PS Vertical Changes in Shale Sedimentary Facies, Organic Content and Composition, Carbonate Content, and Clay Mineralogy of a Thick Shale-Dominated Succession of the Carlile and Niobrara Formations, Southwestern Saskatchewan and Southeastern Alberta - Paleo-Oceanographic Circulation and Depositional Setting Controls

Samantha E. Taylor[1], Per Kent Pedersen[1], Ron Spencer[1], Haiping Huang[1], Steve Larter[1], and Andrew Aplin[2]

Search and Discovery Article #50450 (2011)
Posted July 31, 2011

*Adapted from poster presentation at AAPG Annual Convention and Exhibition, Houston, Texas, USA, April 10-13, 2011

[1]Department of Geoscience, University of Calgary, Calgary, AB, Canada (taylorse@ucalgary.ca)
[2]Civil Engineering and Geosciences, Newcastle University, Newcastle, United Kingdom

Abstract

Detailed core studies and geochemical analysis of the 230-metre thick shale-dominated deposits of the Carlile and Niobrara formations, Bigstick Pool area (southeastern Alberta and southwestern Saskatchewan), have revealed significant changes in shale sedimentary facies, organic and carbonate content, and clay mineralogy. Sequence stratigraphic correlations show the succession is characterized by gently basinward-tapering units. This, and the abundance of interbedded silt and sand ripples, suggests the shales were deposited in a shallow water basin characterized by ramp-style morphology, with no significant shelf break or deep water deposits present.

Within the Carlile and Niobrara formations, the presence of ripple bedforms and basal scour surfaces in mudstone and sandstone laminae/beds indicate traction current was a prevalent transport mechanism. These currents may have been generated by storms, tides and/or geostrophic circulation. Depositional setting of these formations is a matter of debate, as both prodeltaic and shelf settings have been proposed. In a shallow-water ramp-style basin, both settings have similar bedforms, ichnofacies, and diminutive ichnofauna due to stressed conditions from frequent dysoxia and/or storm/wave reworking. Thus, facies boundaries in a ramp setting between the offshore prodeltaic and shelf environments become non-distinct.

The Carlile and Niobrara formations are both characterized by similar bedforms, ichnofacies and strata geometries, indicating deposition in a relatively similar setting. However, both formations are characterized by unique geochemical characteristics. These may reflect significant changes in depositional setting, climate, ocean circulation, seaway width and connection to the Boreal and Tethyan seas. For instance, the change from non-calcareous Carlile shales to calcareous nannoplankton-rich Niobrara shales likely reflects the introduction of warm Tethyan waters into the basin. The influx of Tethyan water likely also caused a change in water circulation, chemistry, salinity and nutritional levels of the seawater.

The fabric and geochemistry of the Carlile and Niobrara shales and thus their shale gas prospectivity are likely more influenced by changes in paleo-oceanography and basin scale processes than changes in depositional setting. Observations from this study provide insight on the understanding of deposition of thick shale units and distribution of shale-dominated reservoirs, which is applicable to other shale gas reservoirs.

References

Leckie, D.A., J.P. Bhattacharya, J. Bloch, C.E. Gilboy, and B. Novis, 2008, Cretaceous Colorado/Alberta Group of the Western Canada Sedimentary Basin *in* G.D. Mossop, and I. Shetsen (eds.), Geological Atlas of the Western Canadian Sedimentary Basin: Canadian Society of Petroleum Geologists and the Alberta Research Council, Special Report 4.

Nielsen, K.S., C.J. Schroder-Adams, and D.A. Leckie, 2003, A new stratigraphic framework for Upper Colorado Group (Cretaceous) in southern Alberta and southwestern Saskatchewan, Canada: Bulletin of Canadian Petroleum Geology, v. 51/3, p. 304-346.

Nielsen, K.S., C.J. Schroder-Adams, D.A. Leckie, J.W. Haggart, and K. Elberdak, 2008, Turonian to Santonian paleoenvironmental changes in the Cretaceous Western Interior Sea: The Carlile and Niobrara formation in southern Alberta and southwestern Saskatchewan, Canada: Palaeogeography, Palaeoclimatology, Palaeoecology, v. 270, p. 64-91.

Robinson, C., 2008, A multidisciplinary approach to evaluating shale gas potential in a
biogenic gas system; the upper Colorado Group shales in southeastern Alberta, M.Sc. Thesis, University of Calgary, Calgary, Alberta, Canada, unpublished.

Website

Blakey, R.C., Colorado Plateau Geosystems, Inc., Reconstructing the Ancient EARTH: Web accessed 25 July 2011, http://www.gpgeosystems.com, http://www.cpgeosystems.com/namK100.jpg,http://www.cpgeosystems.com/namK85.jpg

Vertical Changes in Shale Sedimentary Facies, Organic Content and Composition, Carbonate Content, and Clay Mineralogy of a Thick Shale-Dominated Succession of the Carlile and Niobrara Formations, Southwestern Saskatchewan and Southeastern Alberta - Paleo-Oceanographic Circulation and Depositional Setting Controls

Samantha E. Taylor[1], Per Kent Pedersen[1], Ron Spencer[1], Haiping Huang[1], Steve Larter[1], and Andrew Aplin[2]

1. Department of Geoscience, University of Calgary, Calgary, AB, Canada

2. Civil Engineering and Geosciences, Newcastle University, Newcastle, United Kingdom

1. Abstract

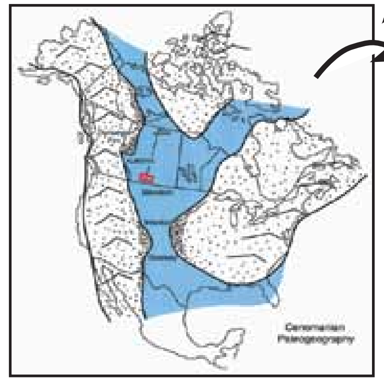
Detailed core studies and geochemical analysis of the 230-metre thick, shale-dominated deposits of the Carlile and Niobrara formations, Bigstick Pool area (southeastern Alberta and southwestern Saskatchewan), have revealed significant changes in shale sedimentary facies, organic and carbonate content, and clay mineralogy. Sequence stratigraphic correlations showthe succession is characterized by gently basinward-tapering units. This, and the abundance of interbedded silt and sand ripples, suggests the shales were deposited in a shallow water basin characterized by ramp-style morphology, with no significant shelf break or deep water deposits present.

Within the Carlile and Niobrara formations, the presence of ripple bedforms and basal scour surfaces in mudstone and sandstone laminae/beds indicate traction current was a prevalent transport mechanism. These currents may have been generated by storms, tides and/or geostrophic circulation. Depositional setting of these formations is a matter of debate, as both prodeltaic and shelf settings have been proposed. In a shallow-water ramp style basin, both settings have similar bedforms, ichnofacies, and diminutive ichnofauna due to stressed conditions from frequent dysoxia and/or storm/wave reworking. Thus, facies boundaries in a ramp-setting between the offshore prodeltaic and shelf environments become non-distinct.

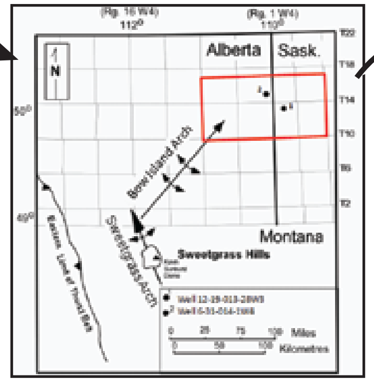
The Carlile and Niobrara formations are both characterized by similar bedforms, ichnofacies and strata geometries, indicating deposition in a relatively similar setting. However, both formations are characterized by unique geochemical characteristics. These may reflect significant changes in depositional setting, climate, ocean circulation, seaway width and connection to the Boreal and Tethyan seas. For instance, the change from non-calcareous Carlile shales to calcareous nannoplankton-rich Niobrara shales likely reflects the introduction of warm Tethyan waters into the basin. The influx of Tethyan water likely also caused a change in water circulation, chemistry, salinity and nutritional levels of the seawater.

The fabric and geochemistry of the Carlile and Niobrara shales and thus their shale gas prospectivity are likely more influenced by changes in paleo-oceanography and basin scale processes than changes in depostional setting. Observations from this study provide insight on the understanding of deposition of thick shale units and distribution of shale-dominated reservoirs, which is applicable to other shale gas reservoirs.

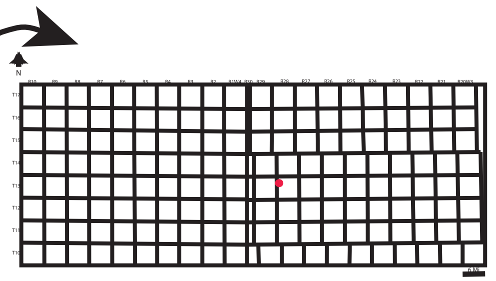
2. Study Area



Modified from Leckie et al., 2008

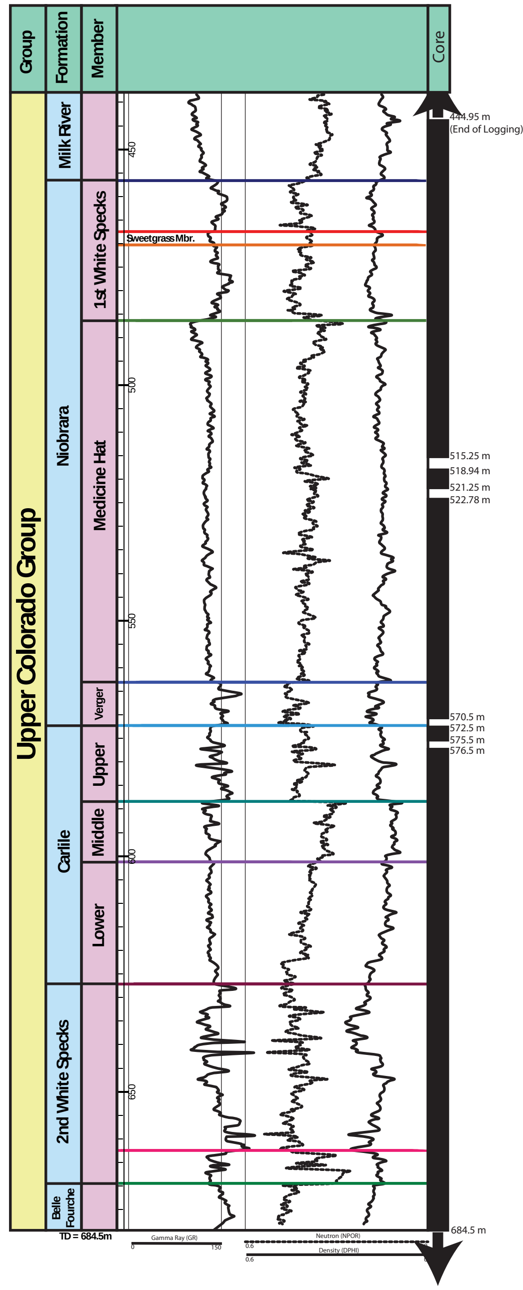


Modified from Nielsen et al., 2003

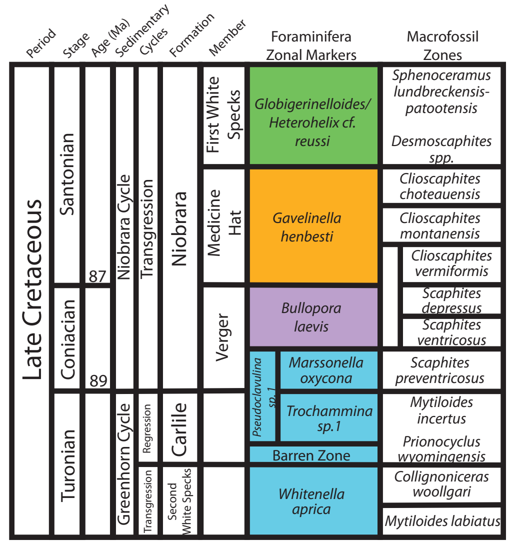


Indicates location of type well

3. Bigstick Pool Type Well



4. Stratigraphic Framework And Biostratigraphy



Modified from Nielsen et al., 2008

Carlile Formation

- Anoxic bottom water conditions in early Carlile deposition
- Temporary disappearance of benthic foraminifers, planktic foraminifers, and nannoplankton
- Monospecific benthic foraminifers and rare planktic foraminifers during late Carlile deposition
- Greenhorn regression = narrow seaway
- Tethyan waters not present in northern WIS

Niobrara Formation

- Abundance and diverstity of agglutinated, benthic calcareous and planktic foraminifera throughout deposition
- Well oxygenated bottom water conditions
- Increasing abundance of planktic forams into Saskatchewan (east)
- Optimal marine conditions along eastern basin margin
- Freshwater/mud input to west
- Niobrara transgression = wide seaway
- Boreal sea and Gulf of Mexico connected during late Niobrara Fm. deposition
- Circulation of Tethyan waters present in WIS

Modified from Blakey (www.cpgeosystems.com)

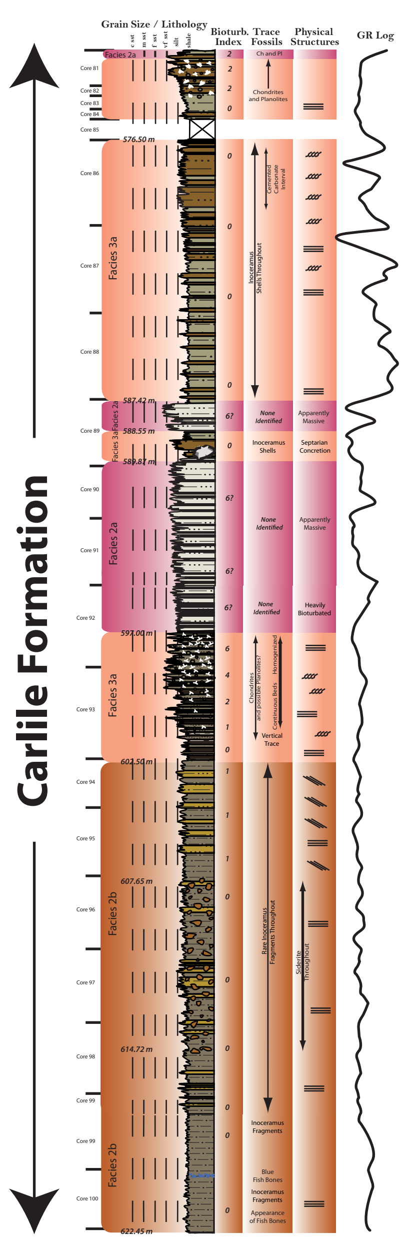
Vertical Changes in Shale Sedimentary Facies, Organic Content and Composition, Carbonate Content, and Clay Mineralogy of a Thick Shale-Dominated Succession of the Carlile and Niobrara Formations, Southwestern Saskatchewan and Southeastern Alberta - Paleo-Oceanographic Circulation and Depositional Setting Controls

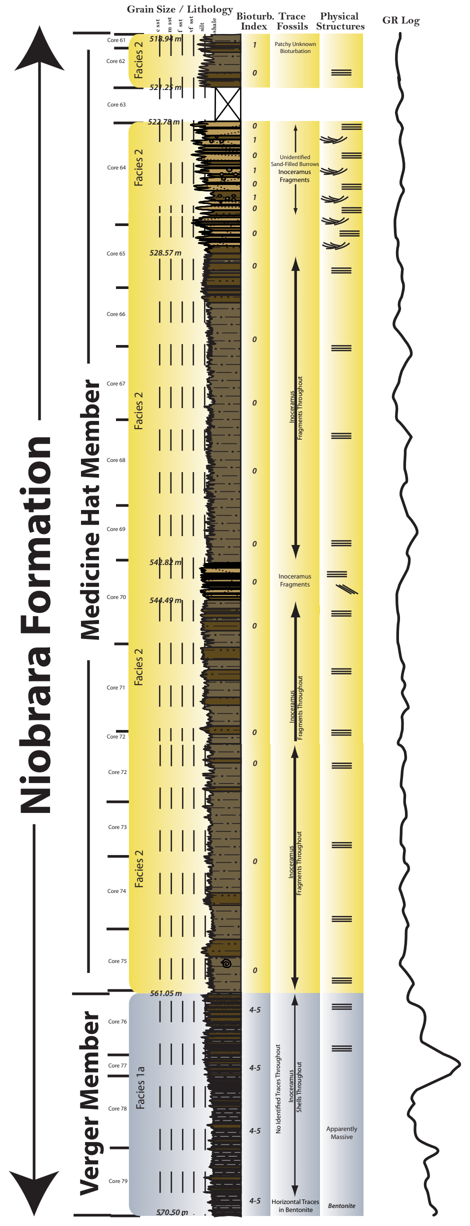
Samantha E. Taylor[1], Per Kent Pedersen[1], Ron Spencer[1], Haiping Huang[1], Steve Larter[1], and Andrew Aplin[2]

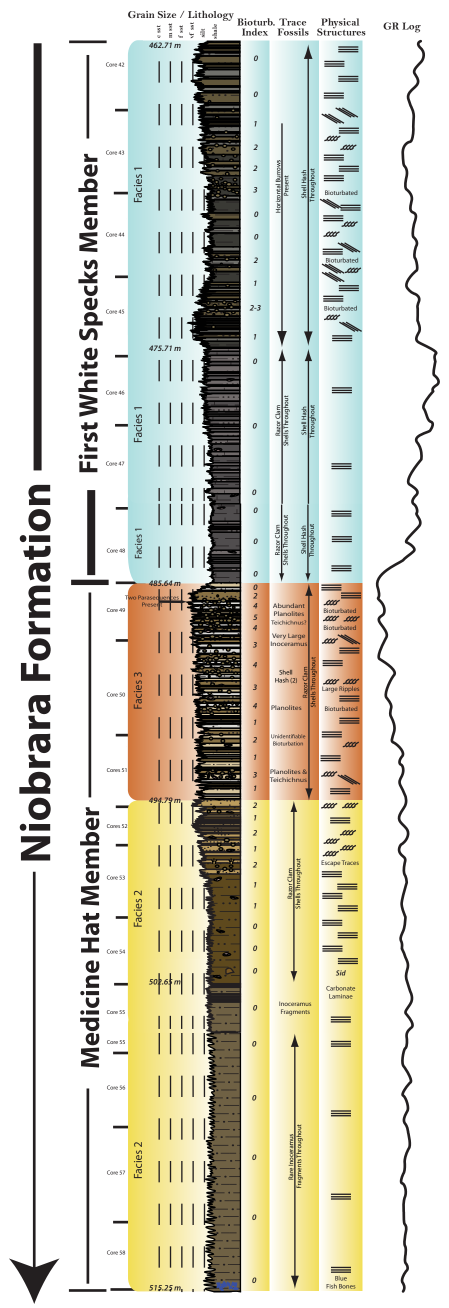
1. Department of Geoscience, University of Calgary, Calgary, AB, Canada

2. Civil Engineering and Geosciences, Newcastle University, Newcastle, United Kingdom

5. Facies and Lithology



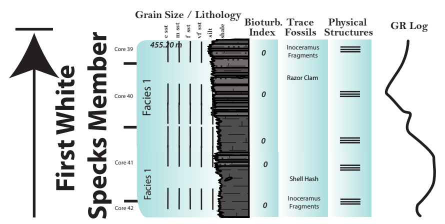




Facies of the Upper Colorado Group, defined in the type well		
Facies Notation	**Lithology**	**Found Within**
F1	Grey-Brown Calcareous Silty Mudstone with Carbonate Silt/Very Fine Carbonate Sand and Sand Laminae	• Belle Fourche Formation • 2nd White Specks Formation • 1st White Specks Formation
F1a	Bioturbated Dark Grey/Grey-Brown Non-Calcareous Silty Mudstone with Silt/Very Fine Sand Laminae	• Verger Member (entirely)
F2	Brown-Grey Calcareous Silty Mudstone with Interspersed Silt, and Silt and Very Fine Sand Laminae and Basal Blue Fish Bones	• Base to Upper Medicine Hat Member
F2a	Grey to Brown-Grey Non-Calcareous Silty Mudstone to Muddy Siltstone with Silt and Very Fine Sand Laminae	• Belle Fourche Formation • Top of Carlile Formation
F2b	Brown-Grey Non-Calcareous Silty Mudstone to Muddy Siltstone with Silt Laminae, Unidentified 'Concretions' and Blue Fish Bones	• Base of Carlile Formation
F3	Light Grey Calcareous Very Fine to Fine Sand with Mud, Silt, and Carbonate Sand Laminations to Interbeds	• Belle Fourche Formation • Top of Medicine Hat Member
F3a	Bioturbated Light Grey Non-Calcareous Very Fine to Fine Sandstone with Interspersed to Laminated Mud and Silt	• Top of Belle Fourche Formation • Middle Carlile Formation • Base of Milk River Formation

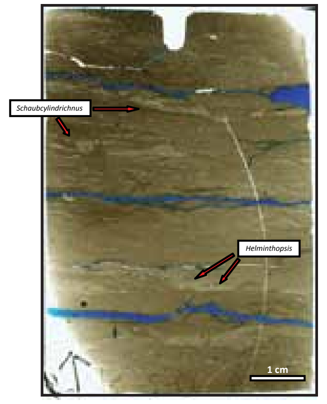
Legend

- *Planolites*
- *Chondrites*
- *Teichichnus*
- Vertical Traces
- Escape Traces
- Razor Clam Shells
- Cephalopod Shell
- Blue Fish Bones
- Planar Laminations
- Angular Laminations
- Ripples
- Cross-laminae
- Septarian Concretion
- Siderite Concretions
- Bentonite



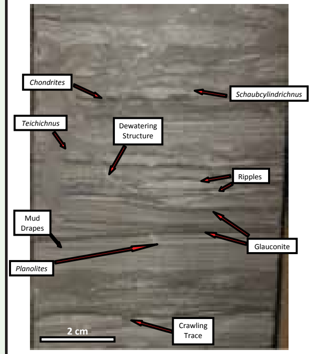
6. Carlile Formation

Lower Carlile



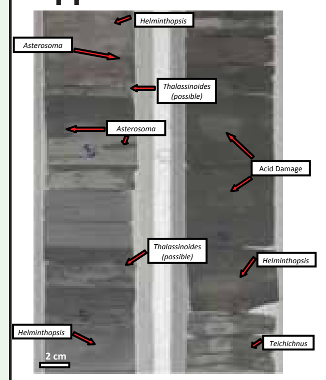
- Non-calcareous siltstone
- Upward-coarsening
- Heavily bioturbated (unseen in core)
- Siderite concretions
- Any carbonate content attributed to shell fragments
- Low TOC (1.49-1.68 wt. %)

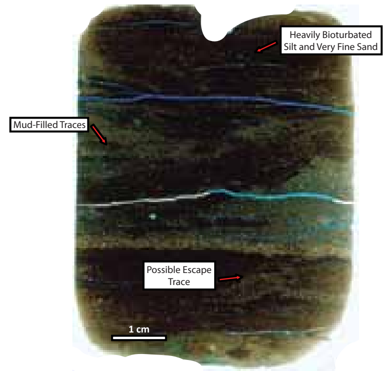
Middle Carlile



- Non-calcareous fine sandstone
- Upward-coarsening
- Heavily bioturbated to pale homogenized appearance in core
- Any carbonate content attributed to shell fragments
- High TOC (3.78-4.35 wt. %)

Upper Carlile

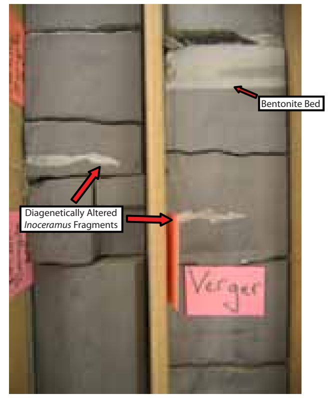


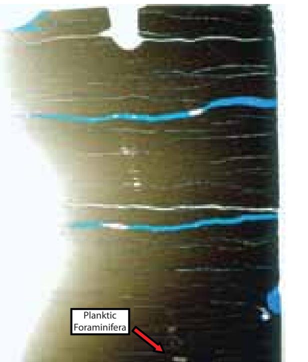


- Non-calcareous, upward-coarsening siltstone with vf sand laminae
- Abundant coarse-grained bentonites
- Clay clasts readily observed in thin section and microscope
- Shell fragments, carbonate-cemented horizon, pyritized foraminifers
- Moderate TOC (2.22-3.68 wt.%)

7. Niobrara Formation

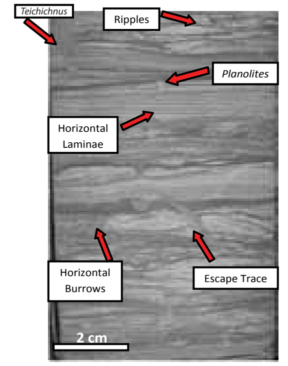
Verger Member

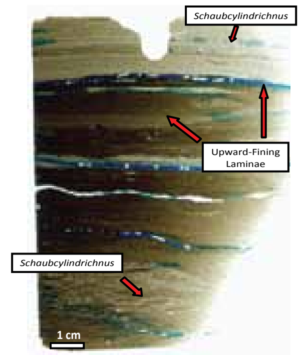




- Non-calcareous or faintly calcareous mudstone with silt/vf sand laminae
- Sparsely to heavily bioturbated
- Shell fragments and foraminifers present
- Coarse-grained bentonites present
- Low TOC (1.49-2.20 wt. %)

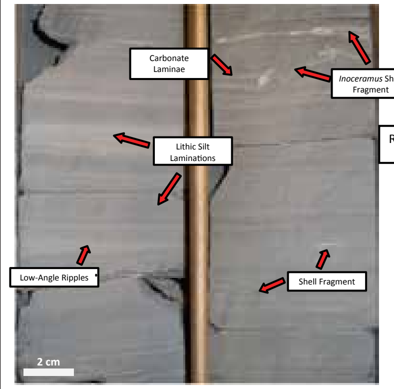
Medicine Hat Member

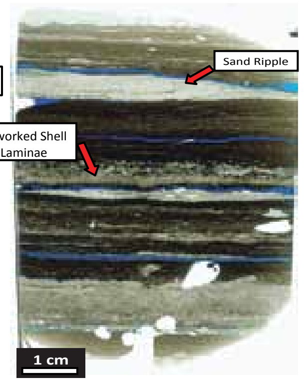




- Calcareous, upward-coarsening silt to very fine sand
- Sands comprised of quartz and calcite grains
- Shell fragments, foraminifers and heavily carbonate-cemented intervals throughout
- Punctuated bioturbation
- Variant TOC (1.09-4.27 wt. %)

First White Specks Member





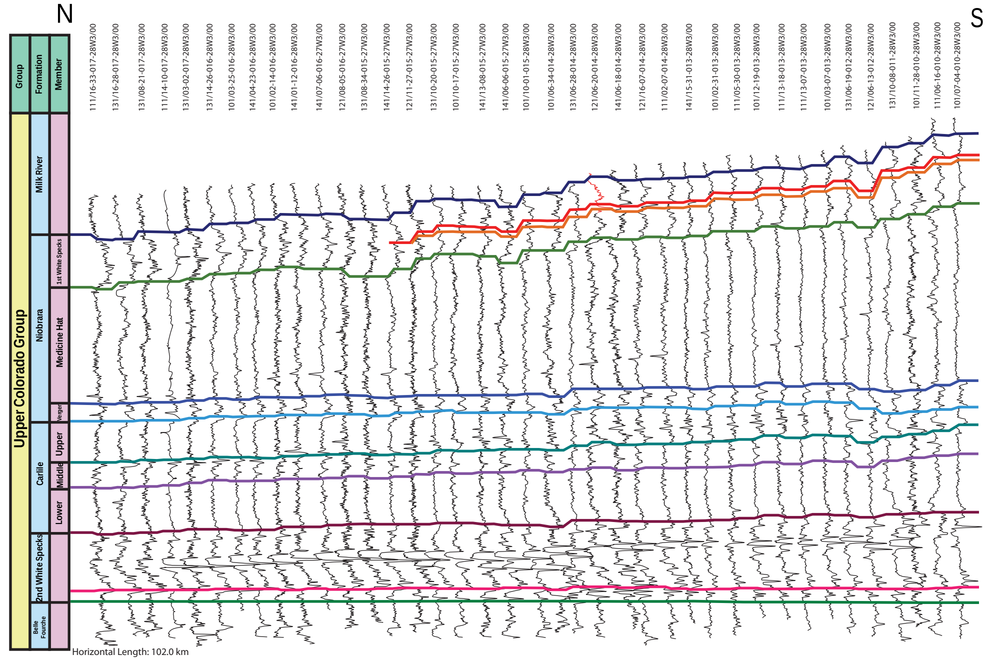
- Calcareous, upward-coarsening mudstone with silt/vf sand laminae
- Calcite and quartz-rich sand laminae
- Laminae distinguishable as coarsening- or fining-upward
- Shell fragments and clay clasts present
- Variant TOC (1.10-3.47 wt. %)

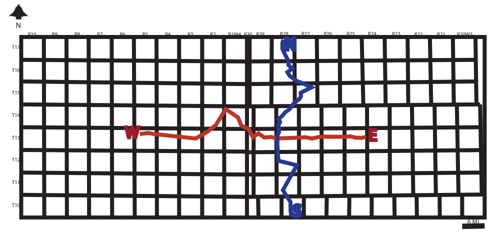
Vertical Changes in Shale Sedimentary Facies, Organic Content and Composition, Carbonate Content, and Clay Mineralogy of a Thick Shale-Dominated Succession of the Carlile and Niobrara Formations, Southwestern Saskatchewan and Southeastern Alberta - Paleo-Oceanographic Circulation and Depositional Setting Controls

Samantha E. Taylor[1], Per Kent Pedersen[1], Ron Spencer[1], Haiping Huang[1], Steve Larter[1], and Andrew Aplin[2]

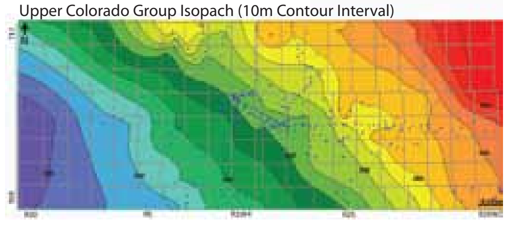
1. Department of Geoscience, University of Calgary, Calgary, AB, Canada
2. Civil Engineering and Geosciences, Newcastle University, Newcastle, United Kingdom

7. 2- and 3-Dimensional Geometry of the Carlile and Niobrara Formations



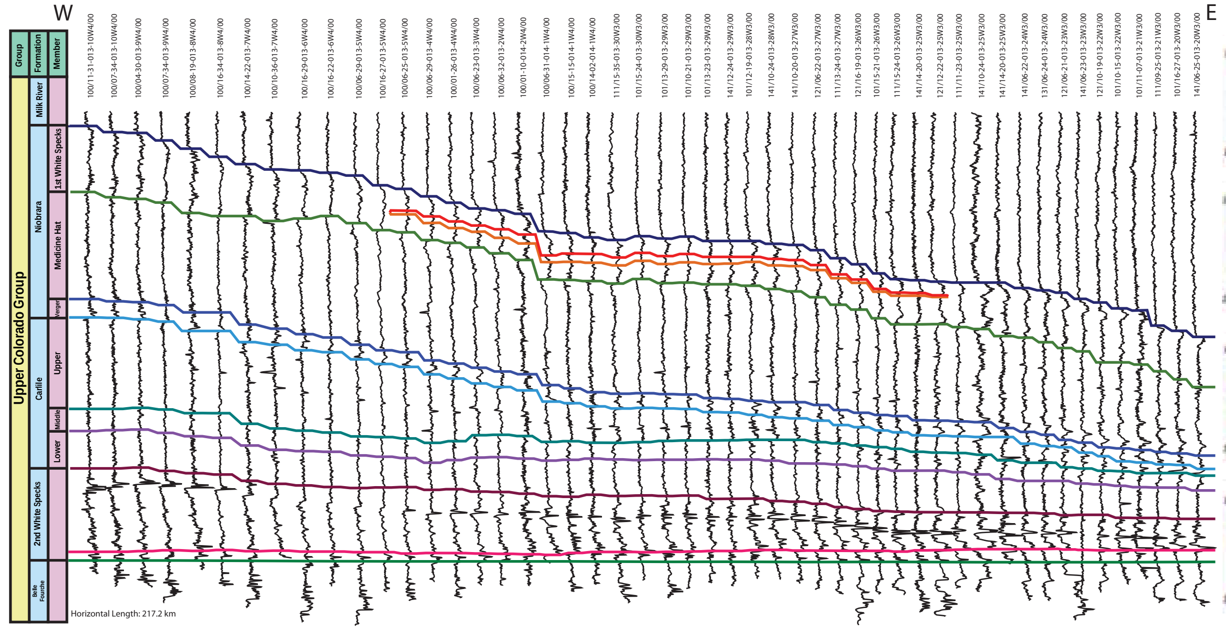


Upper Colorado Group Isopach (10m Contour Interval)

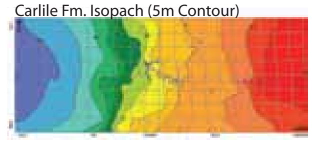


Note: Blue dots denote locations of wells used in project.

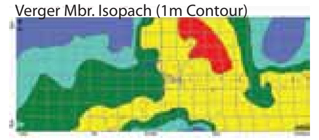
The Upper Colorado Group thins from southwest to northeast as an overall unit, but when considered on a formation scale, observed shelf orientation changes from Carlile Formation to Niobrara Formation deposition (see isopach maps below). This has been interpreted as a change in sediment depocenter.



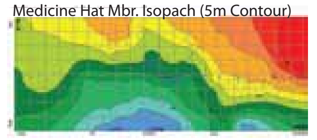
Carlile Fm. Isopach (5m Contour)



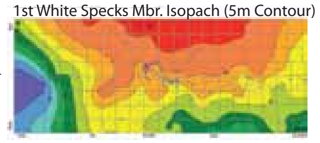
Verger Mbr. Isopach (1m Contour)



Medicine Hat Mbr. Isopach (5m Contour)



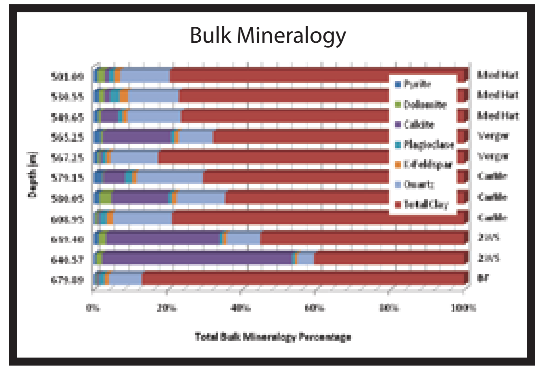
1st White Specks Mbr. Isopach (5m Contour)



8. Bulk Mineralogy and Clay Mineralogy

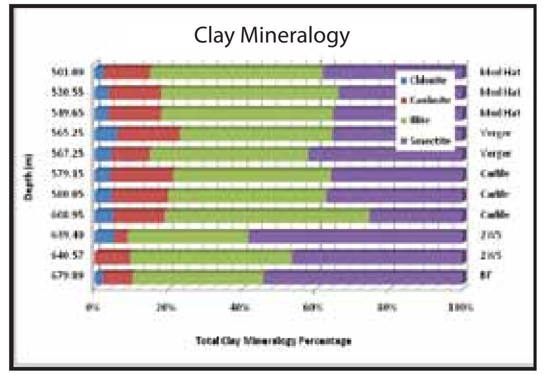
Depth (m)	Formation	Whole Rock Weight Percentage (%)							Total
		Quartz	K-Feldspar	Plagioclase	Calcite	Dolomite	Pyrite	Total Clay	
501.09	Medicine Hat Mbr.	13	2	1	1	2	1	79	100
530.55	Medicine Hat Mbr.	14	2.14	2.75	1.49	1.42	1.34	77	100
549.65	Medicine Hat Mbr.	14.5	1.2	1.2	4.7	0.7	1.2	77	100
565.25	Verger Mbr.	9.53	0.98	0.99	18.46	0.48	1.86	68	100
567.15	Verger Mbr.	12.9	0.99	1.17	0.43	0.62	1.10	83	100
579.15	Carlile Fm.	17.97	1.05	1.89	5.88	0.26	2.20	70	99.25
580.05	Carlile Fm.	13.14	1.09	1.03	15.59	3.07	1.47	65	100
608.95	Carlile Fm.	16.19	1.46	1.85	0.48	0.69	0.46	79	100
639.40	2nd White Specks Fm.	9.3	0.87	0.81	30.86	1.86	1.28	56	100
640.57	2nd White Specks Fm.	4.61	0.59	0.75	51.42	1.49	0.63	41	100
679.89	Belle Fourche Fm.	8.98	1.16	1.42	0.51	0.32	0.62	88	100

Quartz content is low throughout (<18%), and total clay content is considerably lower in the Carlile and Niobrara formations than in the 2nd White Specks Formation. Calcite content appears highest in the Upper Carlile Formation, Verger Member, and 2nd White Specks Formation. Unlike the latter two, calcite content in the Upper Carlile is attributed to shell content, as it is non-calcareous.



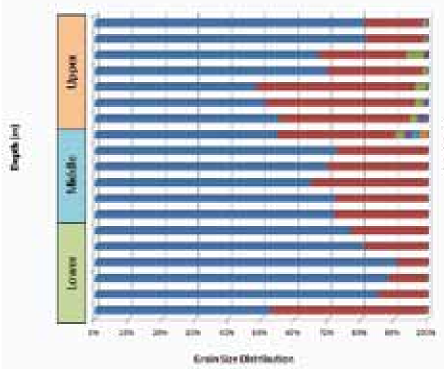
Depth Interval (m)	Formation	Relative Clay Percentage (%)				Total
		Chlorite	Kaolinite	Illite	Smectite	
501.09	Medicine Hat Fm.	2.53	12.66	46.84	37.97	100
530.55	Medicine Hat Fm.	3.90	14.29	48.05	33.77	100
549.65	Medicine Hat Fm.	3.90	14.29	46.75	35.06	100
565.25	Verger Mbr.	5.88	16.18	39.71	33.77	100
567.15	Verger Mbr.	4.65	10.47	43.02	41.86	100
579.15	Carlile Fm.	4.29	17.14	42.86	35.71	100
580.05	Carlile Fm.	4.62	15.38	43.08	36.92	100
608.95	Carlile Fm.	5.06	13.92	55.70	25.32	100
639.40	2nd White Specks Fm.	5.45	3.64	32.73	58.18	100
640.57	2nd White Specks Fm.	0	9.76	43.90	46.34	100
679.89	Belle Fourche Fm.	2.30	8.05	35.63	54.02	100

Clay mineralogy within the Upper Colorado Group is largely comprised of illite and smectite, whereas chlorite and kaolinite are minor components. There appears to be a slight decrease in chlorite content within the Medicine Hat Formation.

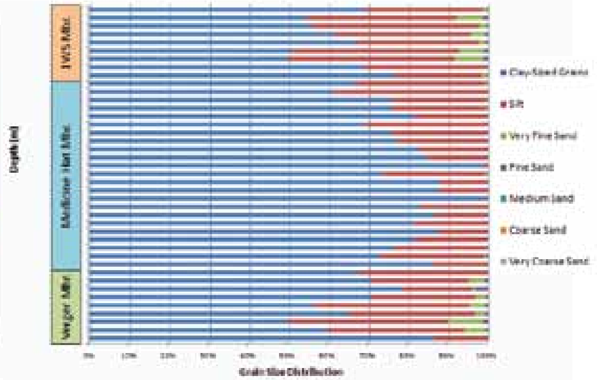


9. Grain Size

Carlile Formation

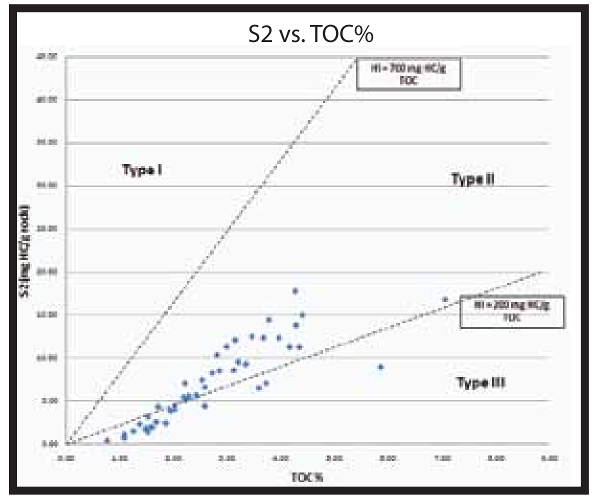


Niobrara Formation



Both the Carlile and Niobrara formations are generally comprised of clay-sized and silt-sized sediments. Very fine- and fine-grained sand is present within the Upper Carlile Fm., at the top of the Middle Carlile Fm., and in the 1st White Specks and Verger members. The Carlile Formation demonstrates an upward-coarsening trend up to the Upper Carlile, which is upward-fining. The Niobrara Formation is upward-fining up to the middle of the Medicine Hat Member. Following this, an upward-coarsening trend is observed up to the top of the Niobrara.

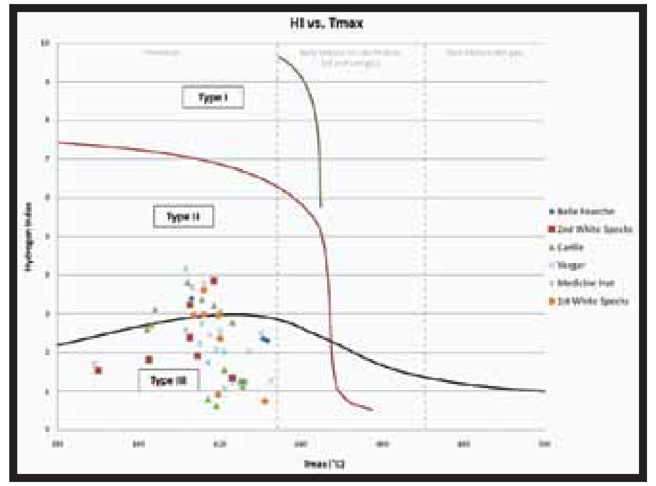
10. TOC and Organic Matter Type



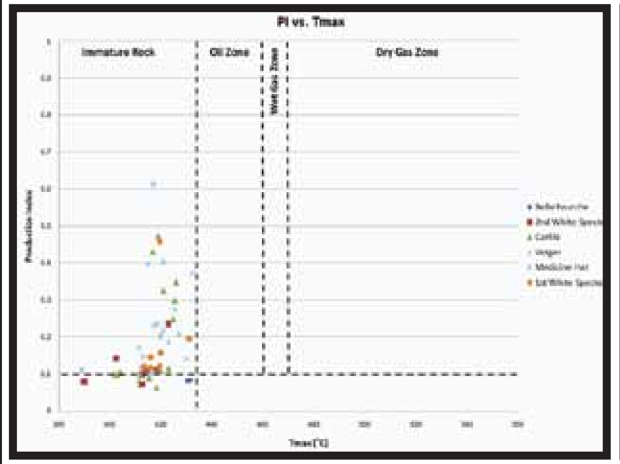
Kerogen Type	Type of Organic Matter	Chemical Attributes	Hydrogen Index (HI) mg HC/g TOC	Depositional Environment	Potential for Petroleum Generation	Maceral and Organic Precursor
I	Algae and Bacteria	Hydrogen-rich, oxygen-poor	600 - 900	Lacustrine, quiet, oxygen-poor	Good potential for oil and gas generation	Alginite – freshwater algae
II	Algae, pollen, spores, leaf cuticle, bacteria	Hydrogen-rich, oxygen-poor	300 - 600	Reducing, marine	Oil generation	Exinite – spores, pollen Cutinite – plant cuticle Resinite – plant resins Liptinite – plant lipids, marine algae
III	Higher plants, terrestrial-derived woody materials	Hydrogen-poor, oxygen-rich	50 - 300	Oxidizing, marine	Gas generation (often with oil if HI is 150-300)	Vitrinite – woody material
IV	Oxidized debris	Very hydrogen-poor, oxygen-rich	< 50	Oxidizing, marine	None (inert kerogen)	Inertinite - charcoal

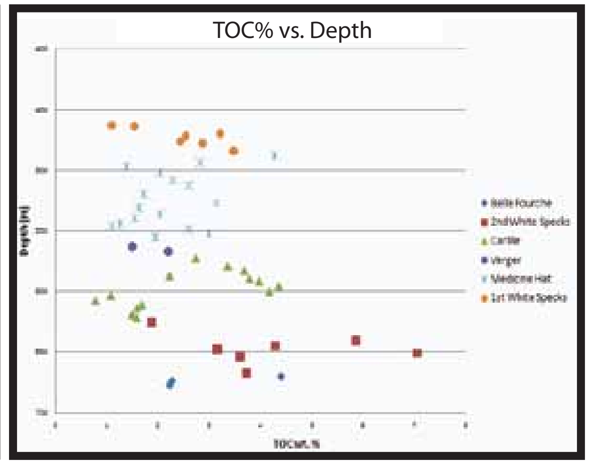
Modified from Robinson (2008)

Plots of S2 vs. TOC% and HI vs. Maximum Temperature (Tmax) have determined that organic matter in the Upper Colorado Group is comprised of Type II and Type III kerogen types. These types are sourced from a mixture of algae, pollen/spores, leaf cuticles, bacteria, and higher, terrestrially derived woody plants. This organic matter is indicative of a combination of reducing and oxidizing depositional environments.



11. TOC Variation and Maturity





A plot of production index (PI) vs. maximum temperature (Tmax) indicates that all formations within the Upper Colorado Group are immature. All maximum temperatures derived from Rock-Eval data are found to be less than 435ºC. A general comparison of TOC percentage versus depth demonstrates that the 2nd White Specks Fm. has the highest but most erratic TOC values. TOC is upward-increasing within the Carlile Fm., and is quite variant within the Niobrara Fm.

Acknowledgments

This project is part of the Shale Gas Research Consortium of 2008. All those involved are acknowledged for their ongoing input and support.
Thanks are extended to Nexen Inc., ConocoPhillips, Imperial Oil, and Lundin for their sponsorship.

References

Leckie, D.A., Bhattacharya, J.P., Bloch, J., Gilboy, C.E., and B. Novis, 2008. Chapter 20: Cretaceous Colorado/Alberta Group of the Western Canada Sedimentary Basin. In: Geological Atlas of the Western Canad Sedimentary Basin. Mossop, G.D., and I. Shetsen (eds.). Canadian Society of Petroleum Geologists and the Alberta Research Council, Special Report 4.

Nielsen, K.S., Schroder-Adams, C.J., and D.A. Leckie, 2003. A new stratigraphic framework for Upper Collorado Group (Cretaceous) in southern Alberta and southwestern Saskatchewan, Canada. Bulletin of Canadian Petroleum Geology, vol. 51, no. 3, pp. 304-346.

Nielsen, K.S., Schroder-Adams, C.J., Leckie, D.A., Haggart, J.W., and K. Elberdak, 2008. Turonian to Santonian paleoenvironmental changes in the Cretaceous Western Interior Sea: The Carlile and Niobrara formation in southern Alberta and southwestern Saskatchewan, Canada. Palaeogeography, Palaeoclimatology, Palaeoecology, vol. 270, pp. 64-91.

Robinson, C., 2008. A multidisciplinary approach to evaluating shale gas potential in a biogenic gas system; the upper Colorado Group shales in southeastern Alberta. M.Sc. Thesis, University of Calgary, Calgary, Alberta, Canada.