Introduction

High crude oil and natural gas prices, and the constant threat of declining world petroleum reserves, have industry looking for new, less traditional petroleum resources. In Manitoba, the two areas that are the least tested are the deep Devonian to Cambrian and the shallow Mesozoic formations. Shallow shale gas occurrences have been recorded in Manitoba for over a century, but understanding of and geoscientific data on this potential economic resource are limited. The goal of the Shallow Unconventional Shale Gas Prospects Project is to help address some of these issues, by providing potential investors with the basic information they need to undertake exploration in the new and risky shallow unconventional shale gas plays. The current project is targeting the Cretaceous formations, including the Ashville, Favel, Carlile and Pierre formations (Figure 1).

The source of the shallow shale gas in Manitoba is likely biogenic, formed by in situ biodegradation of organic matter. This microbiological activity is thought to have been rejuvenated by an inflow of fresh water after the retreat of the glaciers (Grasby, pers. comm., 2008). Producing this type of gas is typically associated with a high water production. Alternatively, although less likely, the gas could be thermogenic, with the hydrocarbons being generated elsewhere, migrating and then being trapped.

The presence of natural gas in Cretaceous rocks of Manitoba has been documented in a number of gas shows (Manitoba Industry, Economic Development and Mines, 2005).

Project Details

The Shallow Unconventional Shale Gas Prospects Project is in the first year of a four-year investigation of the shallow gas potential in Manitoba's Mesozoic shale sequences, particularly the Ashville, Favel, Carlile and Pierre formations (Figure 1). The project has been divided into two phases. Phase 1 is aimed at testing the overall project objectives in a geographic subarea, where outcrop sampling is limited to the Pembina Hills region and subsurface data are limited to wells south of Twp. 13 (Figure 2). Phase 2 of the project will be based on the results from Phase 1, broadening the project area to include outcrop data from the Riding Mountain, Duck Mountain and Porcupine Hills regions and subsurface data up to Twp. 44.

Phase 1 will also include logging of Mesozoic subsurface core and a few drill cuttings south of Twp. 13. Samples of the shale will be taken and sent for a combination of analyses, including Rock-Eval® geochemistry, whole-rock and trace element geochemistry, X-ray diffraction and clay speciation. Detailed log analysis will be conducted on wells to get sand-silt-shale ratios, and water resistivity and formation temperature where possible. Payson gas readings will be compiled to give a qualitative assessment of the gas content in each formation. Water samples, which were collected during Phase 1, have been sent for dissolved gas, dissolved solids, alkalinity, sulphates and stable isotope analysis to determine the composition of the gas and whether the gas is biogenic or thermogenic. A scanning electron microscope (SEM) will also be used to evaluate mineralogical and porosity characteristics of the host rocks, such as pore geometry and permeability.

The goal of this project is to summarize the shallow shale gas prospects for Manitoba, and identify intervals within the prospective formations with the greatest potential to contain gas, the distribution of these zones on a map, and a map and/or listing of historical and new gas shows.

Phase 1 Fieldwork

Phase 1 fieldwork was conducted to sample Late Cretaceous shale from the Pembina Hills and Pembina Valley region in southwestern Manitoba, shown in Figure 2. A total of 36 individual field sites were examined and sampled, representing four east–west stratigraphic transects through the Pembina region's outcrop formations, which include the Favel, Carlile and Pierre Shale formations (Figure 1). Selected samples will be sent for various geochemical and mineralogical analyses, as mentioned above.

Additional fieldwork was conducted to collect water and free gas samples from domestic wells. A total of two gas wells (Figure 3a) and 13 water wells (Figure 3b and 3c) were sampled. The Geological Survey of Canada in Calgary (GSC-C) is analyzing the water samples for dissolved solids, alkanitiy and sulphates. Also, both the water and free gas samples are being analyzed for gas composition and various stable isotopes. Tables 1, 2 and 3 shows gas composition results for three wells.

Lithological variations were notable within some of the formations, particularly the Boyne Member of the Carlile Formation and the Odanah Member of the Pierre Shale (Figure 1). In contrast, the Morden Member of the Carlile Formation and the Pembina and Millwood members of the Pierre Shale no lithological variations were observed in their sections, except for numerous bentonite seams within the Pembina Member.

Most outcrops sampled are uniform fissile shale. One roadside outcrop in the Boyne Member (located in the Snow Valley along Roseisle Creek southwest of Roseisle, Manitoba); however, contains a 2 m thick, shaly siltstone bed underlain by a dark black shale and topped by a medium brown shale. The shaly siltstone, being more resistant to weathering than the overlying and underlying shale beds, stands out prominently in the roadcut (Figure 3d). This resistant unit can be subdivided into two beds: 1) a lower shaly siltstone, and 2) an upper shaly siltstone to sandstone. Possibly due to its resistant character, this unit is characterized by abundant centimetre-scale, horizontal and vertical fracturing, as well as decimetre- to metre-scale jointing. The lower shaly siltstone is calcareous, and displays internal bedding, crossbeds, thin laminae, and lenses of siltstone to fine sandstone (Figure 3e). The upper shaly siltstone to sandstone is similar to the lower unit, but contains thin beds and lenses of fine sandstone throughout. This outcrop was the only location visited that displayed this particular siltstone bed. One quarry outcrop northeast of Notre Dame de Lourdes along the Manitoba Escarpment edge, contains a thin siltstone bed in the upper Boyne Member (Figure 3f), but its exact stratigraphic position relative to the Roseisle Creek outcrop is uncertain.

The discovery of siltstone beds within the Boyne Member is significant because it indicates that porous gas-bearing siltstone beds, similar to those that host Saskatchewan's gas fields, are present in Manitoba. The extension of the siltstone beds into the subsurface, where they can serve as a gas reservoir, has yet to be investigated in full, but preliminary log analysis indicates that they extend westward to the Saskatchewan border.

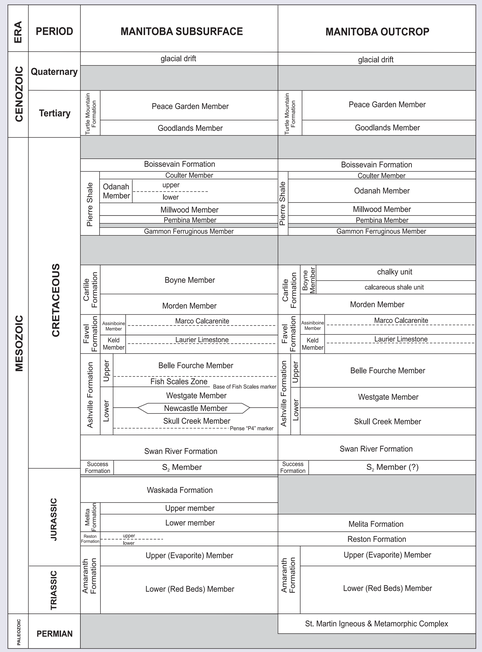


Figure 1: Mesozoic and Cenozoic stratigraphy of southwestern Manitoba within the subsurface and outcrop belt.

Figure 3: Summer 2008 fieldwork photos: **(a)** free gas sampling from gas well near Notre Dame de Lourdes; **(b)** water well sampling near Darlingford; **(c)** water well sampling equipment and set-up; **(d)** outcrop of Boyne Member near Roseisle with shaly siltstone beds more resistant to weathering than the overlying and underlying shale; **(e)** close-up of outcrop in (d), showing lower shaly silstone bed; **(f)** shaly siltstone bed at quarry outcrop near Notre Dame de Lourdes.

Historial Overview

Wallace and Greer (1927) reported that natural gas was being used for domestic lighting and cooking purposes at several sites in southwestern Manitoba. Kerr (1949) documented eleven gas well localities, including those of Wallace and Greer. These natural gas occurrences can generally be grouped into the Treherne, Manitou, and Waskada-Sourisford areas.

Modern Gas Exploration Plays

- Modern exploration for shallow shale gas in Manitoba has been ongoing since 2003, with EOG Resources Canada Inc. drilling three shallow wells (10-17-1-24W1, 3-27-1-25W1 and 1-3-2-25W1) in the Waskada Field and perforating them in the Assiniboine Member of the Favel Formation (Figure 1). Unfortunately, these wells produced only water and were subsequently abandoned. Preliminary evaluation of the EOG wells suggests that formation damage during drilling may have been the reason for the lack of gas production.

- In 2006–2007, Tundra Oil and Gas Partnership drilled three wells (4-6-4-29W1, 32-11-4-29W1 and 8-29-4-29W1) to test the Cretaceous shale. The 4-6-4-29W1 well was abandoned after a short distance of 348.0 m, terminating in the Millwood Member of the Pierre Shale (Figure 1). The other two wells were terminated in the Fish Scale interval of the Belle Fourche Member of the Ashville Formation; both wells were cored in the Boyne Member of the Carlile Formation, but no production has yet been reported.

Waskada-Sourisford District

Since Wallace and Greer's report, the following gas shows have also been documented in the Waskada-Sourisford district:

- 16 oil wells drilled in Twp. 3 to 8 and Rge. 28 to 29W1 reported gas shows within Cretaceous shales ranging from the Millwood Member of the Carlile Formation down to the Ashville Formation (Figure 1). The Favel Formation is mentioned as the source for many of these shows (Manitoba Industry, Economic Development and Mines, 2005).

- A strong gas smell was reported from cut core from the Favel Formation (Figure 1) from a hole drilled in 11-29-1-25W1. Gas pressures of 97 kPa were also measured in two holes in Pierre Shale in NE¼ 5-2-25W1 and 8-2-25W1. A pressure of 117 kPa was measured in Pierre Shale in a hole drilled in SW¼ 10-2-27W1.

- A petroleum well being drilled near Pierson was damaged in a gas blowout on August 1, 2005. The well was Big Sky #5 on Tundra Pierson Prov. 16-36-3-29W1. The gas was trapped in Quaternary (Figure 1) gravels beneath a layer of cemented till. The well had been drilled down 139 m (at the time of blowout) within a shale bed that is believed to have contained the gas that caused the blowout.

Treherne Area

- A local natural gas source is situated along the Manitoba Escarpment, 6 km north-northeast of Notre Dame de Lourdes within a water well (located in 1-30-7-8W1). The well, drilled around 1930, produces a weak petroleum smelling gas with 221 kilopascals (kPa) pressure that burns for at least 0.5 hours when ignited. After ignition the gas pressure drops to 21 kPa, but the well recharges in 12 hours when the valve is closed. Carlile (formerly Niobrara) Formation (Figure 1) bedrock is exposed at two locations, a short distance to the southeast and to the southwest of the well. The exposures are at about the same elevation as the top of the well. The 52 m deep well likely penetrated the Favel Formation (Figure 1), which is an oil shale. Poor quality drinking water has been encountered in all wells drilled in Section 30.

- Two other gas sources, identified in SW¼ 21-7-8W1 and NE¼ 28-7-10W1, were also utilized in the past for household consumption. Gas was also found within a water well in 11-5-7W1. The Favel Formation (Figure 1) is believed to be the source of all these gas occurrences.

Manitou Area

- Two capped gas wells, with about 276 kPa pressure, are situated in the south half of Section 23, Twp. 2, Rge. 9W1, about 13 km south of Manitou. One of the wells has produced gas since it was drilled into the Boyne Member (Figure 1) in 1907. The other well was drilled around 1933. Both wells were ignited by the landowner during water and gas well sampling visits in September and October, 2008. The 1933 well feeds a small storage tank and a typical gas barbecue. Another gas occurrence is present, a short distance to the west, in a domestic farm water well in 2-22-2-9W1 into Morden Shale.

- Gas shows were also reported in the 1930s from Cretaceous shale in petroleum test wells drilled in NE13-2-10W1 and 8-26-2-9W1.

Other Areas

- A petroleum test well near Miniota caught fire during formation testing over 20 years ago and has since been abandoned. The well is believed to be Champlin Birdtail Creek 1-29-14-26W1, drilled in 1968 to a depth of 629.41 m. The Favel Formation (Figure 1) was penetrated at a depth of 253.7 m. Another test well in NW¼ 23-10-26W1 had a gas pressure of 172 kPa in Pierre Shale.

- An initial gas pressure of 331 kPa, followed in a few hours by a drop to 241 kPa, was reported from Pierre Shale (Figure 1) in a well drilled near Hartney in NW¼ 4-6-22W1.

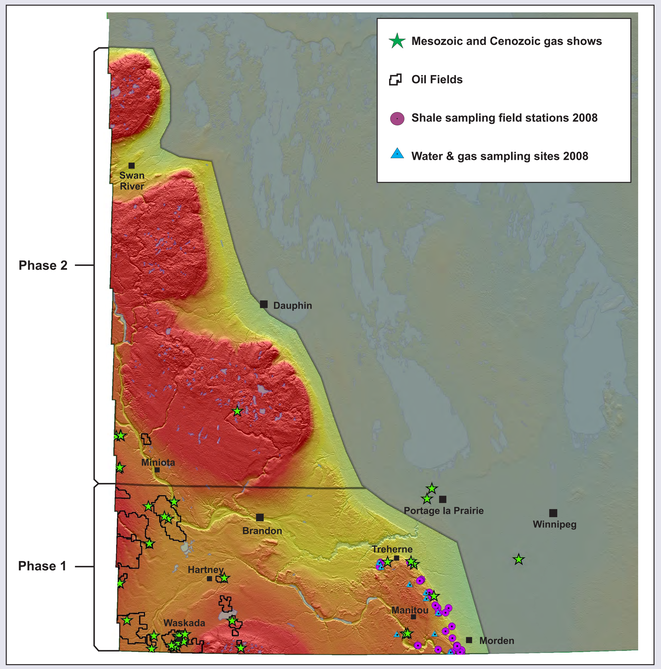
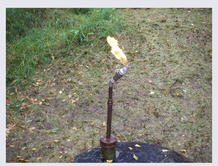


Figure 2: Digital elevation model showing the study area of the Shallow Unconventional Shale Gas Prospects Project, the location of Phase 1 and Phase 2 of the project, Mesozoic and Cenozoic gas shows in relation to extisting oil fields, field station and water/gas sampling sites of the 2008 sampling program.



Flaring of gas well near Notre Dame de Lourdes, Manitoba; well drilled in 1936.

Table 1: Gas composition of free gas sample of gas well near Notre Dame de Lourdes.

methane (CH_4)	81.87 %
nitrogen (N_2)	16.79 %
oxygen (O_2)	0.460 %
carbon dioxide (CO_2)	0.37 %
ethane (C_2H_6)	0.219 %
argon (Ar)	0.151 %
helium (He)	0.1350 %
propane (C_3H_8)	0.0038 %

Gas bubbles in water well near Notre Dame De Lourdes, Manitoba; well drilled in 1936.

Gas well head and storage tank near Manitou, Manitoba; well drilled in1933.

Table 2: Gas composition of free gas sample of gas well near Manitou.

methane (CH_4)	89.69 %
nitrogen (N_2)	9.34 %
oxygen (O_2)	0.375 %
ethane (C_2H_6)	0.260 %
carbon dioxide (CO_2)	0.180 %
argon (Ar)	0.0896 %
helium (He)	0.0379 %
propane (C_3H_8)	0.0171 %
iso-butane (C_4H_{10})	0.0063 %

Flaring of gas well head with storage tank near Manitou, Manitoba; well drilled in1907.

Collection of effervescent water sample; note gas bubbles in water and gas-filled head space in bottle.

Table 3: Gas composition of free gas sample of water well near Manitou.

methane (CH_4)	84.80 %
nitrogen (N_2)	13.34 %
carbon dioxide (CO_2)	1.40 %
argon (Ar)	0.249 %
oxygen (O_2)	0.192 %
helium (He)	0.0118 %
ethane (C_2H_6)	0.0028 %

Cretaceous Shale Geochemistry

To assist in the mineralogical analysis of Manitoba's Cretaceous shale sequences in southwestern Manitoba, a review of historical whole rock and trace element analyses was initiated during the summer of 2008. The results of the whole rock portion of the search, available in Bamburak (2008), indicated that only 110 samples have been analyzed from 10 outcrop localities; and that only 48 samples have been processed from 8 mining company and stratigraphic coreholes.

A similar review of trace element distribution by formation, member and/or bed mainly captured from Open File Report 98-2 by Fedikow et al. has been initiated. A preliminary listing summarizing the results of 81 stratigraphic holes of the MGS and GSC drilled in southwestern Manitoba is available in Bamburak (2008). Future work will involve the compilation and integration of trace element distribution by formation, member and/or bed from oil company exploration core and outcrops, also described in Open File Report 98-2.

To date, the literature search has revealed that there are many gaps in the whole rock and trace element geochemical knowledge of the Cretaceous stratigraphic package. The sampling carried out during Phase 1 should go a long way to addressing these deficiencies in the Manitoba Geological Survey's chemostratigraphic database.

Shown below in Figure 4 are two examples of selective retrievals of data contained in the chemostratigraphic database of major and trace elements of outcrop samples collected several years ago in the Phase 1 area (Fedikow et al., 1998). The major element chart (Figure 4a) shows the weight percent of Al, Ca, Fe, K, Mg, Na, P and Ti found in the samples, arranged by formation, member or bed in their stratigraphic position from top to bottom, as shown in Figure 1. Figure 4b depicts the analytical values in parts per million for rare earth metals (Th, U, La, Ce, Nd, Sm, Eu, Tb, Yb, Lu), also arranged stratigraphically.

The **Ca** plot on the major element chart shows that the Gammon Ferruginous Member of the Pierre Shale and the buff and grey beds of the Boyne Member of the Carlile Formation (Figure 1) relatively enriched in Ca; as are the Assiniboine Member (including as expected, the Marco Calcarenite beds) and the Keld Member of the Favel Formation. **P** shows a similar pattern, but is substantially decreased within the grey beds of the Boyne. The **Mg** and **Na** plots generally follow a reciprocal relationship to the Ca plot.

The **Fe** plot indicates the Gammon Ferruginous Member contains a significant amount of iron, as expected, but also has a major decrease in the vicinity of the Marco Calcarenite. The **Al, K** and **Ti** plots also indicate a major reduction in values relative to the position of the Marco Calcarenite, but only show a slight decrease/increase, or no response in the vicinity of the Gammon.

The **rare earth metals** (REE) values shown in the trace element chart generally show a close correspondence to the **Fe** plot shown in the major element chart. The notable exceptions to this observation is the apparent decrease in **Sm** within the Gammon Ferruginous; and the slight decrease in **U** values corresponding to the Marco Calcarenite.

Similar conclusions, to the above, can be determined from other element data contained in the chemostratigraphic database. Using the database, it should be possible to separate geological units by their distinctive geochemical signature where stratigraphic control is weak or absent. It is also speculated that as more data becomes available that it may be possible to determine, which elements might be diagnostic in the search for shallow gas resources. The presence of shale gas might be accompanied by the relative increase or decrease in certain elements compared to the "normal" chemistry of the formation, member or bed; and this could become a tool for its detection.

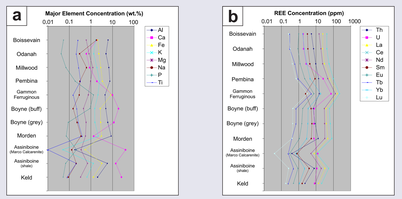


Figure 4: Chemostratigraphy of the Late Cretaceous, based on selective retrievals of data from the chemostratigraphic database of (a) major and (b) trace elements (REE) of outcrop samples.

Economic Considerations

Despite a long history of oil and gas exploration in Manitoba, unconventional shallow gas prospects are still poorly understood. The goal of the Shallow Unconventional Shale Gas Prospects Project is to provide potential investors and companies with the basic information needed to undertake exploration in the new and risky unconventional shallow shale gas plays in southwestern Manitoba. Since the potential area for shallow gas production is large, extending from the Manitoba Escarpment west to the Saskatchewan-Manitoba border and from the Porcupine Hills south to the Canada–United States border, economic benefits—if resources are present—could be significant.

Acknowledgments

The authors would like to thank S. Grasby of the GSCC for his interest in this project and his generous offer to covering the cost of the geochemical water and gas analyses.

We would like to further acknowledge R. Betcher and T. Harrison of Manitoba Water Stewardship for lending us the field equipment and providing field support during our water sampling program.

References

Bamburak, J.D. 2008: Geochemistry of Upper Cretaceous shale in southwestern Manitoba – potential source rocks for shallow unconventional shale gas prospects (NTS 62F, G and H/4): *in* Report of Activities 2008, Manitoba Science, Technology, Energy and Mines, Manitoba Geological Survey, p.

Fedikow, M.A.F., Bezys, R.K., Bamburak, J.D., Conley, G.G. and Garrett, R.G. 1998: Geochemical database for Phanerozoic black shales in Manitoba; Manitoba Energy and Mines, Geological Services, Open File Report 98-2, 123 p. + 1 diskette.

Kerr, L.B. 1949: The stratigraphy of Manitoba with reference to oil and natural gas possibilities; Manitoba Mines and Natural Resources; Mines Branch, Publication 49-1, 132 p. + 1 map @ 1:1_267_200.

Manitoba Industry, Economic Development and Mines 2005: Mesozoic DST and oil and gas shows listing, Pierre Shale to Amaranth, December 31, 2004; Manitoba Industry, Economic Development and Mines, Petroleum Branch, booklet, 12 p.

Wallace, R.C. and Greer, L. 1927: Non-metallic mineral resources of Manitoba; Industrial Development Board of Manitoba, 93 p.