GS2017-15

Stratigraphy and geochemistry of the Cretaceous Boyne Member, Carlile Formation, in the Manitoba Potash Corporation core at 3-29-20-29W1, southwestern Manitoba (part of NTS 65K1)

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In Brief:

- Boyne Member has potential for shallow, clean natural gas resources
- High TOC values (up to 11.18 wt. %) and low thermal maturity indicate an excellent biogenic gas source rock
- Stratigraphic and lithofacies mapping suggest potential for long-range continuity of the Babcock beds

Citation:

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Summary

The Upper Cretaceous Boyne Member of the Carlile Formation, in the Manitoba Potash Corporation core at 3-29-20-29W1, was described and analyzed to provide the first subsurface description of this unit in Manitoba. The Boyne Member is a widely distributed mudstone horizon in southwestern Manitoba, with good potential for gas-bearing reservoirs, which could serve as a future, clean natural gas resource for the province. The stratigraphy, lithofacies analyses and organic geochemistry provide a basis for evaluating its economic potential.

Introduction

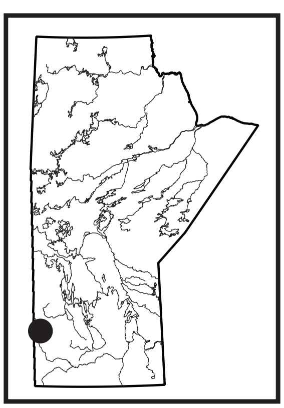
In 1986, Canamax Resources Inc. drilled a potash testhole, which is now owned by Manitoba Potash Corporation (MPC), as a pilot for the construction of a mine shaft for an underground potash mine located in L.S. 3, Sec. 9, Twp. 20, Rge. 29, W 1st Mer. (abbreviated 3-29-20-29W1). Continuous core was acquired during this drilling, with excellent recovery from 14.00 to 900.00 m vertical depth. The upper 420.00 m of this core includes the entire Cretaceous section, from the Swan River Formation to the Coulter Member of the Pierre Shale (Figure GS2017-15-1). Nicolas (2016) reported on the upper 360.00 m, with a focus on the Ashville Formation to Pierre Shale section, as part of the ongoing Shallow Unconventional Shale Gas (SUSG) Project (Nicolas and Bamburak, 2009). This core will be referred to herein as the MPC core.

Following this reconnaissance overview of the MPC core, Shaw (2017) completed a detailed stratigraphic and lithofacies analysis, and organic and inorganic geochemistry profiling of the Boyne Member of the Carlile Formation in the MPC core, as well as in an outcrop located along the Vermillion River. This report focuses only on portions of the core section examined by Shaw (2017), in particular those pertaining to the lithofacies analysis, mineralogy and organic geochemistry.

The Boyne Member of the MPC core was chosen for detailed study because

- it may be a target for unconventional shale gas exploration on the basis of production from this unit in other parts of the Williston Basin (Nicolas 2009); and
- siltstone beds present in the Boyne Member, the Babcock beds, are exposed in outcrop in southwestern Manitoba, but have yet to be correlated successfully into the subsurface (Nicolas et al., 2010).

These Babcock beds are suspected to be correlative to the Boyne sand, which is a productive shallow-gas reservoir in the Kamsack area of southwestern Saskatchewan (Nicolas et al., 2010).



Stratigraphy and cyclothems

The Upper Cretaceous (Turonian to Santonian) Boyne Member of the Carlile Formation in southwestern Manitoba comprises mainly grey, variably calcareous mudstone. The Boyne Member is underlain by the Morden Member of the Carlile Formation, which is a black, non-calcareous mudstone. It is overlain by the black, non-calcareous mudstone of the Campanian Pembina Member or laterally discontinuous brown siltstone to mudstone of the Gammon Ferruginous Member of the Pierre Shale. The stratigraphic equivalent of the Boyne Member in other jurisdictions is a topic of considerable debate (e.g., McNeil and Caldwell, 1981; Christopher et al., 2006; Bamburak and Nicolas, 2009; Diaz and Velez, 2016). It is generally considered equivalent to the First White Speckled Shale in Alberta and the Niobrara Formation in southwestern Saskatchewan. The Babcock beds occur midway through the Boyne Member, near the top of the calcareous shale unit (Figure GS2017-15-1).

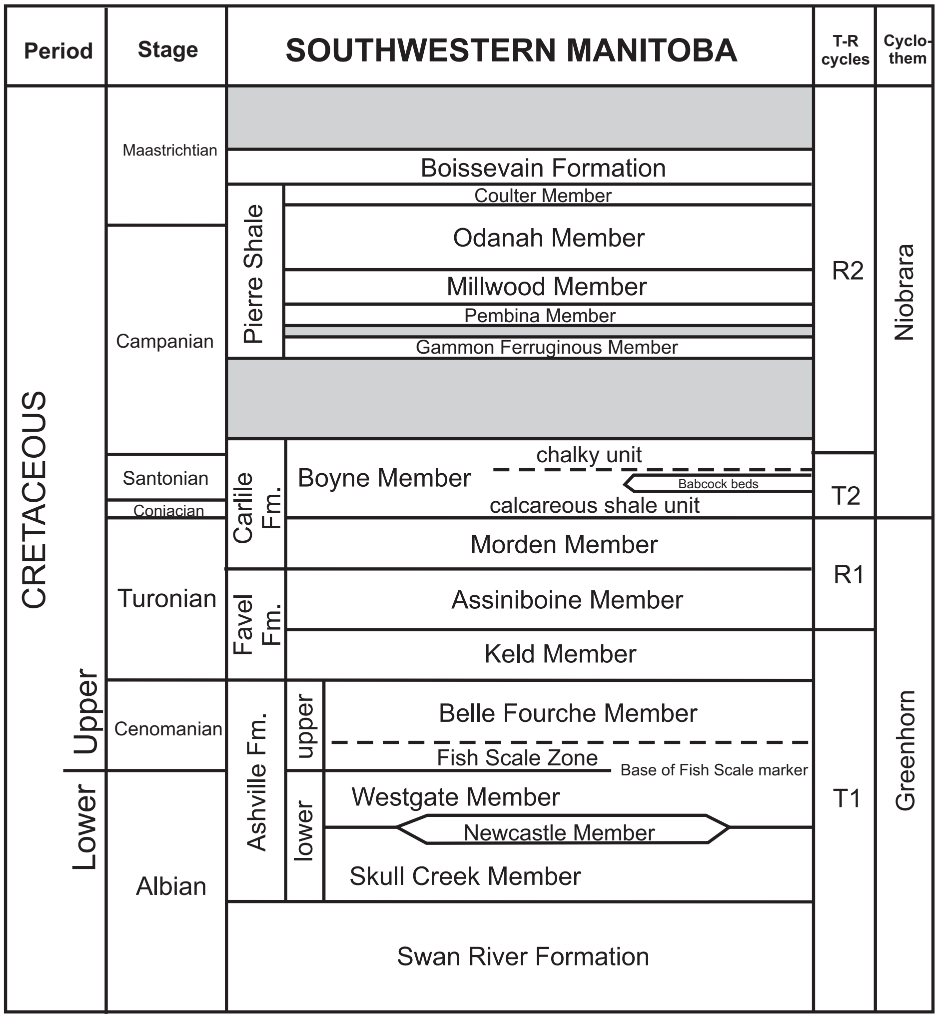


Figure GS2017-15-1: *Cretaceous stratigraphy of southwestern Manitoba, modified from Nicolas and Bamburak (2011), and the T-R cycles and cyclothems from McNeil and Caldwell (1981). Abbreviations: Fm., Formation; T-R, transgressive-regressive.*

The Cretaceous rocks of the Manitoba escarpment represent two major transgressive–regressive cycles: the earlier Greenhorn cyclothem and later Niobrara cyclothem (Figure GS2017-15-1; McNeil and Caldwell, 1981). The Greenhorn cyclothem reached its transgressive (T1 in Figure GS2017-15-1) peak in the early Turonian stage, corresponding to the deposition of the Keld Member of the Favel Formation, and its regressive (R1) trough in the middle to late Turonian stage, corresponding with the deposition of the Assiniboine and Morden members (Figure GS2017-15-1; McNeil and Caldwell, 1981). The transgressive (T2) cycle of the Niobrara cyclothem is represented overall by the Boyne Member and the transgressive peak corresponds to the deposition of the upper chalky unit. Within outcrops of the Boyne Member, there are up to four minor transgressive–regressive fluctuations reported by McNeil and Caldwell (1981), although they are difficult to identify and some cycles may be absent due to erosion or nondeposition. The resulting disconformities create difficulties in resolving stratigraphic correlations across the Williston Basin, as well as locally.

Lithofacies analysis

Detailed lithofacies analysis was conducted on the MPC core, despite its deteriorated condition (Shaw, 2017). Although the core recovery through this section was excellent, parts of the core were lost due to humidity causing them to expand out of their boxes as a result of poor storage conditions over decades. Extensive flaking and breaking of the dried-out core and prolific formation of tertiary gypsum crystal blooms on the surface have obscured features of the core. These conditions make it difficult to observe the lithology, textures and sedimentary structures. Using modern evaluation techniques specifically devised for mudrocks (Potter et al., 2005; Lazar et al., 2015), the lithology, textures and structures of the MPC core were described and interpreted. Figure GS2017-15-2 shows the detailed core log of the Boyne Member in the MPC core, for which the stratification, grading and clay content were determined using these techniques.

The variations in sedimentary structures and texture of the Boyne Member, consisting predominantly of grey, fine- to coarse-grained mudstone, were primarily used to distinguish

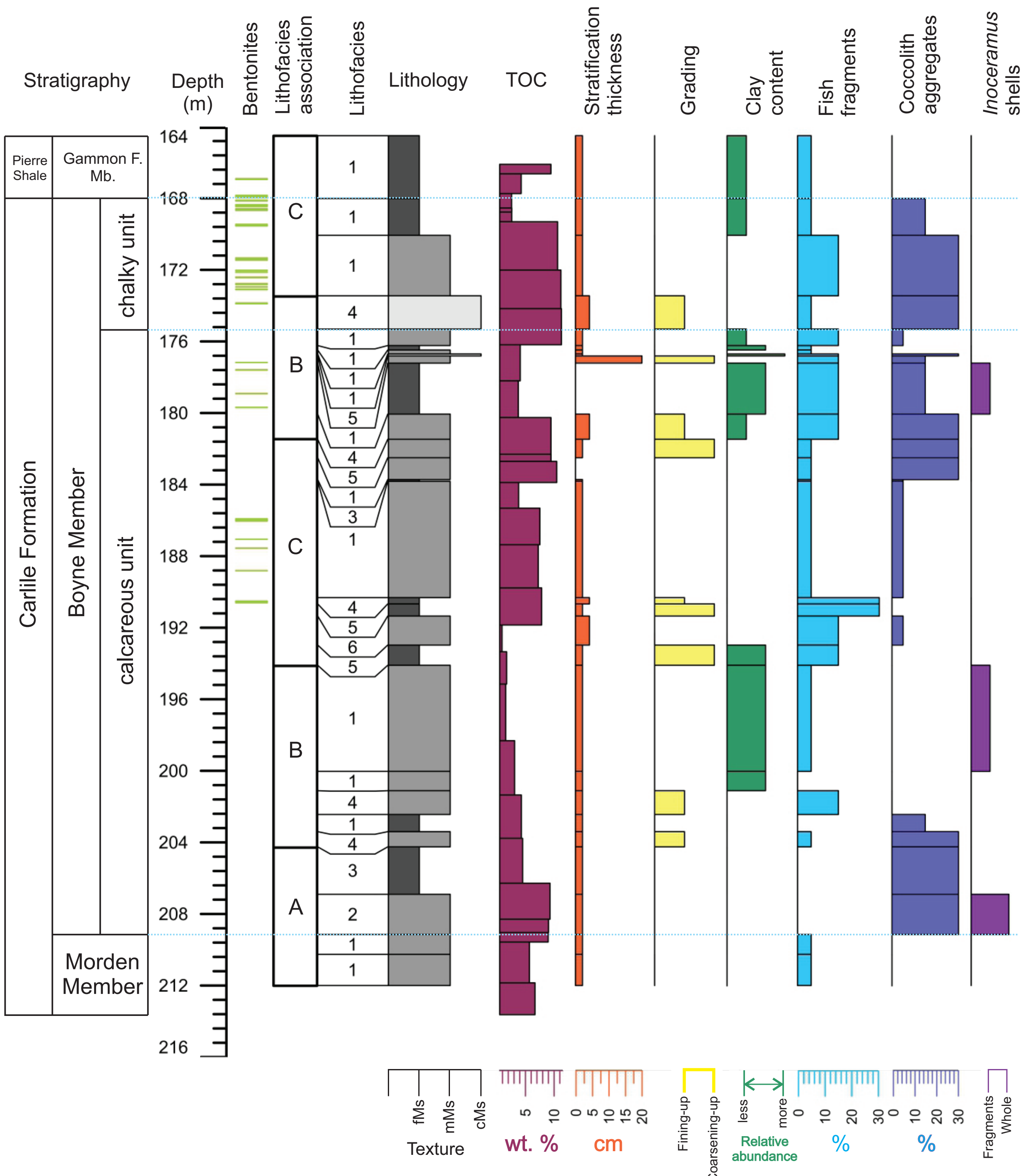


Figure GS2017-15-2: *Stratigraphic, lithological, textural and total organic carbon profile of the Cretaceous Boyne Member, Carlile Formation, in the core at 3-29-20-29W1, southwestern Manitoba. Depth track is true vertical depth, as measured in the core. Lithology-texture scale is based on Potter et al. (2005) and Lazar et al. (2015). Abbreviations: fMs, fine-grained mudstone; mMs, medium-grained mudstone; cMs, coarse-grained mudstone.*

the following seven lithofacies: 1) laminated mudstone; 2) medium-grained mudstone with fine-grained mudstone clasts; 3) fine-grained mudstone with medium-grained mudstone clasts; 4) fining-upward mudstone; 5) coarsening-upward mudstone; 6) burrowed mudstone; and 7) bentonite. A summary of these lithofacies is provided in Table GS2017-15-1.

These lithofacies are grouped on the basis of sedimentary structures, presence of *Inoceramus* and ichnofossils, and clay and total organic carbon (TOC) content into three lithofacies associations: A) outer shelf to upper slope deposits; B) upper slope to lower slope deposits; and C) lower slope to basin deposits (Figure GS2017-15-3).

Lithofacies association A: outer shelf to upper slope deposits

Lithofacies association A (LA-A) consists of laminated mudstone, medium-grained mudstone with fine-grained mudstone clasts and fine-grained mudstone with medium-grained mudstone clasts (lithofacies 1–3). It occurs in the MPC core from 204.25 to 212.00 m depth (Figure GS2017-15-1). This lithofacies

Table GS2017-15-1: Summary of lithofacies of the Boyne Member, Carlile Formation, in the MPC core at 3-29-20-29W1, southwestern Manitoba. Abbreviation: NA, not available.

Lithofacies		Thickness (m)	Lithology	Colour	Contacts	Sedimentary structures	Biological features
1	Laminated mudstone	0.11-6.5	Fine-grained mudstone; medium-grained mudstone; coarse-grained mudstone. Up to 15% silt grains, including up to 5% lithic clasts	Medium dark grey to very light grey	Lower and upper: sharp or gradational	Thick to thin laminations	None to few fish fragments. None to few coccolith aggregates. *Inoceramus* concentrated in 1 cm layers in some units (198.25, 179.45 m depth)
2	Medium-grained mudstone with fine-grained mudstone clasts	2.35	Medium-grained mudstone. Up to 15% silt grains	Brownish medium grey	Lower and upper: sharp	Medium laminations. Few clasts of fine mudstone (~1 mm wide, up to 1 cm long)	Few fish fragments. Few coccolith aggregates. *Inoceramus* throughout (3-7 mm, few)
3	Fine-grained mudstone with medium-grained mudstone clasts	0.1-2.65	Fine-grained mudstone	Medium to light grey	Lower: sharp; Upper: sharp or gradational	Medium laminations. Few clasts of medium mudstone (~2 mm wide, up to 1 cm long)	None to very sparse fish fragments
4	Fining-upward mudstone	0.35-1.83	Fine- to coarse-grained mudstone that show fining upward trends. Up to 15% silt grains (mostly lithic clasts)	Medium to light grey	Lower and upper: sharp or gradational	Medium laminations	Very sparse to few fish fragments. None to few coccolith aggregates.
5	Coarsening-upward mudstone	0.4-1.13	Fine- to coarse-grained mudstone that show coarsening upward trends. Up to 15% silt grains (up to 1/3 lithic clasts)	Medium light grey	Lower and upper: sharp or gradational	Medium laminations to very thin beds	Very sparse to few fish fragments. Sparse to few coccoliths
6	Burrowed mudstone	1.62	Medium-grained mudstone with up to 50% coarse mudstone throughout. Up to 10% silt grains	Light grey	Lower and upper: sharp	Medium to thick laminations	Sparse fish fragments. Very sparse coccolith aggregates. Burrows of *Planolites*, *Chondrites* and *Zoophycus* throughout section; highly burrow mottled at 192.48-192.62 m depth. Small gastropod at 191.85 m depth
7	Bentonite	0.005-0.13	Very fine clay	Pale yellow	Lower and upper: sharp	None	None

Abbreviations: TOC, total organic contents; NA, not available; UV, ultraviolet

Table GS2017-15-1 *(continued)*: Summary of lithofacies of the Boyne Member, Carlile Formation, in the MPC core at 3-29-20-29W1, southwestern Manitoba. Abbreviation: NA, not available.

	Lithofacies	TOC (wt. %)	Other features	Depositional environment	Lithofacies association
1	Laminated mudstone	1.56-10.46	Calcareous concretion at 195.13-195.38 m depth. Crosscut by calcite-filled fracture (2.6 cm wide, dip 65°, sharp contacts). Scattered framboidal pyrite occurs as low as 200.03 m depth. Scattered manganese oxide occurs as low as 200.03 depth (appears to be replacing fish fragments)	Suspension settling under relatively low-energy conditions; *Inoceramus*-rich zones likely transported, possibly lag deposits	LA-A, -B, and -C
2	Medium-grained mudstone with fine-grained mudstone clasts	8.96-9.28	Strong petroliferous odour and streaming white cuts that fluoresced under UV light (209.15-208.90 m depth). Fracture dipping at 32° at 207.94-208.14 m depth	Erosion and bedload transport by turbulent bottom flows	LA-A
3	Fine-grained mudstone with medium-grained mudstone clasts	4.51	Vertical open fracture at 206.54-206.84 m depth. Gypsum nodules in fractures (up to 1 mm wide, 1 cm long, ovoid). Rare framboidal pyrite as low as 183.82 m depth	Erosion and bedload transport by turbulent bottom flows	LA-A
4	Fining-upward mudstone	4.96-11.28	Few to common, round white gypsum nodules (190.32-190.67 m depth, very fine sand sized). Some mud clasts present in coarse mud unit (173.45-175.31 m depth, closer to bottom, possible rip up clasts)	Low-energy turbidity currents	LA-B
5	Coarsening-upward mudstone	1.72-9.46	Scattered framboidal pyrite as low as 194.1 m depth	Low-energy deep marine; increasing energy conditions	LA-C
6	Burrowed mudstone	0.91	Rare pyrite (more cubic than framboidal)	Dysoxic, low-energy conditions that allowed biogenic reworking	LA-C
7	Bentonite	NA	Beds at 169.45-169.35 m and 168.58-168.51 m include glassy blue mineral (melanterite)	Periods of volcanic activity during deposition	LA-B and -C

Abbreviations: TOC, total organic contents; NA, not available; UV, ultraviolet

association has low clay content (Figure GS2017-15-2) and is distinguished by the presence of lithofacies 2 and 3, which have mudstone clasts. Whole *Inoceramus* shells are present within lithofacies 2 of LA-A.

LA-A is interpreted to have been deposited in the outer shelf to upper slope environment. The laminated mudstone and intact *Inoceramus* shells indicate generally low-energy conditions, likely below storm-wave base (Eriksson and Reczko, 1997; Potter et al., 2005). *Inoceramus* has also been shown to present the highest diversity in middle to outer shelf sediments (Thiede and Dinkelman, 2007). The clasts in lithofacies 2 and 3 may have been produced by episodic density currents that flowed along the shelf bottom into deeper water (Potter et al., 2005) and were triggered by storm events.

Lithofacies association B: upper to lower slope deposits

Lithofacies association B (LA-B) consists of laminated mudstone, fining-upward mudstone and bentonite beds (lithofacies 1, 4 and 7). It occurs from 173.45 to 181.47 m and 192.97 to

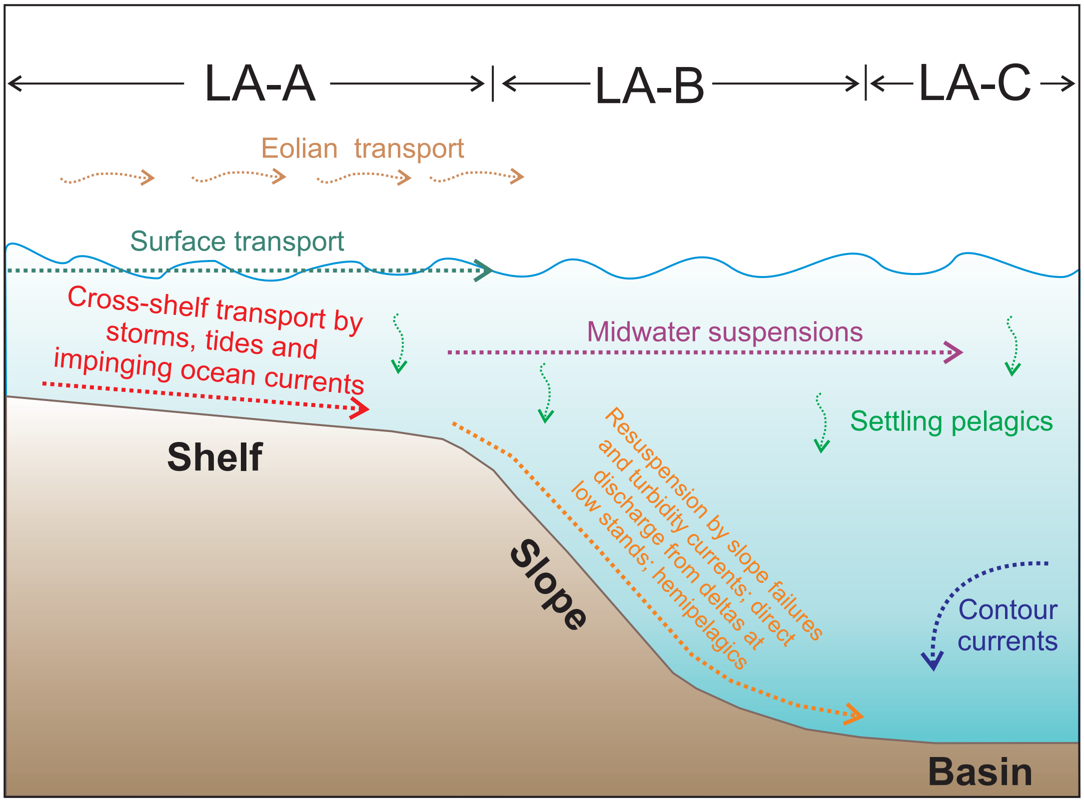


Figure GS2017-15-3: *Schematic interpretation of the lithofacies associations in the Boyne Member and the principal sediment transport on the shelf, slope and basin (modified from Stow, 1981). Abbreviations: LA-A, lithofacies association A; LA-B, lithofacies association B; LA-C, lithofacies association C.*

204.25 m depth in the MPC core (Figure GS2017-15-1). This lithofacies association is distinguished by the presence of lithofacies 4, comprising fining-upward units. *Inoceramus* fragments are present within lag deposits of lithofacies 1. In addition, LA-B has an overall high clay content (Figure GS2017-15-2).

LA-B is interpreted to have been deposited in the upper to lower slope environment. The laminated mudstone of lithofacies 1 again indicates low-energy conditions, but the fining-upward sequences in lithofacies 4 are interpreted to have been deposited by low-density turbidity currents, which commonly occur in slope settings (Potter et al., 2005; Lazar et al., 2015). Episodic storm events on muddy shelves re-suspended bottom-sediment–forming turbidity currents that flowed down the slope (Potter et al., 2005; Lazar et al., 2015).

The *Inoceramus*-rich lag deposits are interpreted to have been deposited during infrequent events of sediment winnowing by offshore-directed currents, induced by higher energy storm events (Konitzer et al., 2014). These currents likely reworked the shallow shelf and transported (simultaneously breaking up) the valve fragments off the shelf and deposited them onto the slope (Hosseininejad, 2016).

The high clay content of LA-B may be due to the resuspension and transport of shelf fines from storms, and the accumulation of these fines in a slope setting (Potter et al., 2005).

Lithofacies association C: lower slope to basin deposits

Lithofacies association C (LA-C) consists of laminated mudstone, coarsening-upward mudstone, burrowed mudstone and bentonite (lithofacies 1, 5, 6 and 7). It occurs from 164.00 to 173.45 m and 181.47 to 192.97 m depth in the MPC core (Figure GS2017-15-1). This lithofacies association is distinguished from the other associations by the presence of lithofacies 5 and 6, and has a low clay content.

LA-C represents the lowest energy conditions within the Boyne Member in the MPC core, as indicated by the occurrence of parallel laminations and lack of higher energy sedimentary structures in lithofacies 1, 5 and 6, as well as the abundance of burrows in lithofacies 6. The coarsening-upward trend of lithofacies 5 is interpreted as the result of increasing energy conditions, but the parallel laminations still suggest overall low-energy conditions. Collectively these interpretations suggest that deposition of LA-C took place in a lower slope or basinal setting (Potter et al., 2005).

Bentonites

Bentonite beds in the MPC core occur from 166.60 to 190.51 m depth and range in thickness from 1 to 13 cm (Figure GS2017-15-2). These grey-green to grey-yellow beds consist mostly of swelling and nonswelling clay. Of the 100 bentonite beds identified between the upper Swan River Formation and Pierre Shale section of the MPC core (Nicolas, 2016), a total of 26 individual bentonite beds were recorded within the Boyne Member. The concentration of bentonite beds appearing in the middle of the Boyne Member forms the third largest Cretaceous volcanic-episode suite recorded in Manitoba and marks the resurgence of a very tectonically active western margin, resulting in large volcanic eruptions during the Laramide orogeny.

Cyclothems and lithofacies trends

The stacking pattern of lithofacies associations recognized in the Boyne Member in the MPC core (Figure GS2017-15-2) agrees well with the T-R cycles of McNeil and Caldwell (1981), and shows an overall retrogradational trend (LA-A to LA-C) stratigraphically upward. This trend is interpreted to represent an overall rise in relative sea level and corresponds with the overall transgression (T2) in the Niobrara cyclothem. The occurrence of LA-B at 173.45 to 181.47 m depth suggests a minor regression followed by a transgression. This last transgression is recorded in the chalky unit, which finding agrees with the interpretations of McNeil and Caldwell (1981).

Mineralogy

The mineralogical composition of the Boyne Member was evaluated using X-ray diffraction (XRD) analysis at the University of Manitoba crystallography laboratory on one or two samples from each lithofacies, where possible, in order to evaluate the bulk mineral phases present.

All of the Boyne Member samples have similar XRD patterns, indicating a high degree of commonality in their mineral composition. The dominant minerals are calcite, quartz and gypsum. Minor minerals include muscovite, hydronium jarosite, pyrite and clay minerals (possibly halloysite, illite, dickite and montmorillonite). A sample from a bentonite layer at a depth of 168.55 m in the MPC core contains a glassy blue mineral identified as melanterite.

Samples from lithofacies 4 (174.17 m depth) and 5 (182.31 m depth) were found to have very high calcite content. Samples from lithofacies 6 (192.90 m depth) were found to have very high quartz content. As expected, the calcite-rich samples were taken from calcareous intervals and the quartz-rich samples were from noncalcareous intervals. The sample from lithofacies 2 (209.00 m depth) has a very high gypsum content, which is attributed to gypsum blooms that formed as the core dried out in storage.

Organic geochemistry

Rock Eval® 6 pyrolysis was conducted at the Geological Survey of Canada (Calgary) organic geochemistry laboratory on 24 core samples to determine the source-rock potential of the Boyne Member. The samples were collected at 1–5 m intervals from the uppermost Morden Member, the entire Boyne Member and the lowermost Gammon Ferruginous Member. The Rock Eval results are presented in Table GS2017-15-2.

The temperature at which there is a maximum release of hydrocarbons from a gradually heated sample is measured as T_{max}. As such, values of T_{max} from Rock Eval pyrolysis increase linearly with the degree of maturation of a source rock and the thermal oil window is represented by T_{max} values that span from 435 to 470°C (Peters, 1986; Dellisanti et al., 2010). The T_{max} values for samples from the Boyne Member in the MPC core range from 393 to 422°C, indicating that the samples are thermally immature. Due to this immaturity, TOC and hydrogen index/oxygen index (HI:OI) ratio are the most useful parameters for evaluating source-rock potential in this study.

The TOC content is related to the quantity of organic matter (OM) in the rock and can be used to characterize source-rock richness (Peters, 1986). The TOC values in the MPC core range from 0.91 to 11.28 wt. %. Based on these results, the quantity of OM in the Boyne Member would seem to indicate 'very good' source-rock generative potential, as defined by Peters (1986). The TOC values fluctuate throughout the member and appear to be higher in specific intervals: 1) near the bottom of the member at ~208.00 m depth; 2) near the middle at ~183.00 m and ~190.00 m depth; and 3) at the top at ~172.00 m depth (Figure GS2017-15-2). The TOC values also appear to have a negative relationship with clay content. Fine mudstones generally have low TOC values, whereas medium to coarse mudstones have high TOC values.

The HI values range from 59 to 524 mg HC/g C_{org} and OI values range from 31 to 88 mg CO_2/g C_{org}. The modified van Krevelen diagram (HI versus OI) was used to distinguish the potential kerogen types (Figure GS2017-15-4); however, only a preliminary determination can be made because of the small sample set. Samples plot in the fields for Type II (oil prone) and Type III (gas prone) kerogen. The small cluster of values plotting closest to the Type II kerogen curve are from the bottom and middle intervals of high TOC values, as described above (occurring at depths of 209.07 m, 200.12 m, 190.80–188.75 m, 182.31 m and 174.17–169.85 m).

Boyne Member resource potential

Previous work done by the SUSG Project has shown that the Boyne Member in Manitoba has a high TOC content and is thermally immature (Nicolas and Bamburak, 2012). Boyne Member samples generally plot in the Type III (gas prone) field (Figure GS2017-15-3) and due to the thermal immaturity of the member, any gas present in the rocks was generated in situ by biogenic processes (Nicolas and Bamburak, 2012). The gas was produced by biodegradation of OM and is believed to have been rejuvenated with an inflow of meteoric water after the retreat of the Laurentide Ice Sheet (Nicolas and Grasby, 2009). As such, the production of gas in this area is typically accompanied by high water production (Nicolas, 2008).

Zones of medium to coarse mudstone (microporous rock) that contains high levels of organic carbon are good prospects for biogenic gas reservoirs (Nicolas, 2016). Higher quartz

Table GS2017-15-2: Rock Eval® 6 results of Upper Cretaceous units in the MPC core at 3-29-20-29W1, southwestern Manitoba. Table headers are: S1, milligrams of hydrocarbons that can be thermally distilled from one gram of rock; S2, milligrams of hydrocarbon generated by pyrolytic degradation of the kerogen from one gram of rock; S3, milligrams of CO_2 generated from a gram of rock when heated up to 390°C (mg/g); S3CO, milligrams of CO generated from a gram of rock when heated (mg/g); T_{max}, temperature at the point of maximum release of hydrocarbons during pyrolysis; TOC, total organic carbon; MINC, mineral carbon; HI, hydrogen index; OI, oxygen index; PC, pyrolyzed carbon; PI, production index; RC, residual carbon. Abbreviations: GF, Gammon Ferruginous; Mb., Member.

Sample number	Stratigraphic unit	Vertical depth m	S1 mg/L	S2 mg/L	S3 mg CO_2/g	S3CO mg CO/g	Tmax °C	TOC wt. %	MINC wt. %	HI	OI	PC %	RC %	PI
106-16-3384-166.1	GF Mb.	166.10	0.95	30.01	4.11	1.35	407	9.44	0.2	318	44	2.77	6.67	0.03
106-16-3384-167.16	GF Mb.	167.16	0.22	10.72	2.06	0.62	408	4.25	0.1	252	48	1.01	3.24	0.02
106-16-3384-168.31	Boyne Mb.	168.31	0.12	3.91	1.34	0.33	408	2.58	0.2	152	52	0.41	2.17	0.03
106-16-3384-168.77	Boyne Mb.	168.77	0.07	3.76	1.77	0.41	413	2.61	0.2	144	68	0.40	2.21	0.02
106-16-3384-169.85	Boyne Mb.	169.85	1.08	40.81	5.37	1.65	405	10.61	0.2	385	51	3.73	6.88	0.03
106-16-3384-174.17	Boyne Mb.	174.17	0.94	57.49	5.60	1.31	410	11.18	5.4	514	50	5.09	6.09	0.02
106-16-3384-178.2	Boyne Mb.	178.20	0.16	13.12	1.91	0.58	417	4.09	0.1	321	47	1.19	2.90	0.01
106-16-3384-182.31	Boyne Mb.	182.31	0.72	48.07	4.78	1.13	407	9.45	4.9	509	51	4.26	5.19	0.01
106-16-3384-183.1	Boyne Mb.	183.10	0.84	52.33	4.96	1.20	407	10.46	3.4	500	47	4.63	5.83	0.02
106-16-3384-184.67	Boyne Mb.	184.67	0.32	7.67	1.45	0.56	402	3.81	0.2	201	38	0.75	3.06	0.04
106-16-3384-185.97	Boyne Mb.	185.97	0.47	38.09	3.96	0.94	407	7.52	3.7	507	53	3.37	4.15	0.01
106-16-3384-188.75	Boyne Mb.	188.75	0.41	35.77	2.84	0.87	414	7.23	1.2	495	39	3.13	4.10	0.01
106-16-3384-190.8	Boyne Mb.	190.80	0.47	40.94	3.50	0.92	411	7.82	2.8	524	45	3.59	4.23	0.01
106-16-3384-192.9	Boyne Mb.	192.90	0.02	0.54	0.80	0.12	422	0.91	0.7	59	88	0.08	0.83	0.04
106-16-3384-193.79	Boyne Mb.	193.79	0.05	1.26	0.85	0.22	410	1.72	0.1	73	49	0.15	1.57	0.04
106-16-3384-196.51	Boyne Mb.	196.51	0.06	1.60	0.65	0.19	410	1.56	0.1	103	42	0.17	1.39	0.04
106-16-3384-200.12	Boyne Mb.	200.12	0.12	4.14	1.46	0.42	409	3.11	0.2	133	47	0.43	2.68	0.03
106-16-3384-202.58	Boyne Mb.	202.58	0.33	8.81	2.11	0.66	401	4.28	0.2	206	49	0.87	3.41	0.04
106-16-3384-204.97	Boyne Mb.	204.97	0.48	10.99	1.52	0.61	400	4.51	0.2	244	34	1.04	3.47	0.04
106-16-3384-207.59	Boyne Mb.	207.59	0.45	36.05	4.68	1.19	409	9.28	0.7	388	50	3.23	6.05	0.01
106-16-3384-209.0	Boyne Mb.	209.00	0.71	23.20	5.14	1.76	400	9.02	0.4	257	57	2.23	6.79	0.03
106-16-3384-209.07	Boyne Mb.	209.07	0.69	24.25	4.77	1.62	403	8.96	0.3	271	53	2.31	6.65	0.03
106-16-3384-210.07	Morden Mb.	210.07	0.40	11.42	1.77	1.23	393	5.69	0.5	201	31	1.09	4.60	0.03
106-16-3384-213.63	Morden Mb.	213.63	0.52	10.30	3.43	1.75	397	6.66	0.6	155	52	1.08	5.58	0.05

content in a reservoir is necessary to sustain sufficient permeability for gas extraction (Nicolas and Bamburak, 2012). Lower clay content, especially of non-swelling clay, is also preferred in a reservoir rock for gas extraction (Nicolas and Bamburak, 2012). Based on mudstone texture, TOC, quartz and clay content, two intervals in the MPC core are suggested to have the best biogenic gas potential: 185–190 m depth and 169–177 m depth. These sections have high TOC values, consistently higher silicate (likely quartz) and low clay contents, and consist of coarser mud. Another potential gas interval is located at 207–209 m. This interval meets all criteria, with the exception of lower silicate content (Shaw, 2017). Strong petroliferous odours and streaming white cuts that fluoresced in acetone under UV light were observed in samples from 203.90 m and 209.00 m depth. This observation further supports the gas potential of the proposed intervals.

Babcock beds

The Babcock beds, as described in Nicolas et al. (2010), are not clearly identifiable in this core. However, the stratigraphic positioning, variability in the lithology, texture and structure, and high TOC values of the interval between 177.21 and 173.45 m depth have similarities to those reported by Nicolas et al. (2010), suggesting this interval is a possible distal equivalent of the Babcock beds. In addition, this interval occurs within one of the potential gas horizons suggested above, which may also correspond with the gas-producing Boyne sand of the Kamsack reservoir in Saskatchewan. If these correlations are correct, then the Babcock beds and their equivalent distal facies, which potentially extend over a very large prospective area, may provide the key to the stratigraphic position–and targeting–of the best gas-bearing prospect in the Boyne Member.

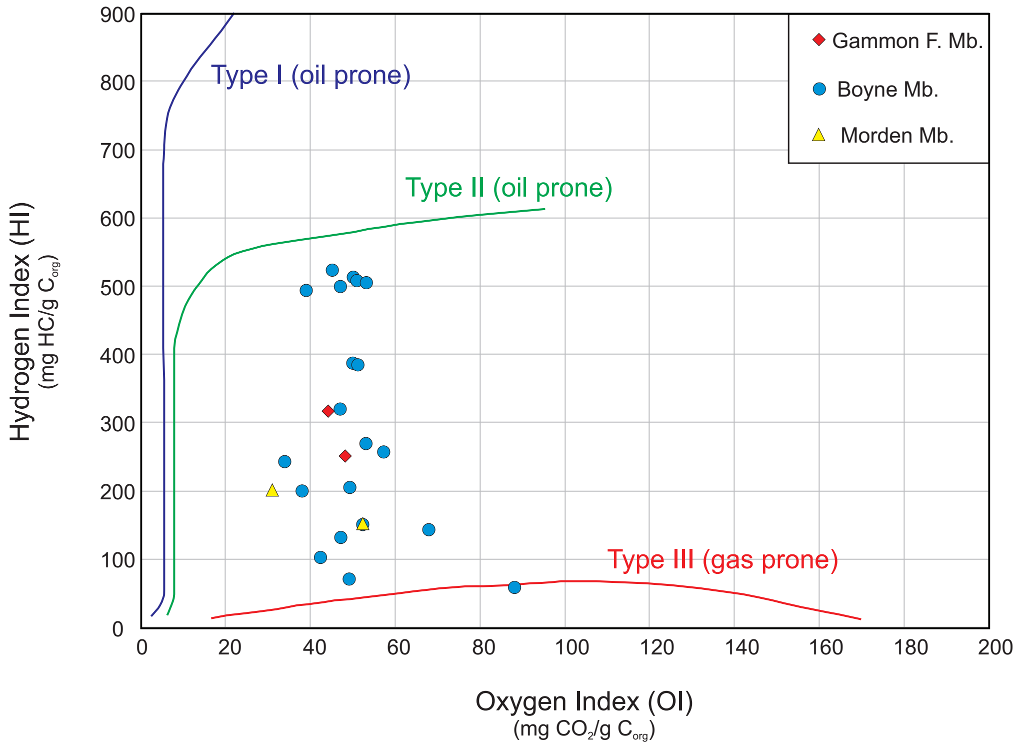


Figure GS2017-15-4: *Modified van Krevelan diagram of Rock Eval® 6 data from the MPC core at 3-29-20-29W1 from the Boyne Member, Carlile Formation, southwestern Manitoba. Abbreviations: F., Ferruginous; Mb., Member.*

Economic considerations

The goal of the SUSG Project is to provide energy exploration companies and investors with basic geoscience information in the risky, underexplored unconventional-gas play in southwestern Manitoba. This detailed evaluation of the Boyne Member offers a rare look into a thick section of this unit at 3-29-20-29W1, and provides important insight into the best horizon to target for potential natural gas production. Although further knowledge can still be gained from this core, this study provides the fundamental basis into this gas-bearing horizon from which to carry out further investigations.

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