very fine grained sand-silt deposits. Siliciclastic grains are regular and well sorted, and are associated with plant remains (PR) and siderite (SI) grains. Note that plant remains are aligned.

2. Glauconite



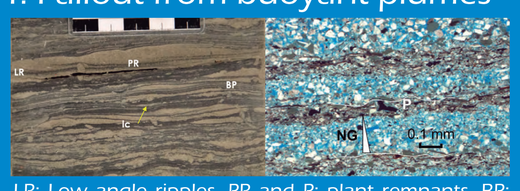
Autigenic glauconite suggests a water depth between 100 and 700 meters. Bornhold et al. (1981).

3. Heterolithics



Heterolithics suggest the cyclic accumulation of sandstones and shales by different and recurrent depositional processes, like traction plus fallout, and fallout from buoyant plumes.

4. Fallout from buoyant plumes

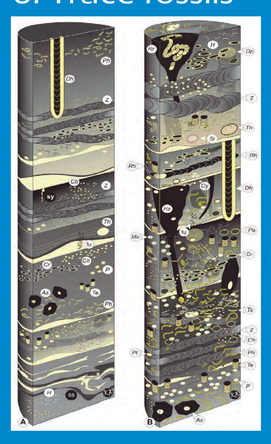


LR: Low angle ripples, PR and P: plant remnants, BP: Buoyant plume deposits, Ic: load casts. NG: Normal gradding

5. Synaeresis cracks

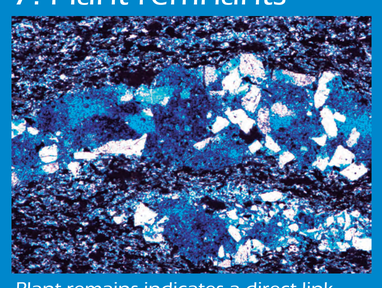
Synaeresis cracks suggest drastic changes in salinity

6. Trace fossils



A trace fossil association typical of prodelta deposits: As: Asterosoma, Pa: Paleophycus, Ch: Chondrites, Pl: Planolites, Ph: Phycosiphon.

7. Plant remnants

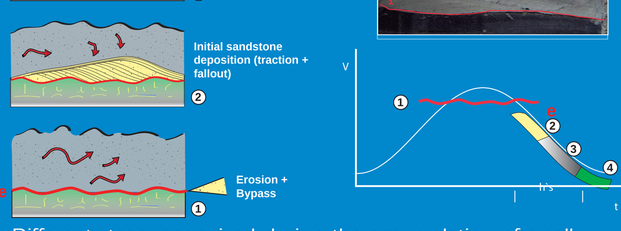


Plant remains indicates a direct link with fluvial discharges.

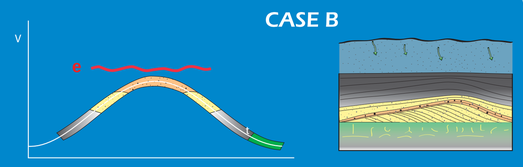
4. CYCLICITY PATTERNS

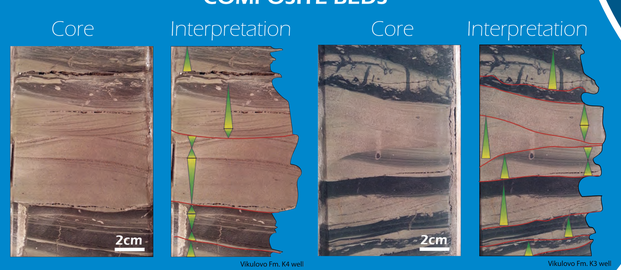
4.1 Bed

Beds are the building blocks of prodelta successions. Cycles are related to punctuated fluvial discharges



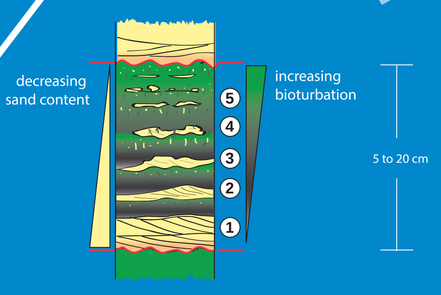
Different steps recognized during the accumulation of small scale graded beds. 1. Erosion plus bypass. 2. Initial sandstone deposition. 3. Final deposition of silts. 4. Bioturbation.

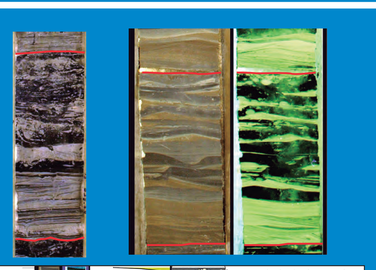


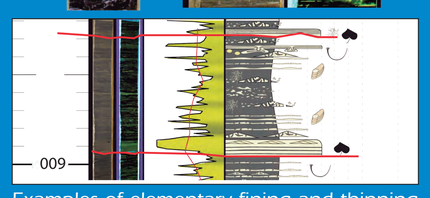


Composite beds display multiple internal erosions and grain size changes, suggesting long lived and fluctating turbulent flows

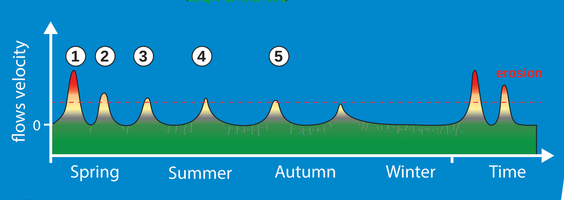
4.2 Bedset





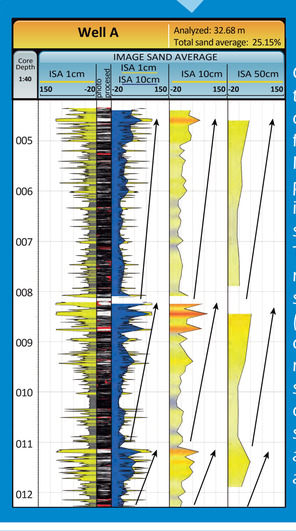


Examples of elementary fining and thinning upward cycles, bounded by sharp or erosional surfaces.

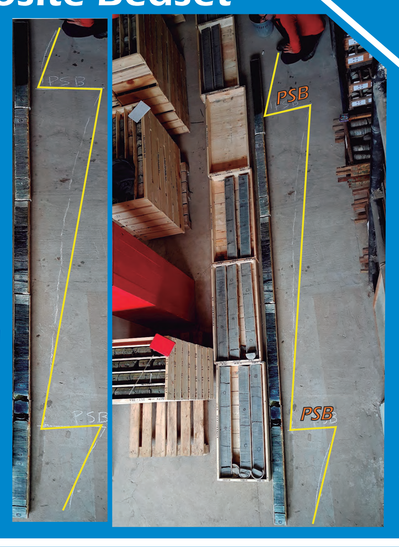


Elementary cycles in the stratigraphic record and their possible stratigraphic significance, as related to seasonal changes in the fluvial discharge in the associated deltas.

4.3 Composite Bedset



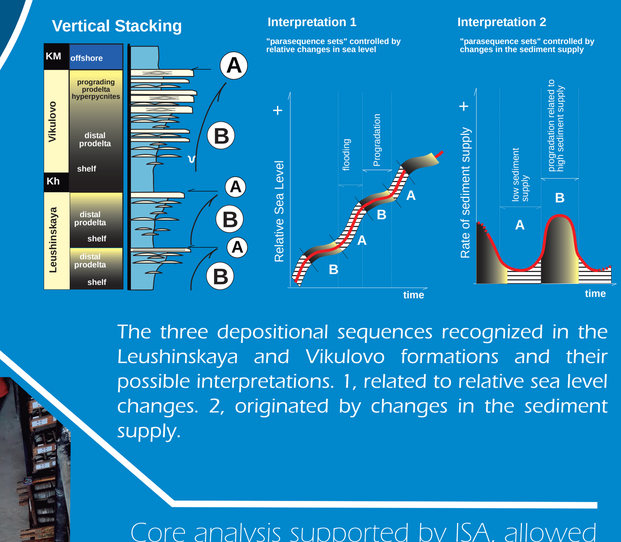
Coarsening and thickening upward cycles recognized from the analysis of ISA. Note the progressive increment in the sandstone content. These cycles can be related to relative sea level changes (shallowing-upward cycles separated by regional flooding surfaces), or changes in the sediment supply in associated deltaic areas.



Core analysis supported by ISA, allowed the distinction of meter to decameter-scale coarsening and coarsening-fining upward cycles, at the scale of parasequences (Van Wagoner, 1990). These parasequences are internally composed by stacked bedsets, and can be considered as composite bedsets.

Small scale coarsening and thickening upward cycles (parasequences).

4.4 Sequences



Calibration of the three recognized depositional sequences with the global standard chronostratigraphy and global sea level changes.

The three depositional sequences recognized in the Leushinskaya and Vikulovo formations and their possible interpretations. 1, related to relative sea level changes. 2, originated by changes in the sediment supply.

5. Distinctive characteristics of muddy prodelta hyperpycnites

1. Dominance of cm-thick graded vf ss - siltstone deposits. Basal erosional scours. **2.** Single beds with internal variations in grain size and sedimentary structures, suggesting fluctuating quasi-steady turbulent flows. **3.** Common wave reworking on top. **4.** Lofting rythmites, suggesting flows with interstitial freshwater in marine setting. **5.** Accumulation in shelfal areas with very gently slopes, typically between 0.2 and 0.01 degree. **6.** Deposits extended for 10´s to 100´s of kilometders with no or limited changes in facies and grain size. **7.** Variable degree of bioturbation (Paleophycus, Chondrites, Planolites, Phycosiphon, Teichichnus, Thallasinoides, Asterosoma, Cylindrichnus). Fugichnia nd Navichnia traces. **8.** Abundant transported phytodetritus and freshwater microfossils from continental and coastal areas. After Bhattacharya & MacEachem, 2009; Zavala et al., 2006, 2011; Wilson & Schiever, 2014.

6. Analogs

Some ancient and recent analogs of the muddy prodelta hyperpycnites of the Leushinskaya and Vikulovo reservoirs.

BASIN	UNIT	AGE	BED THICKNESS	GRAIN SIZE	DISTANCE FROM SHORELINE	SHELF SLOPE	REFERENCES
N. Appalachian	Lower Genesee Gp.	M. Devonian	1- 10 cm	VF SS / SILT	> 130 Km	< 0.3º	Wilson & Schieber, 2014
W. Interior Seaway	Ferron SS. Mb.	Turonian	1-50 cm	VF SS / SILT	> 100 Km	0.04º - 0.2º	Bhattacharya & MacEachern, 2009
W. Interior Seaway	Dunvegan Fm.	Cenomanian	0.1 - 1 cm	VF SS / SILT	30 -120 km	0.01º - 0.03º	Bhattacharya & MacEachern, 2009; Bhattacharya, 2015; Plint, 2012.
W. Interior Seaway	Lewis Shale	Cretaceous	1 - 10 cm	VF SS / SILT			Soyinca & Slatt, 2008
W. Interior Seaway	Blackhawk Fm.	Cretaceous	0.3 - 10 cm	VF SS / SILT	16 - 21 km		Pattison, 2005; Pattison et al., 2007
W. Interior Seaway	Kaspapau Shale	Cretaceous		VF SS / SILT	up to 250 km		Varban & Plint, 2008
Argentine Precordillera	Punta Negra Fm	L-M Devonian	1 - 50 cm	VF SS / SILT			Vieira de Luca & Basilici, 2013
Central Colorado Basin	Minturn Fm	Pennsylvanian	< 2 - 100 cm	VF SS / SILT			Lamb et al., 2008
Mediterranean	Rhone Delta	recent	1 - 5 cm	VF SS / SILT	4 -16 km		Mulder et al., 2015; Fanget et al., 2012