Stratigraphic Analysis of the Mississippian Middle Carbonate-Evaporite Cycles, Steelman Bienfait Area, Southeastern Saskatchewan, Canada

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April 07, 2015

Abstract

Lithostratigraphic and sequence stratigraphic analyses performed from data collected from four wells located in the Steelman Bienfait area in southeastern Saskatchwan, Canada. Lithologic units are separated into three distinct facies: Mudstone Facies (MS), Dolostone Facies (DF) and Evaporite Facies (EV). Related to these facies, the lithostratigraphic units were correlated to a cross-section which used the top of the Midale Beds as the datum. A sequence stratigraphy model seems to better correlate the depositional history of the shallow depositional ramp. In shallow depositional ramp settings, small fluctuations in eustasy will lead to a significant response in what types of sediment will be deposited. Portions of oxidation staining and abundant evaporite minerals are indicative of subaerial exposure and thus represent periods of non-deposition and/or unconformity boundaries. If the overlying vertical profile shifts to deeper marine facies, this point becomes more clear.

1. Introduction

By identifying and interpreting lithofacies and stratigraphic parasequences, Nimgeers (2006) set out to develop a depositional model for the Midale Beds of the Steelman-Bienfait area. Marsh (2005) compiled modern maps of cross-sections from updated, consistent stratigraphic data for the entire Phanerozoic succession in parts of western Saskatchewan. Liu and Qing (2009) expanded upon previous work on sedimentology in the Steelman Midale Pool in an effort to study diagenetic processes of the Midale Beds and with an emphasis on dolomitization and anhydritization and their impacts on hydrocarbon reservoir quality. In order to have a better appreciation of the distribution of hydrocarbon-bearing facies, Nimgeers (2002) presented a depositional model for the Midale Beds in the Steelman area. Kent (1999) reexamined the process of formation and diagenesis of coated-grain accumulations and contiguous facies in the Mississippian in southeast Saskatchewan. In their study, Shen et al.

(2012) described the importance of calcimicrobes and microbial fabrics in the Mississippian carbonates.

Data was gathered in this report from cores and wireline data from four separate wells. Core analysis was performed in a group of four members that included, Austin Guillemin, Dylan Land, Jared Noll and myself, and took place at the Subsurface Geological Laboratory on 201 Dewdney Avenue East, in Regina Saskatchewan. Well 1 (W_1) is located approximately 22 km northeast of Estevan, Saskatchewan and has a location of 16-14-003-06W2. Cores at this location occur from depths of 1526 – 1544 m. Available wireline data exists from approximately 1450 – 1584 m. Well 2 (W_2) is located at 5-28-003-05W2 and is roughly 6.5 km to the northeast of W1. Cores were analyzed from 1484.9 – 1504.3 m. The gamma ray and density wireline logs from this well occur between depths of 1425 – 1540 m. Well 3 (W_3) is located about 5 km to the northwest of W2 and its LSD is 1-08-004-04W2. Available wireline data was examined from depths of 1404 – 1528 m. Core analysis was done 1447 – 1466.7 m. The final well studies (W_4) is 3.8 km to the northeast of W3. More precisely, it occurs at 3-21-004-05W2. Core was analyzed from 1419.5 – 1438.7 m. Wireline data was studied between depths of 1338 – 1450 m. This area covers approximately 67,700 km^2. This report will look correlations between the well data—which will be based on lithostratigraphic and sequence stratigraphic models—and attempt to suggest which of the models best agrees with the collected data. Additionally, data was examined from several studies to help guide this report and may be found in the reference section of this report.

2. Geological Setting

The Williston Basin is a large elliptical intracratonic basin with an area of approximately 345,000 km^2 that encompasses portions of North Dakota, South Dakota, Montana, Saskatchewan, and Manitoba (Figure 8.1) (Liu and Qing, 2009; Nimgeers, 2006). It is believed to have formed due to response to an active Proterozoic wrench-fault system (Nimgeers, 2006). The Midale Beds within the Williston Basin hosts hydrocarbon reservoirs that represent some of the most economically important hydrocarbon reserves in Canada (Shen *et al*., 2012). These reservoirs are located in the uppermost part of the Midale Beds which belong to the Charles Formation, which itself is part of the Madison Group (Shen *et al*., 2012). Sediments from the Madison Group were deposited in a relatively stable and shallow epicontinental sea in a intermittent restricted conditions (Shen *et al*., 2012). The Midale Beds represent one of many transgressive–regressive cycles found within the Madison Group and contain a succession of upward-shoaling, shallow marine carbonate–evaporite sediments of Mississippian age (Shen *et al*., 2012).

3. Lithostratigraphic Analysis

The lithology observed in all studied cores fall into three facies and will be classified in this report as: Mudstone Facies (MS), Dolostone Facies (DS) and Evaporite Facies (EV). These facies will be described in detail in the following section. These related facies are correlated on the attached Figure 8.3, using the top of the Midale Beds as the datum.

3.1 – Mudstone Facies (MS)

The uppermost facies in all cores belongs to MS facies. Because this facies extends beyond what was observed true thickness cannot be described. However, thickness relative to the cores ranges from around 5 m in W_4 to as thick as around 17.5 m in W_1. Grain size is predominantly fine grained, though some instances of very fine to medium grained do occur as well. Colour ranges from shades of beige to grey to dark grey. Darker colours would seem to indicate incorporation of biogenic material in the matrix. Sedimentary structures throughout the facies is quite varied. Prominent fine laminations are quite common. Wavy laminations occur in W_1 at depths between 1487.8–1488.7 m. Grading occurs but is not exceptionally common. Irregular bedding structures are found to occur in W_1. These are best described as inter-bedding of dark and lighter mudstone laminations, possibly incorporating shales. Reaction with HCl is not uncommon, particularly in W_1 where it occurs betweens depths of 1527.4 – 1538.21 m, which is believed to have a slightly dolomitic matrix. Reaction with acid occur occurs in mudstone found in W_2 between the depth of 1484.5 – 1485.5 m, 1486.3 – 1487.5 m and 1489.5 –1490 m.

Occurrence of shales are incorporated into the MS facies. They are typically darker shades of grey to near black and occur as thin laminations surrounded by mudstone. Darker matrix indicates high concentration of biogenic materials. They are not found to be thicker than 0.20 m throughout the cores. Fossil content is found in Mudstone Facies in W1 in depths between 1534.4–1538.1 m.

Oxidation staining occurs in a couple of instances and is thought to be due to subaerial exposure. Likely related to this context, anhydrite nodules are relatively common throughout the Mudstone Facies and occur in every core examined. Sizes are typically of the magnitude of a few centimetres. Anhydrite chicken-wire structure is observed in W_3 at a depth of 1449.8 m. Stylolite occurs at 1439 m and 1441.72 m.

Examples of oil shows in the Mudstone Facies is found all wells except W_4. In W_2 and W3, the oil shows appear to be related more to the Dolostone Facies. Oil shows occur in W_1 between depths of 1530.3 – 1538.21 m in mudstone (perhaps the lithology in this portion of core would be more aptly referred to as dolomudstone due to the dolomitic cement content).

3.2 – Dolostone Facies (DS)

Dolostone facies are distinguished from Mudstone Facies lithologies by differences in texture and more intense reaction to acid. True Dolostone Facies lithologies were not discovered in W_1. Thickness varies between 6.5 m to less than a metre in W_3. Colours of the units in the DS facies is beige to sandy brown to brown to grey to dark grey. Grain size ranges from very fine to medium grained. Thin organic laminations are common in W_2. Fossils are frequently found throughout the Dolostone Facies between wells, although positive identification of fossil types could not be discerned. Fossil content is found in W_3 in depths between 1456.06 – 1459.73 m. Fossils occur in W4 in depths between 1424.15 – 1426.79 m. Bioturbation was noted to occur in W_2 between the depths 1494.7 – 1496.8 m. Dolostone Facies marks the top of or near top of the Midale Carbonates and is strongly associated with oil shows. Oil shows vary between mild to moderately stained. Interpretation of this facies is based on sedimentology, distribution and facies associations and is suggested to have been deposited in a restricted lagoon setting (Nimgeers, 2006).

3.3 – Evaporite Facies (EV)

The Evaporite facies is characterized by the presence of anhydrite nodules in excess of greater than 50% of the matrix material and thicker portions that are massive. As such, this section is divided into two subdivisions based on these characteristics. Presence of anhydrite indicates low sea levels and/or isolated submarine conditions with an oversaturated solution with high concentrations of salts that precipitate into evaporites.

3.3.1 – Massive Anhydrite

Massive anhydrite was only exceptional in W1 and its occurrence takes place near the bottom of the core between the depths 1543.5 – 1543.8 m and again at 1544.2 m. It is characterized by a lack of structures. In both cases, anhydrite grades in and out of surround mudstone lithology. Colour for the massive anhydrite are white to grey.

3.3.2 – Nodular Anhydrite

Nodular anhydrite is more widespread throughout the cores and wells. It is predominately associated with mudstone. Small anhydrite nodules that measure 1 cm or less that make up less than 50% of the matrix is quite common throughout mudstone lithologies, especially near the upper margins of the cores. Distinct grading from smaller anhydrite nodules to larger nodules occurs in W_3 between the depths 1449.41 – 1450.5 m. Anhydrite texture also display a character chicken wire pattern in portions of this section. Oxidization staining is characteristic. These nodules occur within a thinly laminated mudstone matrix. Nimgeers (2006) suggests that this facies is interpreted as a coastal sabkha evaporite at the base of the Midale Beds where gradually or sharply overlies microcrystalline dolomitic mudstone of the underlying Frobisher Beds (Nimgeers, 2006). Replacement nodules occur between depths of 1541.9 – 1542.15 m in W_1. These are considered to be related to an exposure surface.

4. Sequence Stratigraphic Analysis

The sequence stratigraphy analysis presented here is primarily based upon the probable sedimentary environment related to the lithologies discussed in the previous section. Additional information is based on the work by Nimgeers and Qing (2002) and Nimgeers (2006).

Near the bottom of the W_1 core at a depth between 1541.9 – 1542.15 m, an exposure surface is found. This marks the occurrence of subaerial setting that is associated with a regressive system tract. This seems to correlate with the first transgressive-regressive sequence (S1) regressive systems tract from Nimgeers and Qing (2002). In W_4, the evaporites associated with dolostone and mudstone at a depth between 1429.85 – 1440.66 m would likely be correlative. Deeper marine facies overlying these evaporites (dolostone) indicates a period of non-deposition associated with an unconformity. Above the unconformity, W_4 shallows upwards until it reaches a depth of approximately 1422.62 m, when another occurrence of anhydrite would seem to suggest a regressive systems tract, which would mark another unconformity that would correlate with S2 from Nimgeers and Qing (2002). Reoccurrence of anhydrite in W_1 is found at approximately 1530.4 m. Thin laminations of anhydrite indicates shallow to subaerial conditions that is overlaid with deeper mudstone lithologies (distinguished by darker more organic rich matrix) which would suggest a period of non-deposition in between.

W_2 does not display any clear indicators of subaerial exposure below depths of 1484.5 m. Above this depth, oxidization and anhydrite is reasonably consistent throughout. This indicates a period very shallow to subaerial conditions which would mark a maximum regressive surface. In the bottom of the core, shallowing upwards of from dolostone to mudstone is present. W_3 shows considerable oxidation staining and anhydrite nodules from a depth of 1450.5 m and above. This appears to be indicative of a low sea-level environment and likely a maximum regressive surface. It is not clear to the author whether these conditions found in W_2 and W_3 are related to S1 or S2 transgressive-regressive sequences, but it would seem more logical (due to cross sectional correlations in Figure 8.3) if these related to S2.

5. Conclusions

1. Lithostratigraphic analysis based primarily on core descriptions from four wells at the Subsurface Geological Laboratory on 201 Dewdney Avenue East, in Regina Saskatchewan suggests three separate facies in this area. These are associated with mudstones, dolostones and evaporite sedimentary rocks.

2. Data from wireline logs allowed reasonably accurate correlations between the four studied wells (Figure 8.3). As a baseline, the top of the Midale Beds was used. Thickness of the Midale Beds varied considerably and was the thickest in W_4.

3. A sequence stratigraphic analysis was performed and based off of core description data as well as research by Nimgeers and Qing (2002) and Nimgeers (2006). Data collected from the four cores most reasonably correlates the lower sequences (S1 and S2) from Nimgeers and Qing (2002) four transgressive-regressive sequences.

4. Based on analyses performed in this report, a sequence stratigraphy model seems to better correlate the depositional history of the shallow depositional ramp. In shallow depositional ramp settings, small fluctuations in eustasy will lead to a significant response in what types of sediment will be deposited. Portions of oxidation staining and abundant evaporite minerals are indicative of subaerial exposure and thus represent periods of non-deposition and/or unconformity boundaries. If the overlying vertical profile shifts to deeper marine facies, this point becomes more obvious. It is for reasons like this that a sequence stratigraphic model seems more appropriate to explain the Mississippian Middle Carbonate-Evaporite Cycles, Steelman Bienfait Area, Saskatchewan, Canada.

6. Acknowledgements

The author would like to thank the Subsurface Geological Laboratory on 201 Dewdney Avenue East, in Regina Saskatchewan for allowing the Winter 2015 Geology 340 students use their facilities, as well as their effort in setting out and returning the cores after we completed our endeavours. The core description training session provided by Dr. John Lake and Dr. D.M. Kent was a valuable asset in completing this project and the author would like to show his appreciation for their effort. Review by Austin Guillemin improved the original draft of this report. Additionally, the author would like to offer his thanks to Congwei Ji and Ming Lei for their help at the core lab and in the lab sessions and finally to Dr. H. Qing for organizing our tutorial sessions with Dr. Lake and Dr. Kent and in addition for arranging to have to cores kept out for display for an additional week so my group could finish our core descriptions.

7. Notice

The author has provided access to additional content that may be accessed online. This content includes high resolution images and PDFs of the base map, stratigraphic cross section, lithology correlation, well log descriptions, as well as selected photographs taken of the core samples at the Subsurface Geological Laboratory on 201 Dewdney Avenue East in Regina, Saskatchewan. All of these can be found at this link: http://goo.gl/CAczpc. If for any reason the link provided no longer works, please contact michaelraiwet@gmail.com.

8. Additional Figures

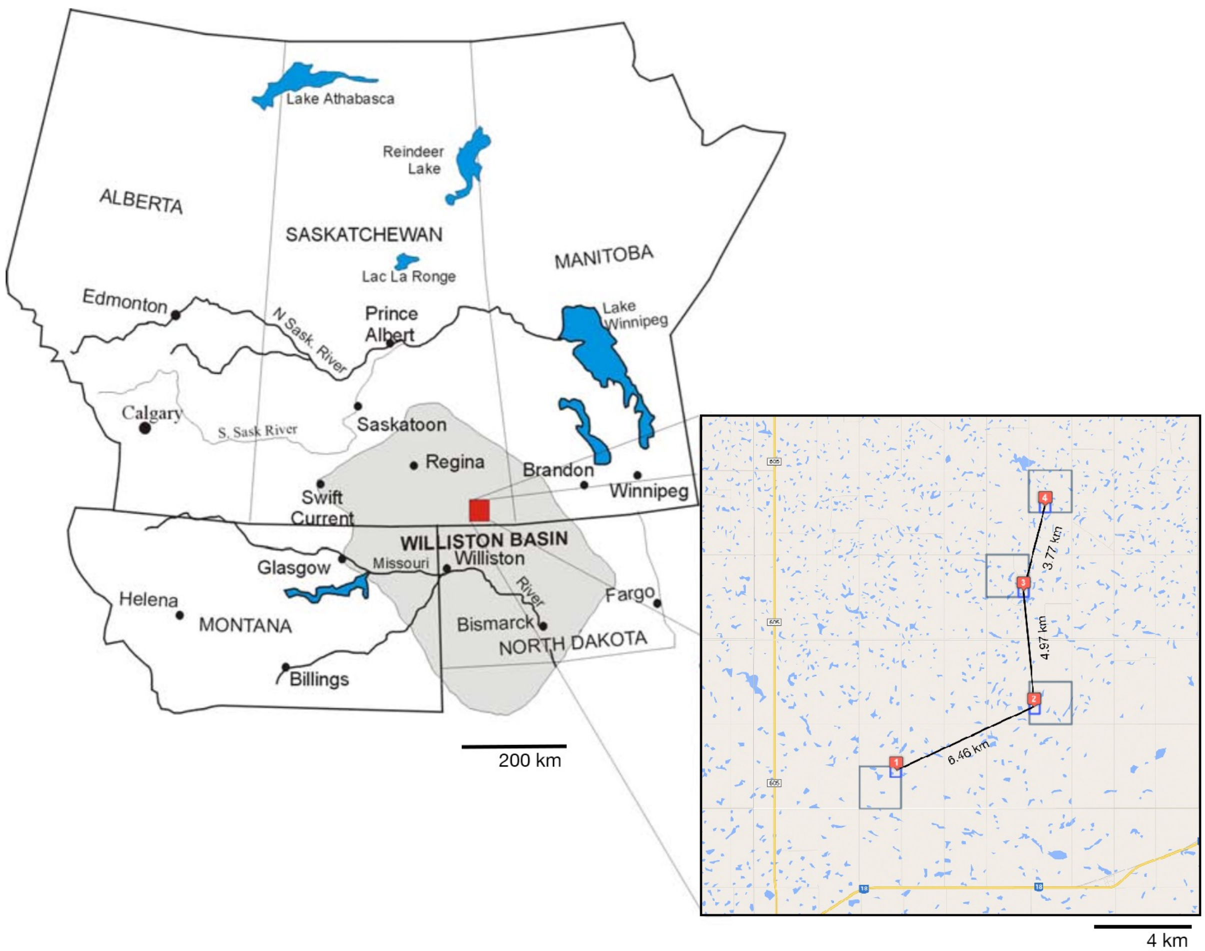

Figure 8.1 – Base map for the region of study within the context of the Williston Basin. The map on the right is the magnified section from the satellite map (indicated by the black box). This map is indicated by the four wells used in this study: Marker 1 = 16-14-003-06 W2; Marker 2 = 5-28-003-05 W2; Marker 3 = 1-08-004-05 W2; Marker 4 = 3-21-004-05 W5. Modified from Nimgeers (2002). Map data captured using Google Maps and LSD Finder.

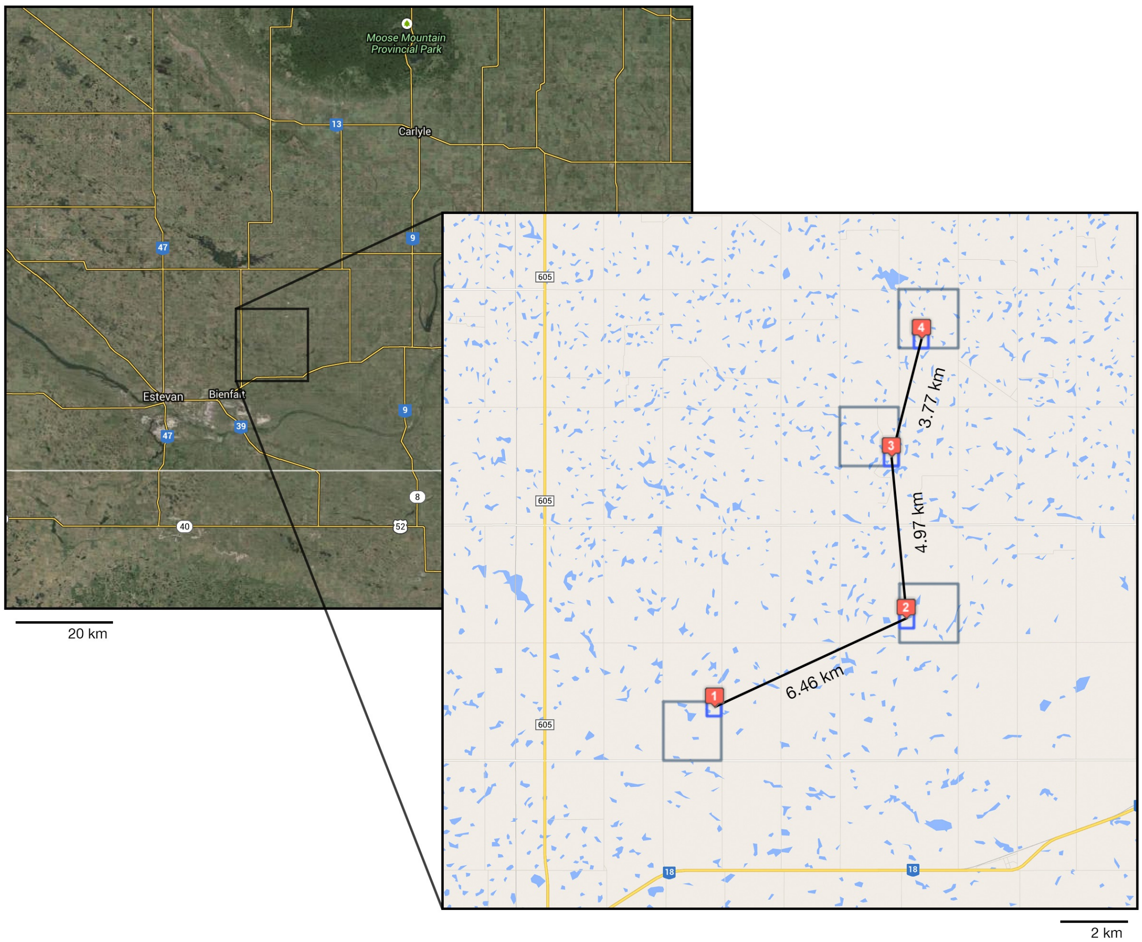

Figure 8.2 – Base map for the region of study. The satellite map on the left is located in southeastern Saskatchewan near the North Dakota border. The map on the right is the magnified section from the satellite map (indicated by the black box). This map is indicated by the four wells used in this study: Marker 1 = 16-14-003-06 W2; Marker 2 = 5-28-003-05 W2; Marker 3 = 1-08-004-05 W2; Marker 4 = 3-21-004-05 W5. Map data captured using Google Maps and LSD Finder.

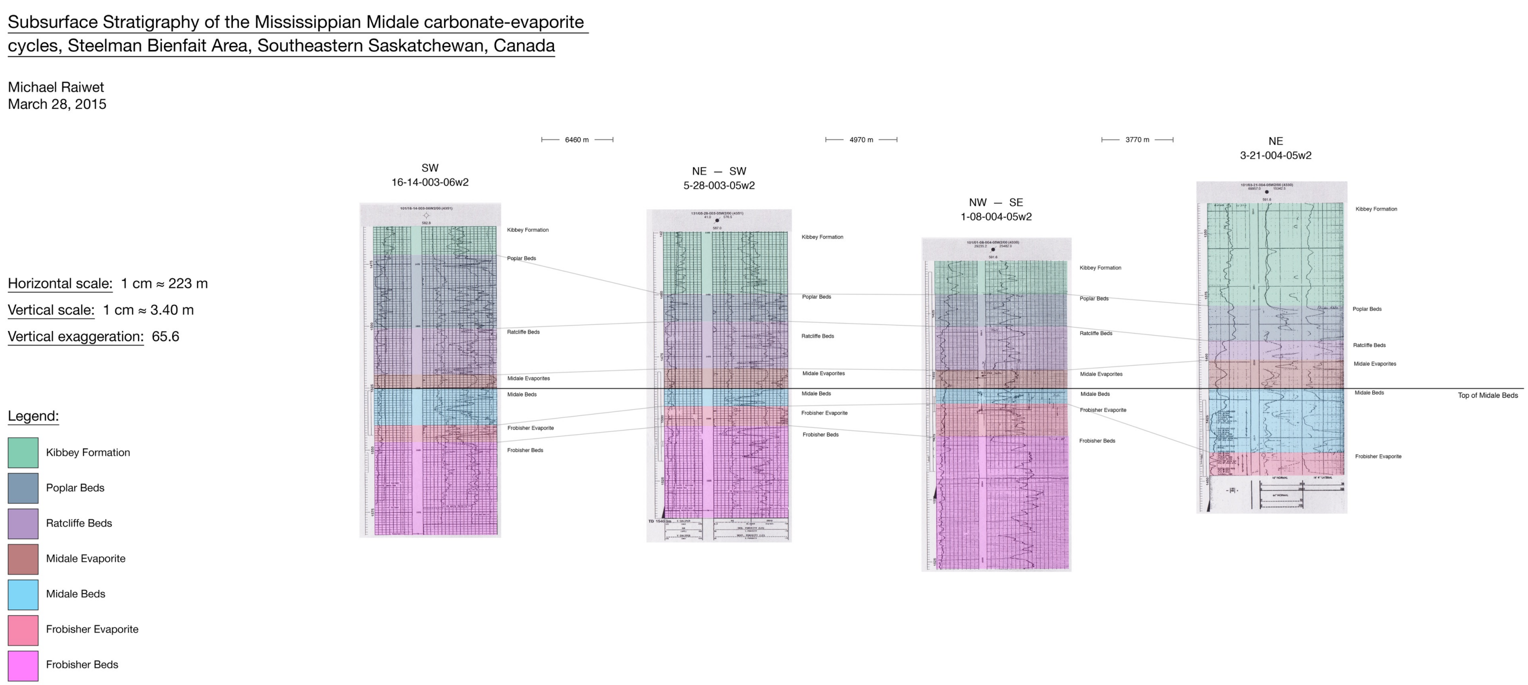

Figure 8.3 – Stratigraphic cross section of study area. The datum used is the top of the Midale Beds. Not to scale, see Section 7 for instructions to download high resolution files from this project.

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