GS2025-14

Electrofacies-based characterization of heterogeneity in the Wymark Member, Duperow Formation, southwestern Manitoba (parts of NTS 62F, G)

by P.E. Fraino

In Brief:

- Electrofacies classification in the Duperow Formation (Wymark Member) was conducted to delineate lithological variability
- Five electrofacies were defined five distinct lithologies
- The workflow provides a continuous and scalable method to assess heterogeneity and lithological trends in subsurface datasets

Citation:

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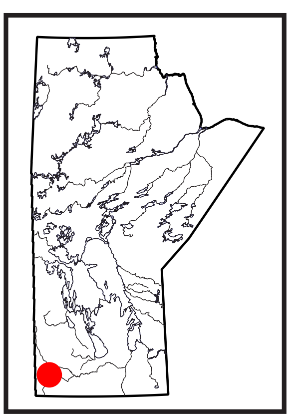

Summary

An electrofacies-based characterization of lithological variability and heterogeneity in petrophysical well log data was conducted on the Wymark Member of the Duperow Formation in southwestern Manitoba. Five electrofacies were delineated, each corresponding to a characteristic log response that is interpreted to represent limestone, dolostone, dolomitic limestone, mudstone and evaporite. These were assigned based on distinctive log responses and compared to available nearby core to validate the lithological expression of these electrofacies. Units within the Wymark Member each exhibit a distinct distribution of electrofacies and associated interpreted lithologies: the lower unit of the Wymark Member electrofacies is characterized by laterally continuous limestone intervals with minor dolostone and dolomitic limestone; the middle unit of the Wymark Member is the thickest and most heterogeneous, characterized by thick dolostone and dolomitic limestone that laterally transition into limestone toward the northern and eastern regions of the study area; and the upper unit of the Wymark Member electrofacies comprises laterally continuous limestone interbedded with thinner, discontinuous dolostone lenses and widespread anhydrite–mudstone seal intervals. These heterogeneous units provide important context for predicting reservoir distribution within the Wymark Member. The electrofacies classification workflow used in this study provides a tool for delineating heterogeneity in data-limited areas and can be applied to other intervals within the Duperow Formation to improve geological characterization.

Introduction

The Upper Devonian Duperow Formation in southwestern Manitoba is a regionally extensive carbonate–evaporite succession deposited within the Williston Basin (Wilson and Pilatzke, 1987). Brine exploration has recently targeted the Duperow Formation as an important interval for the critical mineral lithium. The formation is composed of metre-scale, carbonate–evaporite cycles that were deposited in subtidal, intertidal and supratidal settings that form distinctive brining-upward packages (Wilson and Pilatzke, 1987; Cen and Salad Hersi, 2006; Eggie, 2012; Eggie et al., 2012a; Bates, 2016; Nicolas and Chow, 2018)

Within the Duperow Formation, the Wymark Member is the thickest member, reaching up to 119 m in Manitoba. This member is of particular interest as lithium-rich brine is present in equivalent strata to the west, in Saskatchewan. The Wymark Member is informally subdivided into three units: the lower, middle and upper units. These units comprise interbedded dolostone, limestone, dolomitic limestone, anhydrite and mudstone, forming a heterogeneous lithological framework. This heterogeneity significantly influences reservoir quality, fluid flow and the development of internal baffles and barriers. Therefore, accurately characterizing the distribution and stacking of these lithologies is important for assessing reservoir compartmentalization and predicting brine accumulation zones.

Traditional core-based facies analysis provides invaluable lithological and textural information but is limited by the sparse and discontinuous nature of core. To overcome these limitations, electrofacies classification derived from petrophysical well log curves, specifically digital Log ASCII Standard (LAS) files, was used in this report as a complementary tool to delineate lithologies observed in core descriptions. The objectives of this study are to

1) delineate key electrofacies curve signatures corresponding to major lithologies in the Wymark Member; and
2) identify spatial and temporal variability across the three units of the Wymark Member (lower, middle and upper units).

This integrated electrofacies-based approach refines the understanding of the internal architecture of the Wymark Member and offers a scalable workflow that can be applied to other members of the Duperow and other formations, and to raster data to improve regional mapping and correlations across Manitoba when limited core data are available.

Previous work

Previous studies on the Upper Devonian Duperow Formation in southwestern Manitoba have focused primarily on establishing a stratigraphic framework, characterizing diagenesis and assessing hydrocarbon potential. Regional mapping and stratigraphic correlation were significantly advanced through the Targeted Geoscience Initiative (TGI), Phase II by Bezys and Bamburak (2004) and Nicolas and Barchyn (2008). They extended the formal member-level stratigraphy of the Duperow Formation from Saskatchewan into Manitoba. Subsequent work by Eggie (2012), Eggie et al. (2012a, b), Bates (2016) and Bates et al. (2016) included logging 10 core and conducting detailed petrographic and stable isotope analyses (Sr, O, C) to investigate depositional facies, diagenesis and formation evolution to assess the hydrocarbon potential. More recently, the entire Duperow Formation was logged in the Manitoba Potash Corporation (MPC) core (oil and gas well licence 3884, Manitoba Business, Mining, Trade and Job Creation, Winnipeg) located in L.S. 3, Sec. 29, Twp. 20, Rge. 29, W 1st Mer. (abbreviated 3-29-20-29W1) by Nicolas and Chow (2018). Interest in the Duperow Formation has since expanded with the emergence of lithium exploration, and as a result, previous work on facies architecture, diagenesis and reservoir properties now provides a crucial foundation for evaluating its potential to host lithium-bearing brines. Lastly, the first core-derived lithium concentration data have been reported from the MPC core in Fraino (2025), which highlights the role of intraformational, lithium-enriched mudstone intervals as a potential contributor to lithium in formation waters.

Stratigraphy

The Upper Devonian (Frasnian age) Duperow Formation is a carbonate and evaporite succession up to 260 m thick in the subsurface of the Williston Basin of northern North Dakota, southern Saskatchewan and southwestern Manitoba (Dunn, 1975; Pilatzke et al., 1987; Wilson and Pilatzke, 1987; Nicolas and Barchyn, 2008; Cen, 2009; Eggie, 2012). In Saskatchewan, the Duperow Formation reaches thicknesses between 125 and 260 m, whereas in southwestern Manitoba it thins to 122–195 m (Figure GS2025-14-1). The Duperow Formation conformably overlies the Souris River Formation and, in turn, is overlain by the Birdbear Formation (Nicolas and Barchyn, 2008). In North Dakota and Saskatchewan, the Duperow Formation is divided into four members: Saskatoon, Elstow, Wymark and Seward. These members are distinguished based on regionally extensive marker beds visible in geophysical logs and core. However, in eastern Saskatchewan and southwestern Manitoba, the Elstow Member is not distinguishable from the Saskatoon Member, and only the latter is recognized in this report. The Wymark Member is informally subdivided into lower, middle and upper units. The Seward

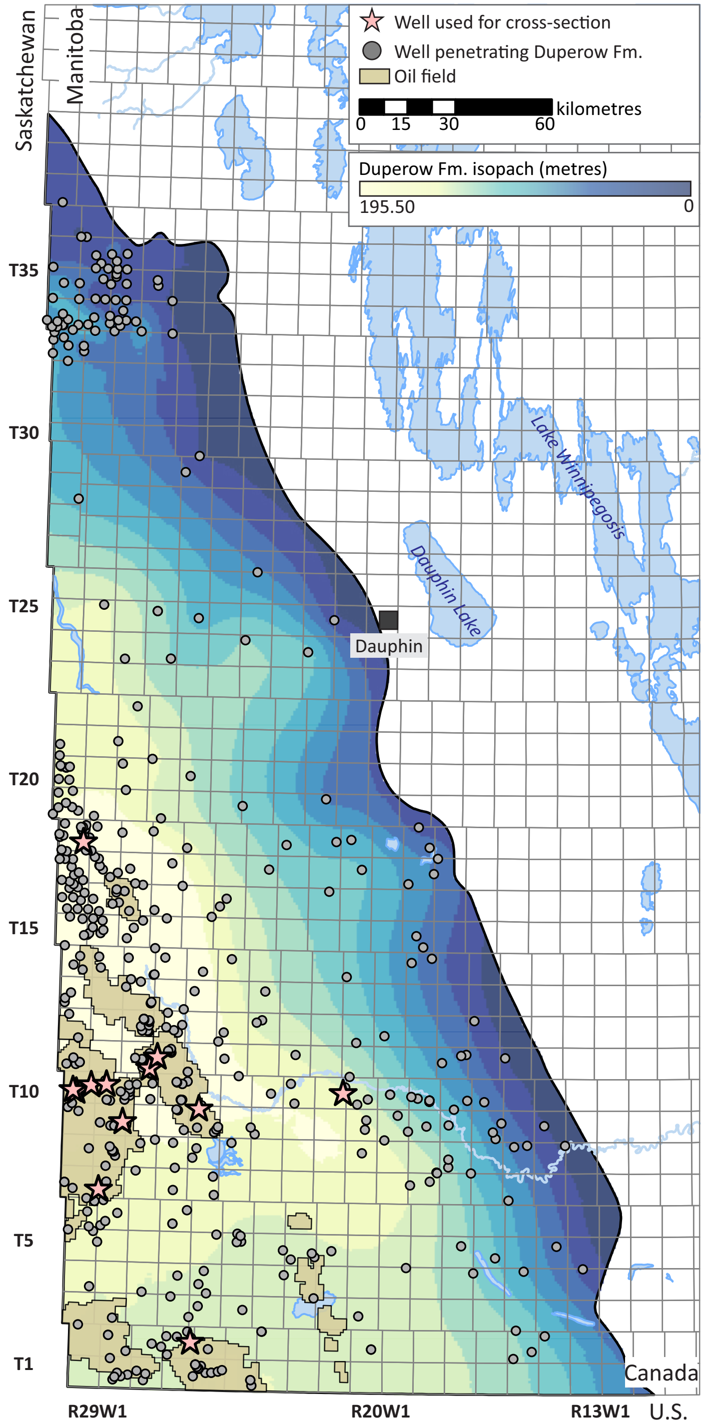

Figure GS2025-14-1: *Isopach map of the Duperow Formation in the study area in southwestern Manitoba, showing all wells that penetrated the Duperow Formation and the wells with Log ASCII Standard log files that were used in the cross-sections for this study (Figures GS2025-14-5, -6; geoLOGICS ltd.'s geoSCOUT™). Data points from geoSCOUT™ were processed using ArcGIS®. Isopach basemap was created using ArcGIS® software by Esri. ArcGIS® is the intellectual property of Esri and is used herein under license. Copyright © Esri. All rights reserved. For more information about Esri software, please visit <https://esri.ca/>.*

Member consists of a discontinuous basal evaporite, the Flat Lake Evaporite, and the upper laterally extensive Seward shale (Nicolas and Barchyn, 2008). In this report, the Wymark Member and its informal units (lower, middle and upper units) are the intervals of interest (Figure GS2025-14-2).

Dataset and electrofacies methodology

In Manitoba, a total of 515 wells penetrate the Duperow Formation, of which 329 wells include a suite of digital LAS log files that were available in geoLOGIC systems ltd.'s geoSCOUT™. For this report, 35 wells with LAS log files were analyzed for their gamma-ray (GR), neutron porosity calibrated to a limestone matrix (Nphi), density porosity calibrated to a limestone matrix (Dphi), photoelectric factor (PEF), bulk density (RHOB) and deep resistivity (RT) curves (Figure GS2025-14-2).

Electrofacies are distinctive groupings of log-curve responses that can be used to infer different lithologies within a wellbore (Davies, 2018). In this study, electrofacies were distinguished primarily using PEF, Nphi and Dphi curves, supported by GR, RHOB and RT curves. A rules-based classification scheme was developed by calibrating lithologies recognized in core to their characteristic log responses in carbonate–evaporite systems (Figure GS2025-14-2). This involved applying numeric cutoff values, starting with known PEF curve values, which provides the clearest separation between lithologies. Dolostone and mudstone intervals exhibit low PEF values (<3.3), whereas limestone and evaporite intervals display higher PEF values (>4.5). Intermediate values (3.3–4.5) are associated with transitional dolomitic limestone. Porosity curves (Nphi and Dphi) were then used to refine these groupings, followed by GR, RHOB and RT curves.

These combined curve relationships define the 'rules' of the electrofacies classification and are illustrated in the example log panel (Figure GS2025-14-2). This process was carried out for each of the 35 wells in the study area, and the resulting electrofacies assignments were compared across wells to ensure consistency and reproducibility. The lithologies applied in this scheme were confirmed by direct observation in Wymark Member core (Figure GS2025-14-3) and then extended to nearby wells. To improve accuracy, intervals were further refined using combined-log pattern recognition, ensuring that subtle variations not captured by simple cutoff values were incorporated into the electrofacies assignments.

To complement the rules-based classification, principal component analysis (PCA) was applied to the variables used for the rules-based electrofacies determination (GR, Nphi, Dphi, RHOB, PEF and RT curves) using a Python code (Figure GS2025-14-4). Prior to analysis, each variable within the dataset was standardized by subtracting the mean and dividing by the standard deviation for each curve. This ensured that all petrophysical logs contributed equally to the PCA, preventing variables with larger numerical ranges from dominating the results. The PCA reduces the number of variables into a few components that capture the majority of the variance in the dataset (see Grunsky, 2010; Jolliffe and Cadima, 2016), allowing log responses of different lithologies to be more easily understood (e.g., Lee et al., 2002; Perez et al., 2003). When plotted, intervals assigned to different electrofacies should theoretically form distinct groupings, confirming that the rules-based cutoffs are an accurate reflection of observed variance within the dataset, which is reflective of lithological changes. In this study, PCA therefore is used as a validation step instead of for classification, demonstrating that the electrofacies defined by rules and supported by core calibration are indeed distinct through PCA.

Electrofacies classification

In the Wymark Member of the Duperow Formation, five electrofacies were identified and are interpreted to represent five lithologies commonly observed in core, including limestone, dolostone, dolomitic limestone, mudstone and evaporite (Figures GS2025-14-2, -3). Each electrofacies exhibits a distinct log response; the responses are summarized in Table GS2025-14-1 and show clear groupings in the PCA space (Figure GS2025-14-4).

Electrofacies 1 is identified by low gamma-ray (<20 API units) and high PEF (>4.5) values, and relatively consistent RT values (<52 Ω•m), RHOB values between 2300 and2710 kg/m^3, and Nphi and Dphi logs that track each other at 2–10%. Based on log responses, this is interpreted to be limestone intervals that correspond to subtidal lithologies, including calcareous mudstone, wackestone-packstone and stromatoporoid framestone lithofacies (Eggie, 2012; Eggie et al., 2012a, b; Bates, 2016; Bates et al., 2016; Figure GS2025-14-3).

Electrofacies 2 consists of low gamma-ray values (<25 API units), low PEF values (<3.3) and high Nphi and Dphi values (>15%) compared to other electrofacies, RHOB values between 2100 and 2810 kg/m^3 and RT values of <50 Ω•m. Electrofacies 2 is interpreted to correspond to dolostone intervals that, in core, appear as intertidal laminated or massive dolostone with pervasive intercrystalline pore space in comparison to limestone lithologies (Bates, 2016; Figure GS2025-14-3).

Electrofacies 3 consists of low GR values (<35 API units), intermediate PEF values (3.3–4.5), high Nphi and Dphi values (5–15%) compared to other electrofacies, RHOB values between 2170 and 2750 kg/m^3 and RT values of <36 Ω•m. Electrofacies 3 is interpreted to be dolomitic limestone intervals as these are intermediate or transitional log responses, falling between the dolostone and limestone responses described above. In core, these are often laminated and partially recrystallized (Figure GS2025-14-3).

Electrofacies 4 and 5 comprise thinner intervals (<5 m thick) in contrast to electrofacies 1, 2 and 3. Electrofacies 4 is characterized by the highest gamma-ray values (>50 API units), low PEF values (<3.3), low RHOB values (<2500 kg/m^3), near zero Nphi and Dphi values and RT values between 1 and 10. Electrofacies 4 corresponds to mudstone intervals and, in core, this electrofacies represents fine-grained, clay-rich mudstone (Figure GS2025-14-3). Whereas electrofacies 5 consists of low GR values (<25 API units), high PEF values (>4.5), high RHOB values (>2800 kg/m^3), highest RT values (>200 Ω•m) and low Dphi and Nphi val-

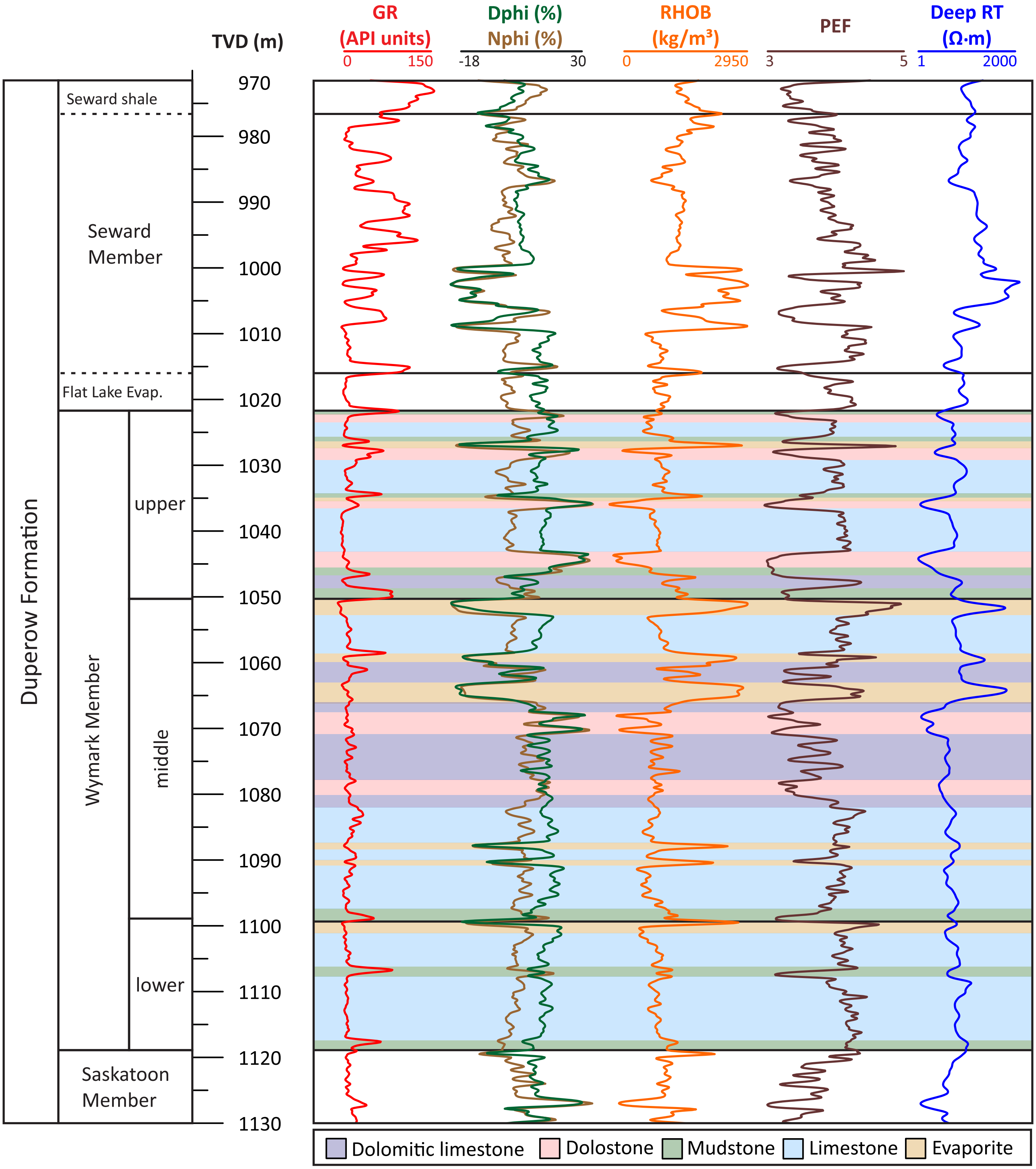

Figure GS2025-14-2: *Stratigraphy and petrophysical well logs for the well at L.S. 15, Sec. 32, Twp. 9, Rge. 29, W 1st Mer. (abbreviated 15-32-9-29W1; oil and gas well licence 5270, Manitoba Business, Mining, Trade and Job Creation, Winnipeg) in southwestern Manitoba with the assigned rules-based electrofacies (dolomitic limestone, dolostone, limestone, evaporite and mudstone). Abbreviations: Ω, ohm; dec, decimal; Dphi, density porosity calibrated to a limestone matrix; Evap., Evaporite; GR, gamma ray; Nphi, neutron porosity calibrated to a limestone matrix; PEF, photoelectric factor; RHOB, bulk density; RT, resistivity; TVD, true vertical depth.*

Figure GS2025-14-3: *Example core logs displaying the typical stacking of lithologies in the* ***a)*** *lower unit of the Wymark Member from the oil and gas well at L.S. 4, Sec. 27, Twp. 11, Rge. 22, W 1st Mer. (abbreviated 4-27-11-22W1; oil and gas well licence 1228, Manitoba Business, Mining, Trade and Job Creation, Winnipeg),* ***b)*** *middle unit of the Wymark Member from the oil and gas well at 7-18-10-20W1 (oil and gas well licence 2456), and* ***c)*** *upper unit of the Wymark Member from the oil and gas well at 13-4-10-20W1 (oil and gas well licence 1456).*

ues (~0%). This electrofacies corresponds to evaporite intervals that, in core, represent supratidal, anhydrite intervals although some thinner intervals likely represent anhydrite nodules enveloped within the carbonate electrofacies described above (Figure GS2025-14-3).

The PCA results confirm that the electrofacies derived from rules-based classification form distinct groupings in multivariate space (Figure GS2025-14-4). The principal component 1 (PC1) space accounts for 47.6% of the variance, primarily reflecting Nphi, Dphi, RHOB and RT curves, whereas PC2 space explains 25.3% and captures variation in GR, with PEF and RHOB having the same loading for PC2 (Figure GS2025-14-4a). Dolostone, limestone, mudstone and evaporite intervals interpreted from electrofacies analysis plot as isolated groupings due to their contrasting petrophysical properties, whereas dolomitic limestone shows partial overlap with both limestone and dolostone, reflecting its transitional composition (Figure GS2025-14-4b). The purpose of this analysis is not to redefine the electrofacies, but to provide an independent statistical validation that the rules-based groups are robust and correspond to lithologies observed in core.

Electrofacies trends and heterogeneity

Using the electrofacies classification and interpreted lithological intervals described above, five distinct vertical and lateral electrofacies variations are observed in the Wymark Member across the study area. Although all five electrofacies occur in the lower, middle and upper units of the Wymark Member, their distribution and occurrence vary spatially and temporally within each unit (e.g., Figure GS2025-14-2). These variations influence reservoir connectivity (Figures GS2025-14-5, -6).

The lower unit of the Wymark Member (13.1–34.9 m thick) is dominated by limestone (averages 14 m thick), with subordinate dolostone and dolomitic limestone intervals (average 3.4 m thick), which are more common along the southern and western margins of the study. The lower unit of the Wymark Member forms two laterally extensive, limestone intervals, separated by a thinner and laterally continuous mudstone interval (1 m thick)

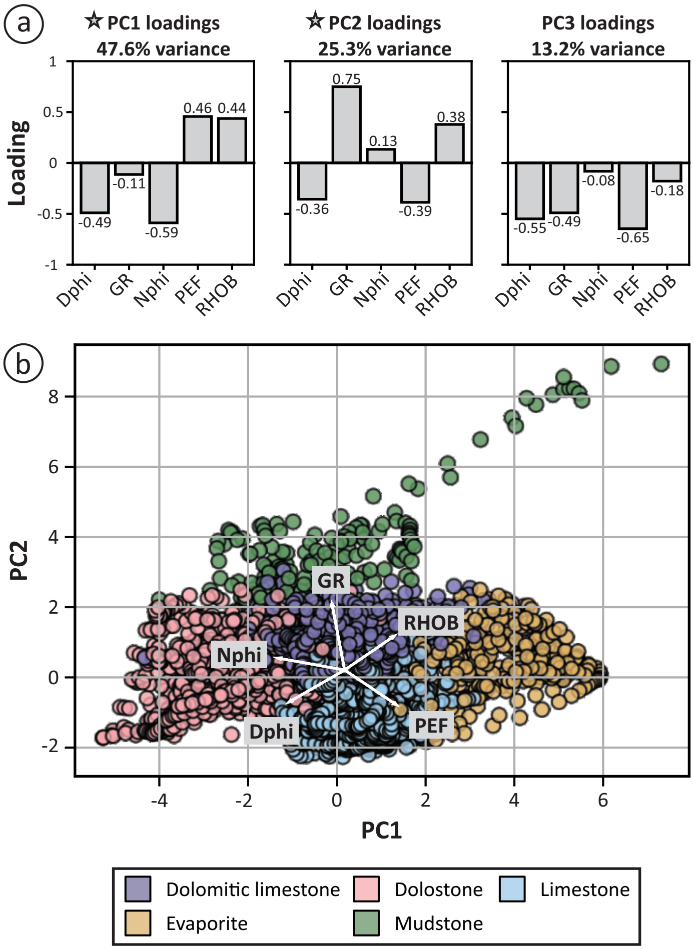

Figure GS2025-14-4: ***a)*** *Principal component analysis (PCA) loadings for the first three principal components (principal component 1 (PC1)–PC3), which together explain the majority (86.1%) of the variance in the petrophysical datasets. Grey stars denote the loadings used for (b).* ***b)*** *PCA biplot of PC1 versus PC2 with samples classified by identified electrofacies. The petrophysical data loadings are shown by the arrows. Abbreviations: Dphi, density porosity calibrated to a limestone matrix; GR, gamma ray; Nphi, neutron porosity calibrated to a limestone matrix; PEF, photoelectric factor; RHOB, bulk density.*

and an anhydrite interval (1 m thick). The spatial electrofacies heterogeneity in this unit is relatively low, as the limestone intervals are continuous; however, subtle lateral and vertical lithofacies transitions or diagenesis overprint within these intervals may affect reservoir continuity.

The middle unit of the Wymark Member (39–68.9 m thick) is the thickest and most heterogeneous interval. The basal interval consists of limestone (averages 15 m thick), which is overlain by a characteristic succession of dolostone and dolomitic limestone (average 25 m thick). Dolostone is common along Twp. 2–15, Rge. 26–29, W 1st Mer., transitioning into limestone toward the northern and eastern parts of the study area. In contrast, dolomitic limestone interfingers with dolostone southward and thickens toward the north (Figure GS2025-14-5). Along the west–east transect (Figure GS2025-14-6), dolomitic limestone occurs as localized intervals enveloped within dolostone intervals that thin to less than 2 m thick and transition into limestone intervals to the east (35 m thick east of the study area). The heterogeneity within the middle unit of the Wymark Member reflects variations in depositional conditions and this heterogeneity influenced laterally extensive electrofacies transitions across the study area. Similar to the lower unit of the Wymark Member, limestone, dolostone and dolomitic limestone intervals are commonly capped by evaporite and mudstone intervals.

The upper unit of the Wymark Member (18.3–30.3 m thick) is primarily composed of limestone interbedded with laterally continuous mudstone (averages 1.5 m thick) and anhydrite intervals (averages 1.6 m thick). Unlike the middle unit of the Wymark Member, dolostone intervals occur as discontinuous lenses (average 7.4 m thick) enveloped within limestone intervals (average 13 m thick) that extend for tens of kilometres. Therefore, the heterogeneity is defined by the spatial extent of the dolostone intervals.

Throughout the Wymark Member, limestone, dolomitic limestone and dolostone intervals are commonly overlain by anhydrite intervals, which in turn are capped by mudstone intervals that develop laterally continuous, internal baffles. The vertically stacked carbonate–anhydrite–mudstone successions reflect repeated brining-upward cycles, marking a transition from open-marine to restricted supratidal, evaporitic conditions (Nicolas and Chow, 2018; Figure GS2025-14-3).

Electrofacies analysis identifies the most porous intervals, based on Nphi and Dphi curves, to occur within thick, laterally extensive dolostone and dolomitic limestone intervals, particularly in the middle unit of the Wymark Member. Although porosity curves (Nphi and Dphi) are calibrated to a limestone matrix, based on core analysis, dolostone consistently shows better-developed, intercrystalline pore networks, compared to limestone lithologies, with up to 28% porosity reported from routine core analysis (Eggie, 2012; Eggie et al., 2012b; Bates, 2016; Bates et al., 2016). In contrast, limestone intervals in the lower, middle and upper units of the Wymark Member consist of lateral continuous intervals with variable porosity.

Conclusion and future work

Electrofacies classification is effective at delineating lithology and heterogeneity within the Wymark Member. This methodology allows for consistent identification of lithology despite variability across wells in areas with limited or absent core data. The application of electrofacies cutoffs to well logs captured key lithological transitions between wells and enabled the detailed interpretation of potential reservoir and seal lithology distribution within the Wymark Member. These electrofacies trends are directly relevant to lithium-brine exploration, as variability in electrofacies stacking, continuity and seal development may influence brine migration, fluid compartmentalization and the vertical isolation of individual reservoir zones. Understanding

Table GS2025-14-1: *Electrofacies classification scheme used in this study, showing diagnostic ranges for gamma rays (GR), photoelectric factor (PEF), bulk density (RHOB), resistivity (RT), and neutron (Nphi) and density (Dphi) porosities calibrated to a limestone matrix. Abbreviation: Ω, ohm.*

Electrofacies	Lithology	GR (API units)	PEF	RHOB (kg/m³)	RT (Ω•m)	Nphi (%)	Dphi (%)
1	Limestone	<20	>4.5	2300 to 2710	<52	2 to 10	2 to 10
2	Dolostone	<25	<3.3	2100 to 2810	<50	>15	>15
3	Dolomitic limestone	<35	3.3 to 4.5	2170 to 2750	<36	5 to 15	5 to 15
4	Mudstone	>50	<3.3	<2500	1 to 10	~ 0	~ 0
5	Evaporite	<25	>4.5	>2800	>200	~ 0	~ 0

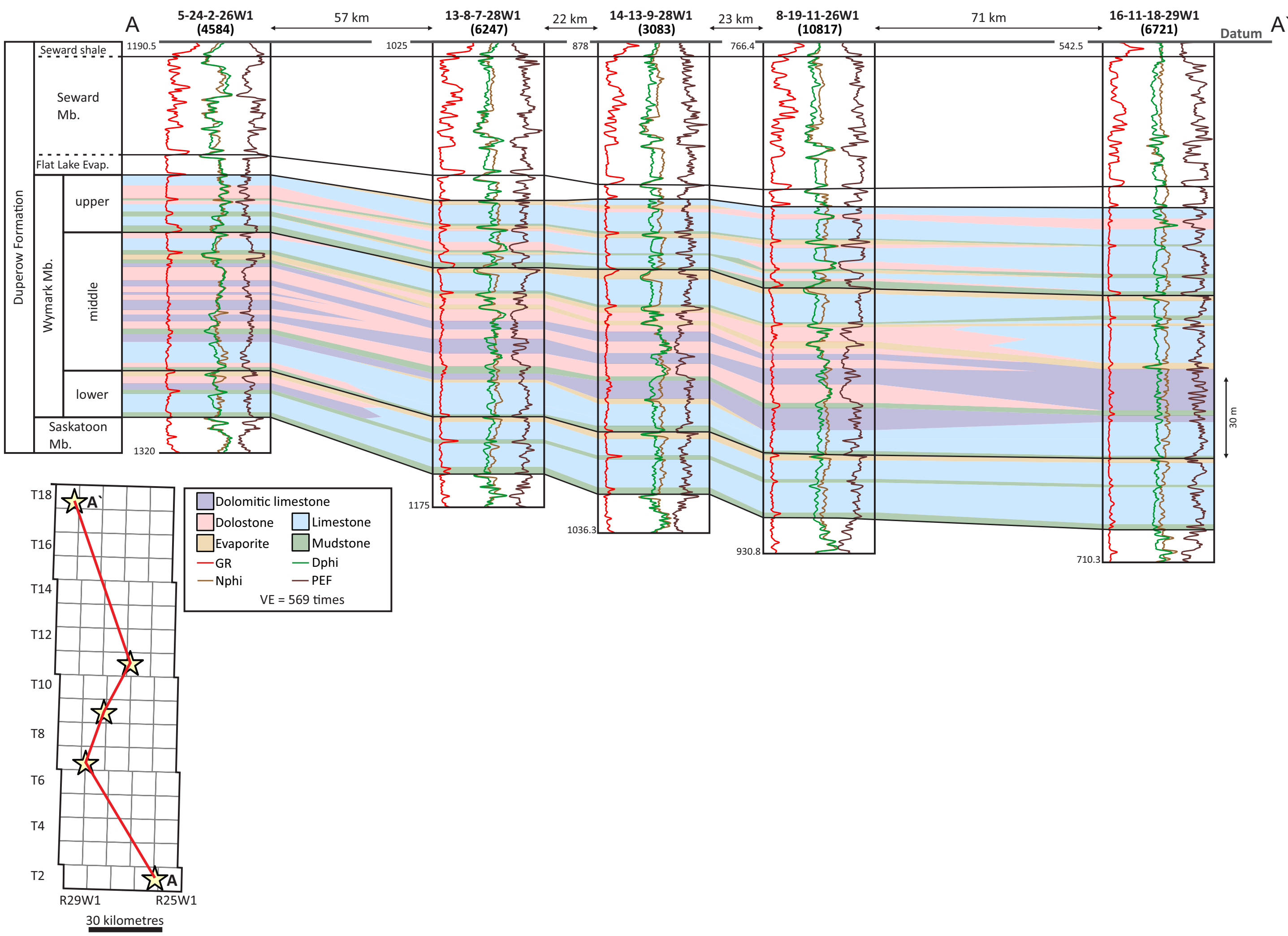

Figure GS2025-14-5: *Regional cross-section correlation from south (A) to north (A') for the Duperow Formation in southwestern Manitoba, with assigned electrofacies. Oil and gas licence number (Manitoba Business, Mining, Trade and Job Creation, Winnipeg) is denoted under the well number at the top of each petrophysical log. For simplicity, only gamma-ray (GR), neutron porosity calibrated to a limestone matrix (Nphi), density porosity calibrated to a limestone matrix (Dphi) and photoelectric factor (PEF) petrophysical well logs are shown in the correlation. Top and bottom depth for each well is shown as true vertical depth in metres. Top of the Duperow Formation is used as the datum. The well at L.S. 8, Sec. 19, Twp. 11, Rge. 26, W 1st Mer. (abbreviated 8-19-11-26W1) has also been included in cross-section B–B' (Figure GS2025-14-6). Abbreviations: Evap., Evaporite; VE, vertical exaggeration.*

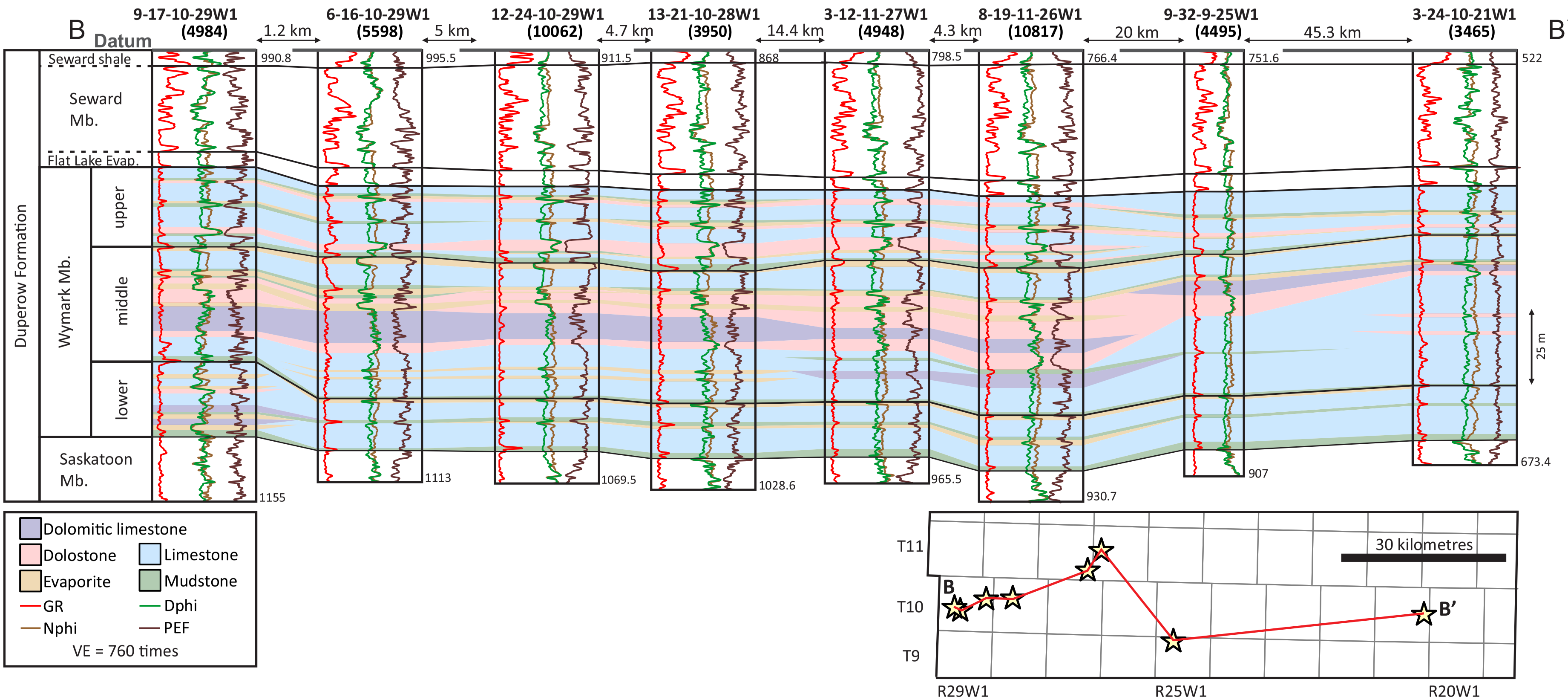

Figure GS2025-14-6: *Regional cross-section correlation from west (B) to east (B’) for the Duperow Formation in southwestern Manitoba, with assigned electrofacies. Oil and gas licence number (Manitoba Business, Mining, Trade and Job Creation, Winnipeg) is denoted under the well number at the top of the each petrophysical log. For simplicity, only gamma-ray (GR), neutron porosity calibrated to a limestone matrix (Nphi), density porosity calibrated to a limestone matrix (Dphi) and photoelectric factor (PEF) petrophysical well logs are shown in the correlation. Top and bottom depth for each well is shown as true vertical depth in metres. Top of the Duperow Formation is used as the datum. The well at L.S. 8, Sec. 19, Twp. 11, Rge. 26, W 1st Mer. (abbreviated 8-19-11-26W1) has also been included in cross-section A–A’ (Figure GS2025-14-5). Abbreviations: Evap., Evaporite; VE, vertical exaggeration.*

and mapping the spatial arrangement of these electrofacies is thus critical for targeting zones with the greatest resource potential.

The workflow developed can be extended to build a more comprehensive understanding of electrofacies distribution and depositional architecture across the Duperow Formation. Future work will focus on integrating electrofacies with core descriptions to better identify electrofacies and lithological extents across southwestern Manitoba.

Economic considerations

As Manitoba expands its critical mineral strategy, lithium is becoming a key exploration focus within the province's deeper Paleozoic formations. The Duperow Formation represents a strategic target for potentially hosting lithium-bearing brines. Although the formation is well-studied in adjacent jurisdictions for hydrocarbons and, more recently, from a lithium-brine perspective, its potential in Manitoba remains largely underexplored. As such, understanding depositional trends and electrofacies distribution within the Wymark Member, as presented in this report, is essential to advancing lithium-brine exploration in southwestern Manitoba.

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