GS-18 Water and gas chemistry of Cretaceous shale aquifers and gas reservoirs of the Pembina Hills area, Manitoba (parts of NTS 62G)

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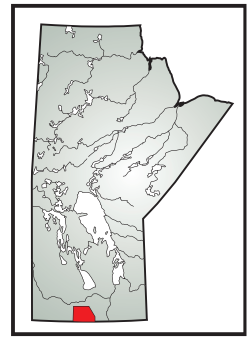

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Summary

Water and gas chemistry of the Cretaceous shale aquifers and gas reservoirs of the Pembina Hills area in southwest Manitoba were analyzed. Chemistry and stable isotope results indicate that accumulations of biogenic natural gas are present in this area. Stratigraphic extrapolations of the water-well and gas-well data suggest that the Assiniboine Member of the Favel Formation and the Boyne Member of the Carlile Formation are the horizons with known gas accumulations.

Introduction

Shallow shale gas occurrences have been recorded in Manitoba for more than a century (Bamburak, 2008), but the understanding of, and geoscientific data on, this potential economic resource is limited. The goal of the Shallow Unconventional Shale Gas Project is to summarize the shallow shale gas prospects for Manitoba, characterize the gas, define the area of the gas occurrence and identify intervals within prospective formations with the greatest potential to contain gas. The project, which is in the second year of a multi-year investigation, aims to address some of these issues.

The project is targeting most of the Cretaceous formations in southwest Manitoba, particularly the Ashville, Favel, Carlile and Pierre Shale formations. Nicolas (2008) provided the project introduction and details, gas shows, and modern gas exploration in Manitoba; Bamburak (2008) provided a historical account of gas exploration in Manitoba. Nicolas and Bamburak (GS-17, this volume) discuss organic geochemistry and mineralogy results from the first suite of samples and the highlights from the collection of the second suite of samples. This paper discusses the gas reservoirs and shale aquifer chemistry to help characterize this gas-bearing system.

Fieldwork

Sampling of 15 wells (Figure GS-18-1; Table GS-18-1) in the Pembina Hills region was carried out in September and October 2008, with follow-up sampling at selected sites in June 2009. Selected domestic water wells were targeted for sampling based on their total depth, aquifer lithology (only shale aquifers were chosen) and location. Location was based on proximity to areas of reported gas shows and geographic distribution throughout the Pembina Hills region to cover the widest area possible. In addition, all the wells are located on the Second Prairie Level, on top of the Manitoba Escarpment, because most of the Cretaceous shale sequences terminate at or near the escarpment edge. The GWDrill database (Manitoba Water Stewardship, 2007), a water-well database of more than 80 000 sites maintained by the Water Resources Branch of Manitoba Water Stewardship, was used to identify potential well sites based on lithology and total depth. The deeper wells were seen as more favourable in terms of sampling deeper formations with higher gas-producing potential. Finding wells deep enough was challenging, since most deep water wells in the database had been abandoned due to poor water quality. Recently, drilling shallower wells in the area by water-well drillers has resulted in a better understanding of aquifer depths. These shallower wells are commonly producing from Quaternary sand and gravel aquifers. In the process of searching for water wells to sample, two old, capped, gas exploration wells from 1906 and 1933 were discovered and added to the sample suite.

A total of 2 gas wells and 13 water wells was selected and sampled. Water samples were analyzed for dissolved solids, alkalinity, sulphates and dissolved gases at the Geological Survey of Canada in Calgary (GSC-Calgary). Free-gas samples were collected from the gas wells and from effervescent water wells (i.e., flowing water with abundant bubbles). These free-gas samples were analyzed for gas composition, and samples with high methane values were also analyzed for carbon- and hydrogen-stable isotope compositions ($\delta^{13}C$ and δD).

Sampling methodology

Most water samples were taken from an exterior hose, with the exception of one well where the sample was taken from an indoor tap. All but one of the water wells were connected in the well to a pump system for domestic use; the one well not connected was an old hand-dug well near Notre Dame de Lourdes where gas can be seen escaping from the surface of the water in the well (Figure GS-18-2). The gas from this well can be collected and is occasionally flared on site. The water was

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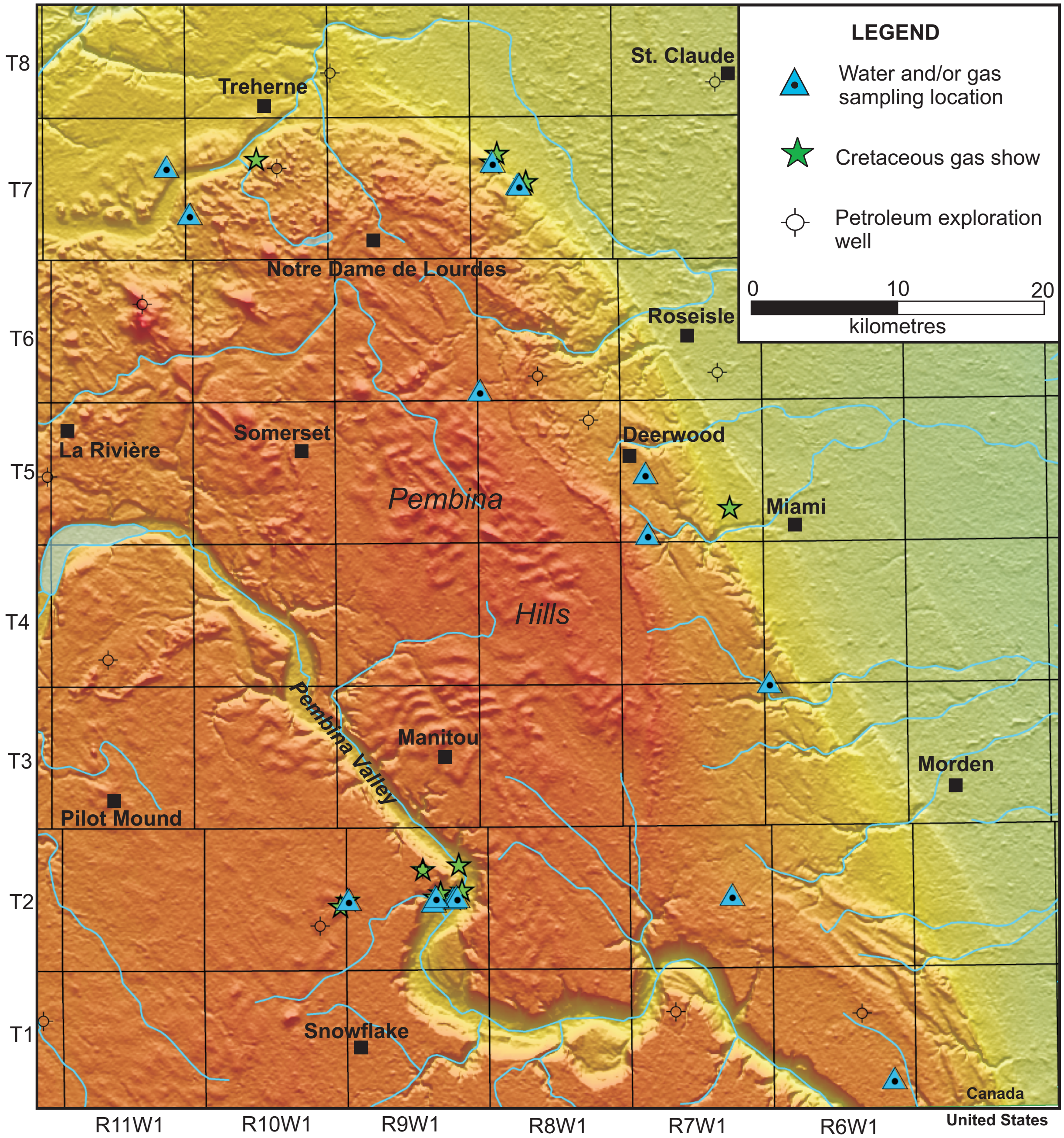

Figure GS-18-1: *Digital elevation map showing water and gas sampling sites in the Pembina Hills region; Cretaceous gas shows and petroleum exploration wells are also shown.*

set up to run through a hose connected to a flow-through cell equipped with three probes to measure conductivity (Eh), acidity (pH) and temperature (Figure GS-18-3). The water was left to run for 10–15 minutes to ensure that fresh groundwater was being sampled and the sample was collected after the conductivity and temperature stabilized. The water was run through a filter to collect samples for dissolved-solids, alkalinity and sulphate analysis, but was bypassed by the filter to collect samples for dissolved-gas, free-gas and isotope analysis. Free-gas samples from effervescent water were collected in glass and plastic bottles that were filled with the effervescent well water, which formed a gas headspace in the closed bottles. The samples were then stored and shipped upside-down to prevent gas loss through the bottle cap (Figure GS-18-4). The same procedure was used to collect free-gas samples from the gas wells, but instead of using water from the dry wells, distilled water in the bottles was displaced as the gas headspace increased.

The samples were packed on ice and sent to the GSC-Calgary laboratory where the water samples were treated to stabilize before analysis. Alkalinity was measured using an Orion 960 Autotitrator with $H_2SO_{4(aq)}$ and ROSS™ pH electrode. Anions were measured using

Table GS-18-1: Water and gas sample location sites, general well information and estimated formation and member at total depth.

Well location	Easting*	Northing*	Rural municipality	NTS sheet	Well type	Drill date	Aquifer lithology	Total well depth (TD; m)	Ground elevation (m)	Subsea at TD (m)	Estimated stratigraphic horizon at TD
SE30-7-8-W1	533936	5493491	South Norfolk	62G10	domestic water well	1916?	Shale	74	369.42	295.42	Boyne Member, Carlile Formation
SW20-7-8-W1	535703	5491941	South Norfolk	62G10	domestic water well	1921	Shale	65.5	361.80	296.30	Boyne Member, Carlile Formation
SW24-7-11-W1	511331	5493136	Victoria	62G10	domestic water well	1986	Shale	32	423.67	391.67	Pembina Member, Pierre Shale
SW18-5-7-W1	544530	5471870	Thompson	62G8	domestic water well	~1980	Shale	15	432.82	417.82	lower Pembina Member, Pierre Shale or upper Boyne Member, Carlile Formation
SW5-5-7-W1	544710	5467653	Thompson	62G8	domestic water well	1988	Shale	29	448.97	419.97	lower Pembina Member, Pierre Shale or upper Boyne Member, Carlile Formation
SW6-6-8-W1	533061	5477613	Lorne	62G7	domestic water well	1997	Shale	12.5	472.44	459.94	Millwood Member, Pierre Shale
NE7-7-10-W1	512947	5489852	Victoria	62G10	domestic water well	1990	Shale	15	414.53	399.53	Pembina Member, Pierre Shale
NW18-2-9-W1	523977	5442268	Pembina	62G2	domestic water well	1966	Shale	55	480.06	425.06	Odanah Member or Millwood Member, Pierre Shale
SE23-2-9-W1	531267	5442380	Pembina	62G2	gas well	1932	Shale	282	399.90	117.90	Waskada Formation at TD; gas zone unknown, but likely Assinboine Member, Favel Formation
SW23-2-9-W1	531500	5442460	Pembina	62G2	gas well	1906	Shale	381	411.48	30.48	Reston Formation at TD; Assiniboine Member, Favel Formation at gas producing zone (180 m depth; 231.48 m subsea)
SE15-2-9-W1	529866	5442159	Pembina	62G2	domestic water well	mid 1940s	Shale	23	414.53	391.53	Millwood Member or Pembina Member, Pierre Shale
SE22-2-9-W1	530038	5442489	Pembina	62G2	domestic water well	1906	Shale	21.03	415.14	394.11	Millwood Member or Pembina Member, Pierre Shale
SE6-4-6-W1	553154	5457377	Thompson	62G8	domestic water well	~1960	Shale	6	411.48	405.48	Pembina Member, Pierre Shale
SW23-2-7-W1	550580	5442633	Pembina	62G2	domestic water well	~1997	Shale	35	453.23	418.23	Odanah Member, Pierre Shale
SW12-1-6-W1	561838	5429899	Stanley	62G1	domestic water well	1993?	Shale	55	457.20	402.20	Odanah Member, Pierre Shale

* UTM NAD 83, Zone 14

Figure GS-18-2: Old hand-dug well near Notre Dame de Lourdes at SE-30-7-8-W1 with visible bubbles at the water-table surface; pipe on the left side captures gas and is flared occasionally for short periods of time. Well is approximately 1 m in diameter.

Figure GS-18-3: Water sampling set-up showing flow-through cell with probes; photo taken at sampling site in SW-6-6-8-W1.

ion chromatography and cations by inductively coupled plasma–emission spectrometry.

Gas chemistry

Dissolved and free-gas compositions

Dissolved-gas compositions were measured for all collected water and gas samples, and free-gas compositions and stable isotopes were measured for the gas wells and effervescent water wells by gas chromatography. Tables GS-18-2 and -3 list the results for the dissolved-gas compositions and free-gas compositions, respectively.

A total of five well samples yielded high methane content and dry gas indices of 0.99–1.00 (water wells at SE-30-7-8-W1, NW-18-2-9-W1 and SE-22-2-9-W1, and gas wells at SE-23-2-9-W1 and SW-23-2-9-W1). A gas index higher than 0.95 is considered biogenic in origin; therefore, indices approaching 1.00, as in these results, strongly indicate an entirely biogenic source for the gas. In contrast, the wells with low methane are high in nitrogen. The water-well sample from SW-23-2-7-W1 was the only effervescent water sample lacking high methane content, but has very high nitrogen content.

Stable isotopes

Stable isotopes of gas samples have $\delta^{13}C$ values from –75 to –85‰, with δD values averaging –270‰ free-gas samples (Table GS-18-3). These values are characteristic of biogenic gas (Whiticar, 1999), and values of >0.99 for these samples are consistent with the very high dry-gas index.

Figure GS-18-4: *Effervescent water sample with gas headspace and gas bubbles in the water; taken at NW-18-2-9-W1.*

Water chemistry

Water-sample compositions range from fresh to brackish and from Ca-HCO_3 to Na-HCO_3–dominated as presented in MGS Data Repository Item DRI2009002[2]. Well samples with the lowest SO_4 concentrations correlate with methane-bearing effervescent water wells. This is consistent with high SO_4 levels supporting sulphate-reducing bacteria that outcompete methanogens and suggest that sulphate concentrations may play an important role in limiting biogenic methane production.

Stratigraphic interpretation

Table GS-18-1 lists the estimated formation and/or member at the total depth of the well. This information may not be accurate, since there is little stratigraphic control in the areas sampled. As there are no core or logs for the water wells, the estimate of stratigraphic horizon was based on several parameters: the geographic location of the well relative to a combination of proximity of the well to formation/member outcrop edges and known outcrop controls, the average regional southwest dip of 1.9 m/km (this dip is applicable only for Cretaceous sequences in the Pembina Hills region) and a few sparse post-1950 oil and gas wells drilled in the area.

There appears to be no direct relationship between the stratigraphic horizon at total depth and the occurrence of methane gas in the sampled wells. The following observations, however, can be made: the well at SE-30-7-8-W1 taps into the Boyne Member of the Carlile Formation and is suspected to penetrate the middle to lower beds of this unit; the middle beds are a highly organic quartz-rich siltstone and sandstone and the lower beds are a dark organic quartz-rich shale (Nicolas and Bamburak, GS-17, this volume). The middle beds are suspected to be excellent source and reservoir rocks in the subsurface (Nicolas and Bamburak, GS-17, this volume).

The two gas wells are both considered to be getting their gas from the Assiniboine Member of the Favel Formation. The authors have a high degree of confidence in the stratigraphic placement of the gas-producing zone for SW-23-2-9-W1 due to its reference in historical records. The authors have less confidence in the gas-producing zone for SE-23-2-9-W1 due to the lack of reliable historical records for this well. Due to its proximity to the well at SW-23-2-9-W1 and very similar gas compositions, however, the assumption is that the Assiniboine Member is the dominant gas-producing zone.

Water wells with very low methane but high nitrogen concentrations appear to be shallow wells that penetrate the Odanah or Millwood members of the Pierre Shale. A couple of wells get their water from the Pembina Member of the Pierre Shale. Although this member may be considered to be a potential gas-bearing horizon, any gas produced by it is not easily liberated into pore spaces due to its abundant bentonite seams and presence of swelling clay minerals.

Discussion and economic considerations

Despite a long history of oil and gas exploration in Manitoba, unconventional shallow gas prospects are still

[2] MGS Data Repository Item DRI2009002, 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, MB R3G 3P2, Canada.

Table GS-18-2: Dissolved-gas compositions for domestic well-water samples from the Pembina Hills region, southwest Manitoba.

Well location	Sample number	He (%)	H_2 (%)	Ar (%)	O_2 (%)	CO_2 (%)	N_2 (%)	CO (%)	C_1 (%)	C_2 (%)	C_2H_4 (%)	C_3 (%)	iC_4 (%)	nC_4 (%)	iC_5 (%)	nC_5 (%)	C_6+* (%)	Dissolved CH_4 cc/L	Dissolved CH_4 mg/L	Specific gravity	BTU	Helium dilution factor **
SE30-007-08-W1	106-08-62G10-W1	0	0	0.507	0.325	3.14	28.5	0	67.21	0.301	0	0.0124	0	0	0	0	0	22.6331	15.0435	0.710	687	0.64
SW-20-007-08-W1	106-08-62G10-W2	0	0	1.4	1.79	5.4	91.11	0	0.299	0	0	0	0	0	0	0	0	0.0804	0.0535	1.004	3	0.72
SW24-007-11-W1	106-08-62G10-W3	0	0	1.23	13.95	10.54	74.28	0	0	0	0	0	0	0	0	0	0	<0.001	<0.001	1.050	0	0.70
SW18-005-07-W1	106-08-62G8-W4	0	0	1.39	11.29	12.26	75.03	0	0.0276	0	0	0	0	0	0	0	0	0.0075	0.0050	0.404	0	0.71
SW05-005-07-W1	106-08-62G8-W5	0	0	1.26	5.72	9.49	83.52	0	0.0083	0	0	0	0	0	0	0	0	0.0026	0.0017	1.033	0	0.67
SW06-006-08-W1	106-08-62G7-W6	0	0	1.29	1.78	3.8	90.91	0	2.22	0	0	0	0	0	0	0	0	0.7011	0.4660	0.987	22	0.67
NE07-007-10-W1	106-08-62G10-W7	0	0	1.47	2.61	7.52	87.61	0	0.794	0	0	0	0	0	0	0	0	0.2141	0.1423	1.015	8	0.71
NW18-002-09-W1	106-08-62G2-W8	0.0249	0	0.379	0.185	1.21	25.8	0	72.4	0.003	0	0	0	0	0	0	0	0	0	0.676	734	0
SE15-002-09-W1	106-08-62G2-W9	0	0	1.51	2.07	2.44	93.9	0	0.0839	0	0	0	0	0	0	0	0	0.0194	0.0129	0.346	0	0.76
SE22-002-09-W1	106-08-62G2-W10	0.0118	0	0.249	0.192	1.4	13.34	0	84.8	0.0028	0	0	0	0	0	0	0	0	0	0.626	860	0
SE06-004-06-W1	106-08-62G8-W11	0	0	1.45	6.23	4.43	87.86	0	0.0294	0	0	0	0	0	0	0	0	0.0076	0.0051	1.006	0	0.73
SW23-002-07-W1	106-08-62G1-W12	0.038	0	1.11	0.255	1.07	97.47	0	0.0575	0	0	0	0	0	0	0	0	0	0	0.978	1	0
SW12-001-06-W1	106-08-62G1-W13	0	0	1.33	12.04	7.12	79.5	0	0.0083	0	0	0	0	0	0	0	0	0.0025	0.0016	1.029	0	0.69

Chemical analysis based on standards accurate to within 2%
* Hydrocarbons with more than six carbon atoms.
** Analysis of gas extracted from water by headspace equilibration, analysis has been corrected for helium added to create headspace.

Table GS-18-3: Free-gas compositions and $\delta^{13}C$ and δD stable-isotope results for domestic effervescent well-water and gas-well samples from the Pembina Hills region, southwest Manitoba.

Well location	Sample name	He (%)	H_2 (%)	Ar (%)	O_2 (%)	CO_2 (%)	N_2 (%)	CO (%)	C_1 (%)	C_2 (%)	C_2H_4 (%)	C_3 (%)	iC_4 (%)	nC_4 (%)	iC_5 (%)	nC_5 (%)	C_6+ (%)	$\delta^{13}CO_2$ (‰)	$\delta^{13}C_1$ (‰)	δDC_1 (‰)	$\delta 13C_2$ (‰)	Specific gravity	BTU	Dry gas index*
SE30-007-08-W1	106-08-62G10-G1	0.1350	0	0.151	0.460	0.370	16.790	0	81.87	0.2190	0	0.0038	0	0	0	0	0	-	-	-	-	0.631	834	0.997
SW23-002-09-W1	106-08-62G2-G2	0.0379	0	0.090	0.375	0.180	9.340	0	89.69	0.2600	0	0.0171	0.0063	0	0	0	0	-	-	-	-	0.598	914	0.997
SW23-002-07-W1	106-08-62G2-G3	0.0584	0	1.260	1.970	0.600	96.100	0	0.02	0.0000	0	0	0	0	0	0	0	-	-	-	-	0.978	0	1.000
SE22-002-09-W1	106-08-62G2-G4	0.0198	0	0.314	0.009	1.450	14.860	0	83.34	0.0031	0	0	0	0	0	0	0	-	-	-	-	0.632	845	1.000
SW23-002-09-W1	106-08-62G2-G5	0.0369	0	0.131	1.610	0.180	10.760	0	87.01	0.2520	0	0.0167	0.0064	0	0	0	0	-	-	-	-	0.611	887	0.997
SE23-002-09-W1	106-08-62G2-G6	0.0497	0	0.141	1.930	0.098	12.410	0	85.13	0.2230	0	0.0120	0.0038	0	0	0	0	-	-	-	-	0.619	867	0.997
NW18-002-09-W1	106-08-62G2-G7	0.0409	0	0.465	0.099	1.140	28.130	0	70.12	0.0030	0	0	0	0	0	0	0	-	-	-	-	0.685	711	1.000
NW18-002-09-W1	106-09-62G2-G8	0.0353	0	0.406	0.188	1.210	26.290	0	71.87	0.0028	0	0	0	0	0	0	0	-18.59	-85.76	-290.4	-	0.679	728	1.000
NW14-002-09-W1	106-09-62G2-G9	0.0327	0	0.136	1.400	0.130	11.230	0	86.80	0.2440	0	0.0168	0.0065	0	0	0	0	-13.58	-76.05	-251.7	-52.48	0.612	885	0.997
NW14-002-09-W1	106-09-62G2-G10	0.0350	0	0.126	1.040	0.086	9.990	0	88.45	0.2470	0	0.0184	0.0065	0	0	0	0	-12.22	-75.73	-255.4	-52.62	0.604	902	0.997
SE30-007-08-W1	106-09-62G10-G11	0.1070	0	0.210	2.010	0.230	20.980	0	76.26	0.1990	0	0.0033	0	0	0	0	0	-11.10	-76.87	-263.2	-49.90	0.656	776	0.997
SE22-002-09-W1	106-09-62G2-G12	0.0029	0	0.268	0.259	1.410	14.210	0	83.85	0.0025	0	0	0	0	0	0	0	-18.08	-81.67	-291.8	-	0.630	850	1.000

Chemical analysis based on standards accurate to within 2%
For the chemical analysis, values reported as zero are Not Detected/Below Detection Limit
* Dry Gas Index = $C_1 / (C_1+C_2+C_2H_4+C_3+iC_4+nC_4+iC_5+nC_5+C_6+)$

poorly understood. Recent work demonstrating significant subglacial water influx into Paleozoic rocks to the east of the study area (Grasby et al., 2000; Grasby and Chen, 2005) raises the possibility that organic-rich shale in the Manitoba Escarpment area was similarly impacted by subglacial water flow. Studies on the Antrim shale in the Michigan Basin show that subglacial water intrusion into organic-rich shale units can initiate the generation of economic accumulations of biogenic gas (McIntosh et al., 2002).

The Shallow Unconventional Shale Gas Project is dispelling some of the mystery surrounding this type of potential gas resource and provides industry with the basic information needed to undertake exploration in the new and risky unconventional shallow shale gas plays in southwest 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 and covering an area of approximately 50 000 km^2, economic benefits—if resources are present—could be significant.

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