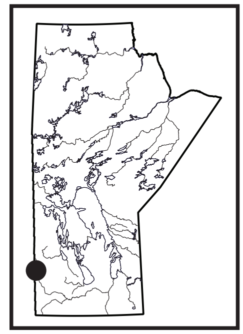
GS-14 Preliminary investigation from the Cretaceous section of the Manitoba Potash Corporation core at 3-29-20-29W1, southwestern Manitoba (NTS 65K1)

by M.P.B. Nicolas

Nicolas, M.P.B. 2016: Preliminary investigation from the Cretaceous section of the Manitoba Potash Corporation core at 3-29-20-29W1, southwestern Manitoba (NTS 65K1); *in* Report of Activities 2016, Manitoba Growth, Enterprise and Trade, Manitoba Geological Survey, p. 150–156.



Summary

In 1986, the Canamax Resources Inc., which is now owned by Manitoba Potash Corporation, drilled a 900.0 m potash testhole with continuous core at 3-29-20-29W1. The upper 360.0 m of this core consist of the uppermost portion of the Lower Cretaceous Swan River Formation to the Upper Cretaceous Pierre Shale. This Cretaceous section provides the first continuous look at this strata in full, with all units preserved. The units reported herein that have been completely penetrated in this core are the Ashville, Favel, Carlile and Pierre Shale formations. The section consists dominantly of a variably fine to coarse mudstone sequence with occasional siltstones, underlain and capped by sandstone. The entire section was sampled for Rock Eval™ 6 and total organic carbon (TOC) analysis. Lithological and chemical information from this core will be used to understand the subsurface stratigraphy of this section, and correlated with outcrops and other cores. The occurrence and variability of the organic matter within the section, which directly affect biogenic gas exploration techniques and strategies, will be studied. Partial results received thus far indicate very high total organic content in the Boyne Member of the Carlile Formation and in the Favel Formation, indicating these units are the best candidates to become future gas resources, but also identify the Gammon Ferruginous Member of the Pierre Shale as another potential gas resource.

Introduction

In 1986, Canamax Resources Inc. drilled a potash testhole as a pilot for the construction of a mine shaft for an underground potash mine in L.S. 3, Sec. 29, Twp 20, Rge. 29, W 1st Mer. (abbreviated 3-29-20-29W1) located at UTM Zone 14, 325102.38W, 5624312.3N, NAD 84. A continuous core was acquired at this location from 14.0 m to 900.0 m vertical depth. With a total core recovery average of 96%, this core represents the first continuous look at the subsurface units in southwestern Manitoba, from the uppermost Cretaceous units to the base of the Devonian Winnipegosis Formation. This stratigraphic testhole is currently owned by Manitoba Potash Corporation (MPC).

The core, held and transferred to various companies for 28 years, was kept in a large storage building in the community of Russell and subjected to extreme yearly fluctuations in temperature and humidity. Despite the fact that the core was entirely bagged in plastic sleeves, the units consisting dominantly of fine-grained rocks (in particular sandstone to mudstone) were affected by chemical changes. Humidity absorption by clay minerals and tertiary mineral blooms (such as gypsum and jarosite) resulted in expansion of the core, to the extent that it broke through the bags and spilled out of the boxes, in some cases, onto the floor. This affected the integrity of the core, particularly the Mesozoic section. In 2014, the Manitoba Geological Survey (MGS) acquired this core from MPC and had it moved to a temperature-controlled environment in a more accessible location at the MGS Midland Sample and Core Library in Winnipeg. The entire core was re-bagged into plastic sleeves and re-packed into cardboard boxes. To maintain the integrity of this valuable core and provide MGS geologists the opportunity to fully and properly catalogue the core, access to it is currently limited.

In 2015, the author began the task of logging and photographing the core in detail before allowing general access to the core. The first priority was to log the late Lower Cretaceous through to the Upper Cretaceous parts of the section, starting from near the top of the Swan River Formation (at 360.0 m depth) up to the top of the core in the Pierre Shale (at 14.0 m depth). This section of the core was prioritized because of its relevance to the Shallow Unconventional Shale Gas Project, as it is currently the only one available to capture some of these formations and offers a rare opportunity to observe the entire Cretaceous section, complete with contact relationships. In addition to logging and photographing this section of core, samples were collected at regular intervals for Rock Eval™ 6 and TOC analysis. The sampling intervals range from 1.0 to 5.0 m, depending on the formation and the lithology.

Lithological and chemical information from this core will be used to understand the subsurface stratigraphy of this section; to determine its correlation with outcrops and other cores; and to further investigate the occurrence and variability of the organic matter within the section, which directly affect biogenic gas exploration techniques and strategies.

Mapping challenges

The Manitoba escarpment in southwestern Manitoba contains excellent exposures of the Cretaceous formations of the Western Canada Sedimentary Basin. These formations gently dip to the southwest, resulting in the basal part of the Lower Cretaceous Swan River Formation being exposed north and south of the Porcupine Hills, and the Upper Cretaceous Boissevain Formation exposures being limited to the south, in the Turtle Mountain area. The Cretaceous section was established by Tyrrell (1890) and, due to its economic potential, was subsequently reported on by several authors, including most notably Wallace and Greer (1927) and Bannatyne (1970), with the latter providing useful comprehensive stratigraphic information and regional maps. The most recent regional mapping was done by Nicolas et al. (2010b), with mapping information ranging in scale from 1:250 000 in the northern part of the area to 1:50 000 in the southern portion. However, McNeil and Caldwell (1981) provided the most comprehensive study of the Cretaceous stratigraphy in the Manitoba escarpment, including the first regional cross-sections of outcrop exposures along the entire escarpment and long distance subsurface geophysical-log correlations. The challenge consists in correlating the outcrop with the subsurface directly. This is a difficult task given that the Cretaceous section is very rarely cored and thus generally inaccessible to researchers. Potash testholes in Saskatchewan are occasionally cored from surface to total depth, but until recently all information about these cores was considered confidential, resulting in a lack of data pertaining to these cored sections being made available to the public. With the confidential status removed from these historical cores, it will now be possible to study them and understanding of this section will improve significantly in the years to come. The core recovered from the MPC shaft is the only stratigraphic testhole core in Manitoba that is equivalent in stratigraphic coverage to those recovered from the potash testholes drilled in Saskatchewan.

Subsurface mapping of the Cretaceous section in Manitoba is based on geophysical-log correlations, mostly derived from correlations in McNeil and Caldwell (1981), and further refined in Nicolas (2009). The MPC core will provide the much needed information obtained by combining subsurface log signatures with true lithological descriptions. These lithological descriptions will then allow correlations to be made with outcrop sections, thus helping to critically link these two, often segregated, pieces of stratigraphic information.

Outcrop to subsurface correlations are difficult, particularly when dealing with a section that is prone to disconformities, irregular nondepositional episodes, repeated depositional packages and apparent limited lithological variation over great distances. Outcrop to outcrop correlations can be equally difficult for some units, even within short distances. However, these challenges must be overcome and a geological understanding of the lithological units of this core is required to tap into the economic potential of these highly organic rocks. Natural gas of biogenic origin (Nicolas and Grasby, 2009) occurs throughout the subsurface within the Cretaceous sequence, in which the rock units act as both source and reservoir rocks, and hold an untapped natural gas resource.

Core stratigraphy and lithology

Although the rate of core recovery is excellent, nearly 100% in the upper Cretaceous section, parts of the core were lost due to expansion out of the core boxes during storage, with the Millwood Member scoring the lowest recovery rate of 80% in places. The poor storage conditions for this core in the past have also resulted in it breaking apart into thin plates and flakes as it dried; in addition, the prolific formation of tertiary gypsum crystal blooms on all surfaces further exacerbated its poor condition. Consequently, it is nearly impossible to observe internal sedimentary structures and textures, making even lithological classification challenging. However, using evaluation techniques described in Potter et al. (2005) and Lazar et al. (2015), a consistent lithological framework was created that allows for a more reliable interpretation of depositional structure and textures throughout the core.

The portion of the MPC core reported here covers from 14.0 m true vertical depth (TVD; 481.3 m asl) to 360.0 m TVD (135.3 m asl). It consists of the uppermost section of the Swan River Formation, and the entirety of the Ashville, Favel, Carlile and Pierre Shale formations. It is dominantly composed of a variably fine to coarse mudstone sequence with occasional siltstone, underlain and capped by sandstone (Figure GS-14-1).The lithological descriptions for each formation and member that follow are for the core from 3-29-20-29W1.

Swan River and Ashville formations

The Swan River Formation logged here represents only the top 4.0 m of the total 65.0 m of the formation preserved in this core. Starting at the base and going upsection, it consists of light to medium grey, very fine-grained, poorly consolidated and well-sorted quartz-rich sandstone with common sub-bituminous coal fragments. This correlates to the upper part of the Cantuar Formation of the Mannville Group in Saskatchewan (Nicolas, 2009). It has a sharp contact with the overlying Skull Creek Member of the Ashville Formation. The Skull Creek Member consists of noncalcareous, fissile, glauconitic, silty to fine mudstone with abundant small fish fragments disseminated throughout; thin bentonite beds occur in the upper half of the member. There is a sharp contact between the Skull Creek Member and the overlying Newcastle Member, which is composed of noncalcareous, variably glauconitic, silty mudstone to muddy siltstone with scattered fish-scale and bone fragments. Another sharp contact separates the Newcastle Member from the overlying Westgate Member, which consists of noncalcareous, bioturbated and laminated fine mudstone. Further

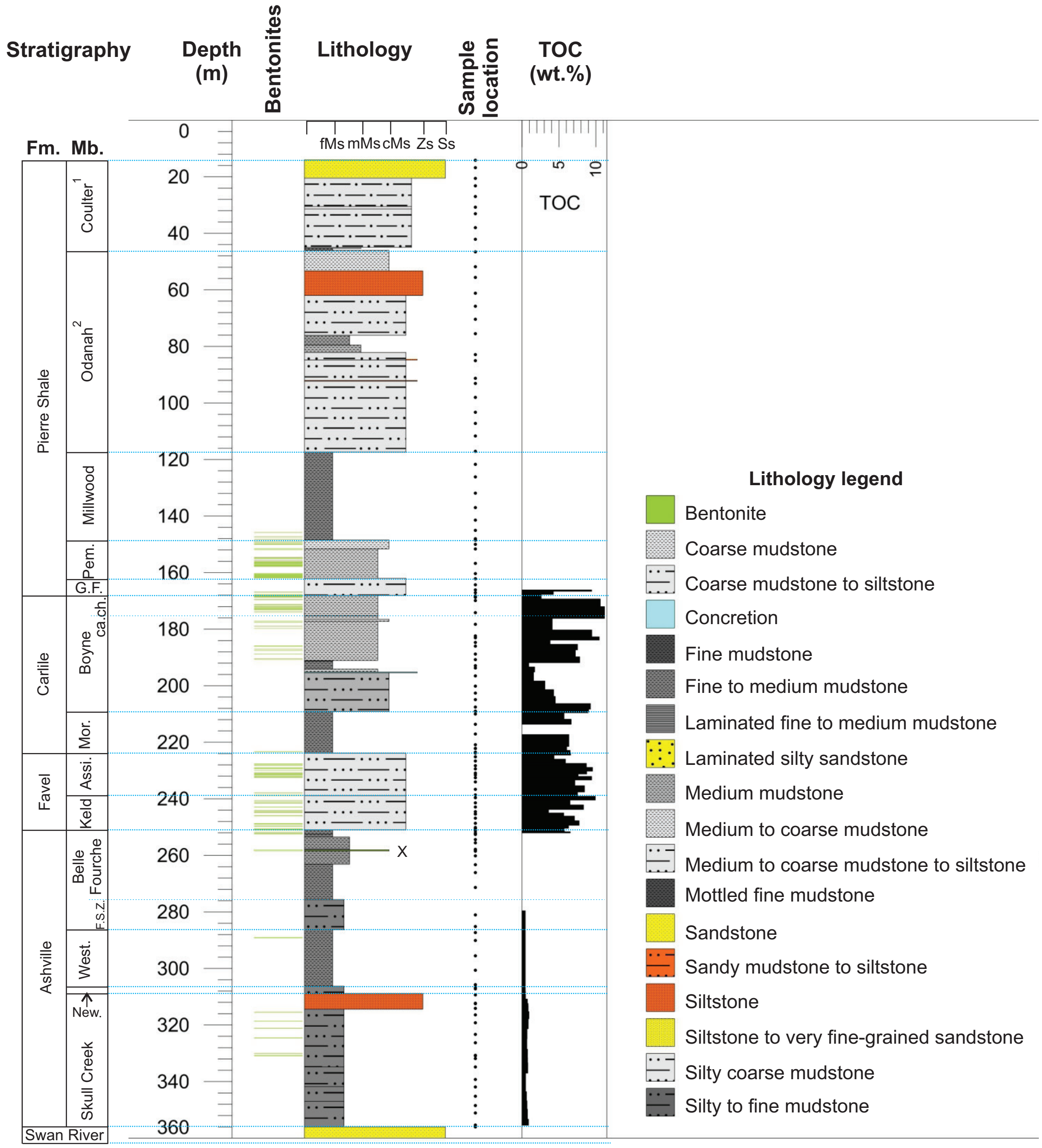


Figure GS-14-1: *Stratigraphic, lithological and partial total organic carbon profile of the Cretaceous section of the 3-29-20-29W1 core. Depth track is true vertical depth, as measured in the core. Blue horizontal dashed lines are stratigraphic boundaries. The 'X' indicates the location of the X-bentonite. The (1) Coulter and (2) Odanah members are equivalent to the Bearpaw Formation of Saskatchewan. Abbreviations: Assi., Assiniboine; ca., calcareous unit; ch., chalky unit; cMs, coarse mudstone; fMs, fine mudstone; F.S.Z., fish scale zone; Fm., Formation; G.F., Gammon Ferruginous; Mb., Member; mMs, medium mudstone; Mor., Morden; New., Newcastle; Pem., Pembina; Ss, sandstone; TOC, total organic carbon; West., Westgate; Zs, siltstone.*

upsection, the occurrence of fine-grained sandstone lenses and a marked increase in fish fragments, corresponding to the basin-wide marker known as the 'fish scale zone', indicates the transition to the Belle Fourche Member. In other jurisdictions, this zone is formally recognized as the Fish Scale Zone (Leckie et al., 1994); based on geophysical logs, it has been correlated with units in Manitoba for years, but has never been confirmed in core until now. The Belle Fourche Member, as a whole, dominantly consists of noncalcareous, fine to medium mudstone with occasional siltstone interbeds and laminae, as well as occasional shell fragments and variable amounts of fish-scale fragments throughout. Near the top of the Belle Fourche, the X-bentonite is preserved as a black-speckled, greenish grey bentonite bed (location marked with an 'X' in Figure GS-14-1) 40 cm thick. The X-bentonite is a distinctive basin-wide marker and is one of the most isochronous markers in the entire Western Interior Seaway (McNeill and Caldwell, 1981). The Belle Fourche grades gradually into the Favel Formation; the contact is picked at the top of a thin bentonite bed and marks the location where white specks within the mudstone markedly increase in abundance.

Favel Formation

The Keld and Assiniboine members of the Favel Formation consist of calcareous, medium grey, planar-laminated, chalk-speckled silty mudstone to muddy siltstone with coccoliths and foraminifers, as well as bivalve and ammonite shells, including *Inoceramus,* and scattered fish-scale fragments. Thin argillaceous limestone beds are present throughout; however, it is not clear which of these beds would correlate with the Laurier Limestone Beds of McNeil and Caldwell (1981) that cap the Keld. In this core, the top was arbitrarily placed at a thin fossiliferous limestone bed; the same difficulty arose when trying to locate the capping Marco Calcarenite of McNeil and Caldwell (1981). The top of the Assiniboine Member was picked in this core at the top of a bentonite bed, where there is a rapid transition from calcareous mudstone to noncalcareous mudstone of the Morden Member of the Carlile Formation. The numerous thin bentonite beds found throughout the Favel Formation were deposited during a period of intense volcanic activity in North America.

Carlile Formation

The basal Morden Member of the Carlile Formation consists of black, noncalcareous, fine mudstone with discontinuous, slightly wavy, nonparallel coarse mudstone lenses in places and occasional thin bentonite beds. The Morden then grades quickly to the Boyne Member, which is composed of medium grey, variably calcareous medium to coarse mudstone to muddy siltstone. The Boyne can be subdivided into two units, the basal calcareous unit and overlying chalky unit of McNeil and Caldwell (1981). The contact between the two units is gradational and marked by an increase in small chalky blebs upsection. The regular occurrence of thin bentonite beds is also common in this formation. The contact with the overlying Pierre Shale is supposed to be an erosional disconformity (McNeil and Caldwell, 1981; Christopher et al., 2006), but proved very difficult to pinpoint in the core and, for this purpose, was picked based on the geophysical-log signature.

Pierre Shale

The Gammon Ferruginous Member of the Pierre Shale is present as a thin, brown to grey, noncalcareous, occasionally mottled layer of coarse mudstone to muddy siltstone with sparse rusty-orange staining near the top of the unit; it is in sharp contact with the Pembina Member. Thin bentonite beds are present.

The Pembina Member is characterized by the occurrence of abundant thin bentonite beds (28 in total) throughout and consists of two distinct units, a lower medium to dark grey noncalcareous medium to coarse mudstone and an upper medium brown-grey coarse mudstone to muddy siltstone. These units are consistent with those described in McNeil and Caldwell (1981).

The Millwood Member consists of olive brown-grey, variably calcareous, dominantly fine mudstone, but with repetitive metre-scale, coarsening-upward sequences grading in places to coarse mudstone or siltstone. It is characterized by the semi-swelling nature of the mudstone due to a high concentration of montmorillonite and/or bentonitic clay, which causes it to form globule-like clusters when wet. Pink-beige noncalcareous concretions, occasional burrow mottles and oval to round, fine-grained, white blebs are present throughout. Distinctive disseminated to aggregated, coarse sand-grained, black manganese oxides and rusty-brown pyrite occurring as blebs and elongate root-like features are also common. Three thin bentonite beds occur in the lower 3.0 m of this member. Rare open vertical fractures up to 30 cm in length begin to occur. This member is in sharp contact with the overlying Odanah Member.

The Odanah Member consists of olive brown-grey noncalcareous, siliceous coarse mudstone to silty mudstone to siltstone to silty sandstone. Some characteristics particular to this unit include lower clay content than the underlying unit, disseminated micaceous flakes, angular glassy black grains, elongate black and rusty brown stick-like features of framboidal pyrite, and fine- to medium-grained sandstone lenses and blebs throughout. Fossils are rare but include small fragments of large bivalve shells and foraminifers. Similarly to the Millwood Member, the Odanah has manganese-oxide grains and occasionally calcareous pink-beige concretions throughout. The open fractures become more abundant upsection and have a common orientation of 035° from vertical. Although the internal structure of the core is not generally observable, it is apparent in places in the Odanah Member, in which both continuous and discontinuous planar-parallel laminae in the lower part of the section and occasional discontinuous wavy parallel laminae occurring further upsection can be seen.

The Odanah Member in this core appears quite different than expected, since in outcrop the Odanah is a very distinctive hard siliceous mudstone/shale (Bannatyne, 1970; Bamburak, 1973, 1978; McNeil and Caldwell, 1981). It is unlikely that this difference is related to the unit being preserved in complete section from the subsurface in core versus in outcrop, where weathering and erosion drastically alter the unit, but may rather be due to a facies change. McNeil and Caldwell (1981) observed no lithological change in outcrops along the Manitoba escarpment from the Pasquia Hills in the north, to the Pembina Hills in the south, to Turtle Mountain in the west. However, they had no subsurface references of this section that they could compare it to moving further west. Going westward, stratigraphically the Odanah is equivalent to the Belly River and Bearpaw formations in Saskatchewan (Nicolas, 2009). The section in this core is identical in lithology and character to the Bearpaw Formation of Saskatchewan as described in Glass (1997) and represents the first evidence in Manitoba that the Bearpaw Formation equivalent may be preserved here, occurring much further east than originally proposed in Nicolas (2009). Initially, the Belly River Formation does not appear to be preserved here, except perhaps as a thin distal remnant at the base, but more detailed work is required to verify this correlation.

The Coulter Member in this core consists of a medium to dark grey or grey-brown noncalcareous and siliceous unit, which grades from a fine mudstone at the base, coarsening up to a sandy mudstone/siltstone in the middle, to a fine- to medium-grained sandstone at the top. It contains sparse fine fish fragments, micaceous flakes, black carbonaceous grains, framboidal pyrite blebs, floating tripolitic chert and quartz grains, and occasional orange-buff concretions. Open fractures are common, all at angles of 035° from vertical, some with orthogonal pairs.

The lithological description of the Coulter Member in this core correlates better with the Bearpaw Formation as described in Glass (1997) than the Coulter Member described in Bamburak (1973), where the Coulter Member in the Turtle Mountain area is correlated with the upper strata of the Bearpaw Formation; therefore, this section may represent more closely a facies of the upper section of the Bearpaw Formation than the true Coulter Member of Bamburak (1973).

Bentonite beds

A total of 100 bentonite beds were counted throughout this section of core. The depth and thickness of all the bentonite beds were logged and their location plotted in Figure GS-14-1. These bentonite beds (deposited as volcanic ash) show the temporal distribution of large volcanic eruptions and episodes in eastern North America during this timeframe of the Cretaceous. There are two dominant volcanic episodes, one spanning from the end of Ashville Formation deposition to the end of Favel Formation deposition, correlating to the Turonian age, and one from the middle of Boyne Member deposition to the beginning of Millwood Member deposition (late Santonian to early Campanian age). From among these, the Pembina Member records the highest occurrence of volcanic activity, with a total of 31 bentonite beds recorded in this section of the core. Trailing off during very early Millwood Member deposition, no other bentonite beds are recorded afterwards, indicating a cessation in volcanic activity, a decrease in eruption size or a change in wind and water currents preventing preservation in this part of the basin.

Geochemical profiling

The continuous nature of this recovered core provides a rare opportunity to conduct geochemical profiling of the Cretaceous section to search for chemical trends and distinctive signatures likely to provide a basis and reference for chemostratigraphy. Chemostratigraphy is a method of correlating stratigraphic sections based on their chemical signatures, and can be used to correlate outcrop to outcrop, core to core and outcrop to core.

The entire cored section discussed in this report was sampled at an average of every 5.0 m with some sections having sample intervals as narrow as 1.0 m. A total of 130 samples were collected for Rock Eval™ 6 and TOC analysis and submitted to the organic chemistry laboratory of the Geological Survey of Canada (sample locations are shown in Figure GS-14-1). The chemical profiles resulting from these analyses provide information on the variability of organic-matter type and abundance throughout the section, as well as pinpoint sections with high organic content that can serve as potential biogenic gas sources and target horizons. At the time of writing this report, some of the results have been received and are shown in Figure GS-14-1. The TOC results shown are for the complete sections in the Skull Creek, Newcastle and Westgate members, the Favel and Carlile formations, and a few sections within the Belle Fourche and Morden members; all other sample results are pending.

Correlating this core's profile with results from other outcrops and cores (Nicolas and Bamburak, 2009b, 2011) will help better understand the geographic variability of the organic matter within the different horizons. Once received and compiled, the Rock Eval™ 6 and full suite of TOC results for all 130 samples will be reported in a future data release.

In addition to the organic geochemical information, the Favel Formation and the Boyne Member were selected for inorganic chemistry profiling. These two units were selected based on the fact that they are the best biogenic gas reservoir candidates. Using a portable X-ray fluorescence (XRF) unit, a series of major and trace elements were analyzed. The XRF methodology and results were reported in Deyholos (2016). Unfortunately, the results from the Favel Formation can only be used qualitatively, more specifically, the information provided can only be used as expressed in terms of relative abundances of an element over the interval. A new methodology was employed for the samples from the Boyne sections and although the results are still pending, these should allow a more quantitative approach. Detailed investigation of the Boyne Member, including the XRF profiles, will be reported in an undergraduate thesis project planned for next year.

TOC and gas occurrences

The highest TOC values thus far occur in the Boyne Member (TOC ranges from 0.91 to 11.18 wt. %; 6.04 wt. % average), but the most consistent over a large interval are in the Favel Formation (TOC ranges from 3.59 to 9.94 wt. %; 7.25 wt. % average). The Skull Creek Member yielded the lowest TOC values, averaging at 0.72 wt. %. The few results received on the Gammon Ferruginous Member show that this unit has good gas potential as well, with a TOC average of 6.85 wt. %. The TOC values for the Gammon Ferruginous and Boyne members and Favel Formation are such that all these units have been classified as having excellent source rock generative potential (Peters, 1986).

Lithologically, the fine mudstone consistently correlates with a low TOC value, while the medium to coarse mudstone has high TOC. The pairing of medium to coarse mudstone (i.e., microporous rock) and high organic content (i.e., gas-source material) indicates a good prospect for a biogenic gas reservoir that relies on the rock, from which the gas is derived, to also have enough pore space to retain that free gas.

The TOC values confirm the predicted best horizons for gas occurrence in Nicolas and Bamburak (2009a) as being the Favel Formation and Boyne Member, and further support the identification of the Gammon Ferruginous Member as an emerging potential reservoir (Nicolas and Bamburak, 2012). The high organic content in all three units supports the consistent high Pason™ gas readings taken in these intervals during drilling operations, regardless of depth. The relative proximity of this core location to the community of Kamsack, Saskatchewan, which has historically produced commercial gas from the Boyne Member, further supports the long-distance correlativity of this unit (Nicolas et al., 2010a) over a large area, which has economic significance.

Economic considerations

The goal of the Shallow Unconventional Shale Gas Prospects Project is to provide potential investors and companies with the basic information needed to understand the geology and undertake exploration in the new and risky unconventional shallow gas plays in southwestern Manitoba. The information gathered in this continuous core goes toward meeting that goal by providing a key look at the entire section where biogenic gas can occur, further narrowing the exploration horizons and understanding their geographic variability in southwestern Manitoba.

Acknowledgments

The author would like to thank the staff of the MGS Midland Core and Sample Library, G. Benger, V. Varga and C. Epp, along with numerous summer students, for their tremendous efforts in moving the MPC core from Russell to Winnipeg, and for their care and attention to detail during preparation of the core for proper storage and viewing. The author thanks D. Shaw from the University of Manitoba for assistance with the core and J. Deyholos for his thesis work on the Favel Formation.

The author would also like to thank H. Sanei and P. Webster from the Geological Survey of Canada for their support of this project through the hydrocarbon potential of Canadian oil shale program.

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