Interstratification of Deltaic and Bay Sedimentation in a Marginal-Marine, Wave-Influenced Coastline: The Glauconite Formation, Alberta, Canada

Scott E. Botterill[1], William Clark[2], M. Ryan King[3], and Murray K. Gingras[1]

[1]Department of Earth and Atmospheric Sciences, University of Alberta

[2]Timberrock Energy Corporation

[3]Natural and Environmental Sciences Department, Western Colorado University

Summary

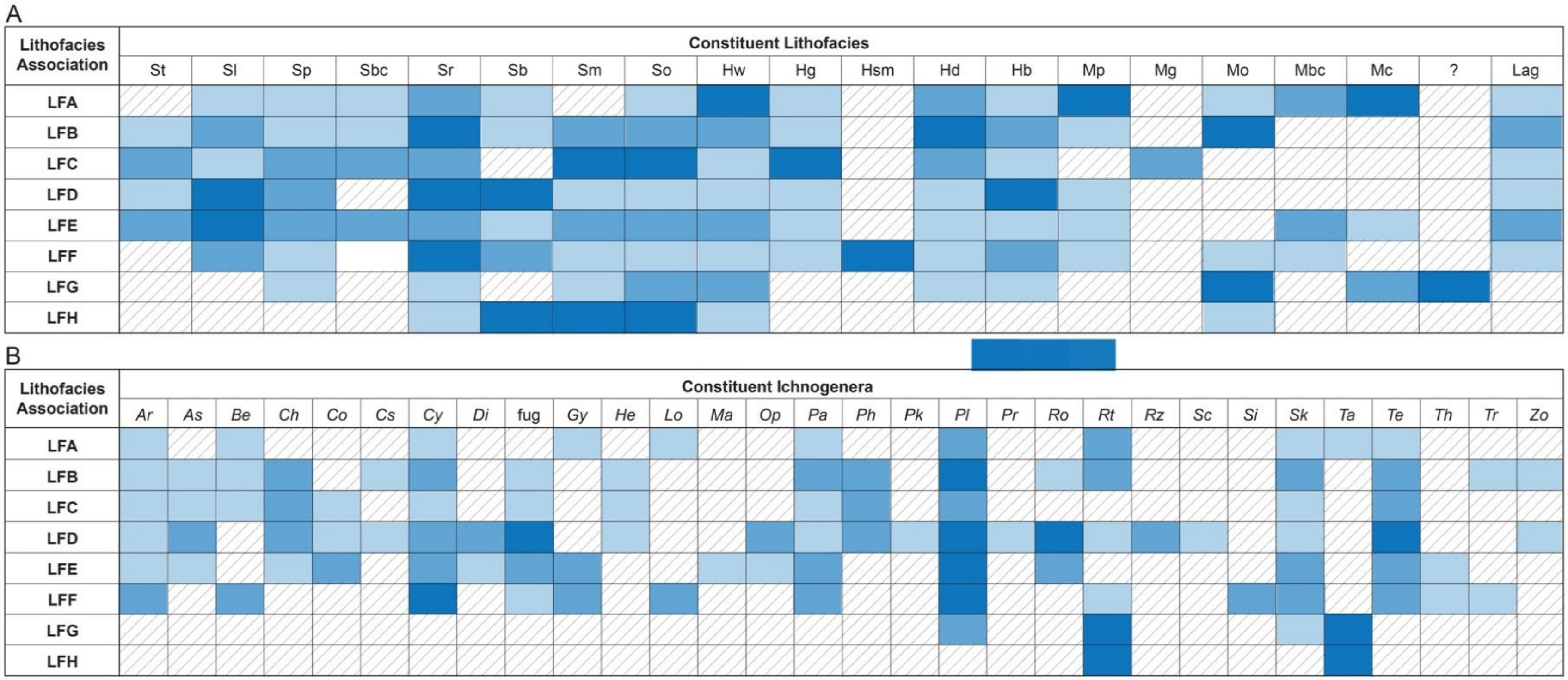
Dr. S. George Pemberton revolutionized ichnology by combining ichnological principles with facies models. In that spirit, the Lower Cretaceous Glauconite Formation in the Garrington Field, Alberta is presented here as an integrated analysis of ichnology, sedimentary facies, and sequence stratigraphy. Previous studies have identified a number of depositional environments within the Glauconite Formation, including prograding shoreface, barrier island, tidal channel and fluvial channel complexes (e.g. Hopkins et al., 1982; Chiang, 1984; Rosenthal, 1988; Strobl, 1988; Brownridge and Moslow, 1991). Within the project area, high-resolution facies analysis including sedimentological, ichnological, and sequence stratigraphic observations are lacking. Such work is important, as the Glauconite Formation in the Garrington Field is a producer of light oil and condensate and an understanding of the architecture and physical properties of reservoir-quality strata is essential for development and future exploration activity.

Database and Methods

35 core and ~ 150 wireline logs within an 800 km^2 area comprise the dataset for this study. No seismic or dip-meter data was available. Here, the Glauconite lies completely within the subsurface at depths between 2300 – 3030 m TVD. Each core was logged at the bed scale using AppleCore© software. In addition to physical sedimentary structures and lithology, bioturbation index (following Taylor and Goldring, 1991), ichnogeneric identification, and ichno-fossil distribution was recoded. A subset of 8 core were processed using PyCHNO (Timmer et. al., 2016) to calculate size diversity index (*sensu* Hauck et al., 2009) and the overall percentage of physical sedimentary structures attributable to wave-, tide- and fluvial-modulation. Stratal packages were then assigned a name base on the tripartite methodology of Ainsworth et al., (2011).

Results and Discussion

Twenty discrete lithofacies, comprising eight lithofacies associations were identified within the dataset. Constituent lithofacies and ichnogenera presence/absence and abundance are summarized in Table 1a and 1b, respectively. Table 1c summarizes the interpretation and diagnostic criteria of each observed lithofacies.



C

Lithofacies Association	Interpretation	Diagnostic Criteria
LFA	Brackish- to Fresh-Water Bay	rare to absent bioturbation; low-energy sedimentation; fresh-water affinity of limestone beds (Holmden et al., 1997); presence of brackish-water ichnofacies
LFB	Brackish, River-dominated prodelta to delta plain	shoaling-upward sequence; highly sporadic bioturbation; diminutive trace fossils; low-diversity assemblage; common convolute bedding; capped by rooted, organic-rich interval.
LFC	Brackish- to Marine River-dominated prodelta to distal delta front	shoaling-upward sequence; highly sporadic bioturbation; diminutive trace fossils; abundant graded beds, synaeresis cracks and fluid escape structures; presence of marine ichnogenera (i.e. *Phycosiphon, Asterosoma, Helminthopsis)*
LFD	Wave-dominated prodelta to delta front	shoaling-upward sequence; sporadic to irregular heterogeneous bioturbation; abundant oscillation ripples; robust, marine-indicative ichnogenera (*Rosselia, Scolicia, Rhizocorallium, Zoophycos);* common interbedding of bioturbated and laminated beds (tempestites)
LFE	Storm-dominated prodelta to delta front (including distributary channel)	shoaling-upward sequence; sporadic bioturbation, amalgamated erosive-based beds; common HCS, local trough cross-bedding; abundant organic detritus; dominance of vertical, robust ichnogenera (i.e. *Skolithos, Ophiomorpha, Conichnus*)
LFF	Tide-influenced sub-tidal to upper inter-tidal estuarine/tidal flat	fining-upward sequence; presence of tidally generated structures (i.e. double mud drapes); low-diversity trace-fossil assemblage; high bioturbation intensity; sharp but non-erosive heterlithic sandstone and mudstone facies.
LFG	Delta plain overbank (floodplain, swamp and palaeosol)	poorly sorted, fine-grained facies; commonly rooted; presence of abundant *Taenidium;* poorly to moderately developed peds and cutans; high organic content; presence of calcareous mudstone facies (palustrine)
LFH	Abandoned beach ridge/fluvial channel?	massive, aggradational, poorly sorted; heavily rooted and organic rich; abundant *Taenidium*; rarely preserved current ripple cross-lamination; evidence of early palaeosol development (leaching of upper surface)

Abbreviations

Ichnogenera

Ar = Arenicolites
As = Asterosoma
Be = Berguearia
Ch = Chondrites
Co = Conichnus
Cs = Cosmoraphe
Cy = Cylindrichnus
Di = Diplocraterion
fug = fugichnia
Gy = Gyrolithes
He = Helminthopsis
Lo = Lockeia
Ma = Macaronichnus
Op = Ophiomorpha
Pa = Palaeophycus
Ph = Phycosiphon
Pk = Polykladichnus
Pl = Planolites
Pr = Protovirgularia
Ro = Rosselia
Rt = Rootlets
Rz = Rhizocorallium
Sc = Scolicia
Si = Siphonichnus
Sk = Skolithos
Ta = Taenidium
Te = Teichichnus
Th = Thalassinoides
Tr = Trichichnus
Zo = Zoophycos

Lithology/Physical Structures

S = Sandstone
H = Heterolithic
M = Mudstone
t = trough cross-bedding
l = low-angle cross-bedding
p = planar bedding
r = ripple cross-lamination
bc = bioclastic
m = massive
o = organic
w = wavy bedding
g = graded bedding
sm = sandstone/mudstone
d = deformed
b = bioturbated
c = calcareous

Abundant **Common** **Rare** **Absent**

A number of observations can be made regarding the results of this research thus far, including: 1) the Glauconite Formation consists of a number of parasequences comprising a parasequence set that is overall progradational; 2) an evolution from mixed river- and wave-dominated into storm-dominated strata is observed; 3) ichnologic and sedimentologic data suggest these parasequences represent a river- and wave- to storm-dominated deltaic complex prograding into a shallow, brackish- to periodically fresh-water bay (Ostracod Member) as opposed to a strandplain shoreface (see Table 1c); and, 4) from a reservoir perspective the Garrington Field is compartmentalized into three reservoir units (units 1-3 on Figure 1) where units 1 and 2 are separated by prodelta and distal delta front facies above a transgressive ravinement surface, and units 2 and 3 are separated by delta plain intertidal and supratidal facies.

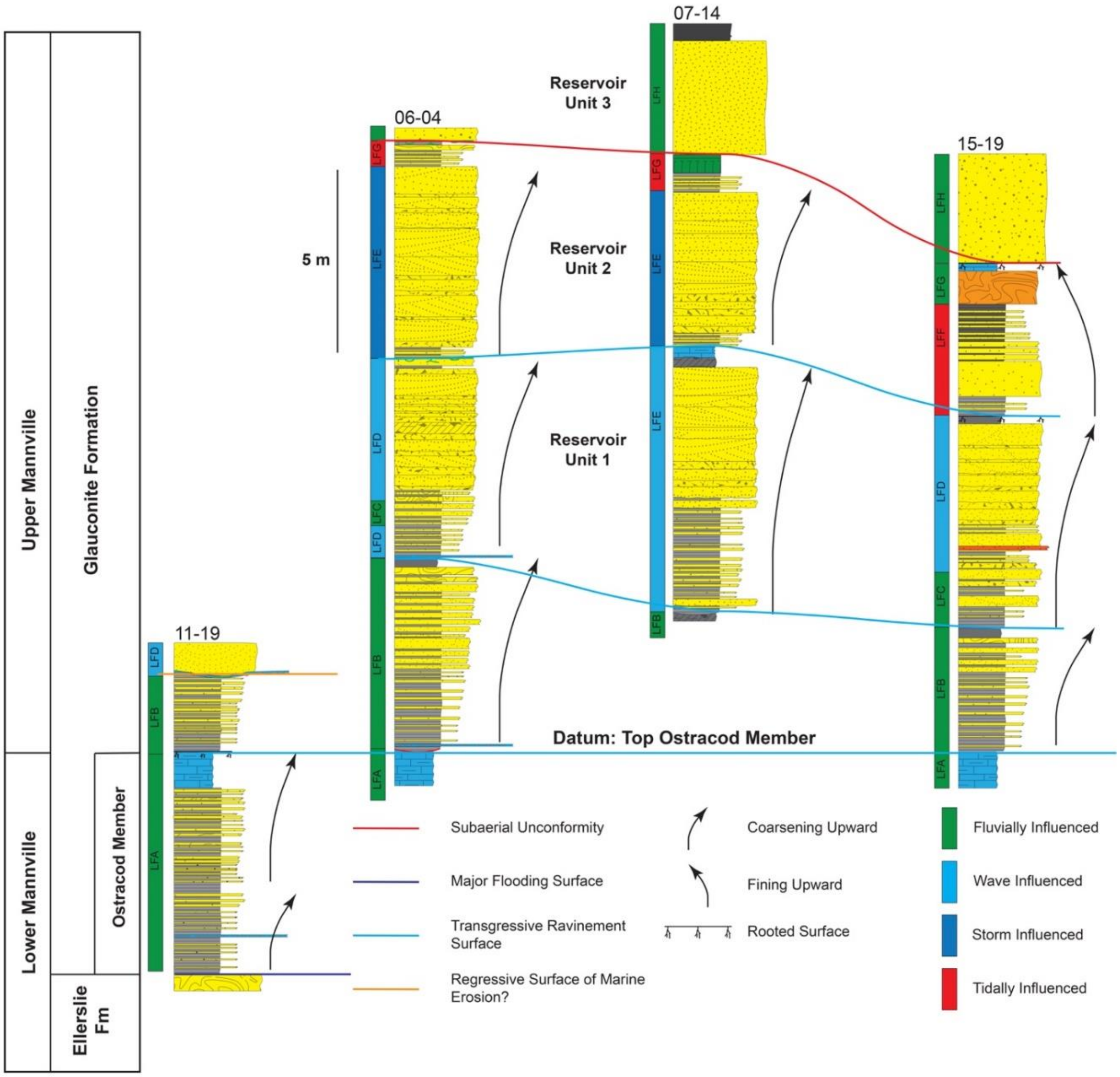


Figure 1. Summary of Glauconite stratigraphy and reservoir distribution in the Garrington Field.

Conclusions

The Glauconite Formation at Garrington consists of up to 3 progradational parasequences deposited in a deltaic environment. The delta progrades into a shallow, brackish- to fresh-water bay and evolves from river-dominated to wave-dominated and finally storm-dominated in an upward stratigraphic direction.

These parasequences are capped by a delta plain succession consisting of rooted over-bank deposits, weakly to moderately developed palaeosols, and calcareous mudstone interpreted as swamp deposits. Finally, a sub-areal unconformity separates deltaic strata below from fluvial strata above. The reservoir is compartmentalized into 3 units, with units 1 and 2 separated by a transgressive ravinement surface and subsequent prodelta to distal delta front deposition, whereas 2 and 3 are separated by variable amounts of delta plain facies (See Figure 1). This study emphasizes the importance of combining ichnologic and sedimentologic data for facies analysis in subsurface datasets and has enabled the prediction of reservoir-quality facies into areas that have been sparsely drilled.

Acknowledgements

The authors would like to thank Timberrock Energy for funding of this research and William Clark for technical support. S.E.B. is grateful to the National Science and Engineering Research Council for project funding through a PGS-D research grant. Finally, Dr. S. George Pemberton is sincerely thanked for the invaluable input, advice and mentorship for the author's ongoing doctoral research.

References

Ainsworth, R.B., Vakarelov, B.K., Nanson, R.A., 2011. Dynamic spatial and temporal prediction of changes in depositional processes on clastic shorelines: Toward improved subsurface uncertainty reduction and management. American Association of Petroleum Geologists, v. 95(2), p. 267-297.

Brownridge, S. and Moslow, T.F. 1991. Tidal Estuary and Marine Facies of the Glauconitic Member, Drayton Valley, Central Alberta. In: Clastic Tidal Sedimentology. D.G. Smith, G.E. Reinson, B.A. Zaitlin, and R.A. Rahmani (eds). Canadian Society of Petroleum Geologists, Memoir 16, p. 107-122.

Chiang, K.K. 1984. The Giant Hoadly Gas Field, South-Central Alberta. In: Elmworth, Case Study of a Deep Basin Gas Field. J.A. Masters (ed). American Association of Petroleum Geologists, Memoir 38, p. 297-315.

Hauck, T.E., Dashtgard, S.E. and Gingras, M.K. 2009. Brackish-water ichnological trends in a microtidal barrier island/embayment system, Kouchibouguac National Park, New Brunswick, Canada. Palaios, vol. 24, p. 478-496.

Holmden, C., Muehlenbachs, K. and Creaser, R.A. 1997. Depositional environments of the Early Cretaceous Ostracode Zone: Paleohydrologic constraints from O, C and Sr isotopes. In: Petroleum Geology of the Cretaceous Mannville Group, Western Alberta. S.G. Pemberton and D.P. James (eds). Canadian Society of Petroleum Geologist, Memoir 18, p. 77-92.

Hopkins, J.C., Hermanson, S.W. and Lawton, D.C. 1982. Morphology of Channels and Channel-Sand Bodies in the Glauconitic Sandstone Member (Upper Mannville), Little Bow Area, Alberta. Bulletin of Canadian Petroleum Geology, vol. 30, p. 274-285.

Rosenthal, L. 1988. Wave Dominated Shorelines and Incised Channel Trends: Lower Cretaceous Glauconite Formation, West-Central Alberta. In: Sequences, Stratigraphy, Sedimentology: Surface and Subsurface. D.P. James, and D.A. Leckie (eds). Canadian Society of Petroleum Geologist Memoir 15, p. 207-220.

Strobl, R. S. (1988). The Effects of Sea-Level Fluctuations on Prograding Shorelines and Estuarine Valley-Fill Sequences in the Glauconitic Member, Medicine River Field and Adjacent Areas. In: Sequences, Stratigraphy, Sedimentology: Surface and Subsurface. D.P. James, and D.A. Leckie (eds). Canadian Society of Petroleum Geologist Memoir 15, p. 221-236.

Taylor, A.M., and Goldring, R., 1993. Description and analysis of bioturbation and ichnofabric. Journal of the Geological Society of London, v. 150, p. 141-148.

Timmer, E.R., Gingras, M.K. and Zonneveld, J.P. 2016. PyCHNO: a core-image quantitative ichnology logging software. Palaios, vol. 31, p. 525-532.