## Introduction

Shallow shale gas occurrences have been recorded in Manitoba for over a century (Bamburak, 2008; Nicolas, 2008), but the understanding of, and geoscientific data on, this potential economic resource was limited.The Shallow Unconventional Shale Gas Project is a four-year investigation of the shale gas potential of Manitoba's Mesozoic stratigraphy. The formations being evaluated for shale gas are the Ashville, Favel, Carlile and Pierre Shale **(Figure 1)**. The preliminary organic geochemistry and mineralogical results of the samples collected in 2008 are indicative of significant shale gas generation potential in the southern part of the study area, namely in the Pembina Hills and Pembina Valley regions. These findings are discussed in detail in Nicolas and Bamburak (2009), and presented in summary here. The 2009 field season was focused on collecting samples from the northern part of the study area, particularly in the Riding Mountain, Swan River Valley, Duck Mountain and Porcupine Hills regions **(Figure 2)**.

Two capped gas wells and select domestic water wells were targeted for sampling in the Pembina Hills area in southwest Manitoba; water well selection was based on their total depth, aquifer lithology (only shale aquifers were chosen), and location (on the Manitoba Escarpment). Water and gas chemistry of the Cretaceous shale aquifers and gas reservoirs were analysed and reported in detail in Nicolas and Grasby (2009). Chemistry and stable isotope results indicate that accumulations of biogenic natural gas are present in this area. Stratigraphic extrapolations of the water 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 in the Pembina Hills region.

An outcrop discovered in 2008 of the Boyne Member of the Carlile Formation showed a two metre thick silty shale-sandy siltstone unit **(Figure 3)**. These beds are unofficially termed the "Babcock" beds because these same beds were mined in the early 1900's to produce natural cement, near the old community of Babcock. Geochemical and mineralogical analysis of these beds indicate that in the subsurface, these beds could be a potential shale gas resource due to their high total organic carbon (TOC) and quartz contents. These same beds correlate to the Boyne Sand, which was the gas-producing reservoir unit in the town of Kamsack, Saskatchewan.

Thin sections examination of the Babcock beds shows that the coarser fractions in this beds are dominantly quartz. Scanning electron microscopic (SEM) examination shows a strong porosity distribution in the horizontal direction, between clay particles due to the fissile nature of the unit **(Figure 3c)**. Silt and sand-sized quartz grains occur throughout, as either quartz-rich lenses or as individual grains within the clay matrix. A vertical permeability is present as random hairline fractures in places, but can also be seen in outcrop as large-scale vertical jointing patterns.

**SOUTHWEST MANITOBA**

| | | |
|---|---|---|
| CRETACEOUS | Pierre Shale | Coulter Member |
| | | Odanah Member |
| | | Millwood Member |
| | | Pembina Member |
| | | Gammon Ferruginous Member |
| | Carlile Formation | Boyne Member |
| | | Morden Member |
| | Favel Formation | Assiniboine Member |
| | | Keld Member |
| | Ashville Formation | Belle Fourche Member |
| | | Westgate Member |
| | | Newcastle Member |
| | | Skull Creek Member |

**Figure 1:** Cretaceous stratigraphic column of southwestern Manitoba showing the target formations for this study; highlighted members have documented gas shows.

## Phase 2 Field Work

The majority of the 2009 fieldwork was conducted in the phase 2 region of the study area **(Figure 2)**. The work was initially planned to consist of outcrop sampling in the Riding Mountain, Swan River Valley, Duck Mountain and Porcupine Hills regions. High water levels and local flooding in creeks and rivers resulted in only 14 (of the approximately 40 planned) individual Cretaceous outcrop sites being examined and sampled. A total of 30 new Cretaceous samples were collected and represent various stratigraphic positions within the Belle Fourche Member of the Ashville Formation, and the Assiniboine and Keld members of the Favel Formation. To compensate for the limited access to outcrops and lack of sampling opportunities, archived samples collected for the black shale investigations (discussed in Bamburak, 1999) will be included in this study to ensure a wide stratigraphic coverage.

## Student Project

S. Edmonds from the University of Manitoba, Department of Geological Sciences is studying the porosity and permeability of the Babcock beds of the Boyne Member of the Carlile Formation. Using a scanning electron microscope (SEM), she is documenting the size, morphology, distribution and connectivity of the pores within this organic-rich bed. **Figure 3c** shows a SEM image of the Babcock beds.

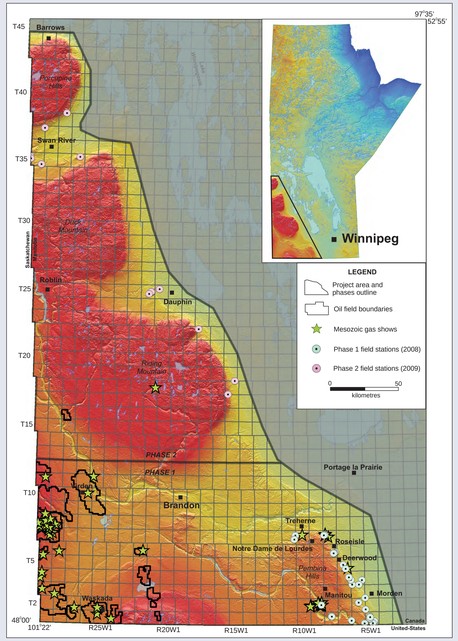


**Figure 2:** Digital elevation model showing the study area of the Shallow Unconventional Shale Gas Project, the location of Phase 1 and Phase 2 of the project, Mesozoic gas shows in relation to extisting oil fields, field station sites of the 2008 and 2009 sampling program.

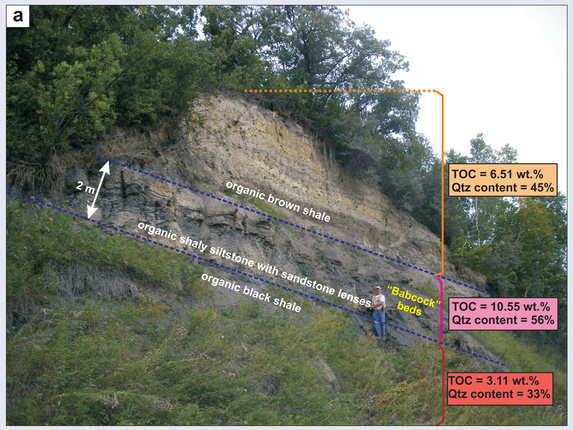


**Figure 3:** Summer 2008 field work photos showing outcrop of the lower Boyne Member beds, an excellent source and potential reservoir rock: **(a)** outcrop of the lower to middle section of the Boyne Member in Snow Valley, near the town of Roseisle, with organic shaly siltstone and sandstone beds ("Babcock" beds) more resistant to weathering than the overlying and underlying shale, well developed, large-scale vertical jointing is also visible; and **(b)** close-up of outcrop in (a), showing the shaly siltstone bed with sandstone lenses. TOC and average quartz contents for each sequence is indicated; **(c)** SEM image of the shaly siltstone in (b) showing horizontal porosity, parallel to bedding, as controlled by the fissile nature of the bed, black spherical voids represent areas where quartz grains fell out during sampling preparation, 1000x magnification.

## Organic Geochemistry

Rock-Eval 6 ®/TOC was conducted on all the outcrop samples collected to date, and the results were compiled with historical Rock-Eval/TOC databases from Nicolas (2009) and Obermayer et al. (2005). The compiled data was then filtered to eliminate false results; in some cases this completely eliminated the Odanah and Millwood members from the charts due to the extreme immaturity of the sediments and low organic content. **Figure 4** shows some of the preliminary results from this geochemical compilation subdivided by member.

The $T_{max}$ and TOC results indicate that the shale formations have not reached thermal maturity, but most of these rocks are good to excellent source rocks, respectively. Despite the immaturity of the sediments, the Production Index (PI) plot several shale members into the thermogenic window. This is due to the high concentration of free or adsorbed gas in the system, suggesting a biogenic origin.

The modified van Krevelen diagram is used to distinguish kerogen types, with some shales plotting between the Type II and Type III kerogen lines, and some below the Type III line **(Figure 5)**. This sort of signature is expected, particularly with an abundance of points below the Type III kerogen line, due to the overall immaturity of these sediments, particularly as the sediment becomes younger.

These preliminary results suggest the Ashville Formation Belle Fourche Member, Favel Formation and Carlile Formation, particularly the Boyne Member, are the best targets for shallow shale gas exploration.

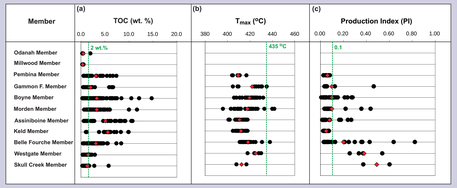


**Figure 4:** Rock-Eval results grouped by member and placed in order of increasing stratigraphic depth. **(a)** The green line in the TOC graph equals 2 wt. %, which indicates the preferred minimum TOC value for a good source rock. **(b)** The green line in the Tmax graph equals 435ºC, which corresponds to the oil window for mature oils. **(c)** The green line in the Production Index graph equals 0.1, which indicates the minimum PI value for thermogenically derived oil and gas. Average values for each member and for each parameter are plotted in red.

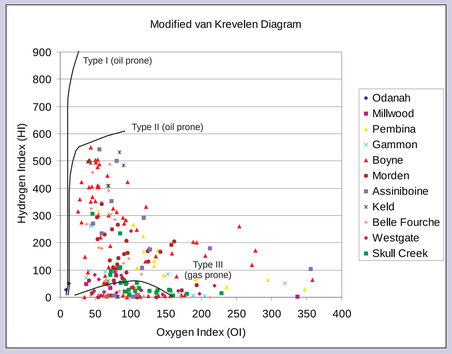


**Figure 5:** Modified van Krevelen diagram of new and archival Rock-Eval data grouped by member.

## Mineralogy

X-ray diffraction (XRD) was conducted on a select suite of 47 samples collected from outcrops. Samples were analysed if they had a TOC > 2 wt%, in addition to all the Odanah Member samples due to its siliceous character. **Figure 6** shows an averaged mineralogy distribution for the samples. Of particular interest is the high quartz content of the shale sequences. With the XRD results, the averaged mineralogy is misleading, since upon closer analysis at the individual results, the Boyne Member, which shows an average of ~35% quartz on the graph, actually has quartz contents ranging from 8% to 89%.

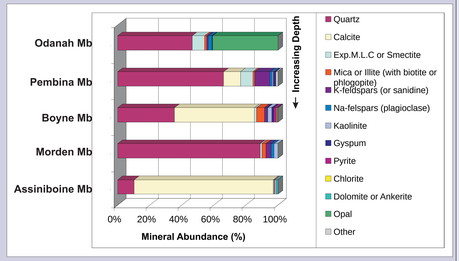


**Figure 6:** Averaged XRD results grouped by member.

## Gas and Water Chemistry

### *Sampling and analysis*

Sampling of 15 wells (two gas wells and 13 water wells) in the Pembina Hills region was carried out in September and October 2008, with follow-up sampling at select 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. Water samples were analyzed for dissolved solids, alkalinity, sulphates, and dissolved gases at the Geological Survey of Canada in Calgary. Free gas samples were collected from the gas wells and from effervescent water wells (i.e. flowing water with abundant bubbles; **Figure 7**). 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 (â$^{13}$C and âD).

### *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.

Of all the samples, five well samples yielded high methane contents and dry gas indices of 0.99 to 1.00 (water wells at SE 30-7-8W1, NW 18-2-9W1, SE 22-2-9W1, and gas wells at SE 23-2-9W1 and SW 23-2-9W1). 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 SW1/4 23-2-7W1 was the only effervescent water sample lacking high methane content, but has very high nitrogen content in contrast.

### *Stable isotopes*

Stable isotopes of gas samples have â$^{13}$C values from -75 to -85‰, with âD values averaging -270‰ free gas samples. These values are distinctive of biogenic gas (Whiticar, 1999) and values of >0.99 for these samples are consistent with the very high dry gas index.

### *Water chemistry*

Water samples compositions range from fresh to brackish and Ca-$HCO_3$ to Na-$HCO_3$ dominated. Well samples with the lowest $SO_4$ concentrations correlate to methane-bearing effervescent water wells. This is consistent with high $SO_4$ levels supporting sulphate-reducing bacteria that outcompete methanogenes, and suggests that sulphate concentrations may play an important role in limiting biogenic methane production.


**Figure 7:** Gas shows in the Pembina Hills in southwest Manitoba: **(a)** gas well head and storage tank near Manitou, Manitoba, well drilled in 1933; **(b)** flaring of gas well head with storage tank near Manitou, Manitoba, well drill in 1907;**(c)** gas bubbles in water well near Notre Dame de Lourdes, Manitoba, well drilled in 1936; **(d)** flaring of water/gas well near Notre Dame de Lourdes, Manitoba, well drilled in 1936; **(e)** collection of effervescent water sample taken from a domestic water well at kitchen sink; note gas bubbles in water and gas-filled head space in bottle; **(f)** collection of effervescent water sample, note gas bubbles in water and gas-filled head space in bottle.

## Economic Considerations

The recognition of silty and sandy beds within the Boyne Member of the Carlile Formation in the Pembina Hills is critical for Manitoba to be considered as a potential player in the business of unconventional shallow shale gas exploration. Aside from having the right lithological characteristics, the use of a combination of organic geochemistry and mineralogical investigations on these beds may result in the discovery of a large natural gas resource in the province. Searching for other units in the Cretaceous shale sequence that have the right geochemical and mineneralogical characteristics is important in order to expand the potential pay zone thickness at any given location to make exploratory drilling more attractive. The historical success of the Kamsack gas field in Saskatchewan, which produced from the same stratigraphic unit, suggest that even as single pay zone, the Babcock beds in Manitoba could potentially be produced economically without the need for commingling with other gas zones.

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 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 (covering an area of approximately 50 000 km$^2$) economic benefits—if resources are present—could be significant.

## Conclusions

Manitoba has a vast shale gas resource that has not been adequetly explored with modern technology. Early results from this study are encouraging. The combination of shale with thick siltstone and sandstone beds, documented gas shows, low Tmax values, high TOC contents and high quartz fractions within the Boyne Member of the Carlile Formation indicate that Manitoba has the right geological conditions for the generation of unconventional shallow shale gas of biogenic origin.

The best Cretaceous shale gas targets in Manitoba are the Carlile Formation, particularly the Boyne Member, Favel Formation and Belle Fourche Member of the Ashville Formation. In the Pembina Hills region, the units with confirmed gas resource is the Assiniboine Member of the Favel Formation and the Boyne Member of the Carlile Formation.

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**Cretaceous shallow unconventional shale gas in southwest Manitoba - evidence for biogenic gas resource**

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