GS-15 Preliminary results from sedimentological investigations and petroleum evaluation of the Upper Devonian Duperow Formation, southwestern Manitoba

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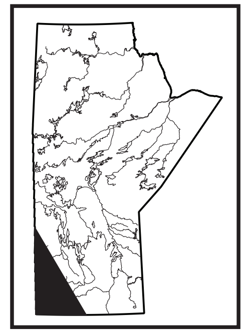

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Summary

The Upper Devonian (Frasnian) Duperow Formation is a carbonate-evaporite platform succession with oil production in Saskatchewan, North Dakota and Montana. This formation extends into the subsurface of southwestern Manitoba, where exploration of the formation has been limited and no oil discoveries have been made to date. This study was initiated to investigate the stratigraphic and sedimentological characteristics of the Duperow Formation, resulting in a better understanding of the controls on the reservoir and the source-rock potential of the formation.

The Duperow Formation in Manitoba reaches a maximum thickness of 220 m and can be divided, in ascending order, into the Saskatoon, Wymark and Seward members using marker beds identified in cores and geophysical logs. Three lithofacies associations, representing a semirestricted interior platform setting of the Duperow embayment, are recognized in this study. These are subtidal lithofacies association (LA 1), intertidal lithofacies association (LA 2) and supratidal/sabkha lithofacies association (LA 3). The subtidal lithofacies association (LA 1) consists of (A) skeletal wackestone-packstone, (B) intraclast wackestone-packstone, (C) stromatoporoid-coral floatstone, (D) stromatoporoid framestone and (F) massive dolostone. The intertidal lithofacies (LA 2) consists of (E) microbial bindstone and (F) massive dolostone. The supratidal/sabkha lithofacies (LA 3) consists of (G) interlaminated dolostone and anhydrite, (H) massive to chicken-wire anhydrite and (I) patterned dolostone. These three lithofacies associations form metre- to decametre-scale, shallowing-upward cycles that are interpreted to be formed by combined regional progradation and/or aggradation and localized tidal-flat island migration.

Diagenetic features observed in the Duperow Formation represent alteration in the marine, burial and meteoric environments. Synsedimentary marine diagenesis resulted in the precipitation of radial fibrous calcite and radiaxial fibrous calcite cements. Burial diagenesis is dominant and includes dolomitization, protracted dissolution and compaction, and precipitation of prismatic calcite, blocky calcite and anhydrite cement. The final stage of diagenesis, which includes dedolomite formation and anhydrite alteration, is attributed to infiltration of meteoric fluids from the pre-Mesozoic unconformity.

The Wymark Member has the best reservoir potential in dolomitized subtidal and intertidal lithofacies, which have porosity up to 25% and permeability up to 173.0 mD. Organic-rich laminae throughout the Wymark Member have good generative potential for oil and/or gas and may be thermally mature in the southwest corner of Manitoba. Potential capping units are the impermeable evaporite beds in supratidal lithofacies. The best potential for conventional petroleum plays exists in possible structural traps related to Prairie Evaporite dissolution and block faulting along the Birdtail-Waskada Zone, as well as stratigraphic traps related to variable dolomitization and truncations along the subcrop edge.

Introduction

The Upper Devonian (Frasnian) Duperow Formation in the Williston Basin is dominated by cyclic deposits of limestones, dolostones and evaporites (Moore, 1988; Wendte, 1992). The formation produces oil in North Dakota, Montana and Saskatchewan and correlates stratigraphically to the economically important Leduc Formation in the Alberta Basin (Pilatzke et al., 1987; Wilson and Pilatzke, 1987; Cen, 2009). In Manitoba, the Duperow Formation is a potential target for petroleum exploration but limited geological knowledge has contributed to low exploration activity and there is currently no commercial production from the formation within the province (Nicolas and Barchyn, 2008; Eggie et al., 2012; Bates, 2016).

This project was initiated in 2011 with the goal of characterizing the lithostratigraphy and sedimentology of the Duperow Formation to understand the controls and evaluate its petroleum potential. Two studies have been completed to date, with one focusing on the lithofacies and diagenesis of the Wymark Member of the Duperow Formation (Eggie, 2012; Eggie et al., 2012) and the other addressing the lithostratigraphy and sedimentology of the entire Duperow Formation (Bates, 2016). Another study is being conducted by G. Dakoru (University of Manitoba) to investigate the sedimentology and chemostratigraphy of the Saskatoon Member and part of the Wymark member of the Duperow Formation. That

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study will concentrate on the well (licence number 3884) Manitoba Potash Harrowby Prov. PTH 100/03-29-020-29W1/00 located at L.S. 3, Sec. 29, Twp. 20, Rge. 29, W 1st Mer. (abbreviated 3-29-20-29W1), which has a full core of the formation.

This paper presents some of the results of the lithostratigraphy, sedimentology and resource evaluation of the Duperow Formation that formed part of a M.Sc. thesis by the senior author at the University of Manitoba (Bates, 2016). The study area comprises the entire occurrence of the Duperow Formation in southwestern Manitoba, which is confined to the subsurface, and can only be studied through 432 geophysical well logs and 30 cores. The study area is defined by the Saskatchewan-Manitoba provincial boundary to the west, the Canada-United States international border to the south and by the Duperow Formation subcrop edge to the northeast, which has a general southeast trend. This area includes Townships 1 to 42 and Ranges 11 to 29W1 (Figure GS-15-1).

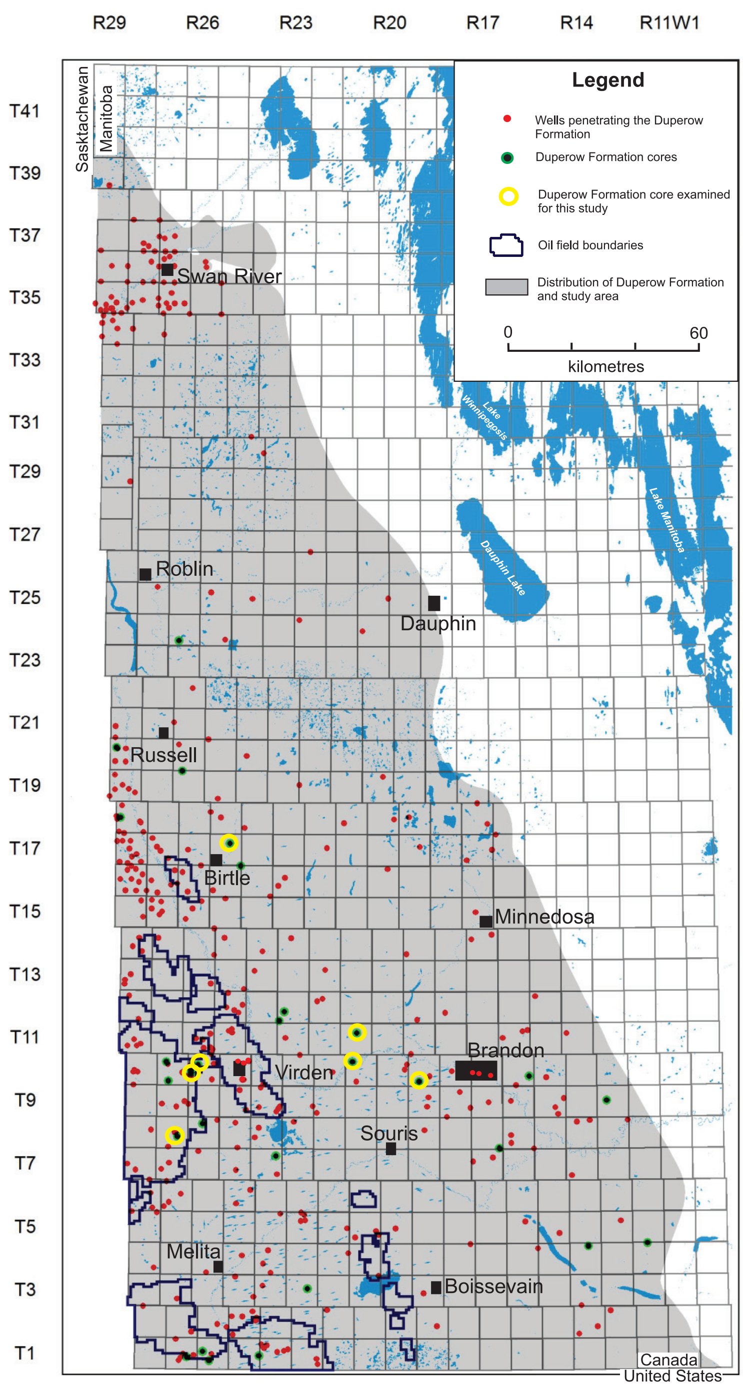

__Figure GS-15-1__: Distribution of the Duperow Formation in southwestern Manitoba, wells that penetrated the formation, wells with cores in southwestern Manitoba and core logged for this study.

Regional geology

The Elk Point Basin, which is a sub-basin of the Western Canada Sedimentary Basin (Figure GS-15-2), comprises a thick Devonian package of cyclic carbonate, siliciclastic and evaporite facies that form five discontinuity-bounded sequences within an overall transgressive succession (Moore, 1988; Wendte, 1992). These sequences, in ascending order, are the Delorme, Bear Rock, Hume-Dawson, Beaverhill-Saskatchewan and Palliser. The basin was generally tectonically stable and the sequences were controlled primarily by eustatic sea-level fluctuation. During the Frasnian, the Elk Point Basin was open in the north and restricted to the south by the Transcontinental arch resulting in the Beaverhill-Saskatchewan sequence being dominated by siliciclastic facies in the north and carbonate facies to the south.

In Manitoba and Saskatchewan, Devonian strata comprise, in ascending order, the Elk Point, Manitoba, Saskatchewan and Three Forks groups (Nicolas and Barchyn, 2008; Nicolas, 2012). The Duperow Formation is part of the Saskatchewan Group (in the Beaverhill-Saskatchewan sequence), which correlates stratigraphically to the Woodbend Group in Alberta and the Jefferson Group in North Dakota (Peale, 1893; Switzer et al., 1994). The Duperow Formation formed in the Eastern Platform interior of the Elk Point Basin (Figure GS-15-2), which was positioned at approximately latitude 15°S, within the arid climate belt (Witzke and Heckel, 1988). Water circulation within the platform interior was semirestricted during this time by growth of the Leduc reefs to the west, resulting in cyclic deposits of carbonate sediments and evaporites.

Methods

Stratigraphic cross sections, isopach maps and structural maps were constructed for this project using the geoSCOUT™ well-logging software. The contact between the Souris River and Duperow formations was used as the datum for the cross-sections, and member contacts were picked using marker beds as described by Sandberg and Hammond (1958) and Kent (1968). Isopach and structural maps of the Duperow Formation and its members were generated based on the Williston Basin Targeted Geoscience Initiative database (TGI Working Group, 2008a) and formation boundary picks from logged wells in this study. Maps and cross-sections generated can be viewed in Bates (2016).

Seven wells with the longest cored intervals of the Duperow Formation, totaling 108 m, were examined in detail at the Manitoba Geological Survey Midland Core and Sample Library between July and November 2012; the cores and intervals logged are listed in Table GS-15-1. A total of 110 thin sections of representative samples taken from the cores were examined using standard petrographic techniques, including epifluorescence and cathodoluminescence microscopy.

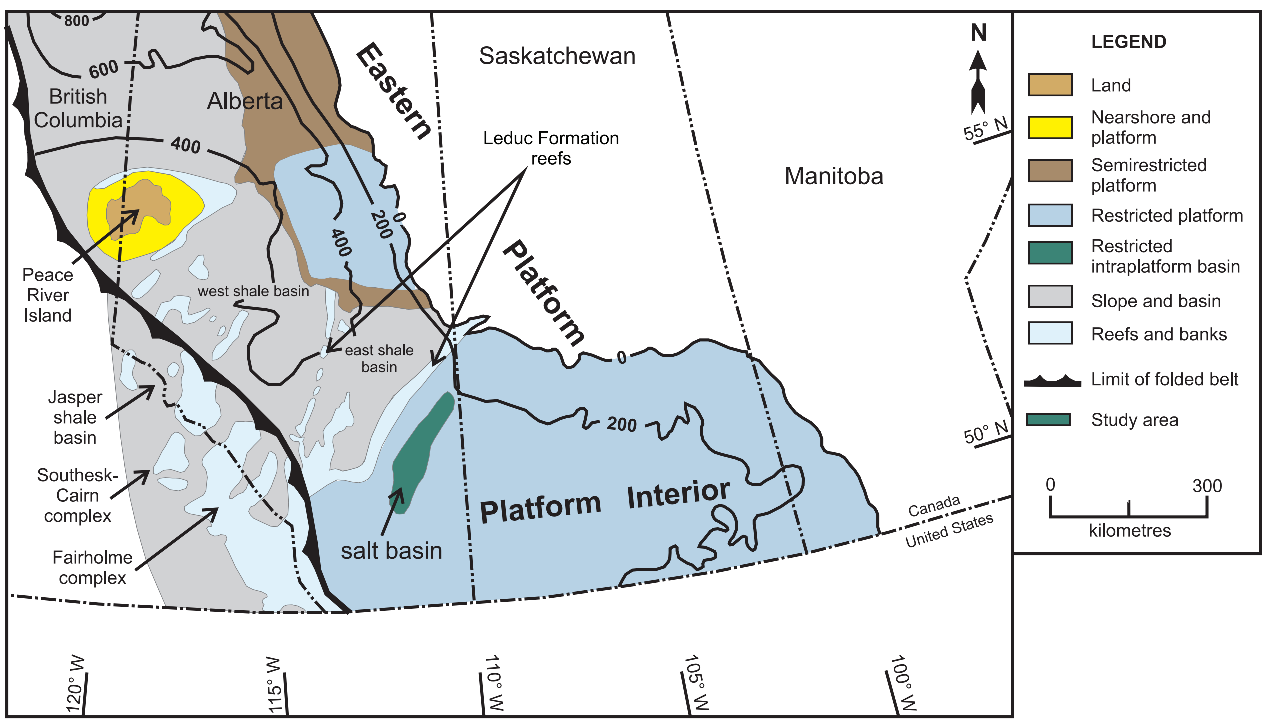

Figure GS-15-2: Paleogeographic reconstruction of the Elk Point Basin during deposition of the Saskatchewan Group (modified originally from Moore [1988] and reproduced directly from Eggie et al. [2012]). Contour lines indicate water depth in metres. © Canadian Society of Petroleum Geologists (CSPG), reprinted by permission of CSPG, whose permission is required for further use.

Table GS-15-1: Duperow Formation cores logged for this study.

Location	Core interval examined (m)	Core interval examined (ft)	Stratigraphic unit
4-14-8-28W1	1033.3–1036.3	3390.0–3400.0	middle Wymark Member
	1090.8–1094.8	3582.0–3592.0	Saskatoon Member
13-4-10-20W1	575.2–610.5	1887.0–2002.9	middle and upper Wymark Member
11-29-10-22W1	664.5–675.0	2180.0–2214.5	Saskatoon Member
7-18-10-27W1	915.0–949.8	3001.9–3116.1	middle Wymark Member
16-20-10-27W1	885.4–888.8	2904.8–2916.0	Seward Member
	893.1–896.1	2930.1–2940.0	middle Wymark Member
4-27-11-22W1	644.7–659.7	2115.0–2164.3	middle and upper Wymark Member
1-27-17-26W1	687.0–690.1	2254.0–2264.0	middle Wymark Member
	705.0–708.1	2313.0–2323.0	middle Wymark Member
	750.7–752.2	2463.0–2468.0	lower Wymark Member

A total of 43 calcite and dolomite samples were analyzed for stable carbon isotopes ($\delta^{13}C$) and stable oxygen isotopes ($\delta^{18}O$) at the Stable Isotope Laboratory at the University of Manitoba. Measurements were done using a Thermo Finnigan™ GasBench II coupled to a Thermo Finnigan Delta V™ Plus isotope-ratio mass-spectrometer. Analytical precision was ±0.1‰ for $\delta^{13}C$ and ±0.2‰ for $\delta^{18}O$. Twenty-one samples of dolomite and mixed calcite-dolomite were analyzed for $^{87}Sr/^{86}Sr$ by the Saskatchewan Isotope Laboratory at the University of Saskatchewan. Analyses were done using a Triton thermal ionization mass spectrometer and data reduction with normalization to $^{86}Sr/^{88}Sr = 0.1194$. Analytical precision was $0.710286 \pm 12 \times 10^{-6}$. Trace-element geochemistry was done at the Regional Microbeam Facility at the University of Manitoba. Analyses were completed on 16 calcite and dolomite samples to obtain concentrations of Ca^{2+}, Mg^{2+}, Mn^{2+}, Fe^{2+} and Sr^{2+}. Samples were analyzed using a New Wave Up-213 laser and Thermo Finnigan Element 2™ inductively coupled plasma–mass spectrometer (ICP-MS); however, detection limits of the analyses were not recorded because of a software error.

Rock-Eval pyrolysis and total organic content (TOC) analysis of 19 organic-rich samples were completed at the Organic Geochemistry Laboratory at the Geological Survey of Canada, Calgary, Alberta. The samples were analyzed using a Delsi Inc. Rock-Eval 6 unit to determine kerogen type and hydrocarbon source potential (Peters, 1986; Behar et al., 2001).

Stratigraphy

Stratigraphic framework

The Duperow Formation in Manitoba reaches a maximum thickness of 220 m and is composed of cyclic successions of limestones, dolostones and evaporites that were deposited in the semirestricted Duperow embayment during the Upper Devonian. The first attempt to formally subdivide the formation in Manitoba into constituent members was through the efforts of the Williston Basin Targeted Geoscience Initiative (www.willistontgi.com), which pioneered cross-boundary mapping of Phanerozoic units between eastern Saskatchewan and western Manitoba (Nicolas and Barchyn, 2008). Based on well-log correlations with the Duperow Formation stratigraphy in Saskatchewan (Kent, 1968; Dunn, 1975; Cen and Salad Hersi, 2006), the members recognized in Manitoba are, in ascending order: the Saskatoon, Wymark and Seward members. Core and petrographic work done by Eggie (2012) and Bates (2016) on the Duperow Formation in Manitoba provided key evidence supporting the correlation of these members in Manitoba. Figure GS-15-3 shows the regional stratigraphic equivalencies from Saskatchewan into Manitoba, and is the suggested stratigraphic framework for the Duperow Formation in Manitoba going forward.

Lithostratigraphic descriptions

In southwestern Manitoba, the Saskatoon, Wymark and Seward members of the Duperow Formation can be correlated throughout the study area using marker beds identified in core and geophysical well logs (Figure GS-15-4).

The Saskatoon Member reaches a maximum thickness of 14 m in southwestern Manitoba and conformably overlies the Souris River Formation. The top of the member is defined by marker bed C2. The cored intervals of this member are predominantly nodular, mottled and massive skeletal wackestones-packstones with minor skeletal floatstones-rudstones (Bates, 2016).

The Wymark Member can be subdivided into lower, middle and upper units. The lower Wymark Member, up to 41 m thick, is defined by marker bed C2 at its base.

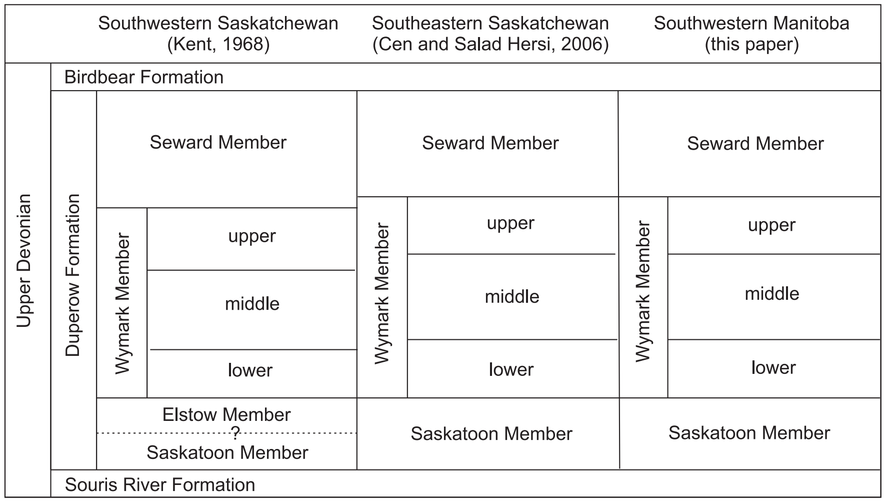

Figure GS-15-3*: Stratigraphic framework of the Upper Devonian Duperow Formation from southwestern Saskatchewan eastward to southwestern Manitoba.*

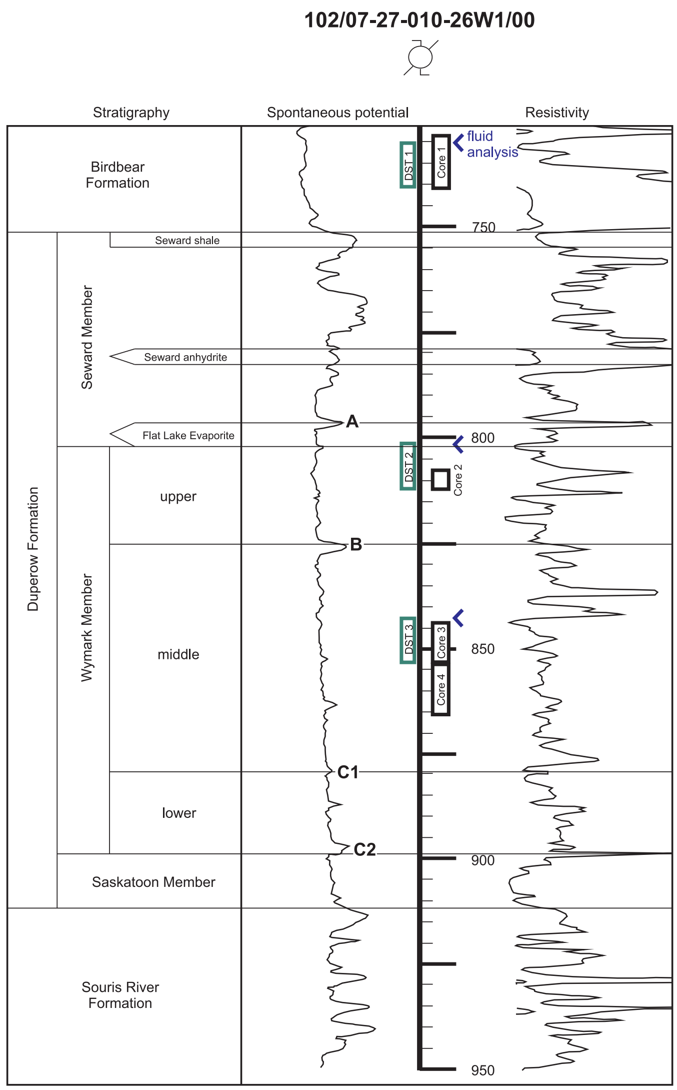

Figure GS-15-4*: Stratigraphy and typical spontaneous potential and resistivity-log signature of the Duperow Formation from the B.A. Union Grose Virden SWD 7-27-10-26W1 well, southwestern Manitoba. Marker beds defining unit contacts are labelled C3, C1, B and A. Depth is in metres (modified from Eggie et al., 2012). Abbreviation: DST, drill stem test.*

This unit is composed of alternating skeletal wackestones-floatstones, microbial bindstones, massive dolostones and anhydrites (Bates, 2016). The middle Wymark Member is defined by marker bed C1 at the base. The unit reaches a maximum thickness of 56 m and comprises skeletal wackestones-rudstones, stromatoporoid floatstones-framestones, microbial bindstones, massive and patterned dolostones and anhydrites (Bates, 2016). The upper Wymark Member, which is up to 30.5 m thick, and is defined by marker bed B at its base. The top contact is defined by either marker bed A or by the base of the Flat Lake Evaporite. This unit is predominantly skeletal-intraclast wackestones-rudstones, microbial bindstones, massive and patterned dolostones and anhydrites (Bates, 2016).

The Seward Member reaches a maximum thickness of 55 m and is defined by marker bed A at its base. The top contact is conformable with the overlying Birdbear Formation. The available core in this study was dominated by skeletal wackestones-floatstones, intraclast wackestones-packstones and dolomudstones (Bates, 2016). Marker beds within the Seward Member include the Seward shale, the Seward anhydrite and the Flat Lake Evaporite (Figure GS-15-4). Geophysical log correlations were used to map these marker beds in Manitoba; no core has been logged through these marker beds for this study. The Flat Lake Evaporite in Saskatchewan is a halite enclosed within anhydrite, but log correlations suggest this salt no longer exists in Manitoba and only distal equivalent facies are preserved, which agrees with the mapping of the Flat Lake salt by the TGI Williston Working Group (2008b).

Lithofacies

A total of nine carbonate and evaporite lithofacies were identified in the Duperow Formation in the study area through detailed core logging and thin-section petrography (Table GS-15-2). Refer to Bates (2016) for details of the lithofacies and lithofacies associations.

These lithofacies can be grouped into three lithofacies associations, representing a semirestricted interior platform setting (Bates, 2016). The subtidal lithofacies association (LA 1) consists of

- A: skeletal wackestone-packstone (Figure GS-15-5a),
- B: intraclast wackestone-packstone,
- C: stromatoporoid-coral floatstone,
- D: stromatoporoid framestone (Figure GS-15-5b) and
- F: massive dolostone (Figure GS-15-5d; Bates, 2016).

These lithofacies are all interpreted to have been deposited between fair weather and storm wave bases. Lithofacies A and B reflect overall low energy conditions with episodic storm events, lithofacies D represents patch reefs and lithofacies C represents reef flank deposits.

The intertidal lithofacies (LA 2) consists of

- E: microbial bindstone (Figure GS-15-5c) and
- F: massive dolostone (Bates, 2016).

Lithofacies F is interpreted as pervasively dolomitized subtidal and/or intertidal lithofacies. The supratidal/sabkha lithofacies (LA 3) consists of

- G: interlaminated dolomudstone and anhydrite (Figure GS-15-5e),
- H: massive to chickenwire anhydrite (Figure GS-15-5f) and
- I: patterned dolostone (Bates, 2016).

The three lithofacies associations form metre- to decametre-scale, shallowing-upward cycles that are interpreted to be formed by combined regional progradation and/or aggradation and localized tidal-flat island migration (Bates, 2016).

Diagenesis

Diagenetic features observed in the Duperow Formation in this study are interpreted to represent alteration in the marine, burial and meteoric environments. Figure GS-15-6 is a diagrammatic summary of the paragenetic sequence. Refer to Bates (2016) for details of the petrographic evidence and geochemical analyses.

Synsedimentary marine diagenesis resulted in the formation of micrite envelopes and precipitation of radial fibrous calcite and radiaxial fibrous calcite cements (Bates, 2016). The results of trace-element analysis (Sr^{2+}, Mn^{2+} and Fe^{2+}) and stable isotope analysis ($\delta^{13}C$ and $\delta^{18}O$) of radiaxial fibrous calcite cements are consistent with other examples of Upper Devonian marine calcite cements. The details of the geochemistry results are in Bates (2016).

Burial diagenesis is dominant and includes pyrite precipitation; dolomitization resulting in an early stage of facies-selective dolomicrite and a later stage of non–facies-selective, nonferroan planar and nonplanar replacement dolomite; protracted dissolution and compaction; nonferroan prismatic and blocky calcite cementation; and anhydrite cementation (Bates, 2016). Trace-element analysis and stable-isotope analysis of calcite cement and dolomite were consistent with similar burial diagenetic features in other Upper Devonian platform successions. Two mechanisms of dolomitization are proposed: the sabkha reflux model (early dolomicrite) and the seepage reflux model (later replacement dolomite).

The final stage of diagenesis included ferroan and nonferroan blocky calcite cementation, dedolomite formation and alteration of anhydrite to gypsum (Bates, 2016). This final stage is attributed to percolation of meteoric fluids from the pre-Mesozoic unconformity surface.

Table GS-15-2: *Summary of lithofacies of the Duperow Formation, southwestern Manitoba.*

Lithofacies		Lithology	Thickness	Cement	Dolomite	Porosity	Lithofacies association
A	Skeletal wackestone-packstone	Massive and nodular to mottled skeletal wackestone-packstone, skeletal-intraclast wackestone-packstone, peloidal-skeletal wackestone-packstone	0.4–5.3 m	Trace–20%, aphanocrystalline to coarsely crystalline, nonferroan and ferroan calcite. 0–10%, finely to very coarsely crystalline anhydrite and gypsum	1–95%, aphanocrystalline to coarsely crystalline, planar, nonplanar and mimetic	Trace–15%, intercrystalline, interparticle, intraparticle, vuggy, moldic, fracture	LA1–subtidal
B	Intraclast wackestone-packstone	Intraclast wackestone-rudstone, intraclast-skeletal wackestone-rudstone	0.2–5.5 m	0–10%, very finely to coarsely crystalline, nonferroan and ferroan calcite; 0–10%, very finely to very coarsely crystalline anhdrite and gypsum	5–80%, finely to medium crystalline, planar, nonplanar and mimetic	1–15%, intercrystalline, interparticle, intraparticle, vuggy, moldic, fracture	
C	Stromatoporoid-coral floatstone	Massive stromatoporoid floatstone-rudstone, stromatoporoid-coral floatstone, *Amphipora* floatstone; matrix: skeletal-peloidal wackestone-packstone	0.2–3.0 m	0–5%, very finely to coarsely crystalline, nonferroan calcite; 0–10%, very finely to coarsely crystalline anhydrite and gypsum	20–60%, finely to medium crystalline, planar and mimetic	5–10%, intercrystalline, interparticle, intraparticle, vuggy, moldic, fracture	
D	Stromatoporoid framestone	Massive to mottled stromatoporoid framestone; matrix: skeletal-peloidal wackestone-packstone.	0.3-1.8 m	<2%, very finely to medium crystalline, nonferroan calcite. 0-10%, very finely to very coarsely crystalline anhydrite and gypsum.	5-60%, finely to medium crystalline, planar and mimetic	2-10%, intraparticle, intercrystalline, interparticle, vuggy, moldic	
E	Microbial bindstone	Microbial bindstone with local beds of skeletal-peloidal wackestone and intraclast floatstone-rudstone	0.3–3.5 m	<2%, very finely to finely crystalline, nonferroan calcite; 0–5% finely to very coarsely crystalline anhydrite and gypsum	20–40%, aphanocrystalline to medium crystalline, planar	3–10%, intercrystalline, interparticle, vuggy	LA2–intertidal
F	Massive dolostone	Massive to mottled, very finely to medium crystalline dolostone, dolomitic intraclast floatstone-rudstone	0.1–1.7 m	0–5%, very finely to very coarsely crystalline, non-ferroan calcite; 0–25%, very finely to very coarsely crystalline anhydrite and gypsum	Up to 80%, very finely to medium crystalline, planar, nonplanar and dolomicrite	Up to 20%, intercrystalline, vuggy, fracture, interparticle, intraparticle, intracrystalline	Dolomitized LA1, LA2–subtidal, intertidal
G	Interlaminated dolostone and anhydrite	Dolomudstone, very finely to coarsely crystalline anhydrite and gypsum	0.2–2.2 m	Trace–10%, aphanocrystalline to finely crystalline, nonferroan calcite	0–50%, aphanocrystalline to finely crystalline, planar and dolomicrite	Trace–5%, intercrystalline, interparticle, vuggy	LA3–supratidal/ sabkha
H	Massive to chickenwire anhydrite	Massive anhydrite, chickenwire anhydrite	0.1–3.1 m	0–10%, finely to coarsely crystalline calcite	Trace, aphanocrystalline to finely crystalline, planar	None	
I	Patterned dolostone	Dolomudstone	0.2–0.5 m	None	100%, aphanocrystalline to medium crystalline, nonplanar and planar	Trace–15%, intercrystalline, intraparticle, fracture	

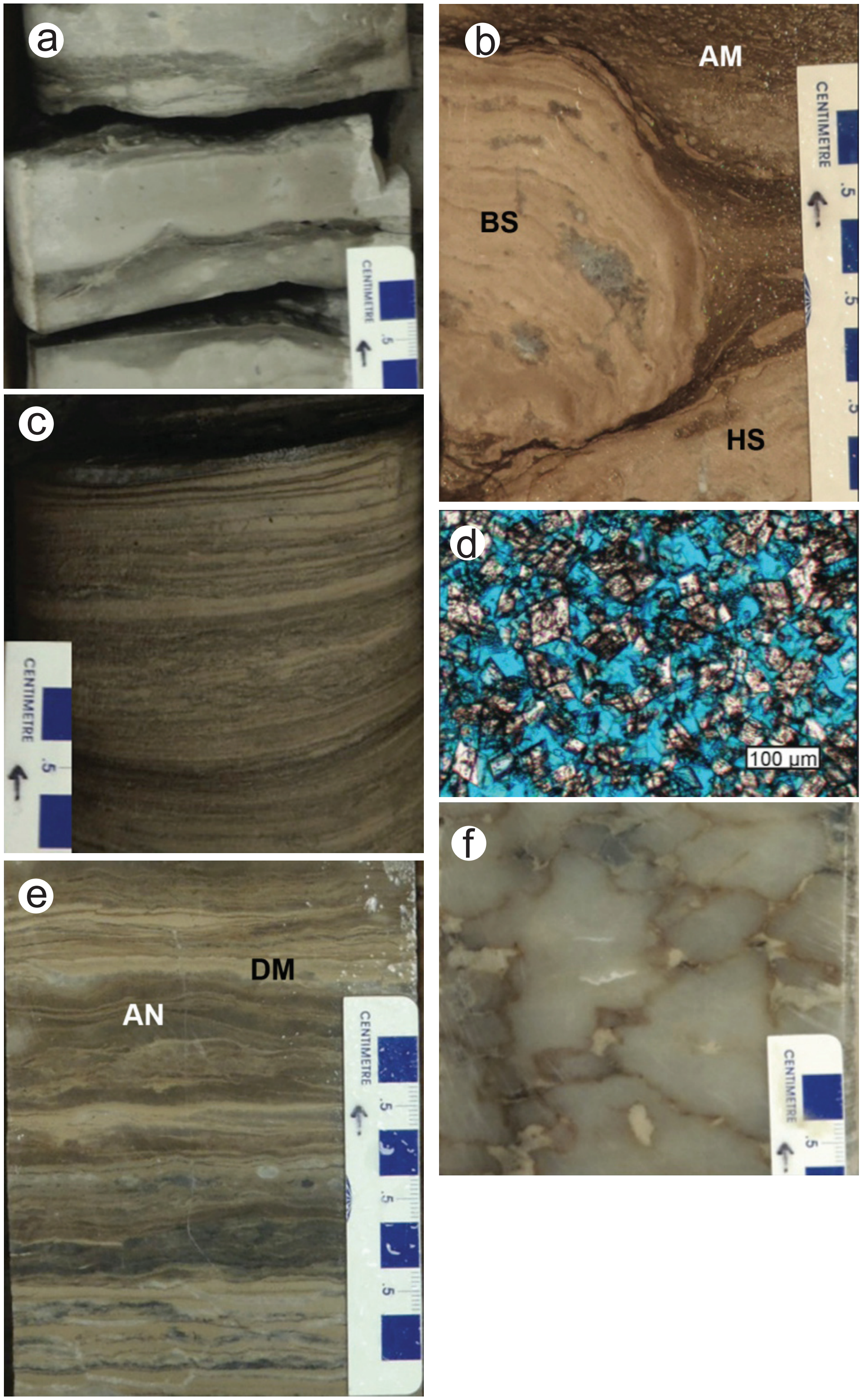

Figure GS-15-5*: Select lithofacies in the Duperow Formation in southwestern Manitoba:* ***a)*** *nodular to mottled skeletal wackestone (lithofacies A);* ***b)*** *stromatoporoid framestone (lithofacies D), showing bulbous (BS) and hemispherical stromatoporoids (HS), overlain by* Amphipora *floatstone (AM);* ***c)*** *microbial bindstone (lithofacies E) with an organic-rich bed near the top of the photo;* ***d)*** *photomicrograph (plane-polarized light) of massive dolostone (lithofacies F) showing good intercrystalline porosity (blue epoxy);* ***e)*** *interlaminated dolomudstone (DM) and anhydrite (AN; lithofacies G);* ***f)*** *chicken-wire anhydrite (lithofacies H).*

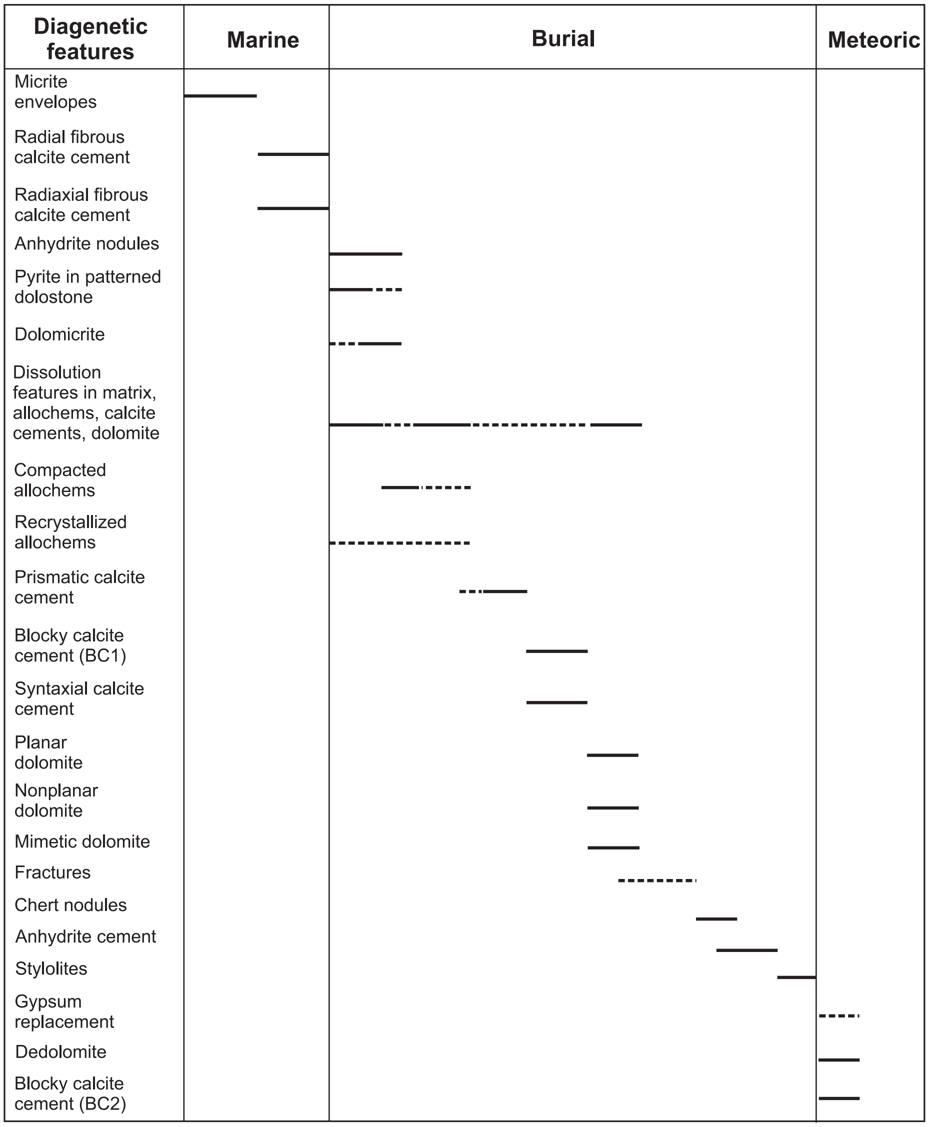

***Figure GS-15-6**: Paragenetic sequence for the Duperow Formation in southwestern Manitoba. The time of formation of each feature is interpreted relative to other described features; the length of the horizontal lines is not an indication of duration (modified from Bates, 2016).*

Petroleum potential

The Duperow Formation produces oil in Saskatchewan, North Dakota and Montana. Its stratigraphic equivalent in Alberta, the Leduc Formation, is a very prolific producer. Very little exploration has been conducted in Manitoba on this formation; therefore, its petroleum potential is not well known.

Reservoirs and caprocks

Potential reservoir units in the Duperow Formation in the study area are lithofacies packages composed of partially to pervasively dolomitized lithofacies associations 1 (subtidal) and 2 (intertidal; Bates, 2016). Live oil staining was observed in core in all three members of the Duperow Formation in the study area. Potential reservoir packages in the Saskatoon and Seward members are difficult to assess due to limited available core but dolomitized intervals can be more than 10 m thick and have porosity as high as 15%. Potential reservoir units in the Wymark Member, which have porosity reaching 25% and permeability up to 173 mD, are stacked in packages that range from 0.6 to 15.0 m thick. The extent of dolomitization within these packages is highly variable vertically (and probably laterally), suggesting that each package is likely affected by internal compartmentalization. Targeting lithofacies F (massive dolostone), which is up to 1.1 m thick, may result in better production due to the consistently high porosity and permeability associated with pervasively dolomitized units; however, this may prove to be difficult because controls on the distribution of lithofacies

F are still unclear. The lateral extent of the reservoir units cannot be determined due to the variable extent of dolomitization and the poor core coverage in the study area.

In the Duperow Formation in Saskatchewan and North Dakota, dolomitization has also been identified as the main control on conventional reservoir quality (Pilatzke et al., 1987; Cen, 2009). Dolomitized stromatoporoid banks, consisting of floatstones and boundstones, are major reservoir units. In Saskatchewan, they are 0.3 m thick on average and have porosity of up to 10% (Cen, 2009). In North Dakota, these banks are 0.6–7.6 m thick and 1.6–2.4 km in lateral extent with porosity as high as 30% (Pilatzke et al., 1987). These deposits are comparable to lithofacies C (stromatoporoid-coral floatstone) and lithofacies D (stromatoporoid framestone) in this study, which are interpreted to be stromatoporoid patch reefs and reef flank deposits (Bates, 2016). These two lithofacies, however, are not significantly more dolomitized than other Duperow Formation subtidal lithofacies in the study area and do not appear to offer better reservoir quality. Partially dolomitized microbial bindstone in the Duperow Formation in Saskatchewan are also significant reservoirs, with thicknesses from 0.15 to 1.2 m, and porosity from 5 to 10%. This lithofacies is lithologically similar to lithofacies E (microbial bindstone) in this study (Bates, 2016).

Potential capping units identified in the study area are the impermeable evaporite beds in supratidal/sabkha lithofacies G (interlaminated anhydrite and dolostone) and lithofacies H (massive to chickenwire anhydrite), which are present at the top of shallowing-upward cycles (Bates, 2016). In the Wymark Member, the capping units examined in core are 0.12–3.82 m thick. For the Saskatoon and Seward members, which have limited core coverage, resistivity logs were used to identify evaporite units. Capping unit thicknesses in these two members could not be accurately determined but are likely variable, similar to those in the Wymark Member. The lateral extent of potential capping units is difficult to determine; however, in the Wymark Member, several evaporite units could be correlated across the study area. Similar evaporite lithofacies are present in the Duperow Formation in Saskatchewan (Cen, 2009).

The best potential for conventional petroleum plays in the Duperow Formation in Manitoba exists in possible structural traps related to salt dissolution in the Prairie Evaporite and block faulting along the Birdtail-Waskada Zone, as well as stratigraphic traps related to laterally and vertically variable dolomitization (porosity pinchouts) and truncations along the subcrop edge at the pre-Mesozoic unconformity (Bates, 2016).

Rock-Eval 6 and TOC results

A total of 19 samples from the Wymark Member were analyzed using Rock-Eval 6 pyrolysis to help characterize the organic content, source-rock potential and thermal maturity of select organic-rich laminites (Bates, 2016). Samples were collected at vertical depths ranging from 575.0 to 943.1 m true vertical depth (TVD). The individual laminae are 0.5–2 cm thick, but tend to occur in beds consisting of numerous stacked laminae. The results are reported in Bates et al. (2016)[2].

Samples of subtidal lithofacies have TOC values ranging from poor to very good (0.20–3.21 wt. %) and T_{max} values from 419 to 434°C. The intertidal lithofacies samples have TOC values that range from poor to very good (0.12–3.06 wt. %) and T_{max} values from 405 to 434°C. The TOC values suggest good generative potential in the subtidal and intertidal lithofacies, but the T_{max} results indicate the laminites are thermally immature to marginally mature in the samples analyzed.

The samples were all taken from moderate depths, with the highest marginally mature T_{max} result of 434°C obtained from laminites at 918.8 m depth at 7-18-10-27W1. Based on the deepest recorded occurrence of the Duperow Formation, which is at 1382.5–1515.0 m TVD at 10-9-1-28W1, and extrapolating the formation in the extreme southwestern corner of Manitoba to approximately SE-6-1-29W1, the maximum depths are estimated at 1440–1575 m TVD. Such extra burial depths could be the tipping point for the occurrence of thermally mature laminites in the Duperow Formation. Supporting this hypothesis is recent preliminary Rock-Eval data from the Ordovician Winnipeg Formation at 11-29-1-25W1 indicating mature to overmature hydrocarbon generating conditions in this region. Combining this information with the water-driving force for the Duperow aquifer, where fluid migration is in a northeasterly direction as mapped by Palombi and Rostron (2013), the Duperow Formation in Manitoba could be both source rock and reservoir rock.

Economic considerations

The Duperow Formation is an oil-producing horizon in Saskatchewan, North Dakota and Montana, but until recently little was known about the Duperow Formation in Manitoba, including its geology or hydrocarbon potential. Preliminary results from this study indicate that the Duperow Formation in Manitoba does have oil potential, both as a conventional and unconventional oil target.

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[2] MGS Data Repository Item DRI2016005, containing the data or other information sources used to compile this report is available online to download free of charge at http://www2.gov.mb.ca/itm-cat/web/freedownloads.html or on request from minesinfo@gov.mb.ca or Mineral Resources Library, Manitoba Growth, Enterprise and Trade, 360–1395 Ellice Avenue, Winnipeg, Manitoba R3G 3P2, Canada.

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