GS-16 A new potential source rock identified within the Paleozoic carbonate succession of the northeastern part of the Williston Basin, west-central Manitoba (NTS 63F5)

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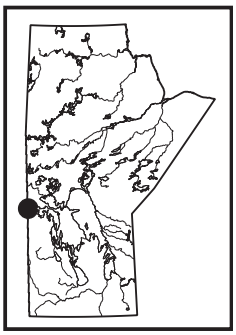

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Summary

An interval of interbedded dark grey, calcareous, organic-rich mudstone and light grey, slightly dolomitic limestone (Rat Creek mudstone unit) was encountered at depths of 82.20–84.85 m in drill hole RC 245-02, approximately 60 km south-southwest of the town of The Pas in west-central Manitoba. The precise stratigraphic position of the interval is still to be determined, but its lithofacies, regional position and organofacies characteristics suggest it is a unit within the Devonian Winnipegosis Formation. Two samples examined under the microscope demonstrate that the Rat Creek mudstone unit is very rich in organic matter, estimated locally to be as high as 40–60% by volume. It is composed dominantly of amorphinite and alginite, both representing marine organic matter. A large fraction of the organic matter is fluorescent and oil prone. High total organic-carbon values (7.32 and 14.17 wt. %) encountered in both rock samples confirm the unit's high generative potential as a source rock. The high hydrogen index obtained from the Rock Eval™ programmed pyrolysis is indicative of oil-prone organic matter; however, T_{max} values of 411 and 420°C suggest that the organic matter is immature. The stratigraphic and lithofacies equivalents of the Rat Creek organic-rich mudstone may be excellent and effective oil source rocks at greater depths. The abundance and low maturity of the organic matter in the samples studied suggest that the Rat Creek unit may be locally an excellent source of biogenic gas.

Introduction

A few effective petroleum systems have been identified in the Williston Basin. The most important and best known is the Mississippian succession, which includes the shale source rock of the Upper Member of the Bakken Formation (Creaney et al., 1994). Recent technological progress in oil extraction from tight rocks has made the Middle Member of the Bakken Formation one of the most attractive oil-exploration targets on the North American continent over the course of the last several years. Far less important are the Jurassic and Lower Cretaceous petroleum systems, which are believed to be sourced by pre-Mannville Group source rocks. The older petroleum systems of the Middle to Upper Devonian and Ordovician have been considered of marginal importance to the Canadian portion of the basin (Allan and Creaney, 1991; Osadetz and Snowdon, 1995). All petroleum source rocks identified in the Williston Basin proved to be thermally mature only within the central, deeper portion of the basin.

In early 2012, Saturn Minerals Inc. (Vancouver, British Columbia) conducted a limited coal exploration drilling program on its Rat Creek quarry permits located approximately 60 km south-southwest of the town of The Pas, in west-central Manitoba (Figure GS-16-1). The drilling targets were selected based on the results of a helicopter-borne gravity and magnetic survey completed during the summer of 2011 by Sander Geophysics Ltd. (Ottawa, Ontario); the targets were characterized by significantly negative, but variable, gravity anomalies. The drill holes were fully cored starting at shallow depths. The holes intersected on top of a thin veneer (10–15 m thick) of Quaternary glacial and younger sediments, which were underlain by a Mesozoic(?) succession of reddish-brown clay, debrite and limestone, and then entered into the Devonian carbonate succession at a very shallow depth of approximately 15 to 20 m. The completed drill holes did not test the Cretaceous deposits in the Rat Creek area.

Devonian succession

The Devonian carbonate succession encountered in the Rat Creek area includes quite a diversified spectrum of lithofacies. The most common and important elements of the succession are relatively thick packages of dark grey marl and/or argillaceous limestone, some of them rich in loose fragments of disarticulated crinoid stems and branches, thick- and thin-shelled bivalve-dominated coquinas, beige nodular to mottled (bioturbated?) limestone and some strongly porous incipient reef and bioherm buildups. Less common is beige, thinly laminated limestone, which grades locally into discernible rhythmic laminations. Thick intervals of reddish-brown, usually strongly argillaceous (and frequently dolomitic) carbonate rocks are characterized by the common occurrence of irregular disrupted laminations, slickenside discontinuities

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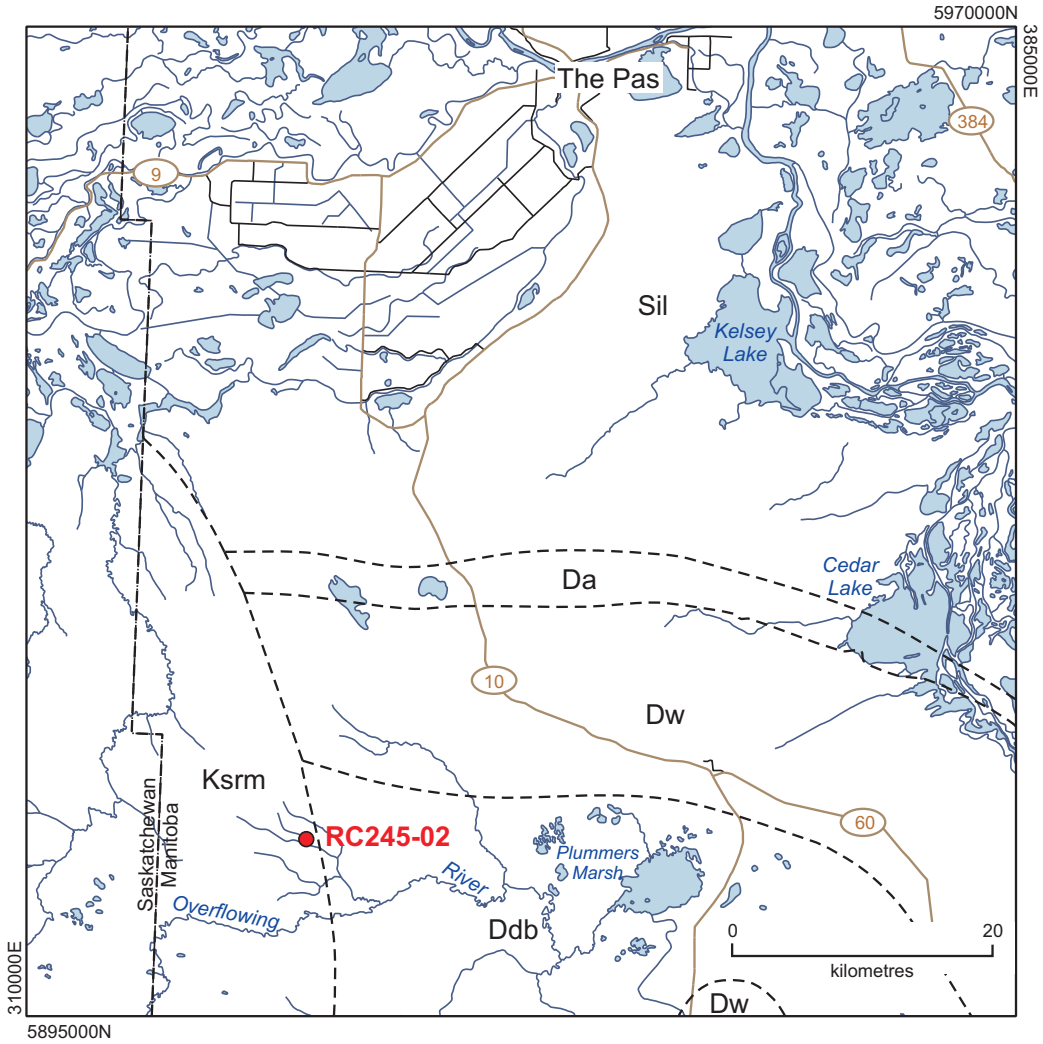

Figure GS-16-1: *Location of Saturn Minerals Inc. drill hole RC 245-02, west-central Manitoba (UTM Zone 14, NAD83). Lithostratigraphic unit abbreviations: Sil, Interlake Formation; Da, Ashern Formation; Dw, Winnipegosis Formation; Ddb, Dawson Bay Formation; Ksrm, Swan River/Mannville Group.*

and incipient, apparently in-place brecciation. Some features of the latter deposits may have originated in association with limited salt dissolution as collapse-related brecciation and due to the early diagenetic growth of evaporitic crystals in unconsolidated sediment.

The top, very irregular surface of the carbonate succession is covered with reddish-brown, very poorly sorted carbonate breccia with a variable amount of muddy matrix. Slickensides commonly occur in these deposits, which resemble typical 'terra rosa' formations and collapse breccia resulting from karst processes, and/or slope breccia of redeposited calcareous regolith material.

An interval of interbedded dark grey to almost black, calcareous, organic-rich mudstone and light grey, slightly dolomitic limestone was encountered at depths of 82.20–84.85 m in drill hole RC 245-02 (Figure GS-16-2). The organic-rich interval, approximately 2.65 m thick, is enveloped by carbonate facies, which display clear evidence that they originated as a result of redeposition in a submarine environment. The organic-rich rocks overlie a set of beige, thick and irregularly bedded to dolomitic limestone. The lower layers of the underlying rock formation display incipient reef-type buildups characterized by abundant mouldic porosity and numerous large vugs filled with coarse, fossilliferous detritus and oncolites. Coarse-grained, very poorly sorted and moderately matrix-rich calcirudite units overlie the reef-like buildups and represent a phase of the latter's vigorous destruction, and subsequent redeposition of the resultant detrital material, most likely by gravity-driven processes.

The organic-rich interval is overlain by beige fossiliferous limestone breccia and conglomerate (calcirudite) with a crude graded bedding. The calcirudite carbonate at the top contact displays evidence of redeposition by high-density gravity flows. Both overlying

Figure GS-16-2: *Core intersection of the organic-rich mudstone on the Rat Creek property, west-central Manitoba. Length of the core-box compartment is approximately 152 cm.*

and underlying carbonate rocks are visibly bituminous; however, the organic matter they contain has not yet been tested for either its composition or its maturity.

The organic-rich interval (herein called the Rat Creek unit) includes numerous, relatively thin layers and laminae of dark grey to black, organic-rich calcareous mudstone, with tiny wisps and blebs of whitish, slightly dolomitic sand-grade carbonate fragments (Figure GS-16-2, -3). Visual examination identified delicate, diffuse, undulatory and parallel laminations, which are accompanied by weak graded bedding. The mudstone laminae, which show no visible signs of bioturbation, range in thickness from a few millimetres to 8–10 centimetres. The organic-rich layers are interbedded with thicker (commonly 5–15 cm) beds, lenses and nodules of light grey, slightly dolomitic calcarenite. The calcarenite displays poorly developed graded bedding and, commonly, quite deep load casts, some with irregular bottom contacts. Compaction-related undulations of the primary horizontal laminations are quite common. However, the most widespread are downwarped undulations of lamination resulting from syndepositional, unstable density stratification (cf. Dżułyński and Walton, 1963).

Organic petrography and vitrinite reflectance

Two core samples labelled RC 245-02 (82.25) and RC 245-02 (84.80) of the Rat Creek organic-rich calcareous mudstone have been examined microscopically to identify the type of organic matter and determine its maturity level. The samples were taken from the uppermost (depth 82.25 m) and the basal (depth 84.80 m) parts of the organic-rich interval. The samples for microscopic examination were prepared as blocks mounted in Lucite, which were then ground and polished following standard procedures used in organic petrography. Microscopic analysis was carried out using a reflected-light microscope with a fluorescent-light attachment. Microscope examination included: 1) visual evaluation of organic-matter types; 2) visual estimation of the fluorescence colour and its intensity; and 3) measurements of vitrinite reflectance. Visual evaluation of organic-matter types provided an assessment of the quality of the source rock and its hydrocarbon potential (oil prone versus gas prone). Vitrinite reflectance (% R) provided an assessment of the thermal maturity of the organic matter.

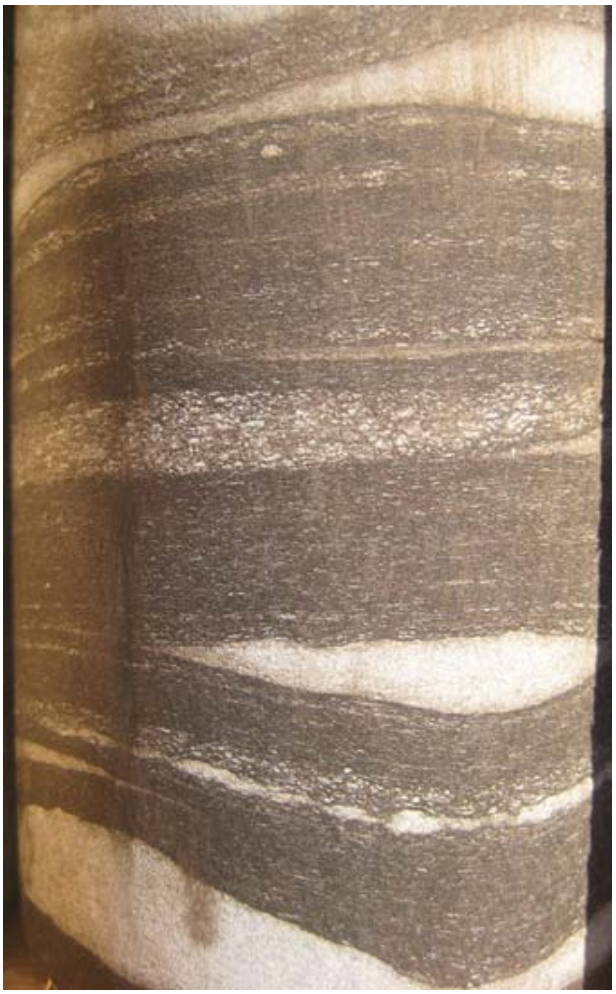

Figure GS-16-3: *Close-up view of the composite layer of the Rat Creek organic-rich mudstone, west-central Manitoba. Note the distinct diffuse lamination and multiple graded bedding of the black mudstone, and load casts of the lighter coloured, slightly dolomitic calcarenite lenses. Core is approximately 6 cm in diameter.*

Both examined samples are very rich in organic matter, which was estimated locally to be as high as 40–60% by volume. Organic matter is composed dominantly of amorphinite (amorphous organic matter) and alginite, both representing marine organic matter. Terrestrial contribution (vitrinite and inertinite) is sporadic. Table GS-16-1 includes the results of the visual assessment of organic-matter types (macerals), demonstrating that a large fraction of the organic matter is fluorescent and oil prone.

Maturity of the samples was determined based on the reflectance of vitrinite (% R) and the average values of 0.49 and 0.50% obtained suggest that the organic matter present in the samples is immature to marginally mature. Such an estimation of maturity level is also supported by a greenish to golden-yellow fluorescence of liptinite macerals and reflectance of massive amorphinite (Figure GS-16-4).

Rock Eval™ pyrolysis

In parallel with microscopic analysis, fragments of both samples were sent to the Weatherford Labs (Houston, Texas) for Rock Eval™ pyrolysis tests; these results are listed in Table GS-16-2.

High total organic carbon (TOC) values encountered in both rock samples confirm the unit's high generative potential as a source rock. The high hydrogen index (HI) is indicative of oil-prone organic matter; the T_{max} values of 411 and 420°C obtained suggest the organic matter is immature.

The high TOC values point to high organic productivity of the depositional environment, whereas lack of bioturbation and other textural and structural features suggests that anoxic syn- and early post-depositional conditions prevailed, resulting in excellent organic-matter preservation. This conclusion is supported by an admixture of minute pyrite disseminations within the deposits (Allan and Creaney, 1991). Similarly, microscopic evidence of the marine-type–dominated organic assemblage suggests anoxic depositional conditions with no water mixing, which resulted both in high organic productivity and excellent organic-matter preservation.

Stratigraphy and regional geology

Stratigraphic position of the Rat Creek mudstone unit is still to be determined. The presence of *Tasmanites* and *Leiosphaeridia* in alginite (by microscope examination)

Table GS-16-1: Results of the visual maceral analysis of the Rat Creek organic-rich calcareous mudstone (in vol. %, mineral-matter–free basis).

Sample ID	Sample depth (m)	Liptinite (%)			Vitrinite (%)	Inertinite (%)	Solid bitumen (%)	Fluorescent OM (%)	Mean value of vitrinite reflectance (%)
		Alginite	Amorphous OM	Other liptinite					
RC 245-02 (82.25)	82.25	35	59	5	trace	1	trace	50	0.49
RC 245-02 (84.80)	84.8	25	65	10	trace	trace	0	40	0.5

Abbreviations: OM, organic matter

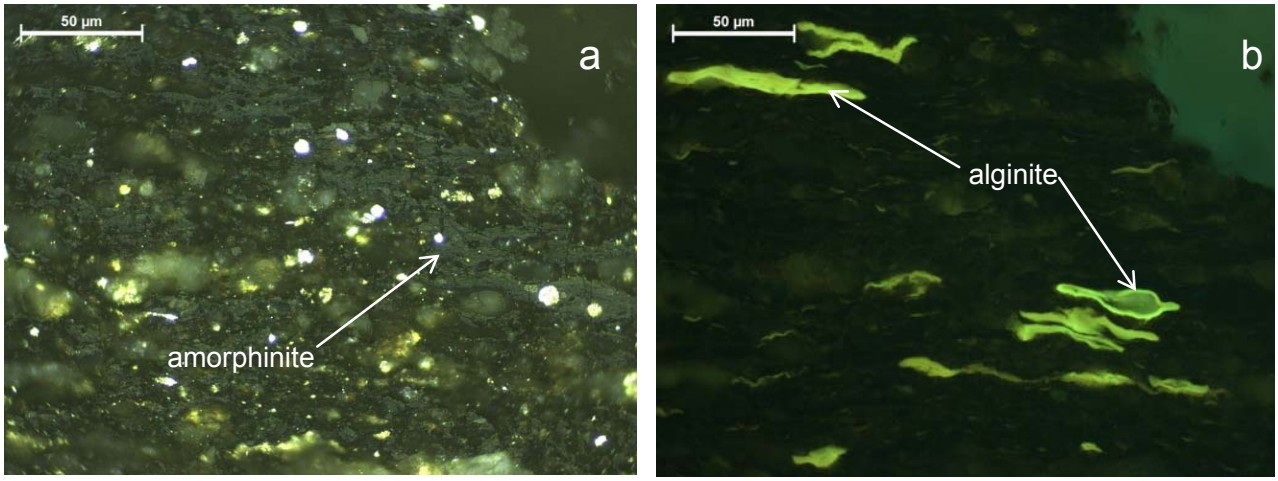

Figure GS-16-4: *Photomicrographs of Rat Creek organic-rich mudstone from sample RC 245-2(84.80), west-central Manitoba, showing* ***a)*** *under reflected light (oil immersion), amorphinite is the dominant organic-matter type;* ***b)*** *under fluorescent light, greenish- to golden-yellow fluorescing alginite is common. Image b) is the same as a) and demonstrates that amorphinite is dominantly nonfluorescent.*

Table GS-16-2: Results of Rock Eval™ analysis of the total organic carbon and programmed pyrolysis of the Rat Creek organic-rich mudstone.

Sample ID	Sample depth (m)	Leco TOC (wt. %)	RE[1]			Tmax [°C]	HI	OI	S2/S3	S1/TOC *100	PI
			S1[2]	S2[3]	S3[4]						
RC 245-02 (82.25)	82.25	7.32	0.72	41.43	1.19	411	566	16	34.8	10	0.02
RC 245-02 (84.80)	84.8	14.17	3.32	81.94	1.55	420	578	11	52.9	23	0.04

[1] Programmed pyrolysis on Rock Eval™ instrument
[2] volatile hydrocarbon (HC) content, mg HC/g rock
[3] remaining HC generative potential, mg HC/g rock
[4] carbon dioxide content, mg CO_2/g rock
Abbreviations: TOC, total organic carbon; HI, hydrogen index; OI, oxygen index; PI, production index

suggests the rocks are Devonian; limited amounts of vitrinite particles within the rock components seem to support this conclusion. Recent examination of the lithofacies points to a preliminary conclusion, whereby the succession encountered in drill hole RC 245-02 ranges from the First Red Bed of the Souris River Formation, through a complete Dawson Bay Formation, down to the Winnipegosis and may reach the top of the Ashern Formation. The Rat Creek unit likely occurs within the Winnipegosis Formation.

The Rat Creek organic-rich unit may correspond to the Brightholme unit represented by an 'open basin' laminate facies coeval with the formation of the Winnipegosis reefs. The Brightholme unit is known from very high contents of organic matter (typically a Type II) with an HI of approximately 615 where immature. The unit's thickness ranges from 15 m in Manitoba (Rosenthal, 1987) to between 0.6 and 1.0 m in southern Saskatchewan, where the constituent organic matter reaches its thermal maturity. The Rat Creek source rock also resembles the stratigraphically younger Duvernay Formation deep-water facies, sedimentary rocks which were deposited in low-energy basinal subenvironments and which are coeval with the formation of the Leduc reefs in Alberta.

The sedimentary features of the carbonate rocks, attributed to obvious redeposition and gravity-flow processes, indicate that the conditions during deposition of the organic-rich interval (and accompanying carbonate rocks) might have locally differed considerably from what was commonly understood for the area (Kent, 1994). McCabe (1971) had identified the thin, fine-grained dolomites and interpreted them as "inter-reef facies" of the starved basin of the Winnipegosis Formation, but did not account for the high organic content of these deposits. The evidence presented here indicates that the paleoenvironment of the described interval (Winnipegosis Formation?) was much more diversified than previously believed and included some deeper water sub-basins apart from the shallow and uniform carbonate platform common to this paleodepositional setting.

If the Rat Creek source-rock horizon belongs to the Devonian Winnipegosis Formation or any older formation, one has to conclude that:

- Structural tops of individual Devonian (and likely the older) formations are locally much deeper than was earlier assessed (Norris and Uyeno, 1971).
- Lateral extents of some of the Devonian (and very likely older) formations within the west-central Manitoba portion of the Williston Basin need to be locally adjusted.

The first of these implications may point to the existence of localized graben-like features, which affected the Paleozoic succession within the area of investigation. Similar features have already been proven to exist nearby and have modified the pre-Cretaceous (mostly top of Devonian) paleosurface, as concluded from the results of the recent coal-exploration programs in west-central Saskatchewan and adjoining Manitoba (Christopher, 2003; Berenyi et al., 2009; McNeill et al., 2011). However, these graben-like depressions have only been attributed to date to pre-Late Cretaceous karstic processes, which operated on an exposed carbonate substrate of the post-Devonian paleosurface, without indications of what might have caused their preferential, strongly localized development in the area.

Conclusions

With regard to the amount and type of organic matter, the Rat Creek unit is an excellent potential source rock with high oil-generation potential; moreover, nonfluorescent amorphinite may be gas prone. However, the low maturity level of the samples indicates that not much hydrocarbon has been generated thermogenically from these rocks to date in this area.

The stratigraphic and lithofacies equivalents of the Rat Creek organic-rich mudstone might be excellent and effective oil source rocks if they were buried deeper and exposed to higher temperatures. The abundance of organic matter and its low maturity in the samples studied suggest that they may be an excellent source of biogenic gas, given favourable conditions for the microbial

communities (in situ bacteria and methanogens) to live in the subsurface. Similar rocks are known to generate biogenic gas in economic quantities in other Devonian sedimentary basins (e.g., Antrim Shale in Michigan or New Albany Shale in Indiana, see Strąpoć et al., 2010).

Economic considerations

Discovery of the Rat Creek organic-rich mudstone unit provides new evidence for the occurrence of a potential petroleum source rock in the Devonian carbonate succession of west-central Manitoba. With respect to the amount and type of organic matter, the Rat Creek unit may be regarded as a potential source rock with excellent oil-generation potential. Therefore, close attention to this stratigraphic horizon is recommended, while conducting future exploration work for oil in southwestern Manitoba and southeastern Saskatchewan. At shallower depth, the Rat Creek unit may be also an excellent source of biogenic gas.

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