Integration of allostratigraphy with organic geochemistry: Implications for stratigraphic and spatial distribution of organic matter in a foreland basin

Jessica Flynn*, Department of Earth Sciences, Western University, London, Ontario, Canada N6A 5B7

jflynn3@uwo.ca

and

Burns Cheadle, Department of Earth Sciences, Western University, London, Ontario, Canada N6A 5B7

GeoConvention 2012:Vision

Summary

Petroleum system characterization models are required to effectively predict hydrocarbon flow behaviour in complex, heterogeneous, self-sourcing carbonaceous mudstone reservoirs. Integration of high-frequency allostratigraphic framework with organic geochemical characteristics is a fundamental step in recognizing stratigraphic and spatial variability within mudstone petroleum systems. Application of this method to the Upper Cretaceous Colorado Group in the Western Canada foreland basin revealed a distinct stratigraphic and geochemical shift in the backbulge segment of the basin. Implications of this observation suggest organic matter composition, fabric and stratigraphic distribution may be unique to its position within a foreland basin.

Introduction

Recent studies of Colorado Group mudstone-dominated successions (Tyagi et al., 2007; Varban and Plint, 2008; Hu and Plint, 2009; Plint et al., 2009) illustrate tectonic and eustatic controls on sediment dispersal and stratigraphic preservation in the Western Canada foreland basin. The depositional and burial processes resulting from these allogenic controls contribute to observed mineralogical, sedimentological, and textural heterogeneity in mudstones (e.g.: MacQuaker et al., 2007; Aplin and MacQuaker, 2011). Petroleum system characterization must explicitly address process dynamics leading to mudstone heterogeneity in order to predict hydrocarbon flow behaviour in these complex reservoirs (Aplin and MacQuaker, 2011; Cheadle, 2011). Understanding the depositional and burial domain processes governing the relationship between allogenic controls, mudstone fabric and preserved organic matter characteristics is a critical step in dynamic characterization of “shale oil” and “shale gas" petroleum systems.

The Upper Cretaceous Colorado Group spans the foredeep, forebulge, and backbulge segments of the Cretaceous foreland basin of western Canada, preserving a broad spectrum of depositional and burial histories of carbonaceous mudstone strata. This diverse record, along with abundant public domain data, provides an exceptional opportunity for dynamic reservoir characterization of carbonaceous mudstone petroleum systems. The initial phase of our research focuses on integration of organic geochemical characteristics with a basinwide high-frequency allostratigraphic framework. This step provides the foundation for subsequent regional burial history and petroleum system modeling.

Theory

Recent studies have challenged the enduring belief that organic matter preservation is uniquely associated with the “pelagic rain” of suspension deposits in deep, anoxic environments. Experimental and petrographic evidence suggests that advective transport of biologically or chemically produced mud floccules occurs in relatively energetic, and potentially oxic, settings (Schieber et al., 2007; Wright and

Friedrichs, 2006; MacQuaker et al., 2010). Productivity-driven formation of organomineralic aggregates, or “marine snow”, can facilitate organic matter preservation through persistence of intra-aggregate anoxic microenvironments within an otherwise oxic water column (MacQuaker et al., 2010; Aplin and MacQuaker, 2011).

MacQuaker and Plint (2011) have documented long-distance advective transport of organic-rich mud floccule aggregates as wave-enhanced sediment gravity flows in the Kaskapau Formation of the WCSB foredeep, with organization that may be rationalized within a high-frequency allostratigraphic framework. By extension, this suggests that reactive carbon enrichment in Colorado Group mudstones may be related to marine snow depositional processes. Petroleum system analysis of these strata, therefore, must embed regionally-consistent allostratigraphic interpretation in order to reflect high-frequency allogenic controls on source rock properties.

Results

The Upper Cretaceous Colorado Group has been previously divided based on lithostratigraphic (Bloch et al., 1993; Schroder-Adams et al., 1996) and allostratigraphic (Tyagi et al., 2007; Roca et al., 2008; Varban and Plint, 2005) methods. The high-frequency allostratigraphic framework of this study extends the previous work of Tyagi et al (2007) into the forebulge and backbulge segments of the foreland basin. The resulting framework constrains interpretation of organic geochemical properties derived from legacy and new Rock-Eval pyrolysis analyses. Initial results indicate a potential link between stratigraphy and organic geochemical characteristics. A depth versus percent pyrolysable carbon (%PC) plot indicates a distinct stratigraphic break in %PC content in a backbulge basin location. Geochemical data suggest a distinct cluster of type II kerogen in the upper zone with predominately type III organic matter in the underlying section. This relationship has not been observed in our forebulge and foredeep samples to date, suggesting that disseminated organic matter characteristics may be constrained spatially as well as stratigraphically.

Discussion

Preliminary results suggest that a relationship exists between stratigraphic bounding surfaces and organic geochemical characteristics in the backbulge. The observed shift from hydrogen-poor Type III organic matter to hydrogen-rich, type II organic matter could be indicative of a cryptic stratigraphic hiatus. Alternatively, the shift in organic matter type may signify a change in productivity and preservation of organic matter in the backbulge segment of the basin. Such a shift could be reflective of a unique depositional regime, responding to interplay of allogenic drivers in a manner different than the foredeep regime. It remains to be seen if the composition, fabric and stratigraphic distribution of organic matter exhibits consistency between foreland basin segments. Future work will address this question in the context of developing petroleum system models that differentiate regional variation in self-sourcing carbonaceous mudstone reservoirs.

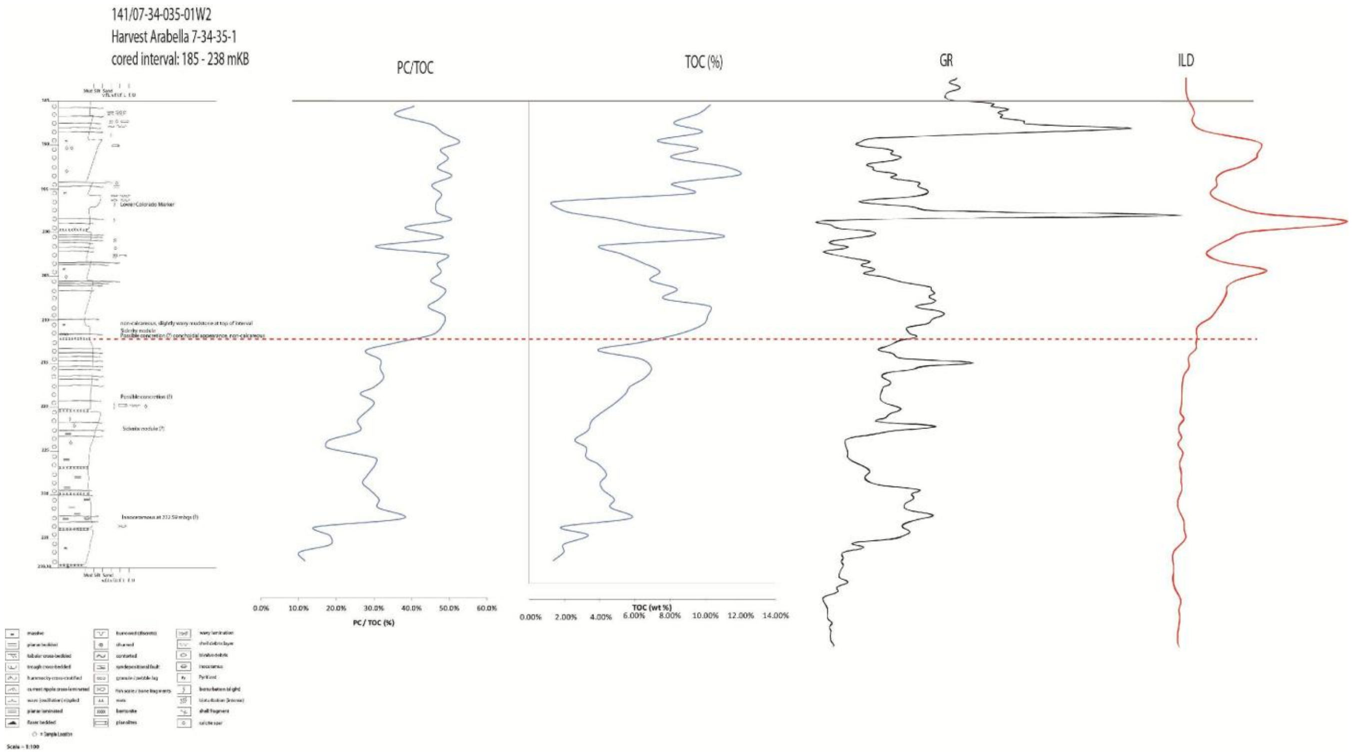

Figure 1. Core-log correlation with Rock-Eval pyrolysable to total organic carbon ratio (PC/TOC) and weight percent total organic carbon (TOC) for Harvest Arabella 7-34-35-01W2. Gamma-Ray (GR) and deep resistivity (ILD) curves shown for reference. The red dashed line indicates an upward shift from hydrogen-poor type III organic matter to hydrogen-rich, type II organic matter.

Acknowledgements

We thank Mr. Bill Bell for his generous support of the petroleum geosciences program at Western, and Dr. Guy Plint for his continual support and guidance.

References

Aplin, A.C., and MacQuaker, J.H., 2011, Mudstone diversity: Origin and implications for source, seal, and reservoir properties in petroleum systems: AAPG Bulletin, **95**, 2031-2059.

Bloch, J., C. Schröder-Adams, D. Leckie, D. McIntyre, J. Craig, and M. Staniland, 1993, Revised stratigraphy of the lower Colorado Group (Albian to Turonian), western Canada: Bulletin of Canadian Petroleum Geology, **41**, 325-348.

Cheadle, B. A., 2011, Reservoir Characterization of Organic-Rich Mudstones: Path to Peril or Profit?: Oral and poster presentation at 2011 CSPG CSEG CWLS Convention, May 9 - 13, Calgary, AB.

Hu, Y.G., and Plint, A.G., 2009, An allostratigraphic correlation of a mudstone-dominated, syn-tectonic wedge: the Puskwaskau Formation (Santonian-Campanian) in outcrop and subsurface, Western Canada Foreland Basin: Bulletin of Canadian Petroleum Geology, **57**, 1-33.

MacQuaker, H.S., Keller, M.A., and Davies, S.J., 2010, Algal blooms and “marine snow”: Mechanisms that enhance preservation of organic carbon in ancient fine-grained sediments: Journal of Sedimentary Research, **80**, 934-942.

MacQuaker, J., and Plint, A.G., 2011, Offshore transport by mud by combined flows: Upper Cretaceous, Western Interior Seaway, northern Alberta, Canada: Oral presentation at 2011 AAPG Annual Conference and Exhibition, April 10-13, Houston, Texas.

MacQuaker, J.H., Taylor, and Gawthorpe, R.L., 2007, High-resolution facies analyses of mudstones: Implications for paleoenviromental and sequence stratigraphic interpretations of offshore ancient mud-dominated successions: Journal of Sedimentary Research, **77**, 324-339.

Schieber, J., Southard, J., and Thaisen, K., 2007, Accretion of mudstone beds from migrating floccules ripples: Science, **318**, 1760-1763.

Schroder-Adams, C.J., Leckie, D.A., Bloch, J., Craig, J., McIntyre, D.J., and Adams, P.J., 1996, Paleoenvironmental changes in the Cretaceous (Albian to Turonian) Coloardo Group of western Canada: microfossil, sedimentological and geochemical evidence: Cretaceous Research, **17**, 331-365.

Tyagi, A., A. G. Plint, and McNeil, D.H., 2007, Correlation of physical surfaces, bentonites, and biozones in the Cretaceous Colorado Group from the Alberta Foothills to southwest Saskatchewan, and a revision of the Belle Fourche - Second White Specks formational boundary: Canadian Journal of Earth Sciences, **44**, 871-888.

Varban, B.L. and Plint, A.G., 2005, Allostratigraphy of the Kaskapau Formation (Cenomanian-Turonian) in Subsurface and Outcrop: NE British Columbia and NW Alberta, Western Canada Foreland Basin: Bulletin of Canadian Petroleum Geology, **53**, 357–389.

Varban, B.L., and Plint, A.G., 2008, Sequence stacking patterns in the Western Canada foredeep: influence of tectonics, sediment loading and eustasy on deposition of the Upper Cretaceous Kaskapau and Cardium Formations: Sedimentology, **55**, 395-421.

Wright, L.D., and Friedrichs, C.T., 2006, Gravity-driven sediment transport on continental shelves: A status report: Continental Shelf Research, **26**, 2092-2107.