Investigations into Petroleum Source Rocks within the Mississippian Madison Group: Bluell Subinterval of Western McKenzie County

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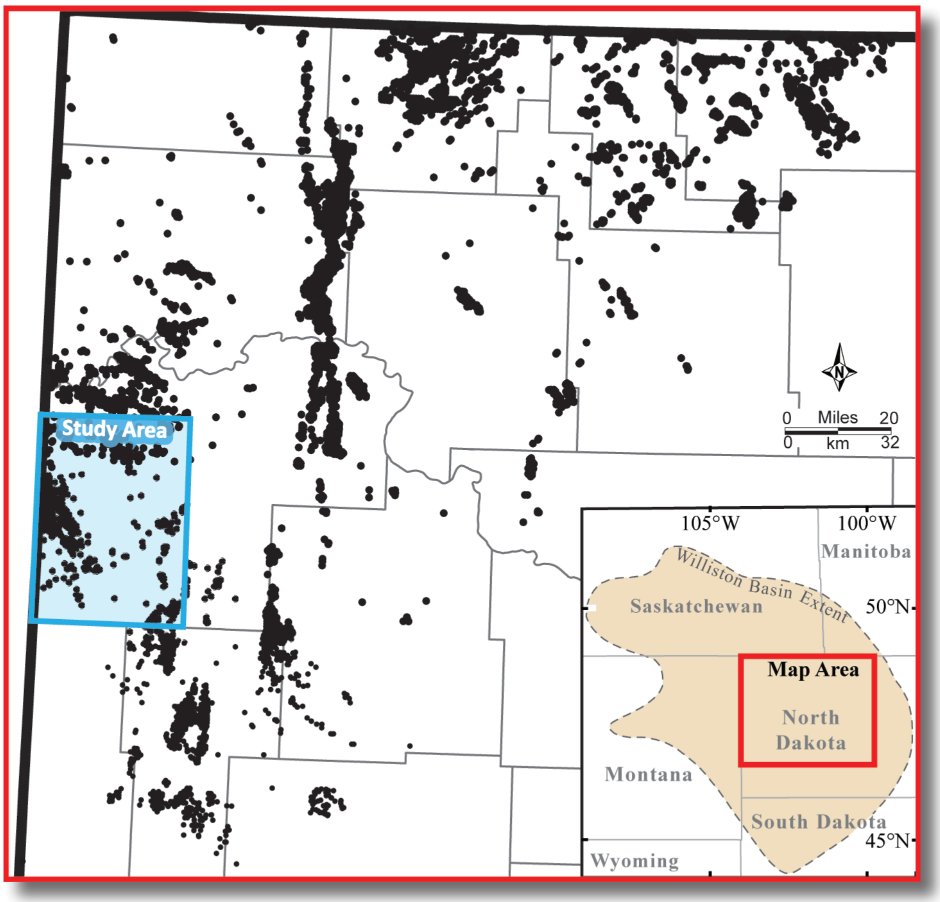

GEOLOGIC INVESTIGATION NO. 255
NORTH DAKOTA GEOLOGICAL SURVEY
Edward C. Murphy, State Geologist
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2021

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INTRODUCTION

Mississippian Madison Group (Madison) reservoirs have combined to produce over 1 billion barrels of oil to date from over 6,000 vertical and horizontal wells within the Williston Basin of North Dakota (Fig. 1) (NDOGD, 2019). Cumulative production from the Madison is second only in the state to the prolific Bakken-Three Forks play. Prior to the emergence of the Bakken-Three Forks play (~2006), Madison reservoirs served as the primary target for hydrocarbon production in the state and accounted for approximately 64% of the state's oil production through the end of 2005 (NDOGD, 2019).

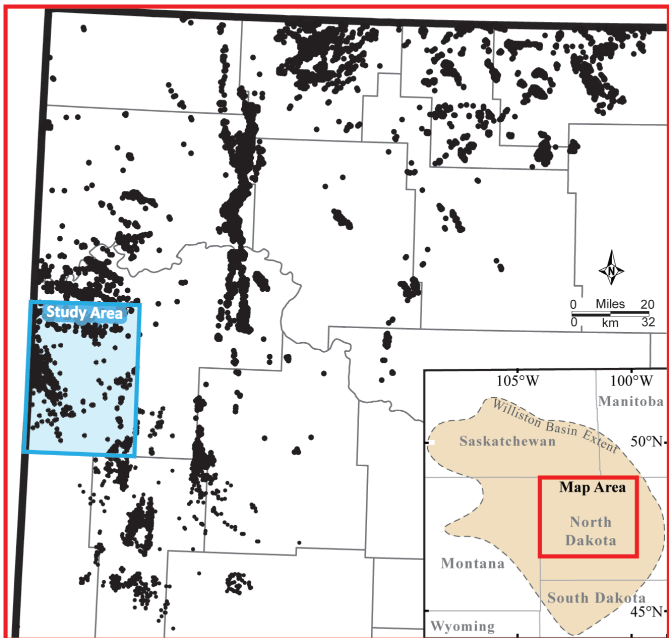

Figure 1. Map of western North Dakota showing the distribution of oil and gas productive Madison wells (black dots) and the study area. County lines are shown as light gray lines.

Madison production began shortly after the discovery of oil in North Dakota during the early 1950's. Through the 1980's, exploration and development of the unit was completed using primarily vertical wells (LeFever, 1992). Horizontal well drilling (non-hydraulically fractured) emerged in the Madison beginning in the late 1980's to early 1990's (LeFever, 1992). More recently, the Midale-upper Rival play of northern Burke County has transitioned into the first in-state Madison play undergoing unconventional-style development, horizontal drilling coupled with multi-stage hydraulic fracturing, and may hold potential for the drilling and completion of several hundred horizontal wells (Nesheim, 2018; 2019). The Midale-upper Rival play may represent the beginning of a transition of the greater Madison play into an unconventional, resource play that centers around targeting oil accumulations within tight, low porosity-permeability reservoirs.

Identifying and characterizing the petroleum source beds that have charged Madison reservoirs may serve as a key step in furthering exploration and development in the unit. Initial geochemical studies of produced oil and core extracts concluded that the Madison reservoirs were sourced by hydrocarbons generated and expelled by the underlying Bakken Formation (Dow, 1974; Williams, 1974; Thode, 1981; Leenheer and Zumberge, 1987). However, continued oil geochemical studies found that while some inter-mixing with Bakken oils occurs proximal to faulting/fracturing, Madison reservoir oils are distinct of Bakken oil and therefore, the Madison likely contains one or more organic-rich source bed horizon(s) (Price and LeFever, 1992; Osadetz and Snowden, 1995; Jarvie, 2001; Jiang et al., 2001). Organic-rich horizons have been described within the Mission Canyon and Lodgepole Formations, which comprise the middle and lower portions of the Madison (Osadetz and Snowdon, 1995; Jarvie, 2001; Jiang et al., 2001; Chen et al., 2009). However, limited information exists regarding the stratigraphic and vertical extent, organic-richness, and thermal maturity of prospective petroleum source beds within the Madison section. Therefore, the purpose of this report is to review TOC-RockEval analysis data from select Madison cores, in combination with wireline logs, to identify and evaluate prospective Madison source bed horizons.

STRATIGRAPHY

The Madison is predominantly a carbonate-evaporite unit that is subdivided into the Lodgepole, Mission Canyon, and Charles Formations in ascending order within the North Dakota portion of the Williston Basin (Fig. 2) (Murphy et al., 2009). The Mission Canyon and Charles Formations are further subdivided into the Tilston, Frobisher-Alida, Ratcliffe, and Poplar Intervals, from which the Frobisher-Alida and Ratcliffe Intervals contain the majority of oil producing reservoirs in the Madison section (Fig. 2) (LeFever and Anderson, 1986: Murphy et al., 2009).

The Frobisher-Alida Interval has been described as an upward-shoaling cycle which began with open-marine sedimentation that transitioned into widespread sabkha-saline evaporites (Petty, 1988). The Frobisher-Alida has been

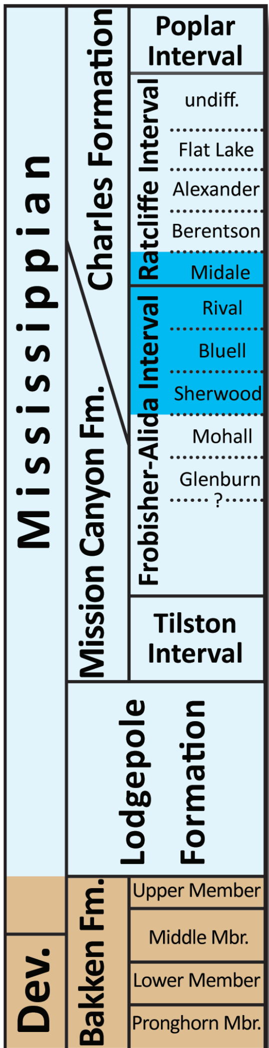

Figure 2. Stratigraphic column of the Mississippian Madison Group section. The dark blue portion represents the section examined in this report. Dev. = Devonian; Fm. = Formation; Mbr. = Member; undiff. = undifferentiated

subdivided into upwards of seven subintervals, which listed in ascending order consist of the Landa, Wayne, Glenburn, Mohall, Sherwood, Bluell, and Rival subintervals (Fig. 2) (LeFever and Anderson, 1986; Petty, 1996). The subintervals are defined by widespread marker beds, generally range from 30 to 100 feet (10 to 30 meters) in thickness and vary between different aggradation/progradation styles (Petty, 1996).

PREVIOUS WORK

Using early geochemical analysis techniques on both produced and core extract oil samples, Williams (1974) concluded that Madison reservoir oils comprised of a unique oil family that was sourced from organic-rich shales in the underlying Bakken Formation (Fig. 2). Vertical oil migration from the Bakken shales to the overlying Madison reservoirs was hypothesized to have occurred along faulting/fracturing trends such as the Nesson anticline with lateral migration through intraformational porous and permeable carrier beds (Dow, 1974). Initial subsequent studies further examining both produced and core extract oil samples yielded similar interpretations about the Madison-Bakken Petroleum System (Thode, 1981; Leenheer and Zumberge, 1987).

However, as oil geochemistry studies continued in the Williston Basin, Bakken and Madison oils have been found to be notably distinct from one another. Price and LeFever (1992) observed that Madison oils are more paraffinic and display higher gas chromatogram peaks in the n-C20 to n-C30 range than Bakken oils, which conversely are less paraffinic and display higher gas chromatogram peaks in the n-C10 to n-C17 range. Furthermore, Madison reservoir oils are distinct from Bakken oils across the US Williston Basin based upon light hydrocarbon and C8+ fingerprints (Jarvie, 2001). Madison oils are commonly noted to have a C35 hopane predominance, which is limited to absent within Bakken oils (Osadetz and Snowden, 1995; Jarvie, 2001). Also, Madison reservoir oils have also been found to differentiate from Bakken oils in North Dakota and Montana based upon pristane-phytane ratios, where Madison oils have overall lower pristane-phytane ratios (Price and LeFever 1992; Jarvie, 2001). Similarly, oil extracts from Bakken shale core samples consistently have higher reported pristane-phytane ratios than oil extracts from organic-rich lime mudstone core samples from the Lodgepole Formation in southern Saskatchewan (Osadetz et al., 1992; Jiang et al. 2001). The organic-rich lime mudstone extracts also displayed a C35 hopane predominance and other factors that are indicative of a Lodgepole source for a portion of Madison reservoir oils (Osadetz et al., 1992; Jiang et al. 2001). Thus, while early geochemistry studies linked Madison reservoir oils to the Bakken shale, continued investigations have differentiated Madison and Bakken oils with some indications of the Madison source originating in the Lodgepole Formation.

Madison source beds may be comprised of differing kerogen type(s) dependent on stratigraphic positioning. Jarvie (2001) inferred two sets of Madison source beds using the methodology from Hughes et al. (1995): 1) carbonate source beds with higher sulfur content that have charged Madison reservoirs along the North Dakota-Montana northern tier counties, and 2) marly shale facies with lower sulfur contents that have sourced reservoirs within the central basin. The higher sulfur, carbonate-sourced oils were described to have lower API oil gravity and interpreted to have been generated at lower thermal maturity while the lower sulfur, marly shale-sourced oils have higher API oil gravities and are believed to be generated at higher thermal maturities (Jarvie, 2001). Lillis (2012) noted that most oils produced from reservoirs in the Frobisher-Alida Interval have high sulfur content, indicative of Type II-S kerogen which thermally matures at lower temperatures compared to Type I and regular Type II kerogen. Meanwhile, oils produced from reservoirs in the Ratcliffe Interval (includes Midale), upper Rival subinterval (Nesson), Landa subinterval (basal Frobisher-Alida), and Tilston Interval were noted to contain mostly moderate to low sulfur concentrations, indicative of non-Type II-S kerogen (Lillis, 2012). Furthermore, Jarvie (2016) noted that Madison source rocks display variability in organofacies based upon light hydrocarbons and biomarker data from samples spanning the Ratcliffe, Frobisher-Alida, and Tilston Intervals. In summary, previous studies indicate that

Madison oils from differing stratigraphic intervals are from multiple source bed horizons with variable organofacies that range from Type II to Type II-S kerogen.

While the Madison appears to have one or more distinct sets of petroleum source beds based upon oil geochemical analysis data, there are areas in the basin which exhibit varying degrees of mixing between Madison and non-Madison sourced oils. Madison reservoir oils from the Richey and Cow Creek Fields of eastern Montana show evidence of mixing between Red River and Madison sourced oils (Jarvie, 2001). Furthermore, Madison reservoir oils from the Poplar Dome area of eastern Montana, as well as the McGregor and Beaver Lodge Fields located along the Nesson anticline of western North Dakota, display a mixed Bakken-Madison sourced signature (Jarvie, 2001: Jiang and Li, 2002). Both the Poplar Dome and Nesson anticline are prominent structural features within the basin where faults may have served as conduits for vertical oil migration (Orchard, 1987). Also, Bakken oil has sourced the Lodgepole mounds near Dickinson, North Dakota, localized reservoir features positioned in the basal Lodgepole Formation that directly overly the Bakken Formation (Jiang et al., 2002a). From the Canadian portion of the Williston Basin, Madison reservoir oils from fields located along regional inferred faulting-fracture trends exhibit geochemical signatures indicative of mixed Bakken and Madison derived oils (Jiang and Li, 2002; Chen et al., 2009). Therefore, some evidence remains of non-Madison sourced oils migrating into Madison reservoirs, particularly along structures that exhibit substantial vertical faulting/fracturing.

Initial studies reported TOC values in the Madison Group consistently <1% (Williams, 1974; Osadetz and Snowdon, 1986). However, Osadetz et al. (1992) and Osadetz and Snowdon (1995) later published datasets (3 and 23 samples) in which organic-rich Lodgepole samples from southern Saskatchewan averaged TOC values of 4.84% and 5.49% with corresponding average HI values of 594 and 401 mg HC/g TOC. Jiang et al. (2001) reported additional data from organic-rich Lodgepole lime mudstone samples (10 samples from 5 cores), also from southern Saskatchewan, that similarly averaged 5.3% TOC (2.1-10.3%) with an average hydrogen index of 591 mg HC/g TOC. Furthermore, Jarvie (2001) reported three organic-rich horizons in the Mission Canyon Formation in one core from eastern Montana that averaged TOC values of 1.96%, 8.50%, and 1.92% with corresponding HI average values of 394, 300, and 274 mg HC/g. More recently, Jarvie (2016) reported that elevated TOC values (>1% present-day values) are present in multiple Madison subintervals spanning the Ratcliffe, Frobisher-Alida, and Tilston Intervals. While previous studies have differentiated Madison reservoir oils from Bakken oils over large portions of the Williston Basin, limited published information exists on the stratigraphic positioning, lateral extent, and organic richness of petroleum source beds in the Madison.

METHODS

Five Madison cores were selected for examination and sampling that extend through the upper portions of the Frobisher-Alida Interval in western McKenzie County (Figs. 3 and 4). In addition to stratigraphic positioning, each core was further selected based upon one or more of the following criteria: 1) previously completed

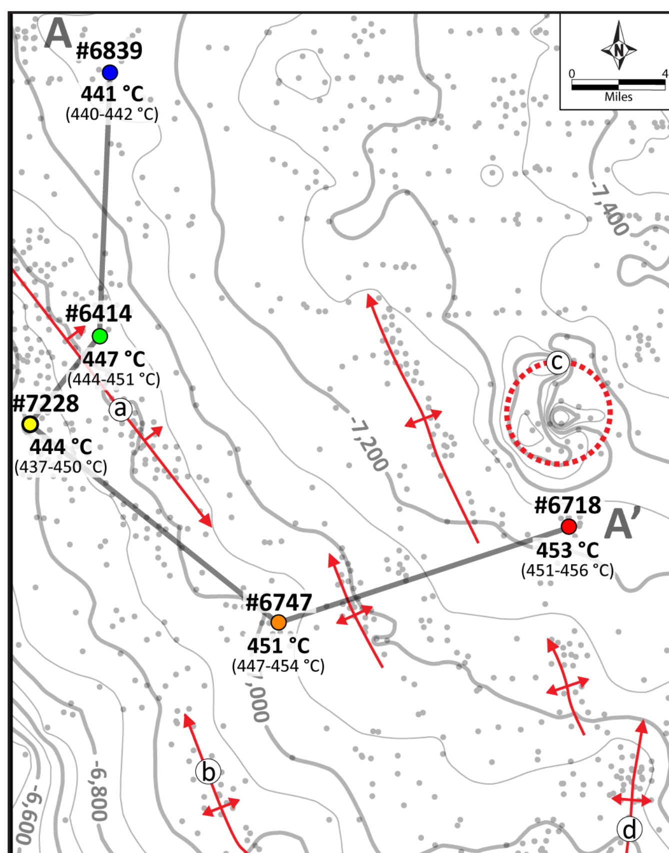

Figure 3. Study area map displaying the five study cores (colored-coded circles to match figure 7) and structure contours on the Frobisher-Alida Interval top in feet below sea level (grey lines). Small grey dots depict wireline log control wells for the structure contours. NDIC (North Dakota Industrial Commission) well numbers are listed above each core location symbol with average reliable Tmax values from the Bluell subinterval below (Tmax value ranges underneath). Study area is depicted on the Figure 1 regional map. Red lines depict documented structures: a = Mondak monocline, b = Beaver Creek anticline, c = Red Wing Creek structure, d = Little Knife anticline

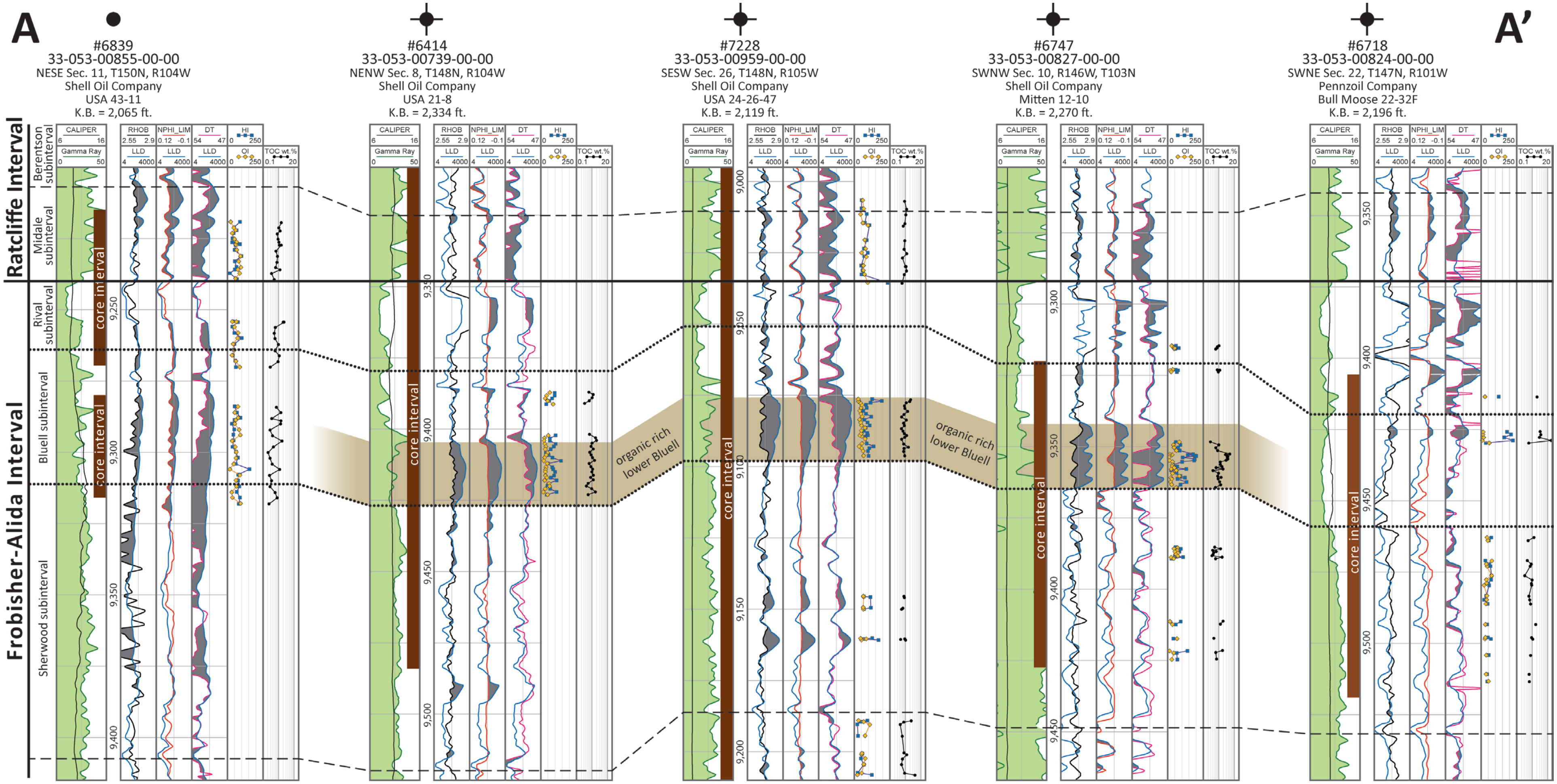

Figure 4. Wireline log cross-section of the lower Ratcliffe and upper Frobisher-Alida subintervals with TOC-RockEval core data. TOC wt. % (total organic carbon by weight percent) is displayed on a logarithmic scale. Cross-plots of deep resistivity (LLD) versus RHOB (bulk density), NPHI_LIM (neutron porosity – limestone matrix) and DT (Delta-T = sonic travel time) are plotted to identify prospective organic-rich rock intervals, in which grey shading indicates a positive crossover signature (Passey et al., 1990). Brown color fill in the lower Bluell denotes where core and wireline log data indicate the interval is organic rich (≥1% TOC). ft. = feet; HI = hydrogen index (mg HC/g TOC, milligrams hydrocarbons per gram total organic carbon): K.B. = Kelly Bushing elevation; OI = oxygen index (mg HC/g TOC)

TOC-RockEval data indicative of organic-rich and oil-prone source rock (≥1-2% TOC, S2 versus S3 ratios of ≥3), 2) elevated core-plug oil saturations (≥40-60% So) within low-porosity core sections (≤2-3% ϕ), 3) darkly colored intervals observed through available core photographs, and/or 4) cores located within previously sampled/identified stratigraphic sections that yielded organic-rich samples.

Each core was examined, described, and correlated to corresponding wireline logs before being sampled. Geologic tops from the lower Ratcliffe (Midale subinterval) and upper Frobisher-Alida (Rival, Bluell, Sherwood, and Glenburn subintervals) Intervals were extracted from Petty (1988; 1996) and McClellan (1995) and subsequently correlated into and across the study area using wireline logs from available wells including the five cored wells of the study (Fig. 4).

TOC-RockEval samples were collected using a drill press that allowed for pinpoint sampling precision while creating a fine, powdered sample adequate for analysis while preserving the integrity of sampled cores. Samples collected from NDIC (North Dakota Industrial Commission) well permit #7228 are approximate 1-foot averages while the other four cores were sampled at specific depth points. Samples from all five cores represent both the darker colored and adjacent lighter colored core intervals. Sample analysis for TOC-RockEval data was completed using the Source Rock Analyzer available through the University of North Dakota.

The organic richness of the analyzed samples was evaluated through the combination of TOC and HI data. TOC values of 1% by weight or greater are generally considered good quality source rock (Peters and Cassa, 1994). Therefore, a 1% TOC threshold was used as a general cutoff to identify prospective, organic-rich, petroleum source rock horizons. HI is a measurement of milligrams of hydrocarbons (mg HC) per gram of total organic carbon (TOC) generated and measured during Rock-Eval pyrolysis. HI essentially represents the ratio of kerogen (organic carbon capable of converting to hydrocarbons) to that of TOC on a scale of 0–1200. HI and TOC both gradually decrease during thermal maturation of a given source rock as kerogen (oil-prone organic carbon) is converted into hydrocarbons and generated hydrocarbons are expelled from the source rock (Dembicki, 2009).

Thermal maturity was evaluated using Tmax generated from the RockEval Pyrolysis analyzes. Increased Tmax values indicate higher levels thermally maturity for sample with respect to hydrocarbon generation and the greater the percentage of original kerogen that has been converted into hydrocarbons (Peters, 1986). Pyrogram curves were visually examined to evaluate the S2 peaks used to determine the Tmax values. Tmax values were also plotted against PI values to determine if there were any notable variances between increasing PI with respect to changes to Tmax.

Core to log (wireline logs) adjustments were made comparing described core lithologies, core gamma-ray, and core-plug porosity data to corresponding wireline logs. The wireline-log signatures through organic-rich horizons identified through TOC-RockEval analysis (generally containing ≥1% TOC) were examined and utilized to correlate the horizons between non-cored and/or non-sampled wells.

RESULTS

CORE GEOCHEMISTRY

A total of 222 core samples were collected and analyzed for TOC-RockEval data. TOC values ranged from 0.21 to 17.02 % by weight with an average of 1.1% (Fig. 5, Table 1). While elevated TOC values (≥1%) were found intermittently throughout the various subintervals comprising lower Ratcliffe and upper Frobisher-Alida Intervals, the majority of higher TOC values of 1% or greater were from the lower half of the Bluell subinterval (lower Bluell) (Fig. 5). Examining HI versus OI, the composite Madison samples plot along a Type I/II to Type III/IV kerogen signatures on a modified Van Krevelen diagram, with higher TOC samples preferentially plotting more towards a Type I/II, oil-prone kerogen signature (Fig. 6).

Including the entire Madison dataset generated from all five cores, a total of 70 reliable Tmax values were identified based upon pyrogram S2 peaks and PI values. Out of those Tmax values, 46 were from the Bluell subinterval, which

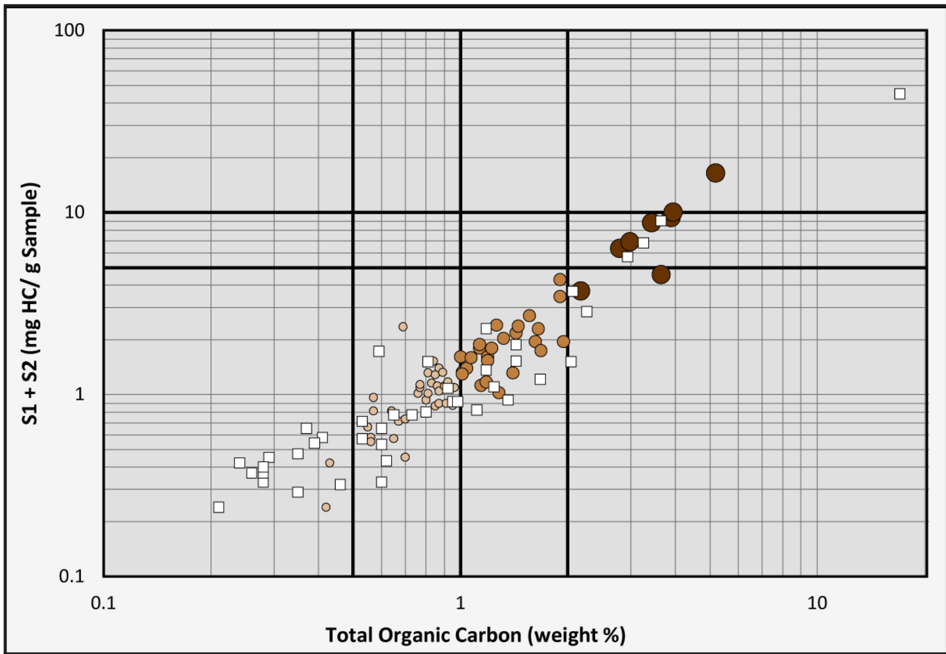

Figure 5. Organic-richness plot of Madison core samples. Brown circles depict samples from the lower Bluell subinterval with size and color shading based upon cutoffs for good (>1%) and excellent (>2%) quality source rock (Dembicki, 2009). Small and light brown circles = <1% TOC, medium sized and colored = 1-2% TOC, large and dark brown = >2% TOC. Small white squares represent non-lower Bluell Madison samples.

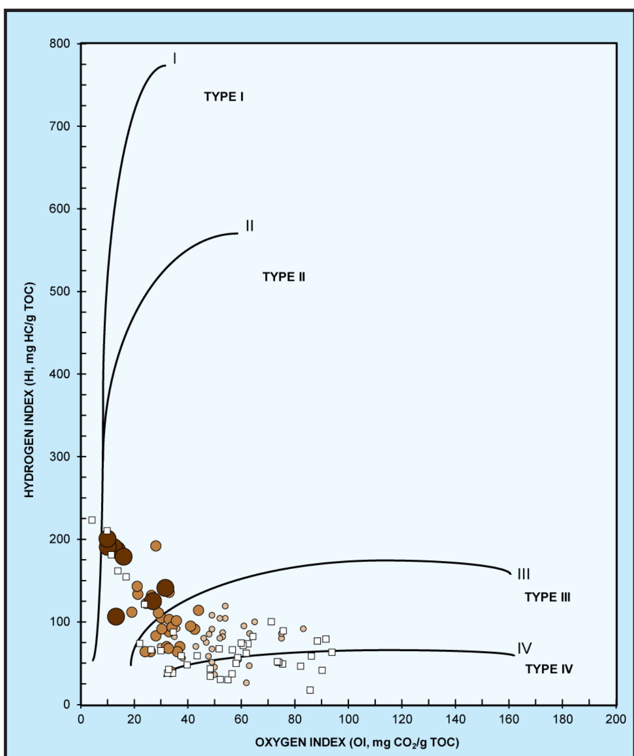

Figure 6. Modified Van Krevelen diagram with brown circles depicting samples from the lower Bluell subinterval: small and light brown circles = <1% TOC, medium sized and colored = 1-2% TOC, large and dark brown = >2% TOC. Small white squares represent non-lower Bluell Madison samples.

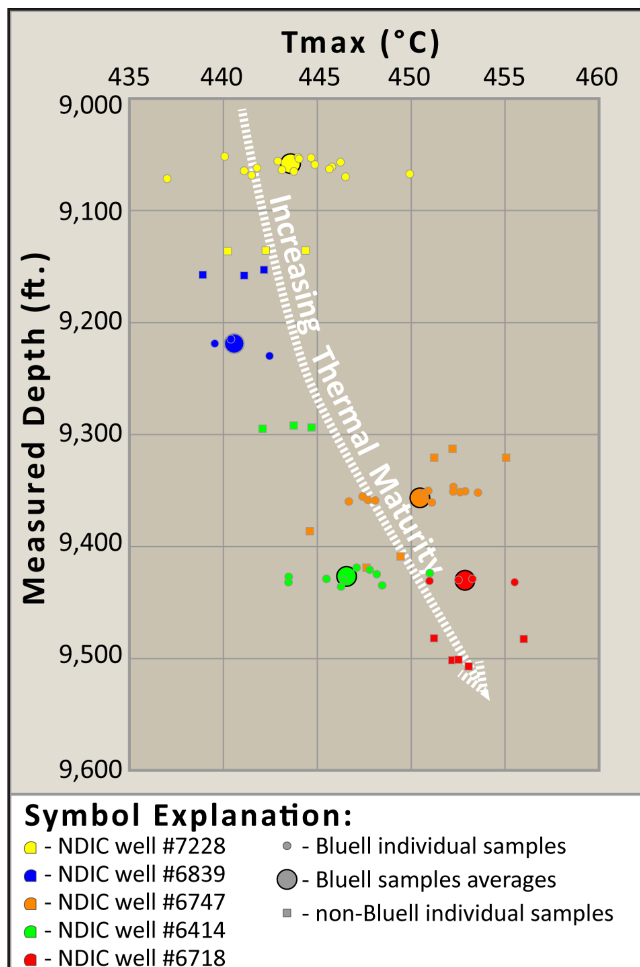

Figure 7. Tmax versus measured depth (below surface) of Madison core samples color coated based upon NDIC well number and symbol shaped based upon Bluell versus non-Bluell subinterval.

ranged from 437.0 to 456.0 °C and averaged 446.8 °C (Table 1). Overall, the Bluell and other Madison Tmax values increase with depth but with a non-linear relationship that varies from one core data set to another (Fig. 7). Spatially, the Bluell Tmax values increase east-southeast across the study area (Fig. 3).

LOWER BLUELL SUBINTERVAL

Samples with ≥1% TOC in the lower Bluell vertically span upwards of approximately 15 to 20 feet in gross thickness within three of the study cores located in the central to western portions of the study area (Figs. 3 and 4 – wells #6414, #7228, and #6747). In those cores, the lower Bluell averages approximately 1-2% TOC, but with highly variable organic-richness in which individual sample TOC and HI values range from upwards of 6% and ≥200 mg HC/g TOC down to <0.5% and ≤50 mg HC/g TOC (Figs. 4-6). In the northern most study core (Figs. 3 and 4 - well #6839), a few of the lower Bluell samples contained ~1% TOC with higher HI (100-200 mg HC/g TOC), but most of the samples of the subinterval were relatively organic-lean with either <1% TOC and/or low HI (<100 mg HC/g TOC). The fifth and eastern most core (Figs. 3 and 4 - well #6718) was not sampled for TOC-RockEval analysis due to the lithological makeup of the lower Bluell which is reviewed below.

LOWER BLUELL CORE LITHOFACIES

In conjuncture with sampling for TOC-RockEval analysis, each study core was logged (described) and correlated to wireline logs for preliminary, regional stratigraphic correlations. Examining the lithological trends of the five study cores, the lower Bluell is primarily comprised of medium brown to very dark grey fossil lime wackestone within the four more westerly cores in the study area (Fig. 8A and 8B, Plate I). The higher TOC values (≥1%) corresponded with dark to very dark grey/black, moderately to well laminated, fossil lime wackestone containing relatively abundant brachiopod shells and crinoid stem fragments (Fig. 8A, Plate I). Meanwhile, the lower TOC values (<1%) corresponded with medium brown, poorly laminated, fossil lime wackestone to floatstone, in which tabulate and/or rugose corals where present in addition to brachiopod and crinoids (Fig. 8B, Plate I). In the fifth and eastern most core examined, the lower Bluell consists primarily of light to medium brown, oolitic-peloidal lime grainstone (Fig. 8C, Plate I), a high energy carbonate facies.

WIRELINE LOG SIGNATURE AND MAPPING

Unlike typical organic-rich petroleum source beds, such as the Upper and Lower Bakken shales, the higher TOC (≥1%) facies of the Bluell cannot readily be differentiated from the lateral or vertically adjacent, lower TOC (<1%)

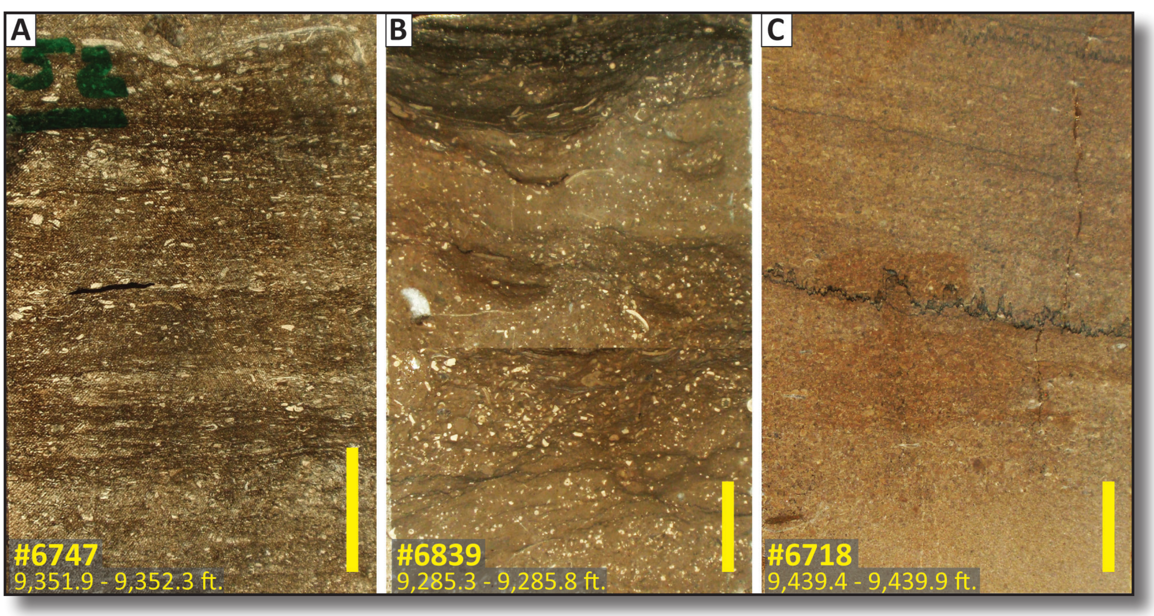

Figure 8. Core photographs from the lower Bluell subinterval. A) Dark grey to black, laminated, fossil lime wackestone, B) medium brown to dark grey, poorly laminated, fossil lime wackstone, and c) medium tan/brown, laminated, oolitic-peloidal lime grainstone. NDIC (North Dakota Industrial Commission) well number and core depth interval in the bottom left corners and one-inch scale bars in the bottom right corners of each photograph.

strata using the gamma-ray wireline log signature. Instead, the high TOC Bluell facies has to be identified on wireline logs using cross-plots of deep resistivity versus sonic travel time, neutron porosity, and bulk density logs (Fig. 4 – cross-section) (Passey et al., 1990). The high TOC Bluell facies appears to correspond with where all three cross-plots display a positive deep resistivity cross-over in which deep resistivity values are above 200 ohmmeters (Fig. 4).

The lower Bluell high TOC facies was first correlated across the study area starting with the core-control wells and their corresponding digitized logs followed by additional available digital wireline logs. Next, raster logs were used to further correlate the lower Bluell high TOC facies. While the raster logs did not allow for wireline log cross-plots, a combination of gamma-ray and resistivity wireline logs along with neutron-density porosities and/or sonic travel time appear adequate for correlation when compared to the digital logs of previously correlated wells.

Overall, the high TOC facies of the lower Bluell ranged from being absent, particularly towards the east-southeast parts of the study area, to reaching gross thicknesses of upwards of 30 ft. towards the northwest, and generally ranges from 10 to 20 ft. thick when present (Fig. 9). As the high TOC facies of the lower Bluell thins and disappears in the subsurface, the thickness of the Bluell interval does not appear to substantially thin or thicken (Fig. 4). Instead, based on both log and core data, the high TOC facies of the lower Bluell laterally grades into either organic-lean fossil lime wackestone or oolitic-peloidal lime grainstone. Also, the gross-thickness of the high TOC Bluell facies decreases to becomes absent proximal to structures, which mostly trend northwest-southeast across the study area (Fig. 9).

INTERPRETATIONS AND DISCUSSION

THERMAL MATURITY

Tmax values indicate that the high TOC facies of the lower Bluell has reached the early to late stages of oil generation within the study area. The early, peak, and late oil generation windows are typically represented by Tmax value ranges of 435-445 °C, 445-450 °C, and 450-470 °C (Peters and Cassa, 1994). The individual reliable Bluell Tmax values ranged from 437 °C to 456 °C, while the core data set averages ranged from 441°C to 453 °C (Fig. 7, Table 1), indicative that the Bluell is within the early to late oil generation windows. However, as previously noted, oils produced from the Frobisher-Alida reservoirs are commonly enriched in sulfur, which is indicative of Type II-S kerogen that thermally matures at lower temperatures (Lillis, 2012). Jarvie (2016) assumed a Tmax of 427 °C to mark the beginning of the oil generation window for Madison source bed samples. Therefore, the lower Bluell may be within the peak to late oil generation window dependent upon the type(s) of kerogen present.

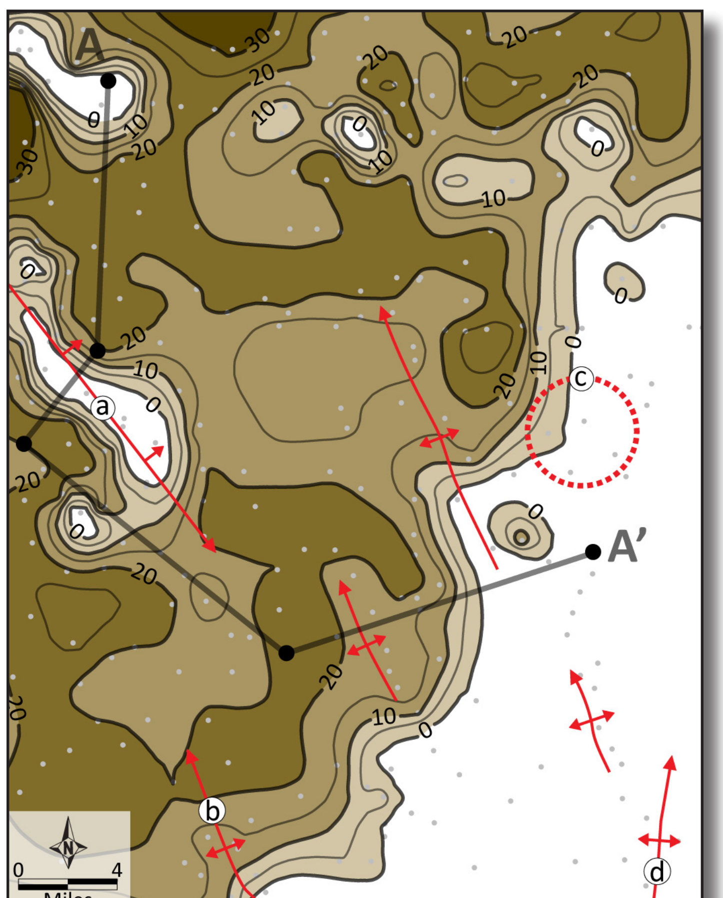

Figure 9. Isopach map of the gross thickness of the high TOC lower Bluell facies. Contours are in 5-foot intervals and the brown contour fill is in 10-foot intervals. Small light grey circles are the wireline log well control and the large black circles are the core control wells. Study area is depicted on the Figure 1 regional map. Red lines depict documented structures: a = Mondak monocline, b = Beaver Creek anticline, c = Red Wing Creek structure, d = Little Knife anticline

KEROGEN TYPE

Regarding kerogen type(s) within prospective Madison source beds, a few general comments/conclusions can be drawn. First, if the lower Bluell and adjacent strata are within the peak to late mature stages of the oil generation window, the majority (≥50%) of the original kerogen has likely been converted into hydrocarbons and the current kerogen signature based on HI versus OI ratios is not fully reflective of the original kerogen signature (Dembicki, 2009). Secondly, Frobisher-Alida reservoirs are primarily known to produce oil with gas as a secondary component. This means any substantial prominence of Type III gas-prone kerogen within Madison source beds is unlikely, and therefore the original kerogen was likely oil-prone Type I, Type II, and/or Type II-S.

ADDITIONAL MADISON SOURCE BEDS

While this report focused on the Bluell because of the prominence of elevated TOC values, core samples with elevated TOC, coupled with increased HI, extended stratigraphically well beyond the Bluell. Furthermore, wireline log cross-plots of deep resistivity versus bulk density, neutron porosity, and sonic velocity in numerous wells examined indicate additional prospective organic-rich horizons of various thicknesses and lateral distributions that are present in both subintervals above and below the Bluell.

CONCLUDING REMARKS

- The Bluell subinterval, particularly the lower Bluell, contains the most prominent vertical and lateral distribution of high TOC values (≥1%) within the sampled cores spanning the upper Frobisher-Alida and lower Ratcliffe intervals.
- Wireline log cross-plots of deep resistivity versus bulk density, neutron porosity, and sonic travel time are useful when combined to identify prospective organic-rich carbonate rock within the Madison Group.
- Core data, combined with wireline log cross-plot mapping, demonstrates the lower Bluell is comprised of upwards 20-30 ft. (gross thickness) of organic-rich carbonate rock along western McKenzie County.
- Tmax values indicate that the lower Bluell within western McKenzie County and any stratigraphically adjacent Madison petroleum source beds range from the early to late, or peak to late mature stages of oil generation depending upon the type(s) of kerogen present.

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Table 1

NDIC #	API Number	Core Depth (ft.)		SRA	S1	S2	S3	Tmax	Tmax	Calc.	HI	OI	S2/S3	S1/TOC	PI	Madison
		Top	Base	TOC				(°C)	Quality	% Ro				*100		Subunit
6414	33053007390000	9292		1.63	0.96	2.16	0.38	444	1	0.83	133	23	5.7	59	0.31	R (un)
6414	33053007390000	9293.8		0.91	0.33	0.81	0.25	445	1	0.84	89	27	3.2	36	0.29	R (un)
6414	33053007390000	9295		1.22	0.48	1.92	0.30	442	1	0.80	157	25	6.4	39	0.20	R (un)
6414	33053007390000	9296		0.95	0.18	0.37	0.53	440	3	0.77	39	56	0.7	19	0.33	R (un)
6414	33053007390000	9305		1.06	0.22	0.38	0.50	439	3	0.74	36	47	0.8	21	0.37	R (un)
6414	33053007390000	9310.85		0.85	0.84	0.75	0.40	438	3	0.72	88	47	1.9	99	0.53	R (un)
6414	33053007390000	9311.8		0.54	0.25	0.31	0.25	444	3	0.83	57	46	1.2	46	0.45	R (un)
6414	33053007390000	9401		0.62	0.86	0.61	0.40	441	3	0.77	98	65	1.5	139	0.59	FA (Bl)
6414	33053007390000	9402		1.18	1.19	1.16	0.48	441	2	0.78	98	41	2.4	101	0.51	FA (Bl)
6414	33053007390000	9403		1.05	0.63	0.84	0.33	447	3	0.88	80	31	2.5	60	0.43	FA (Bl)
6414	33053007390000	9404		0.66	0.41	0.40	0.32	442	3	0.79	61	48	1.3	62	0.51	FA (Bl)
6414	33053007390000	9405		0.33	0.12	0.13	0.29	433	3	0.64	39	88	0.4	36	0.48	FA (Bl)
6414	33053007390000	9416		0.69	1.63	0.72	0.37	438	3	0.72	104	54	1.9	236	0.69	FA (Bl)
6414	33053007390000	9417		1.68	0.66	1.08	0.44	437	3	0.71	64	26	2.5	39	0.38	FA (Bl)
6414	33053007390000	9418		1.94	0.70	1.25	0.46	439	3	0.75	64	24	2.7	36	0.36	FA (Bl)
6414	33053007390000	9419		1.00	0.56	1.05	0.30	447	2	0.89	105	30	3.5	56	0.35	FA (Bl)
6414	33053007390000	9420		0.87	0.59	0.80	0.31	448	2	0.90	92	36	2.6	68	0.42	FA (Bl)
6414	33053007390000	9421		1.18	0.34	0.83	0.38	448	2	0.90	70	32	2.2	29	0.29	FA (Bl)
6414	33053007390000	9422.2		0.70	0.20	0.25	0.35	448	3	0.91	36	50	0.7	29	0.44	FA (Bl)
6414	33053007390000	9423		0.87	0.40	0.49	0.33	446	2	0.86	56	38	1.5	46	0.45	FA (Bl)
6414	33053007390000	9424		1.04	0.53	0.86	0.29	451	2	0.96	83	28	3.0	51	0.38	FA (Bl)
6414	33053007390000	9425		1.45	0.30	2.07	0.31	448	2	0.91	143	21	6.7	21	0.13	FA (Bl)
6414	33053007390000	9426		0.65	0.24	0.33	0.32	450	3	0.94	51	49	1.0	37	0.42	FA (Bl)
6414	33053007390000	9427.2		0.85	0.16	0.70	0.30	443	1	0.82	82	35	2.3	19	0.19	FA (Bl)
6414	33053007390000	9428		1.07	0.65	0.94	0.35	453	3	0.99	88	33	2.7	61	0.41	FA (Bl)
6414	33053007390000	9429		1.01	0.25	1.04	0.33	446	1	0.86	103	33	3.2	25	0.19	FA (Bl)
6414	33053007390000	9430.2		1.19	0.49	1.12	0.41	446	1	0.88	94	34	2.7	41	0.30	FA (Bl)
6414	33053007390000	9431		0.80	0.37	0.56	0.34	444	2	0.83	70	43	1.6	46	0.40	FA (Bl)
6414	33053007390000	9432		1.22	0.43	1.36	0.35	443	1	0.82	111	29	3.9	35	0.24	FA (Bl)
6414	33053007390000	9433		0.56	0.28	0.30	0.33	447	3	0.89	54	59	0.9	50	0.48	FA (Bl)
6414	33053007390000	9434		0.43	0.22	0.20	0.27	443	5	0.81	47	63	0.7	51	0.52	FA (Bl)
6414	33053007390000	9435		0.95	0.24	0.63	0.29	448	1	0.91	66	31	2.2	25	0.28	FA (Bl)

Table 1 continued

NDIC #	API Number	Core Depth (ft.)		SRA	S1	S2	S3	Tmax	Tmax	Calc.	HI	OI	S2/S3	S1/TOC	PI	Madison
		Top	Base	TOC				(°C)	Quality	% Ro				*100		Subunit
6414	33053007390000	9436		1.65	0.45	1.84	0.31	446	1	0.87	112	19	5.9	27	0.20	FA (Bl)
6414	33053007390000	9437		0.56	0.30	0.25	0.28	452	3	0.97	45	50	0.9	54	0.55	FA (Bl)
6718	33053008240000	9416.8		2.06	1.18	2.50	0.49	448	2	0.91	121	24	5.1	57	0.32	FA (Ri)
6718	33053008240000	9429		3.25	0.89	5.89	0.37	453	2	1.00	181	11	15.9	27	0.13	FA (Bl)
6718	33053008240000	9430		3.64	1.31	7.65	0.36	453	2	0.99	210	10	21.3	36	0.15	FA (Bl)
6718	33053008240000	9431		2.94	0.94	4.75	0.41	451	2	0.96	162	14	11.6	32	0.17	FA (Bl)
6718	33053008240000	9432		17.02	6.70	38.01	0.72	456	2	1.04	223	4	52.8	39	0.15	FA (Bl)
6718	33053008240000	9433		0.60	0.15	0.18	0.33	441	3	0.78	30	55	0.5	25	0.45	FA (Bl)
6718	33053008240000	9466		1.31	0.54	0.90	0.51	446	3	0.87	69	39	1.8	41	0.38	FA (Sh)
6718	33053008240000	9467.2		0.54	0.20	0.28	0.24	448	3	0.90	52	44	1.2	37	0.42	FA (Sh)
6718	33053008240000	9474.2		0.48	0.09	0.13	0.35	451	3	0.95	27	73	0.4	19	0.41	FA (Sh)
6718	33053008240000	9475.5		0.88	0.31	0.48	0.30	447	3	0.89	55	34	1.6	35	0.39	FA (Sh)
6718	33053008240000	9476.1		0.74	0.34	0.47	0.29	446	3	0.86	64	39	1.6	46	0.42	FA (Sh)
6718	33053008240000	9479.4		0.33	0.19	0.23	0.24	457	3	1.06	70	73	1.0	58	0.45	FA (Sh)
6718	33053008240000	9480.85		0.99	0.44	0.67	0.34	452	3	0.97	68	34	2.0	44	0.40	FA (Sh)
6718	33053008240000	9482.2		0.89	0.29	0.44	0.31	451	2	0.96	49	35	1.4	33	0.40	FA (Sh)
6718	33053008240000	9482.8		0.92	0.29	0.48	0.16	456	2	1.05	52	17	3.0	32	0.38	FA (Sh)
6718	33053008240000	9486.6		0.61	0.16	0.19	0.23	464	5	1.19	31	38	0.8	26	0.46	FA (Sh)
6718	33053008240000	9487.9		0.68	0.13	0.12	0.24	450	4	0.94	18	35	0.5	19	0.52	FA (Sh)
6718	33053008240000	9489.3		0.79	0.28	0.34	0.24	451	3	0.95	43	30	1.4	35	0.45	FA (Sh)
6718	33053008240000	9496.5		1.69	0.47	0.67	0.45	443	3	0.82	40	27	1.5	28	0.41	FA (Sh)
6718	33053008240000	9501.2		0.92	0.28	0.42	0.25	453	2	0.99	46	27	1.7	30	0.40	FA (Sh)
6718	33053008240000	9501.7		1.08	0.39	0.71	0.26	452	2	0.98	66	24	2.7	36	0.35	FA (Sh)
6718	33053008240000	9507.4		0.78	0.26	0.40	0.26	453	2	1.00	51	33	1.5	33	0.39	FA (Sh)
6718	33053008240000	9514.1		0.63	0.21	0.24	0.20	446	3	0.87	38	32	1.2	33	0.47	FA (Sh)
6718	33053008240000	9516.5		0.65	0.25	0.26	0.32	452	4	0.98	40	49	0.8	38	0.49	FA (Sh)
6747	33053008270000	9312.2		1.03	0.48	0.62	0.30	451	3	0.96	60	29	2.1	47	0.44	FA (Ri)
6747	33053008270000	9312.5		0.82	0.33	0.36	0.29	451	3	0.96	44	35	1.2	40	0.48	FA (Ri)
6747	33053008270000	9313		0.77	0.36	0.61	0.39	452	2	0.98	79	51	1.6	47	0.37	FA (Ri)
6747	33053008270000	9313.3		0.63	0.30	0.35	0.30	453	3	0.99	56	48	1.2	48	0.46	FA (Ri)
6747	33053008270000	9320.6		0.80	0.33	0.47	0.30	455	3	1.03	59	38	1.6	41	0.41	FA (Bl)
6747	33053008270000	9320.8		1.18	0.49	0.87	0.26	455	2	1.03	74	22	3.3	42	0.36	FA (Bl)

Table 1 continued

NDIC #	API Number	Core Depth (ft.)		SRA	S1	S2	S3	Tmax	Tmax	Calc.	HI	OI	S2/S3	S1/TOC	PI	Madison
		Top	Base	TOC				(°C)	Quality	% Ro				*100		Subunit
6747	33053008270000	9321.4		0.95	0.28	0.63	0.25	451	2	0.96	66	26	2.5	29	0.31	FA (Bl)
6747	33053008270000	9346		0.29	0.11	0.17	0.24	451	3	0.96	59	83	0.7	38	0.39	FA (Bl)
6747	33053008270000	9347		1.01	0.40	0.92	0.43	452	2	0.98	91	43	2.1	40	0.30	FA (Bl)
6747	33053008270000	9348		0.64	0.33	0.48	0.30	459	3	1.11	75	47	1.6	52	0.41	FA (Bl)
6747	33053008270000	9349		0.84	0.80	0.72	0.53	453	3	0.99	86	63	1.4	95	0.53	FA (Bl)
6747	33053008270000	9350.3		5.19	7.10	9.29	0.83	451	2	0.96	179	16	11.2	137	0.43	FA (Bl)
6747	33053008270000	9350.5		2.79	2.38	3.94	0.88	453	2	0.99	141	32	4.5	85	0.38	FA (Bl)
6747	33053008270000	9350.8		3.43	2.21	6.54	0.42	453	2	0.99	191	12	15.6	64	0.25	FA (Bl)
6747	33053008270000	9351		3.94	2.09	7.91	0.39	452	2	0.98	201	10	20.3	53	0.21	FA (Bl)
6747	33053008270000	9351.5		3.65	0.65	3.89	0.48	453	2	0.99	107	13	8.1	18	0.14	FA (Bl)
6747	33053008270000	9352		3.89	1.92	7.42	0.39	454	2	1.00	191	10	19.0	49	0.21	FA (Bl)
6747	33053008270000	9352.5		2.98	1.30	5.58	0.40	451	2	0.95	187	13	14.0	44	0.19	FA (Bl)
6747	33053008270000	9353		1.26	1.12	1.28	0.45	446	3	0.87	102	36	2.8	89	0.47	FA (Bl)
6747	33053008270000	9354		1.28	0.51	0.51	0.43	449	3	0.93	40	34	1.2	40	0.50	FA (Bl)
6747	33053008270000	9354.6		1.62	0.85	1.10	0.53	447	3	0.89	68	33	2.1	52	0.44	FA (Bl)
6747	33053008270000	9355		0.67	0.32	0.39	0.32	457	3	1.07	58	48	1.2	48	0.45	FA (Bl)
6747	33053008270000	9355.5		1.90	0.94	2.51	0.50	447	2	0.89	132	26	5.0	49	0.27	FA (Bl)
6747	33053008270000	9356		0.42	0.13	0.11	0.26	460	3	1.13	26	62	0.4	31	0.54	FA (Bl)
6747	33053008270000	9357		0.96	0.46	0.63	0.34	452	3	0.98	66	35	1.9	48	0.42	FA (Bl)
6747	33053008270000	9358		0.83	0.39	0.76	0.69	353	5		92	83	1.1	47	0.34	FA (Bl)
6747	33053008270000	9358.5		1.43	0.42	1.75	0.35	448	2	0.90	122	24	5.0	29	0.19	FA (Bl)
6747	33053008270000	9359		0.91	0.25	0.64	0.27	448	2	0.91	70	30	2.4	27	0.28	FA (Bl)
6747	33053008270000	9360		1.13	0.37	1.51	0.24	447	2	0.88	134	21	6.3	33	0.20	FA (Bl)
6747	33053008270000	9361		1.32	0.82	1.21	0.40	451	2	0.96	92	30	3.0	62	0.40	FA (Bl)
6747	33053008270000	9362		0.61	0.33	0.41	0.38	460	3	1.12	67	62	1.1	54	0.45	FA (Bl)
6747	33053008270000	9383		0.54	0.28	0.32	0.38	449	3	0.92	59	70	0.8	52	0.47	FA (Sh)
6747	33053008270000	9383.5		1.31	1.16	1.24	0.58	450	3	0.93	95	44	2.1	89	0.48	FA (Sh)
6747	33053008270000	9384		0.40	0.35	0.27	0.27	447	3	0.88	68	68	1.0	88	0.56	FA (Sh)
6747	33053008270000	9384.5		0.69	0.40	0.58	0.37	452	3	0.97	84	54	1.6	58	0.41	FA (Sh)
6747	33053008270000	9385		0.47	0.30	0.29	0.35	445	3	0.84	62	74	0.8	64	0.51	FA (Sh)
6747	33053008270000	9385.5		0.43	0.23	0.24	0.26	456	3	1.05	56	60	0.9	53	0.49	FA (Sh)
6747	33053008270000	9386		0.36	0.15	0.19	0.26	447	3	0.89	53	72	0.7	42	0.44	FA (Sh)

Table 1 continued

NDIC #	API Number	Core Depth (ft.)		SRA	S1	S2	S3	Tmax	Tmax	Calc.	HI	OI	S2/S3	S1/TOC	PI	Madison
		Top	Base	TOC				(°C)	Quality	% Ro				*100		Subunit
6747	33053008270000	9386.5		1.65	0.90	1.80	0.43	445	2	0.84	109	26	4.2	55	0.33	FA (Sh)
6747	33053008270000	9387		0.62	0.19	0.18	0.27	445	3	0.84	29	44	0.7	31	0.51	FA (Sh)
6747	33053008270000	9409		1.93	1.13	1.80	0.35	449	2	0.93	93	18	5.1	59	0.39	FA (Sh)
6747	33053008270000	9410		1.28	0.57	0.75	0.44	445	3	0.86	59	34	1.7	45	0.43	FA (Sh)
6747	33053008270000	9415		0.48	0.24	0.20	0.32	447	3	0.88	42	67	0.6	50	0.55	FA (Sh)
6747	33053008270000	9419.3		1.76	0.54	2.43	0.28	448	2	0.90	138	16	8.7	31	0.18	FA (Sh)
6747	33053008270000	9420		0.64	0.33	0.42	0.28	451	3	0.97	66	44	1.5	52	0.44	FA (Sh)
6747	33053008270000	9422.3		0.72	0.43	0.48	0.22	451	3	0.95	67	31	2.2	60	0.47	FA (Sh)
6839	33053008550000	9153		0.66	0.38	0.70	0.37	442	1	0.80	106	56	1.9	58	0.35	R (Be)
6839	33053008550000	9156		0.94	0.63	0.60	0.41	443	3	0.81	64	44	1.5	67	0.51	R (Be)
6839	33053008550000	9157.4		1.29	0.44	0.79	0.48	439	2	0.74	61	37	1.6	34	0.36	R (Be)
6839	33053008550000	9158.2		2.49	1.68	4.55	0.82	441	1	0.78	183	33	5.5	67	0.27	R (Be)
6839	33053008550000	9163		0.50	0.20	0.16	0.31	439	4	0.75	32	62	0.5	40	0.56	R (Be)
6839	33053008550000	9165		0.27	0.08	0.02	0.22	429	4	0.56	7	81	0.1	30	0.80	R (Be)
6839	33053008550000	9215		1.50	0.60	1.30	0.36	440	1	0.77	87	24	3.6	40	0.32	R (Mi)
6839	33053008550000	9217		1.04	0.46	0.47	0.47	430	3	0.58	45	45	1.0	44	0.49	R (Mi)
6839	33053008550000	9218		1.26	0.61	0.77	0.71	427	3	0.52	61	56	1.1	48	0.44	R (Mi)
6839	33053008550000	9219		0.82	0.25	0.35	0.29	440	2	0.75	43	35	1.2	30	0.42	R (Mi)
6839	33053008550000	9221		0.93	0.45	0.33	0.46	436	3	0.69	35	49	0.7	48	0.58	R (Mi)
6839	33053008550000	9222		1.06	0.44	0.35	0.67	426	3	0.51	33	63	0.5	42	0.56	R (Mi)
6839	33053008550000	9223		1.13	0.85	0.99	0.65	424	5	0.47	88	58	1.5	75	0.46	R (Mi)
6839	33053008550000	9223.1		1.49	0.53	0.83	0.95	424	3	0.47	56	64	0.9	36	0.39	R (Mi)
6839	33053008550000	9225		0.68	0.37	0.35	0.44	431	3	0.59	51	65	0.8	54	0.51	R (Mi)
6839	33053008550000	9227		0.85	0.56	0.83	0.78	425	5	0.50	98	92	1.1	66	0.40	R (Mi)
6839	33053008550000	9229		0.79	0.36	0.40	0.63	425	3	0.50	51	80	0.6	46	0.47	R (Mi)
6839	33053008550000	9231		0.65	0.36	0.41	0.61	425	3	0.49	63	94	0.7	55	0.47	R (Mi)
6839	33053008550000	9231.7		1.24	0.46	0.64	0.91	427	3	0.52	52	73	0.7	37	0.42	R (Mi)
6839	33053008550000	9233		0.35	0.23	0.06	0.30	439	4	0.74	17	86	0.2	66	0.79	R (Mi)
6839	33053008550000	9235		0.53	0.22	0.35	0.30	442	2	0.80	66	57	1.2	42	0.39	R (Mi)
6839	33053008550000	9250		2.04	0.74	0.77	0.70	431	3	0.60	38	34	1.1	36	0.49	FA (Ri)
6839	33053008550000	9250.2		2.26	1.18	1.66	1.41	421	5	0.41	73	62	1.2	52	0.42	FA (Ri)
6839	33053008550000	9252		0.62	0.22	0.21	0.30	438	4	0.72	34	48	0.7	35	0.51	FA (Ri)

Table 1 continued

NDIC #	API Number	Core Depth (ft.)		SRA	S1	S2	S3	Tmax	Tmax	Calc.	HI	OI	S2/S3	S1/TOC	PI	Madison
		Top	Base	TOC				(°C)	Quality	% Ro				*100		Subunit
6839	33053008550000	9254		0.53	0.45	0.26	0.40	434	4	0.64	49	75	0.7	85	0.63	FA (Ri)
6839	33053008550000	9256		0.59	1.13	0.59	0.42	431	4	0.59	100	71	1.4	192	0.66	FA (Ri)
6839	33053008550000	9258		0.98	0.44	0.47	0.39	439	3	0.74	48	40	1.2	45	0.48	FA (Ri)
6839	33053008550000	9260		0.60	0.27	0.26	0.29	439	3	0.75	43	48	0.9	45	0.51	FA (Bl)
6839	33053008550000	9262		1.11	0.40	0.42	0.36	441	3	0.78	38	32	1.2	36	0.49	FA (Bl)
6839	33053008550000	9264		0.92	0.56	0.52	0.54	439	3	0.74	57	59	1.0	61	0.52	FA (Bl)
6839	33053008550000	9266		0.29	0.28	0.17	0.25	432	4	0.62	59	86	0.7	97	0.62	FA (Bl)
6839	33053008550000	9280		0.73	0.40	0.37	0.54	421	5	0.42	51	74	0.7	55	0.52	FA (Bl)
6839	33053008550000	9282		1.43	0.91	0.96	0.74	436	3	0.69	67	52	1.3	64	0.49	FA (Bl)
6839	33053008550000	9284		0.37	0.32	0.33	0.28	422	5	0.43	89	76	1.2	86	0.49	FA (Bl)
6839	33053008550000	9284.8		1.43	0.81	0.71	0.83	428	3	0.54	50	58	0.9	57	0.53	FA (Bl)
6839	33053008550000	9286		1.36	0.52	0.41	0.71	424	3	0.47	30	52	0.6	38	0.56	FA (Bl)
6839	33053008550000	9288		0.28	0.20	0.13	0.23	441	4	0.78	46	82	0.6	71	0.61	FA (Bl)
6839	33053008550000	9290		0.41	0.41	0.17	0.37	445	4	0.86	41	90	0.5	100	0.71	FA (Bl)
6839	33053008550000	9292		1.67	0.50	0.71	0.55	436	3	0.68	43	33	1.3	30	0.41	FA (Bl)
6839	33053008550000	9294		0.46	0.15	0.17	0.26	446	4	0.86	37	57	0.7	33	0.47	FA (Bl)
6839	33053008550000	9296		0.21	0.11	0.13	0.13	443	4	0.81	62	62	1.0	52	0.46	FA (Bl)
6839	33053008550000	9298		0.28	0.17	0.20	0.17	459	4	1.10	71	61	1.2	61	0.46	FA (Bl)
6839	33053008550000	9300		0.39	0.31	0.23	0.17	452	4	0.98	59	44	1.4	79	0.57	FA (Bl)
6839	33053008550000	9302		1.18	0.48	1.82	0.20	446	2	0.87	154	17	9.1	41	0.21	FA (Bl)
6839	33053008550000	9304		0.26	0.17	0.20	0.23	451	3	0.95	77	88	0.9	65	0.46	FA (Bl)
6839	33053008550000	9306		0.35	0.21	0.26	0.21	445	3	0.86	74	60	1.2	60	0.45	FA (Bl)
6839	33053008550000	9308		0.28	0.17	0.23	0.18	445	3	0.85	82	64	1.3	61	0.43	FA (Sh)
6839	33053008550000	9310		0.60	0.26	0.39	0.18	453	3	0.99	65	30	2.2	43	0.40	FA (Sh)
6839	33053008550000	9312		0.81	0.80	0.71	0.28	446	3	0.86	88	35	2.5	99	0.53	FA (Sh)
6839	33053008550000	9314		0.24	0.23	0.19	0.22	448	3	0.90	79	92	0.9	96	0.55	FA (Sh)
7228	33053009590000	8982.1		0.90	0.35	0.46	0.53	435	3	0.67	51	59	0.9	39	0.43	R (Be)
7228	33053009590000	8985.0		1.19	0.46	0.59	0.79	440	4	0.75	50	66	0.7	39	0.44	R (Be)
7228	33053009590000	8987.0	8988.0	1.06	0.79	0.92	0.46	438	3	0.73	87	43	2.0	75	0.46	R (Mi)
7228	33053009590000	8990.0	8991.0	0.92	0.67	0.68	0.55	430	4	0.59	74	60	1.2	73	0.50	R (Mi)
7228	33053009590000	8990.8		0.72	0.71	0.77	0.69	437	5	0.71	107	96	1.1	99	0.48	R (Mi)
7228	33053009590000	8996.0	8997.0	0.91	0.43	0.79	0.67	439	3	0.74	87	74	1.2	47	0.35	R (Mi)

Table 1 continued

NDIC #	API Number	Core Depth (ft.)		SRA	S1	S2	S3	Tmax	Tmax	Calc.	HI	OI	S2/S3	S1/TOC	PI	Madison
		Top	Base	TOC				(°C)	Quality	% Ro				*100		Subunit
7228	33053009590000	8999.0	9000.0	0.82	0.49	0.54	0.65	433	3	0.63	66	79	0.8	60	0.48	R (Mi)
7228	33053009590000	9000.5		1.22	0.55	1.14	0.62	437	3	0.71	93	51	1.8	45	0.33	R (Mi)
7228	33053009590000	9002.0	9003.0	0.64	0.28	0.43	0.54	426	4	0.50	67	84	0.8	44	0.39	R (Mi)
7228	33053009590000	9005.0	9006.0	1.05	0.44	0.51	0.66	426	3	0.51	49	63	0.8	42	0.46	R (Mi)
7228	33053009590000	9005.1		1.09	0.55	0.67	0.65	435	3	0.66	61	60	1.0	50	0.45	R (Mi)
7228	33053009590000	9006.7		1.18	0.54	0.67	0.75	433	3	0.63	57	64	0.9	46	0.45	R (Mi)
7228	33053009590000	9008.0	9009.0	0.84	0.31	0.44	0.60	428	3	0.54	52	71	0.7	37	0.41	R (Mi)
7228	33053009590000	9011.0	9012.0	0.60	0.34	1.41	0.56	392	5		235	93	2.5	57	0.19	R (Mi)
7228	33053009590000	9051.8	9052.8	2.17	0.98	2.71	0.58	440	1	0.76	125	27	4.7	45	0.27	FA (Bl)
7228	33053009590000	9052.5	9053.0	1.90	0.62	3.65	0.53	444	1	0.83	192	28	6.9	33	0.15	FA (Bl)
7228	33053009590000	9053.0	9054.0	1.13	0.50	1.29	0.50	445	1	0.84	114	44	2.6	44	0.28	FA (Bl)
7228	33053009590000	9054.0	9055.0	0.87	0.33	0.71	0.46	444	1	0.83	82	53	1.5	38	0.32	FA (Bl)
7228	33053009590000	9055.0	9056.0	0.92	0.39	0.78	0.44	448	2	0.90	85	48	1.8	42	0.33	FA (Bl)
7228	33053009590000	9056.0	9057.0	1.40	0.42	0.89	0.51	443	1	0.81	64	36	1.7	30	0.32	FA (Bl)
7228	33053009590000	9057.0	9058.0	0.81	0.36	0.65	0.37	446	1	0.87	80	46	1.8	44	0.36	FA (Bl)
7228	33053009590000	9058.0	9059.0	0.57	0.28	0.68	0.31	443	2	0.81	119	54	2.2	49	0.29	FA (Bl)
7228	33053009590000	9059.0	9060.1	1.14	0.32	0.80	0.42	445	1	0.85	70	37	1.9	28	0.29	FA (Bl)
7228	33053009590000	9060.1	9061.0	0.76	0.30	0.71	0.33	446	2	0.87	93	43	2.2	39	0.30	FA (Bl)
7228	33053009590000	9061.0	9062.0	0.85	0.36	0.92	0.42	446	1	0.86	108	49	2.2	42	0.28	FA (Bl)
7228	33053009590000	9062.0	9062.9	0.55	0.22	0.44	0.41	442	2	0.79	80	75	1.1	40	0.33	FA (Bl)
7228	33053009590000	9062.9	9063.8	0.70	0.26	0.47	0.34	446	2	0.86	67	49	1.4	37	0.36	FA (Bl)
7228	33053009590000	9063.8	9064.5	0.86	0.33	0.78	0.42	443	2	0.82	91	49	1.9	38	0.30	FA (Bl)
7228	33053009590000	9064.5	9065.0	1.19	0.40	1.13	0.49	441	1	0.78	95	41	2.3	34	0.26	FA (Bl)
7228	33053009590000	9065.0	9065.8	0.90	0.39	0.72	0.47	444	1	0.83	80	52	1.5	43	0.35	FA (Bl)
7228	33053009590000	9065.8	9067.4	0.57	0.32	0.49	0.43	438	3	0.72	86	75	1.1	56	0.40	FA (Bl)
7228	33053009590000	9067.4	9068.5	0.77	0.42	0.67	0.41	450	1	0.94	87	53	1.6	55	0.39	FA (Bl)
7228	33053009590000	9068.5	9069.0	1.56	0.59	2.12	0.51	442	1	0.79	136	33	4.2	38	0.22	FA (Bl)
7228	33053009590000	9069.0	9070.0	0.81	0.47	0.84	0.42	441	2	0.78	104	52	2.0	58	0.36	FA (Bl)
7228	33053009590000	9070.0	9071.7	0.77	0.40	0.73	0.47	447	2	0.88	95	61	1.6	52	0.35	FA (Bl)
7228	33053009590000	9071.7	9072.0	0.89	0.43	0.89	0.58	437	2	0.71	100	65	1.5	48	0.33	FA (Bl)
7228	33053009590000	9121.0	9122.0	0.81	0.50	0.50	0.50	436	3	0.69	62	62	1.0	62	0.50	FA (Sh)
7228	33053009590000	9121.3		0.85	0.59	0.96	0.55	444	3	0.84	113	65	1.7	69	0.38	FA (Sh)

Table 1 continued

NDIC #	API Number	Core Depth (ft.)		SRA	S1	S2	S3	Tmax	Tmax	Calc.	HI	OI	S2/S3	S1/TOC	PI	Madison
		Top	Base	TOC				(°C)	Quality	% Ro				*100		Subunit
7228	33053009590000	9125.0	9126.0	0.68	0.39	0.79	0.42	436	3	0.70	116	62	1.9	57	0.33	FA (Sh)
7228	33053009590000	9125.5		0.56	0.28	0.38	0.35	440	3	0.77	68	63	1.1	50	0.42	FA (Sh)
7228	33053009590000	9135.8		0.92	0.33	1.17	0.40	444	1	0.84	127	43	2.9	36	0.22	FA (Sh)
7228	33053009590000	9136.0	9137.0	0.49	0.18	0.34	0.41	442	2	0.80	69	84	0.8	37	0.35	FA (Sh)
7228	33053009590000	9136.3		1.02	0.37	1.74	0.50	440	1	0.76	171	49	3.5	36	0.18	FA (Sh)
7228	33053009590000	9164.7		2.38	2.06	2.19	0.70	435	3	0.68	92	29	3.1	87	0.48	FA (un)
7228	33053009590000	9165.0	9166.0	0.78	0.32	0.36	0.51	438	3	0.73	46	65	0.7	41	0.47	FA (un)
7228	33053009590000	9166.0		0.46	0.19	0.10	0.50	427	4	0.52	22	109	0.2	41	0.66	FA (un)
7228	33053009590000	9170.0	9171.0	0.62	0.21	0.16	0.47	435	4	0.67	26	76	0.3	34	0.57	FA (un)
7228	33053009590000	9176.0	9177.0	0.81	0.43	0.45	0.44	436	4	0.70	56	54	1.0	53	0.49	FA (un)
7228	33053009590000	9176.5		1.21	0.58	0.62	0.61	437	4	0.70	51	50	1.0	48	0.48	FA (un)
7228	33053009590000	9178.0	9179.0	0.64	0.30	0.28	0.49	434	4	0.65	44	77	0.6	47	0.52	FA (un)
7228	33053009590000	9180.0	9181.0	0.56	0.26	0.38	0.37	434	4	0.66	68	66	1.0	46	0.41	FA (un)
7228	33053009590000	9183.0	9184.0	0.88	0.27	0.21	0.45	438	4	0.72	24	51	0.5	31	0.56	FA (un)
7228	33053009590000	9183.6		4.14	2.05	5.12	0.90	441	1	0.77	124	22	5.7	50	0.29	FA (un)
7228	33053009590000	9330.4		0.66	0.24	0.34	0.77	441	3	0.78	52	117	0.4	36	0.41	FA (un)
7228	33053009590000	9332.5	9333.5	0.43	0.12	0.19	0.37	426	4	0.51	44	86	0.5	28	0.39	FA (un)
7228	33053009590000	9333.0		0.35	0.15	0.28	0.36	423	4	0.46	80	103	0.8	43	0.35	FA (un)
7228	33053009590000	9370.0	9370.5	0.52	0.25	0.25	0.46	438	4	0.73	48	88	0.5	48	0.50	FA (un)
7228	33053009590000	9415.0	9415.3	0.51	0.39	0.42	0.48	442	4	0.80	82	94	0.9	76	0.48	FA (un)
7228	33053009590000	9418.0	9419.0	0.53	0.31	0.47	0.42	440	3	0.76	89	79	1.1	58	0.40	FA (un)
7228	33053009590000	9419.1		1.29	0.59	1.26	0.89	436	3	0.69	98	69	1.4	46	0.32	FA (un)
7228	33053009590000	9429.4		0.52	0.28	0.38	0.36	440	4	0.76	73	69	1.1	54	0.42	FA (un)
7228	33053009590000	9444.0	9445.0	0.54	0.23	0.21	0.56	430	4	0.59	39	104	0.4	43	0.52	FA (un)
7228	33053009590000	9448.0	9449.0	0.60	0.45	0.44	0.57	436	4	0.69	73	95	0.8	75	0.51	FA (un)
7228	33053009590000	9457.0	9458.0	0.76	0.44	0.53	0.42	439	4	0.74	70	55	1.3	58	0.45	FA (un)
7228	33053009590000	9457.3		0.67	0.38	0.42	0.47	434	4	0.66	63	70	0.9	57	0.48	FA (un)
7228	33053009590000	9460.0		0.23	0.13	0.09	0.35	474	4	1.37	39	152	0.3	57	0.59	FA (un)
7228	33053009590000	9461.0	9462.0	0.67	0.48	0.45	0.56	423	4	0.45	67	84	0.8	72	0.52	FA (un)
7228	33053009590000	9461.6		1.07	0.65	0.71	0.70	423	4	0.46	66	65	1.0	61	0.48	FA (un)
7228	33053009590000	9462.0		1.29	1.04	0.93	1.06	422	4	0.44	72	82	0.9	81	0.53	FA (un)
7228	33053009590000	9478.5	9479.5	0.60	0.81	0.38	0.41	437	4	0.71	63	68	0.9	135	0.68	FA (un)

Table 1 continued

NDIC #	API Number	Core Depth (ft.)		SRA	S1	S2	S3	Tmax	Tmax	Calc.	HI	OI	S2/S3	S1/TOC	PI	Madison
		Top	Base	TOC				(°C)	Quality	% Ro				*100		Subunit
7228	33053009590000	9479.3		0.70	0.36	0.42	0.47	437	4	0.70	60	67	0.9	51	0.46	FA (un)
7228	33053009590000	9484.0		1.07	0.49	0.67	0.52	441	3	0.77	63	49	1.3	46	0.42	FA (un)

***Tmax Quality:** 1 = excellent, 2 = good, 3 = questionable, 4 = questionable/unreliable, 5 = unreliable

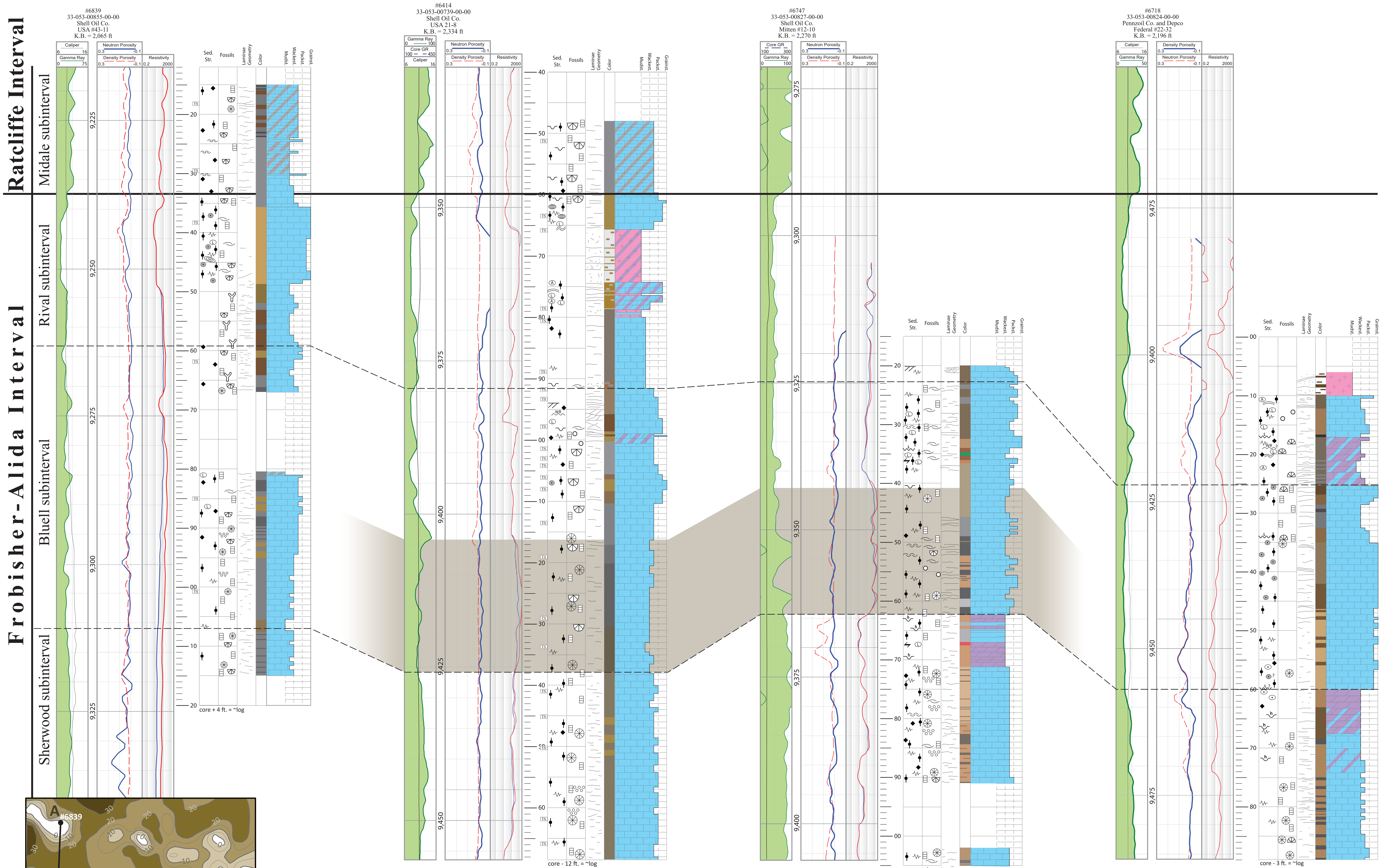
***Madison subunits:** R = Ratcliffe Interval; FA = Frobisher-Alida; Bl = Bluell subinterval; Mi = Midale subinterval; Sh = Sherwood subinterval; Be = Berentsen subinterval; Ri = Rival subinterval; un = undifferentiated

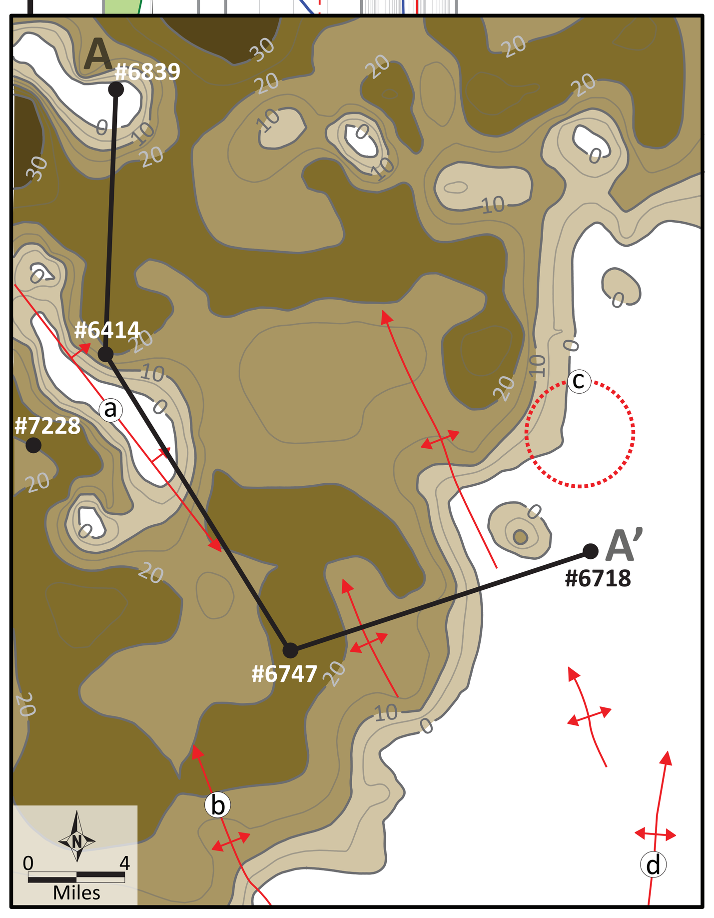
***Abbreviations:** Calc. = Calculated; ft. = feet; HI = Hydrogen Index (mg HC/g TOC); OI = Oxygen Index (mg CO2/g TOC); PI = Production Index; SRA = Source Rock Analyzer; TOC = Total Organic Carbon (by weight percent);

North Dakota Geological Survey
Geological Investigations No. 255 - Plate I

Edward C. Murphy - State Geologist
Lynn D. Helms, Director Dept. of Mineral Resources

Plate I:
Stratigraphic Cross-Section





Explanation: Stratigraphic cross-section (above) of the Sherwood, Bluell, Rival, and Midale subintervals of the Mississippian Madison Group with wireline logs and core description illustrations. Isopach map (left) of the gross thickness of the high TOC lower Bluell facies. Contours are in 5-foot intervals and the brown contour fill is in 10-foot intervals. Small light grey circles are the wireline log well control and the large black circles are the core control wells. See Figure 1 for study area location. Red lines depict documented structures: a = Mondak monocline, b = Beaver Creek anticline, c = Red Wing Creek structure, d = Little Knife anticline

Sedimentary/Core Symbols:

- microbiolites
- wave ripple laminae
- lag
- scouring
- Mud cracks
- burrows
- horizontal burrows
- pyrite
- nodule/s
- lithoclast/s
- anhydrite nodule/s
- Ooids
- Oncolite
- peloids
- styolitic
- contorted lam./bedding
- Fossil bed/laminae
- Birdseye structure
- Cross-bedding
- breccia
- rip up clasts
- Shells
- Brachiopod
- Crinoid/s
- Gastropod/s
- Solitary (rugose) Coral
- Tabulate Coral
- Ostracod/s
- Bryzoan

Core Lithology:

- Limestone
- Dolomitic Limestone
- Argillaceous Limestone
- Dolostone
- Calcareous Dolostone
- Anhydrite
- Dolomitic anhydrite