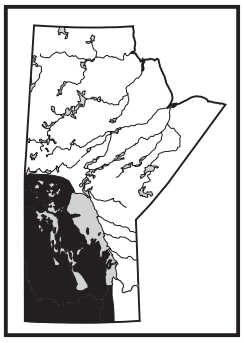
GS-16 Summary report on petroleum and stratigraphic investigations, southwestern Manitoba

by M.P.B. Nicolas



Nicolas, M.P.B. 2008: 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.

Summary

Stratigraphic and petroleum investigations in the Phanerozoic of southwestern Manitoba focused on three major projects during the past year: 1) Williston Basin Targeted Geoscience Initiative 2 (TGI-2), 2) Devonian Three Forks Formation Project, and (3) Shallow Unconventional Shale Gas Prospects Project.

Key components of the Williston Basin TGI-2 Project in 2008 are the release of the formation-tops database and the final stratigraphic-map series. Using tops information from more than 9000 wells, 98 maps covering 58 different horizons from the Precambrian surface to the Belly River Formation (equivalent to the Pierre Shale, Odanah Member in Manitoba) were mapped and are available for free download at www.WillistonTGI.com.

The Devonian Three Forks Formation Project is in its second phase of study, expanding the core and drill cuttings logging over the entire Three Forks depositional area in Manitoba, examining producing pools outside the Sinclair Field and evaluating the potential of less-explored areas. New oil shows have been discovered, and a Sanish-like sandstone was identified in a couple wells.

The Shallow Unconventional Shale Gas Project is in its first year of a four-year investigation of the shale gas potential in Manitoba's Mesozoic shale sequences, particularly the Ashville, Favel, Carlile and Pierre formations. Historical and new gas shows will be mapped, and geochemical (including rock pyrolysis using Rock-Eval® and total organic carbon [TOC]) and mineralogical analysis will be conducted on samples from these horizons. Field investigations identified a thick siltstone unit in the Boyne Member of the Carlile Formation that can potentially serve as a gas reservoir in the subsurface.

Introduction

Three major stratigraphic and petroleum projects were in progress during the past year in southwestern Manitoba: 1) Williston Basin Targeted Geoscience Initiative 2 (TGI-2), 2) Devonian Three Forks Formation stratigraphy and hydrocarbon potential, and 3) Shallow Unconventional Shale Gas Prospects.

Currently in its fifth year, the Williston Basin TGI-2 Project is nearing completion. The past year has seen many of the major tasks in this project come to completion, including the completion of the formation-tops database, the stratigraphic-map series and the hydrocarbon-assessment compilation.

Manitoba's oil patch has seen record high production and drilling activity in the last two years. The discovery of the Sinclair Field in 2004 has introduced the Devonian Three Forks Formation as the new play in Manitoba. Prior to this discovery, the Three Forks Formation was poorly understood and often overlooked as a potential hydrocarbon reservoir in Manitoba. Development and exploration drilling to test and exploit this formation has been the focus of many oil companies active in Manitoba, and their success has started to trigger outside oil companies' interest in investing in Manitoba. The purpose of the current geoscientific examination of the stratigraphy and hydrocarbon potential of the Devonian Three Forks Formation is to assist ongoing exploration and promote future oil exploration in southwestern Manitoba.

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 decades, 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 needed to undertake exploration in the new and risky unconventional shallow shale gas plays. The current project is targeting mostly the Mesozoic formations, including the Ashville, Favel, Carlile and Pierre formations (Figure GS-16-1).

Williston Basin TGI-2 Project

Several main products have been finished and released during the final phase of the Williston Basin TGI-2 Project (Figure GS-16-2), notably the formation-tops database, a final stratigraphic-map series and a hydrocarbon-assessment compilation. The 98 stratigraphic maps, using formation tops information from 9012 wells, include 58 different stratigraphic horizons from the Precambrian surface to the Belly River Formation (equivalent to the Pierre Shale, Odanah Member in Manitoba).

The final formation-tops database includes 2606 wells from Manitoba, 5046 wells from Saskatchewan, 771 wells from North Dakota and 589 wells from Montana. Computer-generated structure and isopach maps for 58 geological horizons, spanning Manitoba, Saskatchewan, North Dakota and Montana, were created using this database. North Dakota and Montana data are

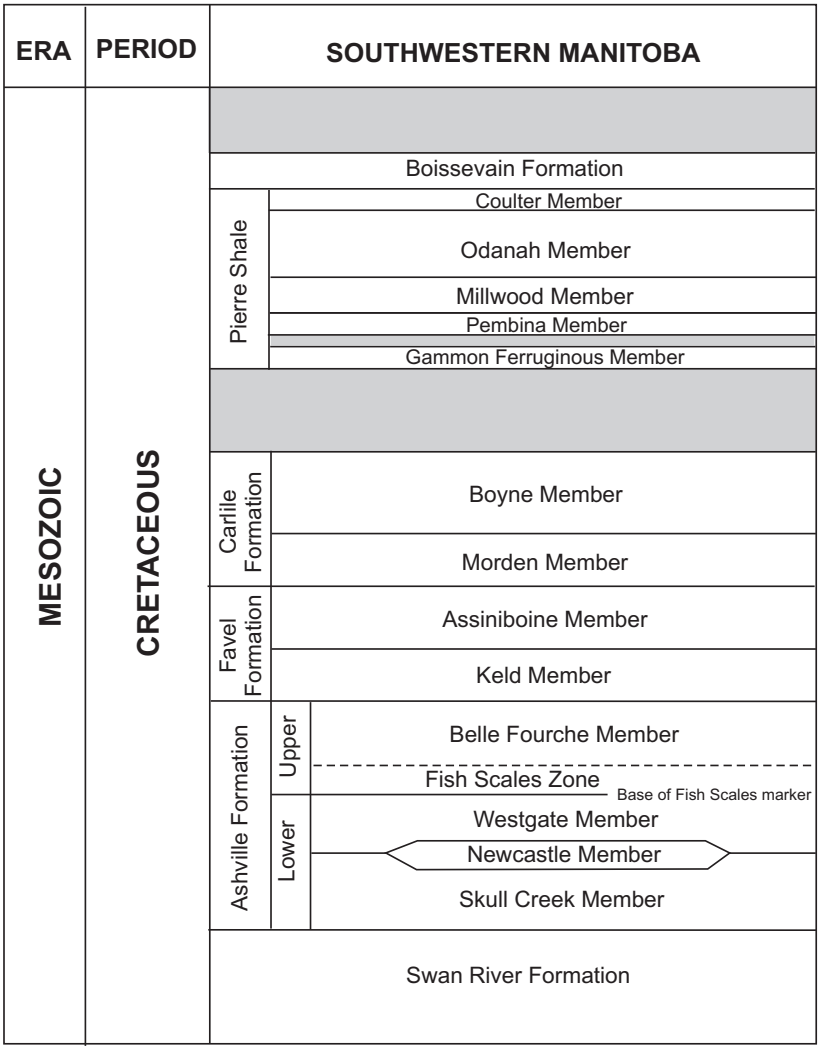


Figure GS-16-1: *Cretaceous stratigraphy of southwestern Manitoba.*

hidden on the final suite of maps, but were used during map generation to maintain geological accuracy of the contours at the Canada–United States border. Structure and isopach maps were all computer generated using ArcInfo® GIS Spatial Analyst (version 9.2). All maps are drawn at a 1:1 000 000 scale. Map specifications are as follows: Universal Transverse Mercator projection with a central meridian of 101°W; North American Datum (NAD) 1983; and tension spline spatial interpolation used for the structure maps and inverse distance weighted spatial interpolation used for the isopach maps. The database and maps are available for free download at www.WillistonTGI.com.

The compilation of hydrocarbon assessment contains public data from government reports, maps and files, including oil field, pool and unit boundaries, reserves information, core listings, oil and gas shows, drill-stem test results, and source-rock geochemistry (Rock-Eval®–TOC) data. The data compilation is integrated in an interactive GIS-based ArcExplorer® map, with accompanying Excel® and shape files available for download.

To further the geological knowledge base of the TGI team on the Phanerozoic stratigraphy of the Williston Basin, two field trips at the beginning of the project visited field sites, most of which are located in Manitoba's outcrop belt. The first field trip focused on the lower to middle Paleozoic stratigraphy of southwestern Manitoba (Bezys and Bamburak, 2004), from north of Winnipeg through the Interlake region to the west side of Lake Winnipegosis. The second field trip focused on Mesozoic stratigraphy along the Manitoba Escarpment (Bamburak and Christopher, 2004), from Turtle Mountain north to the Pasquia Hills in Saskatchewan. In 2008, the guidebook notes, photographs and GPS co-ordinates for each site were compiled and are presented as a virtual field trip, utilizing Google Earth's platform for viewing. The virtual field trip file is available for free download from the TGI-2 website.

In collaboration with the University of Saskatoon, the Williston Basin TGI-2 Project acquired seismic, aeromagnetic and gravity data to produce a comprehensive report on geophysical investigations of the Precambrian

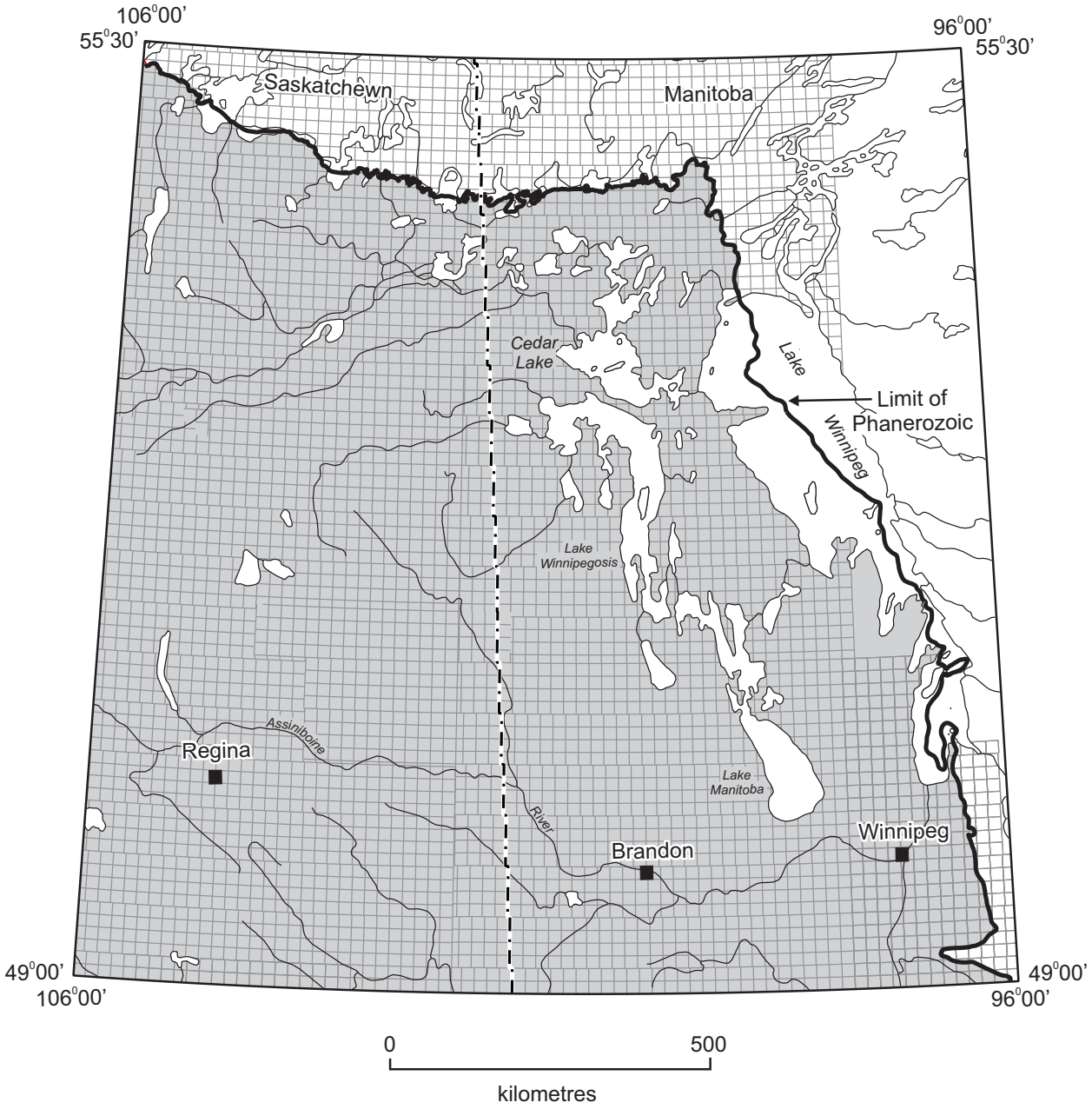


Figure GS-16-2: *Williston Basin TGI-2 Project area in Saskatchewan and southwestern Manitoba (grey shading).*

basement beneath the Williston Basin in the TGI-2 project area. The final report on the geophysical investigations by Li and Morozov (2007) can be downloaded free from the TGI-2 website.

A series of maps consisting of total dissolved solids, freshwater head and water driving force for each of the 18 hydrostratigraphic units (from basement to surface) has been completed, in conjunction with hydrochemical and hydraulic cross-sections. The hydrogeology maps were built using the established stratigraphic horizons developed for the project. The final report, being prepared by D. Palombi from the University of Alberta as M.Sc. thesis, is near completion.

A regional grid, consisting of six east–west and eight north–south cross-sections throughout the study area, is in progress. Due to the great thickness of the Phanerozoic section represented in these cross-sections, each cross-section line is subdivided into individual sections for the Mesozoic, Mississippian, Devonian and Lower Paleozoic (Silurian to Cambrian) strata. This task is being led by M. Yurkowski of Saskatchewan Energy and Resources. When completed, all cross-sections will be available in PDF format for free download from the TGI-2 website.

The following summary reports for the project have been recently released by the Manitoba Geological Survey or are in progress:

- results of the biostratigraphy sampling program for the Manitoba samples (Nicolas, 2008)

- stratigraphy, mapping and hydrocarbon assessment of each formation of the Paleozoic sequence (Nicolas and Barchyn, 2008)
- stratigraphy, mapping and hydrocarbon assessment of Mesozoic formations, from the base of the Amaranth Formation to the top of the Pierre Formation (Nicolas, work in progress, 2008)

Devonian Three Forks Formation Project

The Sinclair Field (Figure GS-16-3; Twp. 7–8, Rge. 28–29, W 1st Mer.) is the newest oil field discovery in Manitoba and has greatly expanded in size and production since its discovery in 2004. The area had been previously explored in the 1960s, but the producing interval was missed by early exploration efforts. The Sinclair Field has produced approximately 1.44 million m^3 of oil (cumulative to March 31, 2008) and, in 2008, represents 43% of Manitoba's total oil production. Proven and probable reserves are estimated at 6.8 million m^3.

The study area consists of the entire subsurface distribution of the Three Forks Formation in southwestern Manitoba, from the Saskatchewan and United States borders east and north to the Three Forks erosional subcrop edge (Figure GS-16-3).

The Devonian Three Forks Formation is a cyclical transgressive-regressive sequence of shaly to silty dolomitic arenite, interbedded with silty shale, and is brecciated in many places. Deposition of the formation was controlled by repetitive transgressive and regressive cycles and basin tectonics. The formation is subdivided into (from bottom to top) units 1, 2, 3 and 4, as described in Nicolas (2006, 2007).

Unit 4 is the primary and most productive reservoir in the Sinclair Field. Units 2, 3 and 4 are productive at the unconformity surface as a subcrop-type play. In contrast, the production from unit 1 is due to a stratigraphic-type play. Thinning of the Three Forks Formation and truncation of the best reservoir units towards the east suggest that the eastern expansion of the Sinclair Field may be limited. Mapping of these units towards the south along Rge. 29, W 1st Mer. indicates that unit 4 is preserved to the Manitoba–United States border, thereby extending the reservoir potential to the south.

The Three Forks oil play in Manitoba is related to the popular and highly productive Bakken oil play of Saskatchewan and North Dakota. In Manitoba, the absence of the Lower Bakken shale, which acts as a seat seal for the Bakken oil play in other parts of the basin, means the oil system of the Middle Bakken in Saskatchewan and North Dakota extends into the Middle Bakken in Manitoba but also includes the Three Forks Formation as part of the same petroleum migration system. The Middle Bakken in Manitoba is thin compared to other parts of the basin due to erosion, but the gross reservoir thickness of the Middle Bakken and the Three Forks siltstone-rich units is as much as 25 m, making it a formidable exploration target.

Fifteen cores from the Sinclair Field and two cores from outside the field were logged during phase 1 of this study (Nicolas, 2006). As part of phase 2, 30 additional cores and drill cuttings were logged in 2008 to help characterize the regional Three Forks Formation both inside and outside the Sinclair Field. Geophysical logs for all wells that penetrate the Three Forks Formation (1355 wells in total) were examined, and formational, member and unit tops were picked where available in the Bakken, Three Forks and Birdbear formations.

Preliminary findings from phase 2 include the discovery of oil staining within the Three Forks exploration target areas recommended in Nicolas (2007), as well as some outside the target areas. Outside the current Bakken–Three Forks producing areas, oil shows in core were found in the Bakken Formation and/or Three Forks interval in L.S. 2, Sec. 35, Twp. 2, Rge. 26, W 1st Mer. (abbreviated 2-35-2-26W1), 6-7-4-21W1, 5-3-4-25W1, 4-17-4-29W1, 4-4-6-29W1, 5-11-11-26W1, 9-28-12-28W1, 6-31-14-27W1, 9-9-14-29W1, 2-14-16-28W1 and 2-16-17-28W1. The oil shows were found to be associated with units with a high silt content.

Of particular interest are two wells exhibiting log signatures comparable to the highly productive Sanish sandstone in the uppermost part of the Devonian Three Forks Formation in the North Dakota part of the Williston Basin (LeFever, 2004). In North Dakota, the Sanish sandstone is a medium brown, highly burrowed argillaceous siltstone to very fine grained sandstone, with dolomite and anhydrite cement; it has a maximum isopach of 7.3 m and is mappable on geophysical wireline logs (LeFever, 2004). It occurs at the top of the typical Three Forks assemblage (unit 4 *in* Nicolas, 2006) below the Bakken Formation, typically in contact with the Lower Bakken shale. LeFever (2004) reported that formation of the Sanish sandstone appears to be related to the dissolution of the Devonian Prairie Evaporite.

The wells in 2-35-2-26W1 and 5-3-4-25W1 have a thickened Three Forks interval, with an additional sandstone-siltstone package above the Three Forks unit 4 cycle. The drill cuttings indicate a dolomitic argillaceous siltstone to very fine grained sandstone, typical of the Sanish sandstone. In 5-3-4-25W1, this interval had oil staining and pale yellow UV fluorescence. Both wells are sites of salt-collapse structures related to the dissolution of the Devonian Prairie Evaporite. The 2-35-2-26W1 well has the Lower Bakken shale preserved above the possible Sanish interval, indicating that erosion would not have removed the Sanish if it had been deposited. In contrast, the Lower Bakken in 5-3-4-25W1 is absent and was likely eroded, preserving the thick Sanish interval in the collapse structure. LeFever (2004) reported a maximum thickness of 7.3 m for the Sanish sandstone in North Dakota, whereas the wells in 2-35-2-26W1 and 5-3-4-25W1 show preserved thicknesses of 8.7 and 14.0 m, respectively.

The possibility that a Sanish-like sandstone is present in Manitoba and is associated with salt collapse, as it is

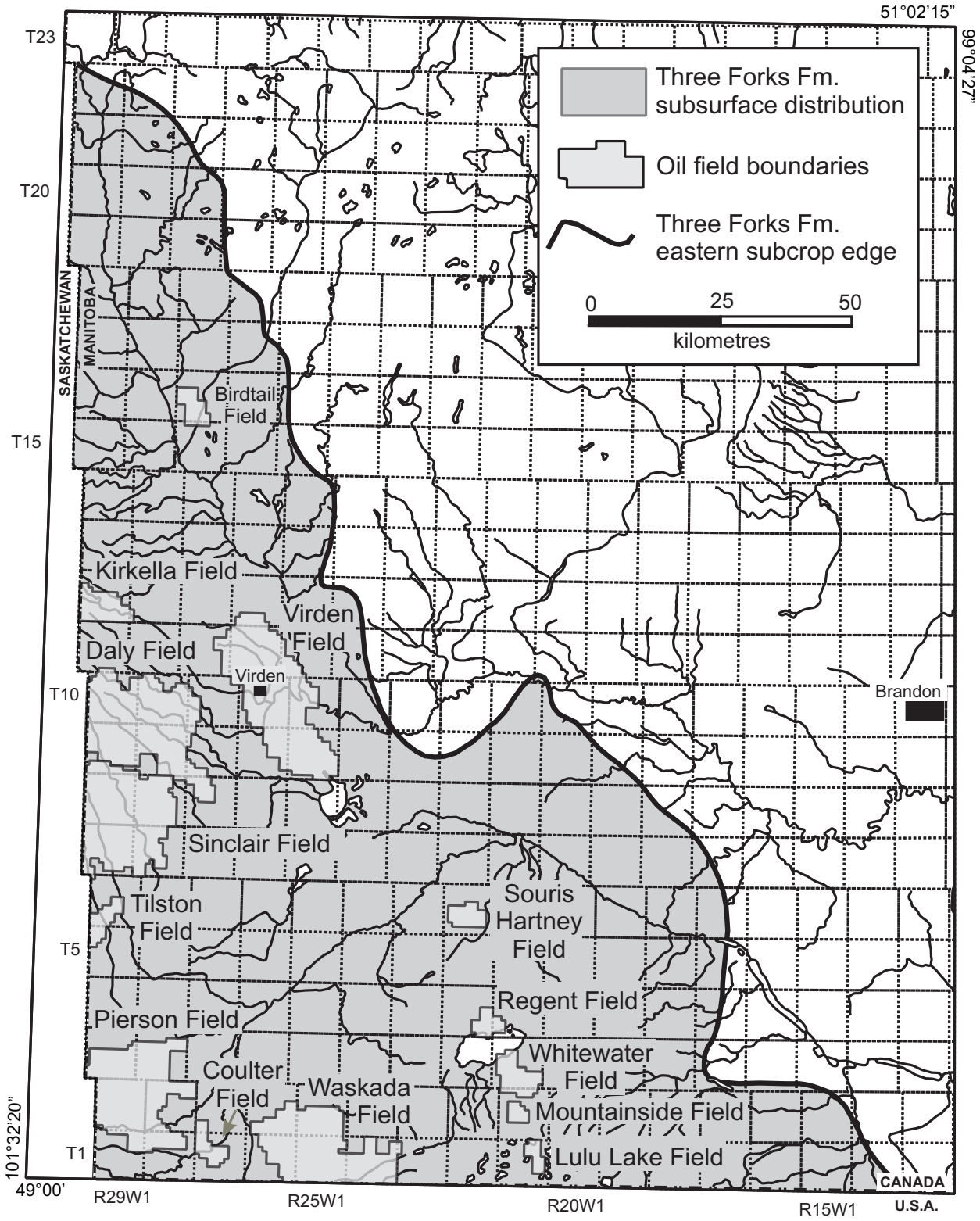


Figure GS-16-3: *Study area for the Devonian Three Forks Formation Project, showing the subsurface distribution of the formation and areas of cores/cuttings logged in southwestern Manitoba (i.e., oil fields).*

in North Dakota, raises the question of where to explore for this unit in Manitoba. The Waskada Field, known for its multistage salt collapse, may be a priority target for exploration. Very few wells in the Waskada Field, however, have been drilled beyond the Mission Canyon Formation, making it a prime area for a deep-drilling exploration program to test these deeper prospective horizons.

Shallow Unconventional Shale Gas Prospects Project

Introduction

The presence of natural gas in Cretaceous rocks of Manitoba is documented in a number of gas shows (Figure GS-16-4; Manitoba Industry, Economic Development and Mines, 2005). Variations in the character of the rock and the best locations for trapping the Cretaceous shale gas, however, are insufficiently known and need to be further investigated to pursue this play to the next level. If the Cretaceous shale sequences of Manitoba are found to be exploitable, the economical impacts for Manitoba could be significant. The potential area for gas production extends from the Manitoba Escarpment west to the Saskatchewan-Manitoba border and from the Porcupine Hills south to the Canada–United States border (Figure GS-16-4).

The shallow gas fields of western Saskatchewan and southern Alberta are the largest Canadian gas fields discovered to date. These mature gas fields are characterized by shallow depths, low-permeability clay-rich sandstone and locally generated biogenic gas (O'Connell, 2003). These gas fields produce from the Second White Specks, Medicine Hat and Milk River Formations, and production from these fields is expanding eastward in Saskatchewan, with much interest extending into Manitoba. The field limits of these shallow gas accumulations are strongly dependent on economic conditions rather than reservoir size of gas pools, as is the case for conventional oil accumulations. Drilling density for shallow gas fields, however, is much lower than for oil pools, averaging one well per section as opposed to as many as 16 wells or more per section for oil.

Exploiting the shallow shale gas has its challenges: the reservoirs tend to be tight, consisting mostly of silty shale with some siltstone lenses, and have a high clay content. Understanding the clay mineralogy, particularly the adsorption properties and swelling capability, plays an important role in shale gas plays. Irreversible formation damage during drilling can damage the permeability of the shale by clogging up the small pore spaces with the migration of fine-grained particles or by swelling of the clay. Modern noninvasive drilling techniques are therefore required to effectively and successfully produce the gas; underbalanced air drilling is preferred, often in association with multistage fracturing techniques.

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.

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. 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. The other two wells were terminated in the Fish Scale interval of the Belle Fourche Member, Ashville Formation; both wells were cored in the Boyne Member of the Carlile Formation; their current status is 'completing', with the companies awaiting a decision to either attempt production or to abandon the wells.

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 GS-16-1). 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 GS-16-4). 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 (Figure GS-16-4).

Phase 1 will 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®–TOC geochemistry, X-ray diffraction and clay speciation. J. Bamburak (GS-17, this volume) will be conducting a whole-rock geochemistry program and evaluation on the samples. Detailed log analysis will be conducted on wells to get sand-silt-shale ratios, and water resistivities and formation temperatures where possible. Payson gas readings will be compiled to give a qualitative assessment of the gas content in each formation. Water samples will be collected and sent for dissolved gas, dissolved solids, alkalinity and stable isotope analysis to determine the composition of the gas and whether it is biogenic or thermogenic. A scanning electron microscope (SEM) will be used to evaluate mineralogical and porosity characteristics, such as pore geometry and permeability.

At the end of the project, a Geoscientific Report will summarize the shallow shale gas prospects for Manitoba,

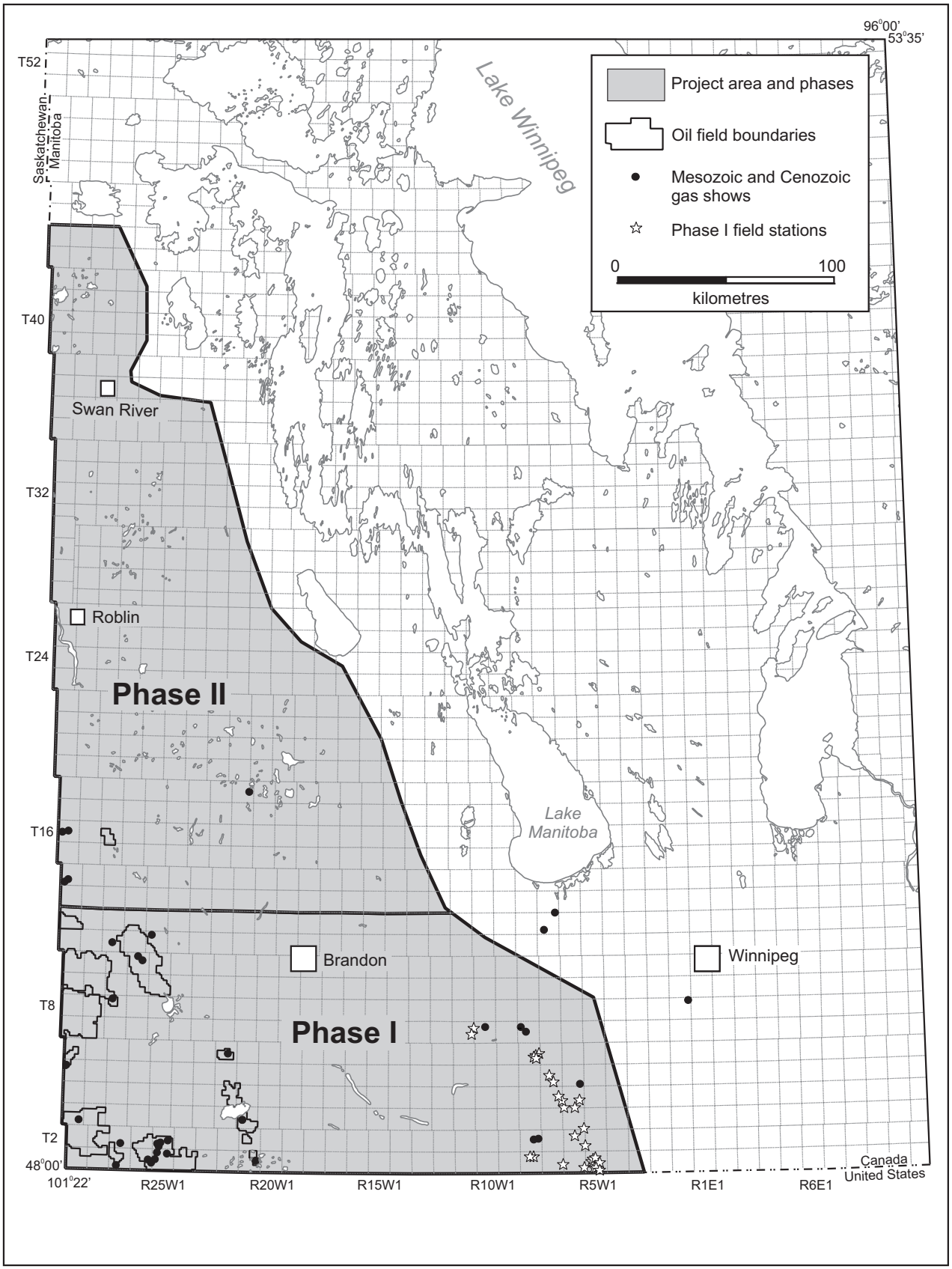


Figure GS-16-4: *Study area for the Shallow Unconventional Shale Gas Prospects Project, location of phases 1 and 2 of the project, Mesozoic and Cenozoic gas shows in relation to existing oil fields, and field station sites of the 2008 sampling program.*

and will include the identification of 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

Fieldwork was conducted over a five-day period to sample Late Cretaceous shale from the Pembina Hills and Pembina Valley region in southwestern Manitoba. A total of 35 individual field sites (shown on Figure GS-16-4) 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. Selected samples will be sent for various geochemical and mineralogical analyses, as mentioned above. Two additional days of fieldwork are scheduled for this fall to collect water samples from domestic 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. In contrast, the Morden Member of the Carlile Formation and the Pembina and Millwood members of the Pierre Shale showed no lithological variations 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, 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. This resistant unit can be subdivided into two beds: a lower shaly siltstone and 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. The upper shaly siltstone to sandstone is similar to the lower unit, but contains thin beds and lenses of fine sandstone throughout. The outcrop, located in the Snow Valley along Roseisle Creek southwest of Roseisle, Manitoba (UTM Zone 14U, 541157E, 5480360N, NAD 83), is the only location visited that displayed this particular siltstone bed; all other Boyne outcrops were stratigraphically higher. One quarry outcrop northeast of Notre Dame de Lourdes along the Manitoba Escarpment edge (UTM 533411E, 5493093N), contains a thin siltstone bed in the upper Boyne Member, 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.

Economic considerations

The Williston Basin TGI-2 Project is a large multijurisdictional program focused on mapping the entire stratigraphy from the top of the Precambrian to the uppermost subsurface-mappable Cretaceous, which includes all potential hydrocarbon-bearing formations in Manitoba. All products derived from this project are available for free download from the www.WillistonTGI.com website by anyone interested in taking a closer look the Saskatchewan and Manitoba Paleozoic and Mesozoic units. In Manitoba, the two least-explored parts of the section are 1) the deep Devonian- to Cambrian-age formations, and 2) the shallow Mesozoic-age formations. The results from the Williston Basin TGI-2 Project have already significantly improved the knowledge base on these formations, and have provided a new perspective and understanding of the traditional hydrocarbon target formations. The new, continuous subsurface map provides a new standard for evaluating the economic potential of the Phanerozoic in southwestern Manitoba, particularly for companies whose current exploration is limited to Saskatchewan.

The Devonian Three Forks Formation oil play in Manitoba is a spin-off from the large Bakken Formation play of North Dakota, Montana and Saskatchewan. The 'Bakken' rush resulted in most promising lands being tied up quickly throughout the entire Williston Basin area, including the Manitoba portion. This rush has left little room for new or smaller companies to participate in the oil play. Understanding the subtleties of the Three Forks deposition and erosion in Manitoba has helped identify other sites in which this profitable formation may have potential. New exploration activities, including geophysical surveys and drilling, together with land-sale revenues, will have a direct, positive economic impact, particularly in currently less explored areas.

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 author would like to thank R. Bezys for her extensive knowledge, guidance, motivation and support throughout these projects, and J. Bamburak for helping provide an understanding of the Mesozoic strata in Manitoba, his patience with endless questions, his exceptional knowledge and guidance in the field, and his peer review of this paper. The mentorship received from both of them is greatly appreciated.

Thanks are also due to the staff of the MGS Midland Core Facility for pulling out endless boxes of cores, and a special thanks goes to V. Varga for the making of the difficult thin sections. B. Lenton is gratefully acknowledged for the preparation of the figures.

References

Bamburak, J.D. and Christopher, J.E. 2004: Mesozoic stratigraphy of the Manitoba Escarpment; Manitoba Industry, Economic Development and Mines, WCSB/TGI II Field Trip Guidebook, Sept. 7–10, 2004, 83 p.

Bezys, R.K. and Bamburak, J.D. 2004: Lower to Middle Paleozoic stratigraphy of southwestern Manitoba; Manitoba Industry, Economic Development and Mines, WCSB/TGI II Field Trip Guidebook, May 25–28, 2004, 72 p.

LeFever, J.A. 2004: PTTC-RMAG Bakken core workshop, September 24, 2004; North Dakota Geological Survey, GI-4, URL https://www.dmr.nd.gov/ndgs/bakken/Bakkencd/Bakkencd.zip [October 3, 2008].

Li, J. and Morozov, I. 2007: Geophysical investigations of the Precambrian basement of the Williston Basin in southeastern Saskatchewan and southwestern Manitoba; University of Saskatchewan, Final Project Report, URL http://seisweb.usask.ca/Reports/TGI2/ [October 3, 2008].

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.

Nicolas, M. 2006: Petroleum geology of the Devonian Three Forks Formation, Sinclair Field and surrounding area, southwestern Manitoba; *in* Saskatchewan and Northern Plains Oil and Gas Symposium Core Workshop Volume, E.H. Nickel (ed.), Saskatchewan Geological Society, Special Publication 20, p. 32–49.

Nicolas, M.P.B. 2007: The Devonian Three Forks Formation, southwestern Manitoba (NTS 62F and parts of 62G and 62K); *in* Report of Activities 2007, Manitoba Science, Technology, Energy and Mines, Manitoba Geological Survey, p. 175–185.

Nicolas, M.P.B. 2008: 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. and Barchyn, D. 2008: Williston Basin Project (Targeted Geoscience Initiative II): summary report on Paleozoic stratigraphy, mapping and hydrocarbon assessment, southwestern Manitoba; Manitoba Science, Technology, Energy and Mines, Manitoba Geological Survey, Geoscientific Paper GP2008-2, 21 p.

O'Connell, S. 2003: The Second White Specks, Medicine Hat and Milk River Formations: a shallow gas core workshop; Belfield Resources Inc. core workshop, October 17, 2003, Calgary, Alberta, unpublished report.