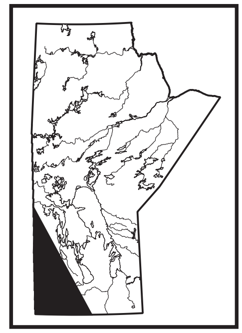
GS-12 Update on the Shallow Unconventional Shale Gas Project, southwestern Manitoba (parts of NTS 62C, F, G, H, J, K, N, O, 63C)

by M.P.B. Nicolas and J.D. Bamburak



Nicolas, M.P.B. and Bamburak, J.D. 2012: Update on the Shallow Unconventional Shale Gas Project, southwestern Manitoba (parts of NTS 62C, F, G, H, J, K, N, O, 63C); *in* Report of Activities 2012, Manitoba Innovation, Energy and Mines, Manitoba Geological Survey, p. 134–140.

Summary

The Shallow Unconventional Shale Gas Project started in 2008 and is a multiyear investigation of the shale gas potential of the Late Cretaceous shale strata of southwestern Manitoba. This project has studied many different facets of the Cretaceous strata, including geochemistry, mineralogy, water and gas content, and stratigraphy. Most of the project thus far has been focused on outcrop data, but recent work is focused on subsurface extrapolations and interpretations. The subsurface characteristics of these strata are currently being investigated as part of a Ph.D. thesis project at the University of Calgary. A closer look at the Gammon Ferruginous Member of the Pierre Shale as a potentially important reservoir zone is also underway. Acquisition of drill cuttings from the lowermost Millwood Member of the Pierre Shale down through to the uppermost Morden Member of the Carlile Formation has provided new subsurface samples to analyze. RockEval™ 6 results of these cuttings indicate high total organic carbon contents through the Gammon Ferruginous and Boyne members, and thermal immaturity throughout the entire sampled section, which was expected since the gas in situ is biogenic in origin. Bulk mineralogy of the cuttings was determined by X-ray diffraction; the results show a marked difference in the mineralogy of fresh subsurface samples versus those collected from outcrops. Relative abundances of quartz in the subsurface samples are lower than those in outcrop samples, whereas clay minerals have lower relative abundances in outcrop samples compared with subsurface samples. The subsurface samples lack secondary minerals formed as a result of weathering processes but have high amounts of illite, compared to the high smectite amounts in outcrop samples. This difference is attributed to smectite illitization, a process in which smectite changes to illite through burial.

Introduction

The Shallow Unconventional Shale Gas (SUSG) Project started in 2008 and is a multiyear investigation of the shale gas potential of the Late Cretaceous shale sequences of southwestern Manitoba. The project involves several components, including outcrop mapping (Nicolas et al., 2010b), outcrop sampling and analysis (Bamburak, 2008a, b; Nicolas, 2008a; Nicolas and Bamburak, 2009a–c; Bamburak and Nicolas, 2010b; Nicolas et al., 2010a; Nicolas and Bamburak, 2011a–d), groundwater and free gas analysis (Nicolas and Grasby, 2009a, b), soil geochemistry (Fedikow et al., 2009) and stratigraphy (Bamburak and Nicolas, 2009; Bamburak et al., GS-13, this volume).

In southwestern Manitoba, the Cretaceous strata are well exposed along the Manitoba Escarpment from south of the international border all the way to the northern tip of the Porcupine Hills. This exposure provides an excellent opportunity to study the strata in outcrop on a scale not available further west into Saskatchewan, where the rocks can only be examined in drillcore and cuttings.

Project update

In the first phases of this project, outcrop mapping and sampling were paramount in getting a modern understanding of the Cretaceous strata, including its chemistry and mineralogy. The next logical step in this project was therefore to extrapolate this knowledge to extend correlations from outcrop to the subsurface. This task was hindered by the lack of available drillcore for Cretaceous strata in Manitoba as compared with Saskatchewan. Due in large part to poor recovery, only a handful of drillcore has been collected, and most of this is old and in bad condition. The few good cores preserved provide the basis for detailed facies evaluation, geochemistry, mineralogy and petrophysical interpretation. These aspects are being studied by S. Hosseininejad, a Ph.D. student at the University of Calgary, whose project is to study the Cretaceous shale sequence in Manitoba, as an extension of the SUSG Project. Hosseininejad et al. (GS-14, this volume) details some of the new subsurface findings.

During the past year, the authors have focused on the stratigraphic complexities of the Gammon Ferruginous Member of the Pierre Shale. This unconformity-bound member is not always present in outcrop. Subsurface mapping of the Gammon Ferruginous Member as part of the Targeted Geoscience Initiative (TGI Williston Working Group, 2008) was the first recent attempt at mapping this unit. Previous subsurface mapping suggested this unit pinched out west of the Manitoba Escarpment (Nicolas, 2009), but fieldwork during the SUSG Project confirmed that this unit does outcrop locally, as further detailed in Bamburak et al. (GS-13, this volume).

Interest in this unit, from the SUSG Project perspective, was due to

- high Pason™ gas readings consistently measured during well drilling,
- geophysical log expressions of ‘coarser’ clastic beds (i.e., relative to the shale and mudstone beds typical of the Cretaceous strata), and
- its history of gas production in Saskatchewan (the Gammon Ferruginous Member correlates to the Milk River Formation in the west, Figure GS-12-1).

New investigations

Drill cuttings

In 2010, the authors had the opportunity to acquire drill cutting samples from a portion of the Cretaceous section during drilling of the vertical portion of a horizontal well, Relative Daly Sinclair HZNTL [8-31-7-29W1] well (Bamburak and Nicolas, 2010a). The drill collar is located at L.S. 16, Sec. 30, Twp. 7, Rge. 29, W 1st Mer. (abbreviated 16-30-7-29W1), whereas the bottom of the hole is located at 8-31-7-29W1. The samples were collected every 5 m from the base of the Millwood Member down to the top of the Morden Member (Figure GS-12-1) in the vertical portion of the well, which corresponds to 330–450 m true vertical depth. Inorganic geochemistry results from this sample suite are also detailed in Nicolas and Bamburak (2011a) and Bamburak et al. (GS-13, this volume).

The washed samples were sent for inorganic geochemistry, RockEval™ 6 organic geochemistry and X-ray diffraction (XRD) bulk mineralogy. The raw geochemistry and mineralogy data for these samples are in MGS Data Repository Item DRI2012003[1]. The inorganic geochemistry results are detailed in Bamburak et al. (GS-13, this volume).

RockEval™ 6 results

The drill cuttings were analyzed by RockEval™ 6 by the Geological Survey of Canada Organic Petrology/Geochemistry Laboratory in Calgary. RockEval™ 6 data

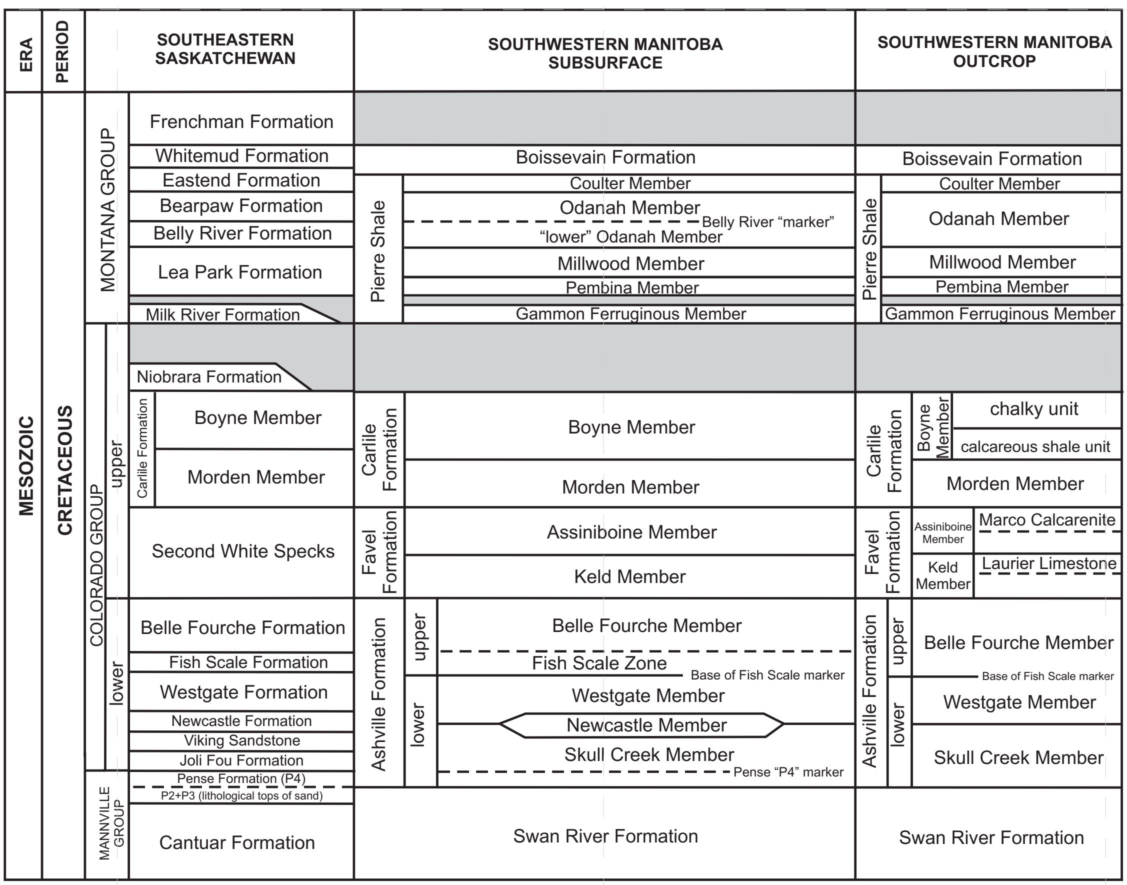


***Figure GS-12-1:** Stratigraphic column of the Cretaceous strata in southwestern Manitoba (subsurface and outcrop) and their correlations to southeastern Saskatchewan (modified after Nicolas, 2008b).*

[1] MGS Data Repository Item DRI2012003, containing the data or other information sources used to compile this report, is available online to download free of charge at http://www2.gov.mb.ca/itm-cat/web/freedownloads.html, or on request from minesinfo@gov.mb.ca or Mineral Resources Library, Manitoba Innovation, Energy and Mines, 360–1395 Ellice Avenue, Winnipeg, Manitoba R3G 3P2, Canada.

are most reliable in large datasets. However, in this case only one well was sampled, which limits the reliability of the interpretations made from this dataset. A couple of sample control issues must also be considered:

- the sample interval was every 5 m and sampling of soft shale at this interval is a challenge due to rapid bit penetration and contamination of samples due to caving; and
- no geophysical log was run on this well to assist in calibrating the formation/member tops with the samples (the nearest available log for calibration is from 10-31-7-29W1 well).

Depth corrections were applied to best assign the stratigraphic unit to the samples; however, there can be up to a 5 m error in the unit assignment for samples, this is particularly important to note for samples occurring near unit boundaries.

Figure GS-12-2 shows the variation in total organic carbon (TOC) contents and temperature at maximum release of hydrocarbons (T_{max}) over the vertical profile through the sampled interval. Despite the potential sampling issues described above, the profiles show marked correlation to the formation and member boundaries and are in agreement with similar profiles in Nicolas and Bamburak (2009a, 2011a). The Gammon Ferruginous and Boyne members have high TOC values indicating their capacity to act as very good source rocks for hydrocarbons. The T_{max} values for all the samples are below the oil window of 435°C, which is needed to reach thermal maturation; such low values are expected due to their shallow burial history. The increased TOC and decreased T_{max} in the Boyne Member samples suggest that T_{max} suppression may be occurring, as described in Snowdon (1995), where samples with very high TOC values inherently result in low T_{max} measurements despite the thermal maturity of the sample.

A plot of the results on a modified van Krevelen diagram (Figure GS-12-3) provides another perspective. This graph predicts the type of hydrocarbons that would be produced from a given source rock if it were to become thermally mature. In this case, the cuttings plot closest to the Type III kerogen field gas-prone line, with some samples of the Boyne Member approaching the Type II kerogen oil-prone line, which is expected since the Boyne Member is known as an oil shale. Since these samples are all thermally immature, meaning no oil or gas has been thermally generated, any gas present in the rocks has been generated in situ by biogenic processes (Nicolas and Grasby, 2009a; Nicolas et al., 2010a).

X-ray diffraction

X-ray diffraction (XRD) was conducted on all the drill cuttings to determine bulk mineralogy. The average mineral abundances are shown in Figure GS-12-4. The dominant phases in the Boyne to Millwood members are illite and quartz, with minor calcite, siderite, pyrite, plagioclase and chlorite. The dominant phase in the Morden Member is calcite, with minor phases being illite and quartz with traces of chlorite and pyrite. At first glance, this might seem an unusual result since the Morden Member is traditionally a noncalcareous shale, however, this can be explained by contamination of the sample by material from the overlying Boyne Member (traditionally calcareous) and/or interlayering of the Boyne and Morden members, which is observed in outcrop.

When comparing the results in Figure GS-12-4 to those in Nicolas and Bamburak (2011a), a striking difference can be seen in the variety and abundance of mineral phases. This relates to the fact that the results shown in Nicolas and Bamburak (2011a) are based predominantly on outcrop samples, while those in Figure GS-12-4 are based entirely on subsurface samples. In outcrop, aside from quartz, the shale mineralogy is dominated by secondary minerals, such as gypsum, jarosite, smectite and kaolinite, which result from weathering. These secondary minerals are not present in the subsurface samples. The overall quartz content in the subsurface samples is significantly lower than that in the surface

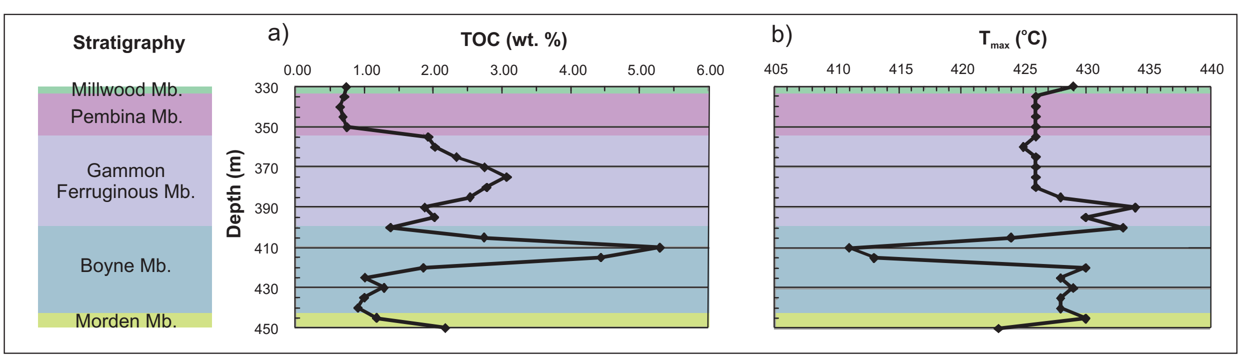


Figure GS-12-2: *New RockEval™ 6 and total organic carbon data grouped by member and placed in order of stratigraphic depth;* ***a)*** *total organic carbon (TOC) and* ***b)*** *temperature at maximum release of hydrocarbons (T_{max}) depth profile of the drill-cutting samples from the Relative Daly Sinclair HZNTL 8-31-7-29W1 well (L.S. 8, Sec. 31, Twp. 7, Rge. 29, W 1st Mer., southwestern Manitoba); sample interval is 5 m.*

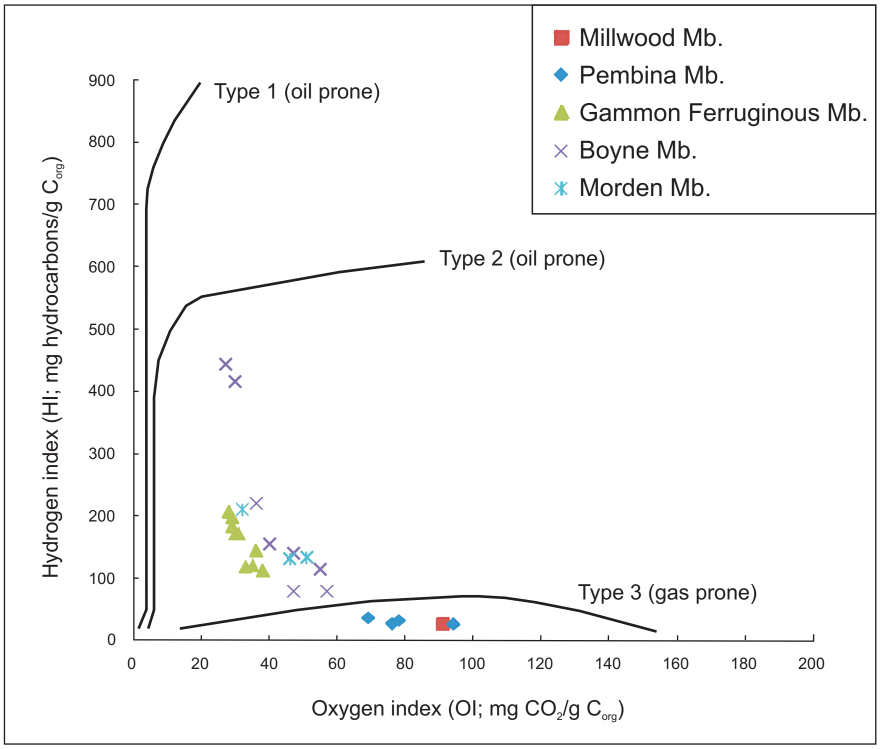


Figure GS-12-3: *Modified van Krevelen diagram of RockEval™ 6 data grouped by member for drill cuttings from the Relative Daly Sinclair HZNTL 8-31-7-29W1 well (L.S. 8, Sec. 31, Twp. 7, Rge. 29, W 1st Mer., southwestern Manitoba).*

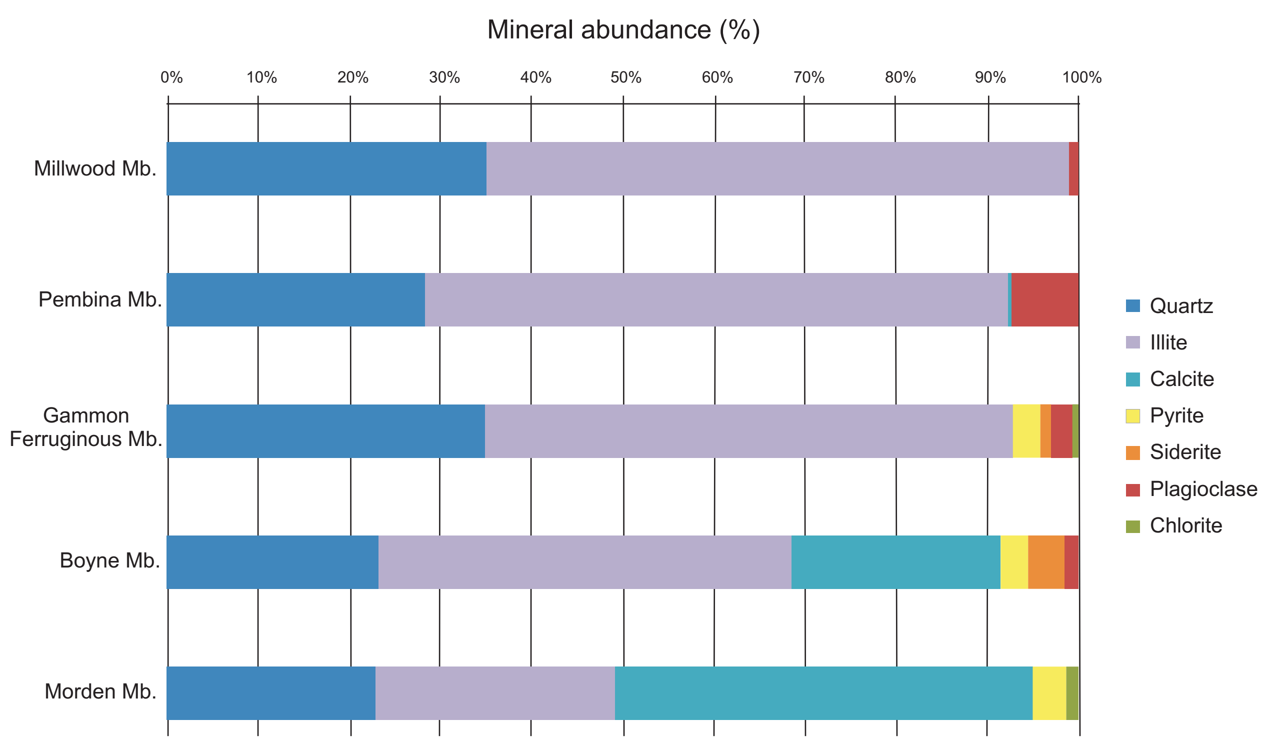


Figure GS-12-4: *Average mineral abundance of Cretaceous drill cuttings from the Relative Daly Sinclair HZNTL 8-31-7-29W1 well (L.S. 8, Sec. 31, Twp. 7, Rge. 29, W 1st Mer., southwestern Manitoba), as determined by X-ray diffraction.*

samples, suggesting either the depositional environment had a higher quartz influx, or there is a relative enrichment in quartz in the outcrop samples during the weathering process. Additional subsurface samples are needed to better determine quartz content, since an abundance of this mineral in the reservoir is required for successful shale gas extraction.

Also of interest is the abundance of illite, a nonswelling clay, and lack of smectite, a swelling clay. Illite and smectite are important minerals to consider when drilling for shale gas due to their reaction, or lack thereof, to drilling fluids, particularly water. The mineralogical relationship between illite and smectite can result in an interlayered clay particle (Altaner and Bethke, 1988). With burial, the clay particles change from smectite-rich to illite-rich, liberating water from the smectite layers in a process called smectite illitization (Altaner and Bethke, 1988). This process also releases SiO_2, Fe and Mg, which can contribute to cementation in sedimentary rocks (Towe, 1962; Boles and Franks, 1979). Whether smectite illitization is the reason for the smectite occurring in outcrop samples and illite occurring in subsurface samples is uncertain, but can be verified with additional analyses of subsurface samples. It should be noted that illite and smectite are generally difficult to differentiate with standard bulk XRD methods, and the sample set presented herein was processed by a different laboratory than the set described by Nicolas and Bamburak (2011a). However, the authors are interpreting the reporting of smectite or illite in the XRD results as the actual phase present in the sample.

Outcrop samples

Outcrop samples of the Gammon Ferruginous Member were collected in the Pembina Hills region, and sent for RockEval™ 6 geochemistry and XRD bulk mineral analysis; the results are recorded in DRI 2012003. The Rock Eval™ 6 results indicate thermally immature sediments but with good TOC results, with values up to 3.99 wt. %. The oxygen index (OI) and hydrogen index (HI) values are low, indicating Type III kerogen, and would thus be gas prone. Type III kerogen is indicative of terrestrially dominated organic sources, which would be compatible with a nearshore environment, as suggested by Bamburak et al. (GS-13, this volume).

During the 2012 field season, an additional outcrop of the Gammon Ferruginous Member was discovered along the Vermilion River near Riding Mountain in southwestern Manitoba, to the west of previously known outcrops. A series of seven samples were collected through a vertical section of the outcrop and will be sent for organic and mineralogical analysis. Further discussion of this outcrop is in Bamburak et al. (GS-13, this volume, Vermilion River locality 1a).

Gammon Ferruginous Member–a potential shale gas reservoir

The Gammon Ferruginous Member shows potential as a shale gas reservoir in Manitoba. Its commonly shaly silt to sand lithology, natural fracture network, high organic content and consistently high Pason™ gas readings are common features of shale gas reservoirs. Its variations in thickness over short distances can provide stratigraphic and hydrological trapping mechanisms to create localized gas accumulations (sweet spots) in an otherwise continuous reservoir. Sweet spots and pool boundaries defined by economic limits are common in shale gas plays, such as the equivalent Milk River Formation play in southwestern Saskatchewan. The Milk River Formation giant gas fields are prolific and long-lived gas-producing plays, which can be used as an analogue for the potential shale gas play that may exist in Manitoba. In the extreme southwestern corner of Manitoba, the Gammon Ferruginous Member occurs at maximum depths of approximately 450 m, which is on par with the producing depths of the Milk River Formation (O'Connell, 2003).

Economic considerations

The data collected during the SUSG Project provides a geoscientific knowledge base for further study and hydrocarbon exploration in the province. Acquiring this information is important to assist in identifying units in Manitoba's Late Cretaceous shale sequences that have the right geochemical and mineralogical characteristics. This is an essential step towards expanding the potential pay-zone thickness at any given location, making exploratory drilling for this new resource attractive, and resulting in new investments in hydrocarbon exploration, drilling and production.

Acknowledgments

The authors would like to thank C. Campbell from Pinnacle Wellsite Consultants for collecting the chip samples and Relative Resources Limited for allowing MGS to sample the chips from their site during drilling.

The authors gratefully acknowledge Centra Gas Manitoba Inc., a subsidiary of Manitoba Hydro, for their generous support of the SUSG Project.

The authors would also like to dedicate this paper to the memory of the late P. Lea of Manitou, Manitoba, who firmly believed in the potential for economic development of Manitoba's shallow gas resources and who, over the past few years, provided many 'hot' lunches in the field utilizing Manitoba's natural gas.

References

Altaner, S.P. and Bethke, C.M. 1988: Interlayer order in illite/smectite; American Mineralogist, v. 73, p. 766–774.

Bamburak, J.D. 2008a: Cretaceous chemostratigraphic database and whole-rock and trace-element analyses for southwestern Manitoba (NTS 63F, G and H4); Manitoba Science, Technology, Energy and Mines, Manitoba Geological Survey, Data Repository Item DRI2008003, Microsoft Excel® file.

Bamburak, J.D. 2008b: Geochemistry of Upper Cretaceous shale in southwestern Manitoba (NTS 63F, G, H4): potential reservoir rocks for shallow unconventional shale gas; *in* Report of Activities 2008, Manitoba Science, Technology, Energy and Mines, Manitoba Geological Survey, p. 180–184.

Bamburak, J.D. and Nicolas, M.P.B. 2009: Revisions of the Cretaceous stratigraphic nomenclature of southwest Manitoba (parts of NTS 62F, G, H, J, K, N, O, 63 C, F); *in* Report of Activities 2009, Manitoba Innovation, Energy and Mines, Manitoba Geological Survey, p. 183–192.

Bamburak, J.D. and Nicolas, M.P.B. 2010a: Gammon Ferruginous Member of the Cretaceous Pierre Shale in southwestern Manitoba: distribution and mineral potential (parts of NTS 62F, G, J, K, N, O, 63C); *in* Report of Activities 2010, Manitoba Innovation, Energy and Mines, Manitoba Geological Survey, p. 170–177.

Bamburak, J.D. and Nicolas, M.P.B. 2010b: Selected analyses of the Gammon Ferruginous Member of the Cretaceous Pierre Shale, southwestern Manitoba (parts of NTS 62F, G, J, K, N, O, 63C); Manitoba Innovation, Energy and Mines, Manitoba Geological Survey, Data Repository Item DRI2010001, Microsoft Excel® file.

Boles, J.R. and Franks, S.G. 1979: Clay diagenesis in Wilcox sandstones of southwest Texas: implications of smectite diagenesis on sandstone cementation; Journal of Sedimentary Petrology, v. 49, p. 55–70.

Fedikow, M.A.F., Bezys, R.K., Nicolas, M.P.B. and Prince, P. 2009: Preliminary results of soil geochemistry surveys in support of shallow gas exploration, Manitou area, Manitoba (NTS 62G2); *in* Report of Activities 2009, Manitoba Innovation, Energy and Mines, Manitoba Geological Survey, p. 193–206.

Nicolas, M.P.B. 2008a: Summary report on petroleum and stratigraphic investigations, southwestern Manitoba; *in* Report of Activities 2008, Manitoba Science, Technology, Energy and Mines, Manitoba Geological Survey, p. 171-179.

Nicolas, M.P.B. 2008b: Williston Basin Project (Targeted Geoscience Initiative II): results of the biostratigraphic sampling program, southwestern Manitoba (NTS 62F, 62G4, 62K3); Manitoba Science, Technology, Energy and Mines, Manitoba Geological Survey, Geoscientific Paper GP2008-1, 28 p.

Nicolas, M.P.B. 2009: Williston Basin Project (Targeted Geoscience Initiative II): summary report on Mesozoic stratigraphy, mapping and hydrocarbon assessment, southwestern Manitoba; Manitoba Science, Technology, Energy and Mines, Manitoba Geological Survey, Geoscientific Paper GP2009-1, 19 p.

Nicolas, M.P.B. and Bamburak, J.D. 2009a: Geochemistry and mineralogy of Cretaceous shale, Manitoba (parts of NTS 62C, F, G, H, J, K, N): preliminary results; *in* Report of Activities 2009, Manitoba Innovation, Energy and Mines, Manitoba Geological Survey, p. 165–174.

Nicolas, M.P.B. and Bamburak, J.D. 2009b: Rock Eval™ 6 results from Cretaceous shale outcrop and core samples from phase 1, Shallow Unconventional Shale Gas Project, southwest Manitoba; Manitoba Innovation, Energy and Mines, Manitoba Geological Survey, Data Repository Item DRI2009003, Microsoft Excel® file.

Nicolas, M.P.B. and Bamburak, J.D. 2009c: Semiquantitative X-ray diffraction results from Cretaceous shale outcrop and core samples from phase 1, Shallow Unconventional Shale Gas Project, southwest Manitoba; Manitoba Innovation, Energy and Mines, Manitoba Geological Survey, Data Repository Item DRI2009004, Microsoft Excel® file.

Nicolas, M.P.B. and Bamburak, J.D. 2011a: Geochemistry and mineralogy of Cretaceous shale, southwestern Manitoba (parts of NTS 62F, G, J, K, N, 63C): phase 2 results; *in* Report of Activities 2011, Manitoba Innovation, Energy and Mines, Manitoba Geological Survey, p. 143–149.

Nicolas, M.P.B. and Bamburak, J.D. 2011b: Inorganic chemistry results from Cretaceous shale outcrop and chip samples from phase 2, Shallow Unconventional Shale Gas Project, southwestern Manitoba; Manitoba Innovation, Energy and Mines, Manitoba Geological Survey, Data Repository Item DRI2011005, Microsoft Excel® file.

Nicolas, M.P.B. and Bamburak, J.D. 2011c: RockEval™ 6 results from Cretaceous shale outcrop samples from phase 2, Shallow Unconventional Shale Gas Project, southwestern Manitoba; Manitoba Innovation, Energy and Mines, Manitoba Geological Survey, Data Repository Item DRI2011003, Microsoft Excel® file.

Nicolas, M.P.B. and Bamburak, J.D. 2011d: Semiquantitative X-ray diffraction results from Cretaceous shale outcrop and core samples from phase 2, Shallow Unconventional Shale Gas Project, southwestern Manitoba; Manitoba Innovation, Energy and Mines, Manitoba Geological Survey, Data Repository Item DRI2011004, Microsoft Excel® file.

Nicolas, M.P.B. and Grasby, S.E. 2009a: Water and gas chemistry of Cretaceous shale aquifers and gas reservoirs of the Pembina Hills area, Manitoba (parts of NTS 62G); *in* Report of Activities 2009, Manitoba Innovation, Energy and Mines, Manitoba Geological Survey, p. 175–182.

Nicolas, M.P.B. and Grasby, S.E. 2009b: Water chemistry results from domestic water wells in the Pembina Hills region, southwest Manitoba (parts of NTS 62G); Manitoba Innovation, Energy and Mines, Manitoba Geological Survey, Data Repository Item DRI2009002, Microsoft Excel® file.

Nicolas, M.P.B., Edmonds, S.T., Chow, N. and Bamburak, J.D. 2010a: Shallow unconventional Cretaceous shale gas in southwestern Manitoba: an update (parts of NTS 62C, F, G, H, J, K, N); *in* Report of Activities 2009, Manitoba Innovation, Energy and Mines, Manitoba Geological Survey, p. 159–169.

Nicolas, M.P.B., Matile, G.L.D., Keller, G.R. and Bamburak, J.D. 2010b: Phanerozoic geology of southern Manitoba; Manitoba Innovation, Energy and Mines, Manitoba Geological Survey, Stratigraphic Map Series, Map 2010-1, scale 1:600 000.

O’Connell, S. 2003: The Second White Specks, Medicine Hat and Milk River formations: a shallow gas core workshop; Belfield Resources Inc., Calgary, Alberta, 247 p.

Snowdon, L.R. 1995: Rock-Eval T_{max} suppression: documentation and amelioration; American Association of Petroleum Geologist, Bulletin, v. 79, p. 1337–1348.

TGI Williston Working Group 2008: Cretaceous Milk River Formation (Gammon Ferruginous): isopach; Manitoba Science, Technology, Energy and Mines, Manitoba Geological Survey, Stratigraphic Map Series SM2008-KMR-I, URL <http://www.gov.mb.ca/stem/mrd/geo/willistontgi/mapfiles/pdfs/004_cret_milk_river_fm_iso.pdf>, scale 1:1 000 000 [September 7, 2012].

Towe, K.M. 1962: Clay mineral diagenesis as a possible source of silica cement in sedimentary rocks; Journal of Sedimentary Petrology, v. 32, p. 26–28.