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Petroleum Investment Opportunities in Manitoba—A Geological, Engineering and Economic Perspective

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Abstract

Southwestern Manitoba occupies part of the northeastern flank of the Williston Basin. Paleozoic, Mesozoic and Cenozoic rocks form a basinward thickening-wedge of sedimentary strata that reach a total thickness of 2,300 m in the southwest corner of the province.

To date, oil production in Manitoba is restricted to the sandstones of the Jurassic Melita and Amaranth formations, the Mississippian Bakken Formation and the carbonates of the Mississippian Lodgepole and Mission Canyon formations. The deeper Ordovician, Silurian and Devonian formations—the Winnipeg, Red River, Stony Mountain, Interlake, Winnipegosis, Dawson Bay, Souris River, Duperow and Birdbear (Nisku)—offer oil and gas potential but remain largely undrilled.

Manitoba enjoyed a resurgence in petroleum activity in 1993 and 1994. In total, 184 wells were licensed over the last two years, compared to an annual average of 61 wells licensed over the previous five years. Over 70% of the Crown land currently under disposition has been leased at land sales during the past two years.

Low Crown land price is one competitive advantage enjoyed by Manitoba producers. Other advantages include: low drilling and completion costs, low drilling density, a competitive and stable fiscal regime, drilling and exploration incentives, and unrestricted access to markets.

This paper presents a brief description of the geology and reservoir characteristics of Manitoba's producing horizons. Recent activity in Manitoba and exploration and development incentives are reviewed. Sample economics are included to illustrate the attractiveness of vertical and horizontal drilling opportunities in Manitoba.

Introduction

Oil was discovered in Manitoba in 1951. At year-end 1994 there were 1,568 producing wells in 125 designated oil pools in Manitoba. Manitoba enjoyed a resurgence in oil activity in 1993 and 1994; 154 wells were drilled including 28 horizontal wells. Production in December 1994 was 1,905 m^3/d, the highest since October 1991.

At Manitoba's Crown land sales in 1993 and 1994, a total of 42,918 ha were disposed under leases and exploration reservations. Not since 1980 – 81, has this much land been disposed in a two-year period.

Manitoba Energy and Mines has undertaken a number of initiatives to ensure the province maintains a competitive investment climate. The province's petroleum legislation has been consolidated and simplified under the new Oil and Gas Act. The Manitoba Drilling Incentive Program provides a Crown royalty and freehold production tax free holiday oil volume for new wells. The Major Workover Incentive Program provides a Crown royalty and freehold production tax free holiday oil volume for re-entries, deepenings, recompletions and casing repairs on marginal wells. The Manitoba Mineral Exploration Incentive Program has been replaced by the Petroleum Exploration Assistance Program which provides assistance, to a maximum of 20%, for eligible exploration costs. A project to digitize the province's oil and gas well geological and engineering data is underway. Historical production data and general well data is now available in digital form. These initiatives, and an increased awareness of Manitoba's petroleum potential, resulted in 20 companies, new to Manitoba, acquiring or drilling wells in the province during the last two years.

Geology

Productive oil pools in Manitoba are located along the northeastern flank of the Williston Basin (Figure 1). The Paleozoic sequence in Manitoba is dominated by limestone and dolostone. The Mesozoic and Cenozoic strata comprises mainly shale and sandstone.

A major angular unconformity separates Paleozoic and Mesozoic strata and probably represents one or more periods of erosion that occurred between Late Mississippian and Early Jurassic time. During this interval, Paleozoic strata, in the northeastern part of the basin, were uplifted and differentially eroded, whereas strata in the southern portion of the basin were relatively unaffected. Successively older strata were progressively truncated toward the basin margin. Deposition resumed during Mesozoic time and a thick sequence of Jurassic and Cretaceous strata were deposited on the eroded Paleozoic surface.

The stratigraphy of the Manitoba portion of the Williston Basin is shown in Table 1. The Lower Paleozoic strata (Cambrian, Ordovician, Silurian and Devonian) comprises 14 formations and five groups. Mississippian strata in southwestern Manitoba form the uppermost part of the Paleozoic carbonate sequence and are divided into four formations in southwestern Manitoba. The Mississippian strata are unconformably overlain by three Middle and Upper Jurassic formations. These strata are, in turn, unconformably overlain by Lower Cretaceous strata.

Producing Formations

Oil production in Manitoba is from the Mississippian Bakken, Lodgepole and Mission Canyon formations, the Middle Jurassic Melita Formation and Jurassic Amaranth Formation.

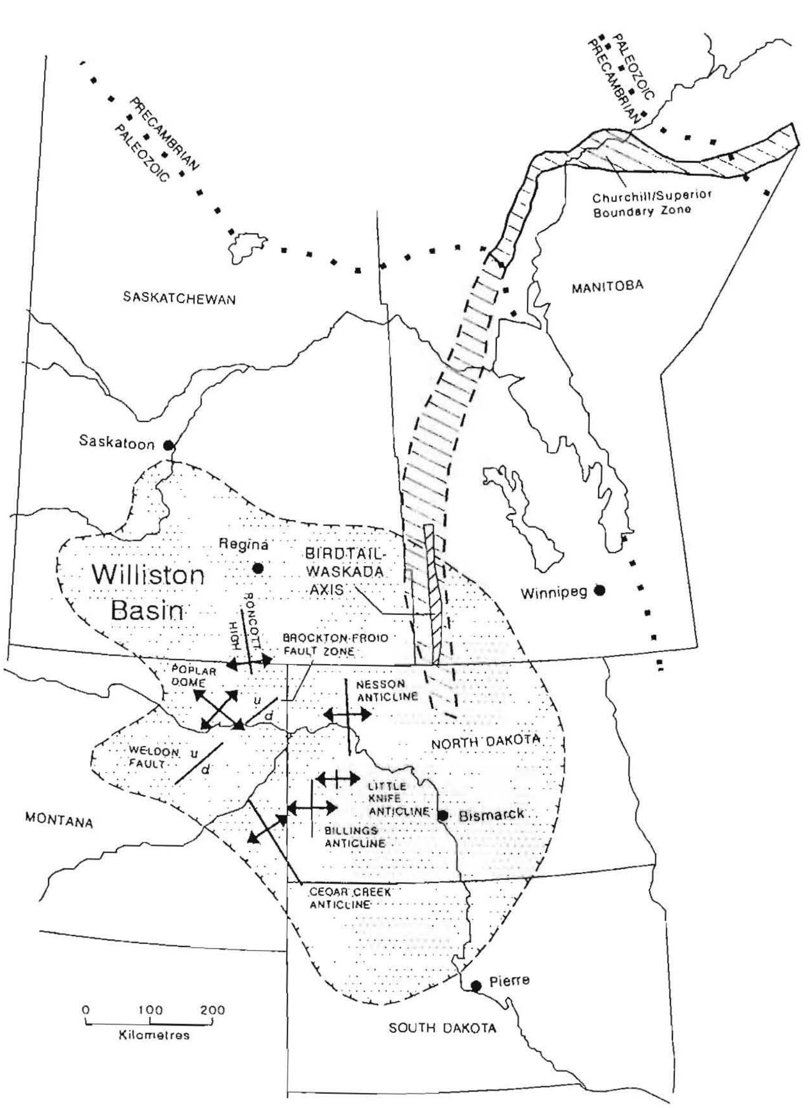

FIGURE 1: Map of the Williston Basin, showing major structural features (after Martiniuk and Barchyn, 1993).

Oil production from the Bakken Formation is presently restricted to the Daly Field, where production is from the Bakken Middle Member (Figure 2). Oil accumulation in the Bakken Formation in the Daly Field is primarily controlled by stratigraphic factors. Stratigraphic trapping within the Middle Member is created by the lateral pinchout and variation of the very fine- to fine-grained basal sandstone facies of the Middle Member in combination with an upward fining to a very fine-grained, finely laminated sandstone facies[1].

In the Lodgepole Formation, major reservoirs occur within the porous, oolitic and crinoidal carbonate facies of the Scallion, Virden and Whitewater Lake members (Table 1).

Oil accumulation in the Lodgepole Formation occurs mainly in truncation traps found at, or near, the subcrop belts of the members of the Lodgepole. Structural highs, paleotopographic highs or permeability barriers are also important to the localization of oil accumulation in the Lodgepole members. In some areas, local structural lows, possibly related to the dissolution and collapse of the Devonian Prairie Formation salt section, are also important for oil accumulation[2].

Virden and Daly are the two principal fields that produce oil from the Lodgepole Formation. In the Virden Field, oil is obtained from reservoir beds in the Scallion, Virden and Whitewater Lake members. These members are also productive in the Souris Hartney, Regent, Whitewater and Lulu Lake fields, as well as several smaller associated pools along the Lodgepole subcrop trend (Figure 2).

In the Daly and Kirkella fields, production is obtained from the Daly Member (equivalent to the Whitewater Lake Member) and the Cruickshank Crinoidal facies (equivalent to the Scallion Member).

Oil production from the Mission Canyon Formation occurs along the subcrop belts of the MC-1 and MC-3 members in the extreme southwest corner of the province. Productive reservoir facies consist of grainstones, packstones and wackestones.

Trapping mechanisms responsible for oil accumulation in the MC-1 and MC-3 members are stratigraphic and structural. The primary trapping mechanism is the truncation of reservoir beds at the Paleozoic unconformity. The impermeable strata of the Jurassic Amaranth Formation provides the top seal. Oil accumulation is localized in four types of stratigraphic traps: structural highs on the Mississippian beds, paleotopographic highs on the Paleozoic erosion surface, updip and lateral variations in porosity and permeability due to diagenetic alteration at the Paleozoic unconformity surface, and updip and lateral depositional facies variations[3,4]. Structural influences on oil entrapment are related to the dissolution and collapse of the Devonian Prairie Formation salt section.

The Waskada, Pierson, Coulter and Tilston fields all produce oil from the Mission Canyon Formation (Figure 2). The majority of this production comes from the MC-3 Member at Waskada and Pierson and the MC-1 Member at Tilston.

In the Jurassic sequence in southwestern Manitoba, oil is produced from two zones. One zone is the Lower Member of the

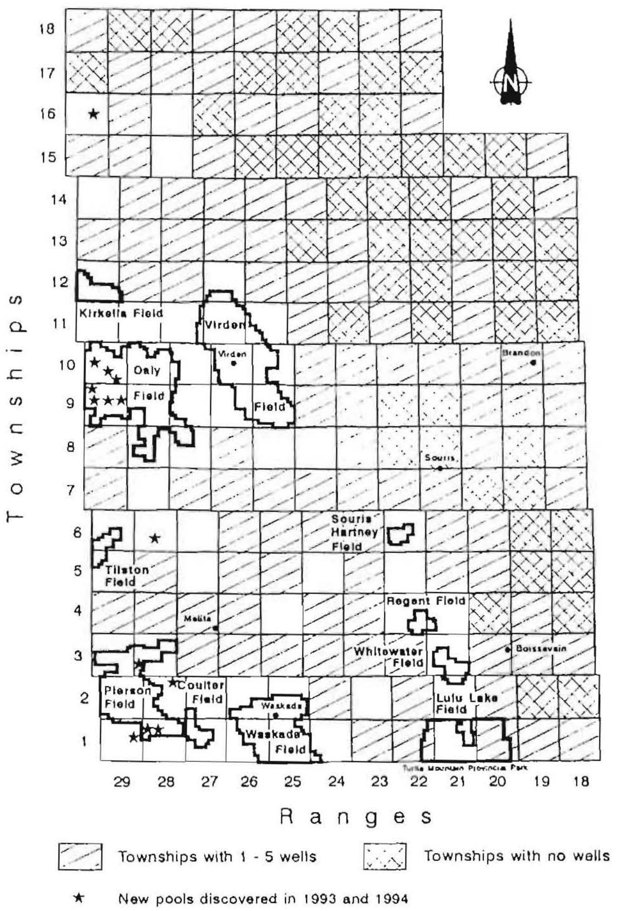

FIGURE 2: Manitoba oilfields and producing areas (map shows drilling area and 1993 and 1994 discoveries).

Amaranth Formation, where reservoir beds occur in laminated sandstone and siltstone facies. Oil production occurs where these reservoir facies overlie productive portions of the Mississippian. Oil that occurs in the Amaranth Formation is believed to have seeped upwards from underlying Mississippian strata[5].

The majority of Amaranth oil production is obtained from the Waskada and Pierson fields.

The most recent oil discovered and shallowest production in Manitoba occurs in the Middle Jurassic Melita Formation in the St. Lazare area. The reservoir is believed to be a delta or distributary channel type sand. Trapping is primarily stratigraphic with an updip change in facies from a channel sand facies to impermeable shaley, interdistributary facies[6]. Oil is believed to have seeped upwards from the underlying porous Mississippian strata, a mechanism similar to that proposed for the oil accumulation in the Amaranth Formation.

Reservoir Characteristics

The average reservoir characteristics of the sandstone reservoirs of the Bakken and Amaranth formations and the carbonate reservoirs of the Lodgepole and Mission Canyon formations are summarized in Table 2. All Manitoba reservoirs are highly undersaturated. In many reservoirs, primary recovery is augmented by water drive. The effectiveness of the water drive is a function of the stand-off from the oil/water contact, structural relief, reservoir lateral and vertical continuity and the extent of vertical fracturing. Waterfloods have been implemented in the larger Lodgepole pools in the Virden and Daly fields, in the Bakken in the Daly Field and in the Amaranth in the Waskada and Pierson fields.

Manitoba oil production in 1994 was divided as follows: Bakken 4.6%, Lodgepole 54.4%, Mission Canyon 10.1%,

TABLE 1: Manitoba stratigraphic column, highlighting producing formations.

SYSTEM					MAXIMUM THICKNESS (m)
MESOZOIC	CRETACEOUS (part)	LOWER	SWAN RIVER FORMATION		75
MESOZOIC	JURASSIC	UPPER	WASKADA FORMATION		200
MESOZOIC	JURASSIC	?	MELITA ★ FORMATION	upper	200
MESOZOIC	JURASSIC	MIDDLE	MELITA ★ FORMATION	lower	200
MESOZOIC	JURASSIC	MIDDLE	RESTON FORMATION		45
MESOZOIC	JURASSIC	MIDDLE	AMARANTH FORMATION	Upper (Evaporites) Mbr.	45
MESOZOIC	JURASSIC	MIDDLE	AMARANTH FORMATION	Lower (Red Beds) Mbr. ★	40
MESOZOIC	TRIASSIC	(?)	St. Martin complex		300
PALEOZOIC	PERMIAN	(?)	St. Martin complex		300
PALEOZOIC	PENNSYLVANIAN	(?)	St. Martin complex		300
PALEOZOIC	MISSISSIPPIAN	MADISON GROUP	CHARLES FORMATION		20
PALEOZOIC	MISSISSIPPIAN	MADISON GROUP	MISSION CANYON FORMATION	MC-3 Member ★	120
PALEOZOIC	MISSISSIPPIAN	MADISON GROUP	MISSION CANYON FORMATION	MC-2 Member	120
PALEOZOIC	MISSISSIPPIAN	MADISON GROUP	MISSION CANYON FORMATION	MC-1 Member ★	120
PALEOZOIC	MISSISSIPPIAN	MADISON GROUP	LODGEPOLE★ FORMATION	FLOSSIE LAKE MBR.	185
PALEOZOIC	MISSISSIPPIAN	MADISON GROUP	LODGEPOLE★ FORMATION	WHITEWATER LAKE MBR.	185
PALEOZOIC	MISSISSIPPIAN	MADISON GROUP	LODGEPOLE★ FORMATION	VIRDEN MEMBER	185
PALEOZOIC	MISSISSIPPIAN	MADISON GROUP	LODGEPOLE★ FORMATION	SCALLION MEMBER	185
PALEOZOIC	MISSISSIPPIAN	BAKKEN FORMATION		UPPER MEMBER	20
PALEOZOIC	MISSISSIPPIAN	BAKKEN FORMATION		MIDDLE MEMBER ★	20
PALEOZOIC	MISSISSIPPIAN / ?	BAKKEN FORMATION		LOWER MEMBER	20
PALEOZOIC	DEVONIAN	QU'APPELLE GROUP	THREE FORKS (LYLETON) FORMATION		430
PALEOZOIC	DEVONIAN	SASKATCHEWAN GROUP	BIRDBEAR (NISKU) FORMATION		430
PALEOZOIC	DEVONIAN	SASKATCHEWAN GROUP	DUPEROW FORMATION		430
PALEOZOIC	DEVONIAN	MANITOBA GROUP	SOURIS RIVER FORMATION		430
PALEOZOIC	DEVONIAN	MANITOBA GROUP	DAWSON BAY FORMATION		430
PALEOZOIC	DEVONIAN	ELK POINT GROUP	PRAIRIE FM.		120
PALEOZOIC	DEVONIAN	ELK POINT GROUP	WINNIPEGOSIS FORMATION		75
PALEOZOIC	DEVONIAN	ELK POINT GROUP	ELM POINT FM.		75
PALEOZOIC	DEVONIAN	ELK POINT GROUP	ASHERN FORMATION		12
PALEOZOIC	SILURIAN	INTERLAKE GROUP			135
PALEOZOIC	?	STONEWALL FORMATION			65
PALEOZOIC	ORDOVICIAN	STONY MOUNTAIN FORMATION		Gunton Member	65
PALEOZOIC	ORDOVICIAN	STONY MOUNTAIN FORMATION		Gunn Member / Penitentiary Mbr.	65
PALEOZOIC	ORDOVICIAN	RED RIVER FORMATION			170
PALEOZOIC	ORDOVICIAN	WINNIPEG FORMATION			60
PALEOZOIC	CAMBRIAN	DEADWOOD FORMATION			60
PRECAMBRIAN					

★ PRODUCTIVE INTERVALS IN MANITOBA

Amaranth 30.8% and Melita less than 0.1%. Production and reserves data by formation are shown in Table 3. A further breakdown of reserves for the province's four largest fields, Virden, Waskada, Daly and Pierson, that accounted for 91.9% of last year's production, is shown in Table 4.

Exploration and Development Activity

In 1993 and 1994, 154 wells were drilled in Manitoba, compared to an average of 57 wells drilled annually over the previous five years. A total of 31 exploratory wells, including two Precambrian tests and 123 development wells, were drilled. The

TABLE 2: Typical Manitoba reservoir characteristics.

Depth	525-1050 m	
Porosity	13-17%	Sandstones
	9-14%	Carbonates
Water saturation	35-50%	
Permeability	< 10 md	
Oil density	25-42° API	
Initial productivity	3-8 m^3/d	
Primary recovery	5-15%	
Secondary recovery	20-35%	

TABLE 3: Manitoba's oil reserves.

Formation	Total Recoverable* Reserves (10³m³)	Remaining Proved* Reserves (10³m³)
Amaranth	4329.9	1791.2
Mission Canyon	1756.6	504.4
Lodgepole	30405.6	3863.1
Bakken	275.0	95.1
Total	**36767.1**	**6253.8**

* as of December 31, 1994

TABLE 4: Manitoba's major producing fields.

Field	Producing Formation(s)	1994 Production (m³/d)	Cumulative* Production (10³m³)	Remaining* Proved Reserves (10³m³)
Virden	Lodgepole	643	20803.9	2760.2
Waskada	Amaranth	308	2167.6	1155.0
	Mission Canyon	61	518.4	110.2
Daly	Lodgepole	252	4919.1	954.3
	Bakken	81	179.9	95.1
Pierson	Amaranth	237	360.0	634.7
	Mission Canyon	63	549.3	270.2

* as of December 31, 1994

overall success ratio was 85.7%, exploratory 58.0% and development 92.7%. Significant activities included:

- the discovery of 14 new oil pools, including the commercial production of Middle Jurassic heavy oil at CN St. Lazare A14-15-16-29 WPM
- the implementation of waterfloods in the Pierson Lower Amaranth-Mission Canyon 3b A Pool and the Daly Bakken A Pool, with expected incremental recoveries of 19.7% OOIP and 17.3% OOIP, respectively
- the drilling of 28 horizontal wells by eight different operators in 17 different pools
- infilling drilling on 8 ha spacing in the Virden Lodgepole B Pool
- the successful deepening of Lodgepole producers in the Daly Field to explore for Bakken oil

Figures 2 and 3 show the approximate location of 1993 and 1994 discoveries, including successful Bakken deepenings, and horizontal wells.

Manitoba Energy and Mines Major Initiatives

This section provides a brief overview of five major initiatives undertaken or implemented by Manitoba Energy and Mines to enhance petroleum investment opportunities in the province.

The Oil and Gas Act

In July 1994, Manitoba's new Oil and Gas Act was proclaimed. The Oil and Gas Act replaces a number of outdated statutes and provides a comprehensive framework for the sustainable development of the province's oil and gas resources. The Oil and Gas Act consolidates under a single statute provisions governing:

- disposition of Crown oil and gas rights
- registration of oil and gas lease agents
- geophysical operations
- licensing of wells and permitting of oil and gas facilities
- oil and gas drilling, production and conservation
- environmental protection
- pooling and unitization

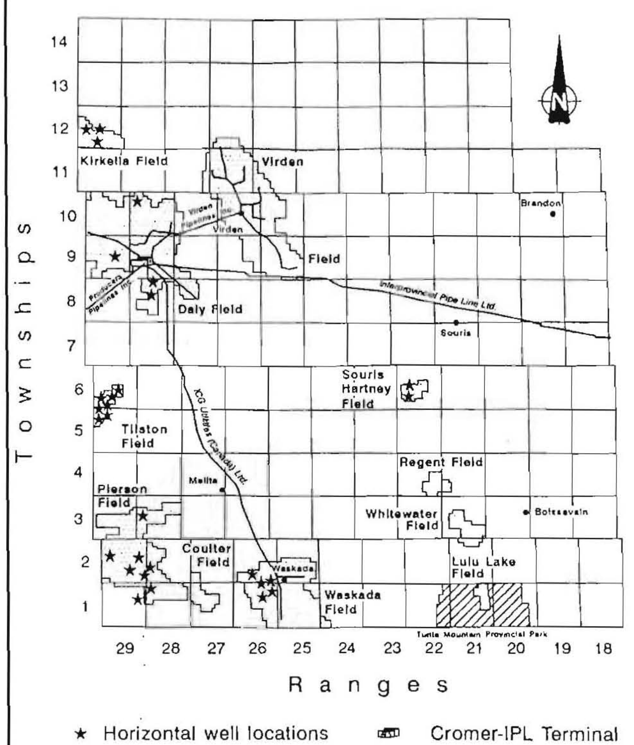

FIGURE 3: Manitoba oilfields and producing areas (map shows horizontal well locations).

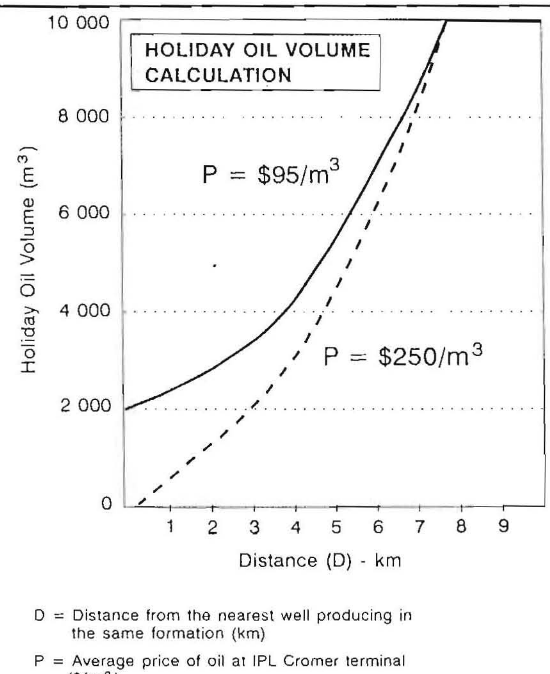

FIGURE 4: Manitoba Drilling Incentive Program (1992 – 1999)—holiday oil volume.

- flowlines and pipelines
- storage of hydrocarbons in underground reservoirs
- administrative and enforcement matters

The Oil and Gas Act and the accompanying regulations were developed in extensive consultation with oil companies, industry associations, service industry representatives, special interest groups and other government agencies. The main objective of the Act is to provide for, encourage and facilitate the safe and efficient development and maximum economic recovery of Manitoba's oil and gas resources. This is accomplished by simplifying and streamlining approval processes, standardizing regulatory requirements with other jurisdictions, where practical and cost effective, and providing flexibility to accommodate technological and economic developments in the oil industry.

The principles of sustainable development are embodied in the Act and require that decisions regarding the development of oil and gas resources be integrated with decisions respecting the protection and management of the environment to ensure oil and gas activities are carried out in a manner that mitigates environmental impacts.

The new Oil and Gas Act and accompanying regulations provide industry with a sound foundation upon which to make petroleum investment decisions in Manitoba.

Manitoba Drilling Incentive Program

Under the Manitoba Drilling Incentive Program, wells drilled prior to January 1, 1999 receive a Crown royalty or freehold production tax free holiday oil volume up to a maximum of 10,000 m^3 or ten years production, whichever comes first. The holiday oil volume is a function of oil price and distance from offset production (Figure 4).

The program provides for establishment of a holiday volume account to allow companies a degree of flexibility in allocating earned holiday oil volumes among newly drilled wells. For multiwell drilling programs, holiday oil volumes earned by dry holes and poor producers can be transferred, in accordance with the regulations, to better producers.

In Manitoba, a horizontal well is defined as a well that achieves an angle of at least 80° from the vertical for a minimum distance of 100 m. Horizontal wells drilled prior to January 1, 1997 receive a Crown royalty or freehold production tax free holiday oil of 10,000 m^3 or ten years production, whichever comes first. Production from horizontal wells is classified as new oil. Where a horizontal well penetrates more than one spacing unit, royalty and production tax is calculated per spacing unit based on production allocated to the spacing unit.

A special new formation holiday oil volume of 50,000 m^3 is available for each well that is the first in Manitoba to produce from a deeper, currently non-productive Ordovician, Silurian or Devonian formation.

Major Workover Incentive Program

The Major Workover Incentive Program provides a holiday oil volume of 500 m^3 for marginal wells on which a major workover is conducted. A marginal well is defined as a well that, over the previous 12 months, has been shut in or has an average production rate of less than 1 m^3 per operating day. Major workovers include re-entry of abandoned wells, deepening of existing wells, recompletion of wells from one pool to another and repair of damaged casing by installation of a liner. The program also provides for allocation of the holiday oil volume earned by a major workover to a company's holiday volume account for application to subsequent new wells or workovers.

Petroleum Exploration Assistance Program

The Petroleum Exploration Assistance Program (PEAP) replaces the province's Mineral Exploration Incentive Program. PEAP is designed to assist companies to explore for oil and gas in Manitoba. The program provides for assistance of up to 20% of the cost of drilling exploratory wells, new field wildcats and deeper pool wildcats (only incremental costs to drill below the deepest productive zone are eligible) and conducting certain geophysical programs. Under the program, $1 million of assistance will be available in each of the next three years. The maximum assistance available to a company is $200,000 per year.

Manitoba Oil and Gas Well Information System

The lack of readily accessible digital well information has been identified as a barrier to attracting new petroleum investment in Manitoba. Manitoba Energy and Mines is in the process of completing an accurate and reliable digital database for the province's oil and gas wells. The Manitoba Oil and Gas Well Information System (MOGWIS) is built on an Oracle software platform.

The initial phase of MOGWIS is complete, and databases containing historical production data, general well data and well UTM coordinates are now available for all Manitoba wells. Plans have been made to incorporate all existing government well records into MOGWIS. Future phases of MOGWIS that will be made available as data is verified and digitized include:

- well licensing information
- drilling and casing details
- DST information
- core data
- geological formation tops
- completion, stimulation and workover summaries

Once completed, MOGWIS will allow rapid retrieval of data to assist companies in making production optimization, reservoir management and exploration and development drilling decisions.

Exploration and Development Prospects

To the end of 1994, 3,937 wells had been drilled in Manitoba, most located in the 200 townships shown in Figure 2. This equates to a drilling density of less than 20 wells per township or slightly more than one well for every two sections. Most of the wells have been drilled in, or adjacent to, producing fields. Much of southwestern Manitoba remains largely unexplored (Figure 2). The following sections discuss exploration and development prospects in the pre-Mississippian formations in Manitoba and in the province's five producing formations.

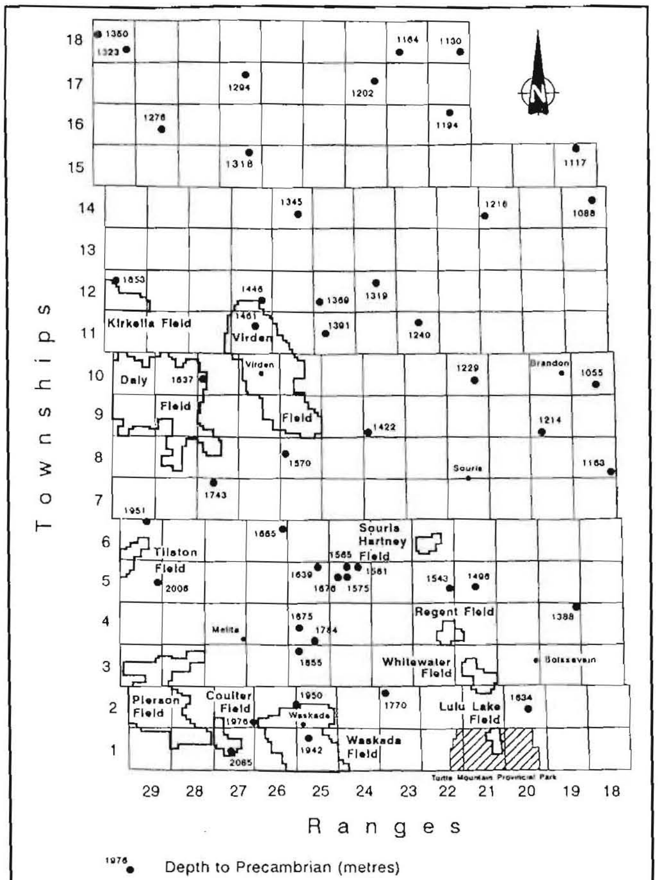

FIGURE 5: Manitoba oilfields and producing areas (map shows deep tests drilled to Precambrian; depth shown in metres).

Pre-Mississippian Formations

To date, the limited deep exploration in southwestern Manitoba has revealed the presence of potential reservoir horizons below the traditional Mississippian targets. Oil shows have been documented in the Winnipeg, Red River, Stony Mountain, Interlake, Winnipegosis, Dawson Bay, Souris River, Duperow and Birdbear (Nisku) formations. These shows may be direct evidence of long distance migration of oils from central basin source rocks into the pre-Mississippian strata of southwestern Manitoba. Figure 5 shows the location of the 48 deep tests drilled to Precambrian basement in southwestern Manitoba.

There is evidence that reservoir development, trapping mechanisms and hydrocarbon charge are present in the pre-Mississippian strata of southwestern Manitoba. Numerous examples of geological conditions analogous to those that provide trapping mechanisms in typical pre-Mississippian Williston Basin play types are present within the pre-Mississippian of southwestern Manitoba.

Large reserves of oil are pooled in basement-controlled structural traps in the Williston Basin. Most of these pools are located on large structures such as the Nesson and Cedar Creek anticlines (Figure 1). Potential for tectonically-generated structures in Manitoba exists particularly along the southern extension of the Churchill/Superior crustal boundary zone (termed the Birdtail-Waskada Axis; Figure 1). The great majority of southwestern Manitoba's oil reserves in Mississippian and Jurassic strata are pooled in traps along the Birdtail-Waskada Axis. This feature is the locus of numerous stratigraphic and structural anomalies throughout the Phanerozoic section. Potential combination structural-stratigraphic traps and multiple-pay zones within the pre-Mississippian may be developed along this axis.

Diagenetic traps are also associated with the Birdtail-Waskada Axis. Localized development of porosity due to dolomitization has been noted in the Red River Formation in the Napinka area (T.4; R.25 WPM).

Several oil accumulations in the Saskatchewan, North Dakota and Montana portions of the Williston Basin are associated with structures generated by salt dissolution and collapse of overlying strata. Dissolution of the Devonian Prairie Formation salt section along or near the Birdtail-Waskada Axis in Manitoba has resulted in numerous structural and isopach anomalies important in controlling oil accumulation within the Lodgepole and Mission Canyon formations at Daly, Virden and Waskada. These same scenarios may be applied to pre-Mississippian strata in southwestern Manitoba.

Winnipegosis Formation pinnacle reefs have been successfully explored in southeastern Saskatchewan. Pinnacle reefs of the Winnipegosis Formation in Manitoba are developed along the basinward edge of the Winnipegosis fringing bank in the southeastern corner of the Elk Point Basin. These reefs show excellent porosity and permeability and, where encased by Prairie Formation salts, have excellent trap potential.

Oil has also been produced from the prograding platform marginal facies of the Winnipegosis Formation, particularly in North Dakota. Similar potential exists in Manitoba along the northeastern platform margin of the Elk Point Basin, which is roughly coincident with the Birdtail-Waskada Axis.

The Birdbear has produced oil in the Williston Basin mostly from stromatoporoid banks and biostromes that border the basin in northeastern Montana and from facies associated with basement-related faulting and Late Devonian salt collapse structures in Saskatchewan and northeastern Montana.

Correlative facies within the Birdbear Formation in Manitoba suggests the potential for the exploitation of similar types of trap settings in Manitoba in addition to several different trap types[7].

Potential stratigraphic-diagenetic traps exist downdip of the Birdbear subcrop edge in Manitoba, where trapping is created updip by secondary dolomitization and anhydritization at the Devonian unconformity. Lateral variation within the *Amphipora* and stromatoporoid bank facies of the Birdbear Formation may also give rise to potential stratigraphic traps.

The current edge of the Prairie Formation salt is definable within Manitoba, and may serve as a control on the distribution of reservoir facies, the enhancement of porosity and entrapment of hydrocarbons. The eastern limit of the present Prairie salt dissolution edge is roughly coincident with the Birdtail-Waskada Axis.

Local, tectonically-generated structures along the Birdtail-Waskada Axis may also give rise to potential deep structural traps within the Birdbear Formation.

Regional truncation of Paleozoic strata along the shelf flank areas of the Williston Basin has created stratigraphic trap settings suitable for oil accumulation. Oil accumulation in, and production from Pre-Mississippian strata occur along the subcrop belts of these strata on the southwestern flank of the Williston Basin. In Manitoba, analogous truncation traps are present within the pre-Mississippian strata, where potential reservoir beds subcrop at the Paleozoic erosion surface[8].

Bakken Formation

In the Daly Field only one of every five wells drilled penetrate the Bakken Formation. In 1993 and 1994, a number of operators deepened marginal Lodgepole producers 40 to 80 m into the Bakken Formation as an inexpensive means of exploration. A typical deepening, including running a liner and completing the Bakken, costs $70,000. Of the 13 wells deepened, liners were run in 11. Initial production from the deepened wells averaged 1.7 m^3/d over the first six months.

As an exploration target, Bakken pools are typically one section in size with original oil in place on the order of $500 \times 10^3 m^3$. Ultimate recoverable reserves per pool, assuming implementation of a waterflood, may exceed $100 \times 10^3 m^3$ [4].

Eastward, in the Virden Field, the Bakken Formation remains largely untested. This is an area of known salt collapse features within the shallower Lodgepole Formation. Possibilities for Bakken Formation subcrop plays may exist along the eastern edge of the field.

Between the Daly and Kirkella fields, the Bakken Formation is

TABLE 5: Horizontal wells in Manitoba*.

Formation	No. of Wells Drilled	Average Depth (m)	Average Horizontal Interval (m)	Initial Productivity – (m^3/d) (1st (6) months or less)		
				Minimum	Maximum	Average
Lower Amaranth	5	1906	917	4.3	18.8	9.2
MC-3	9	1564	534	6.5	27.4	13
MC-1	10	1597	623	14.4	32.8	23.3
Lodgepole	9	1296	527	1.4	10.3	4

* includes results from four horizontal wells drilled in 1995.

prospective. Further north, toward the northeastern limit of the Bakken Formation, several free-oil recoveries have been made from drill stem tests in the Middle Member, specifically from wells in Townships 15 and 16, Range 27 WPM. Several completions have been attempted, but due to high water-cuts these have not been successful.

Lodgepole and Mission Canyon Formations

Reservoir studies of existing pools should reveal opportunities for further development drilling along the poorly defined edges of the pools, especially in the Daly and Virden fields. Old producers upon examination, may also reveal bypassed pay.

Several discoveries along the subcrop of the Lodgepole Formation have been made over the past few years. Drilling north of Whitewater Field led to the discovery of the Regent Field. Drilling to the south led to the discovery at Mountainside. This suggests that the Lodgepole Formation trend has not been fully tested.

Numerous one well completions along this trend appear to be small localized areas of good reservoir facies associated with paleotopographic features. Areas of interest include the portions along the Lodgepole Formation trend between the Virden and Souris Hartney fields.

Future exploration and development opportunities also exist along the Lodgepole shelf slope sequence that extends north-south through the Daly Field. The facies described for Lower Lodgepole in the Daly area are correlative with the facies that have been described at Dickinson in north-central North Dakota. Recent success in the Dickinson Field in North Dakota has lead to renewed interest in the Lodgepole Formation. The productive "mound" facies in the lower Lodgepole observed at Dickinson is correlative with the productive Cruickshank Crinoidal facies at Daly in Manitoba. Comparative regional lithology and similar trapping mechanisms suggests that the Dickinson play may expand regionally from North Dakota to Manitoba along the projected extent of the Lodgepole shelf slope and the projected original edge of the salt of the Prairie Formation[9].

In the Mission Canyon Formation there are potential exploratory and development locations within the Waskada and Pierson fields. Favourable reservoir facies are also developed outside of these fields within the subcrop belts of the MC-3 and MC-1 members.

Amaranth Formation

Development potential for the Amaranth Formation has been best demonstrated at Pierson and Waskada. During the past two years, 40% of the wells drilled in Manitoba have been Amaranth tests in, and between, the Pierson and Waskada fields.

Future prospects for the Amaranth Formation exist within the Waskada-Coulter-Pierson area. This is an area where the Amaranth Formation sandstone facies is best developed, and where Amaranth reservoir beds overlie subcropping Mississippian reservoir beds. As an exploration target, the Amaranth Formation has original oil-in-place per section of 500 to 1500 × 10^3m [4].

Melita Formation

The oil discovery at St. Lazare A14-15-16-29 WPM was significant because it proved that heavy oil (18 to 20° API) could be produced by primary recovery from an unconsolidated Middle Jurassic sandstone reservoir in Manitoba. During 1993 and 1994, the A14-15 well averaged 2.3 m^3/d at a 56% water-cut.

Log evaluation of a number of stratigraphic test holes drilled in Township 16, Range 29 WPM in the early 1980's indicates five wells encountered oil pay at depths of 375 to 450 m. Net oil pay thickness ranges from 4 to 13 m. The oil zone in most wells is underlain by a water leg that is at least 10 m thick. Average porosity is 33 to 37%, water saturation ranges from 26 to 43% and two cored wells show permeabilities of 1.2 to 11.5 darcies. Original oil-in-place ranges from 133.5 to 475.8 10^3m^3 per well.

Oil accumulations in the Middle Jurassic occur where channel sands have been deposited over subcropping Paleozoic strata. If problems associated with formation damage and excessive water and sand production can be overcome, these channel sands may prove an attractive exploration target, with the potential for application of thermal recovery methods.

Horizontal Drilling Prospects

The first horizontal well in Manitoba was drilled in 1991. During the last two years the 28 horizontal wells drilled represented 18% of the province's drilling activity. In December 1994, the 22 horizontal wells on production represented 1.6% of the province's producing wells, but accounted for 13% of the total production. Figure 3 shows the approximate location of the horizontal wells in Manitoba. The average horizontal well production in December 1994 was 12.2 m^3/d, compared to an average vertical well rate of 1.2 m^3/d.

To date, horizontal drilling results have been mixed. Initial production rates range from 1.4 to 32.8 m^3/d. Horizontal production multipliers range from 1.0 to 29.5 times the current average production rates for vertical wells in the same pool. Table 5 provides a list of horizontal drilling results by formation.

Horizontal well applications in Manitoba to date include low permeability sandstone and carbonate reservoirs, carbonate reservoirs with and without underlying aquifer pressure support and vertically fractured carbonate reservoirs. Horizontal wells have been used for infill drilling, step-outs and as an exploratory tool.

The initial production data indicates successful horizontal wells have been drilled in each of the province's producing formations. The most successful application has been in the MC-1 Formation. In December 1994, seven MC-1 horizontal wells averaged 21 m^3/d and accounted from almost 80% of the province's horizontal well production. Overall horizontal drilling results indicate that to drill a successful horizontal well, a good understanding of the geology is necessary and the drilling program must be designed to minimize formation damage, especially in the low permeability reservoirs common in Manitoba[10].

Manitoba Exploration and Development Economics

A number of factors combine to create an attractive petroleum investment climate in Manitoba:

- the availability and low cost of Crown land

TABLE 6: Manitoba oil play model—economic assumptions.

	Base Case	Increased Recovery Case	Horizontal Drilling Case
Capital Costs			
Seismic ($M)	24	24	24
Land Acquisition ($M)	31	31	31
Drill, Complete, Equip ($M)	2475	2475	2300
Dry Hole Cost ($M)	200	200	200
Production Facilities ($M)	150	150	150
Flowlines ($M)	150	150	150
Total	**3030**	**3030**	**2855**
Operating Costs			
Fixed ($/well/month)	1450	1450	1450
Variable ($/m^3)	10	10	10
Production			
Initial Pool Productivity (m^3/d)	43	43	46
Pool Recoverable Reserves (10^3/m^3)	76.9	96.4	83.4
Drilling Incentive Program			
Holiday Oil Volume (10^3/m^3)	31.8	31.8	36.6
Oil Price Forecast ($CDN/m^3)			
1994 113.27			
1995 121.64			
1996 125.86			
1997 – 2006 130.07			

TABLE 7: Manitoba oil play model—economic indicators.

	Base Case Before Tax	Base Case After Tax	Increased Recovery Case Before Tax	Increased Recovery Case After Tax	Horizontal Drilling Case Before Tax	Horizontal Drilling Case After Tax
Project Life (Years)	10	10	13	13	11	11
Undiscounted Cash Flow ($M)	2290	1641	3431	2385	3310	2339
Undiscounted Cash Flow Capital Investment	0.76	0.54	1.13	0.79	1.16	0.82
Net Present Value ($M) (Discount Factor = 12%)	1048	617	1574	946	1762	1117
Rate of Return (%)	32.9	25.0	37.9	29	49.5	37.3
Pay-out (Years)	2.8	3.2	2.7	3.0	2.2	2.6

- the province's competitive and stable fiscal regime
- drilling and exploration incentives
- low drilling and completion costs
- low drilling density
- easy access to markets

Of the approximately 0.4 million hectares of Crown owned oil and gas rights in the area shown in Figure 2, only 59,648 hectares or 15% were under disposition as of December 31, 1994. The average industry land sale bonus paid in Manitoba in 1994 was $57.18/ha. This compares to average 1994 bonuses in Saskatchewan and Alberta of $179.03/ha and $211.53/ha, respectively.

The Interprovincial Pipeline (IPL) system passes through Manitoba with a terminal at Cromer (Figure 3). Manitoba crude enjoys a significant tariff advantage over production entering the IPL system further west. The 1994 IPL transmission charge for light crude delivered to Sarnia is $0.86/m^3 from Cromer, $1.62/m^3 from Regina, and $3.76/m^3 from Edmonton.

The following oil play model is used to illustrate the attractiveness of petroleum investment opportunities in Manitoba (Figure 6). The play is based on the reservoir and production characteristics of the numerous small Lodgepole and Mission Canyon pools that occur along the subcrop edge of the various members of these formations. The play is a seismically defined paleotopographic high along the subcrop edge of one of the Lodgepole or Mission Canyon members. A land position covering three sections is secured. The acquired mix of oil and gas rights is 20% Crown and 80% freehold, similar to the percentages of Crown and freehold owned oil and gas rights in the southwestern corner of the province. A bonus of $40.14/ha is paid to acquire the combination of Crown and freehold acreage.

Economic evaluation of three development scenarios was reviewed.

Base Case

In the Base Case, the pool is discovered and delineated by drilling 13 wells on 16 ha spacing (Figure 6). Based on overall drilling success rates in Manitoba over the past ten years, 62.2% for exploratory wells, 92.5% for development wells and 86.4% overall, the drilling program yields ten producers and three dry holes, one of which is used for water disposal.

The pool is at a depth of 900 to 1,000 m. Wells take five days from spud to rig release. The cost to drill, complete (including an acid job), and equip each well, is $225,000. Dry hole costs are $100,000. Battery construction costs, including water disposal facilities and well tie-ins, is $300,000.

The average initial productivity is 4.3 m^3/d/well or 43 m^3/d for the pool. Total pool recoverable reserves are 76,900 m^3, produced over ten years.

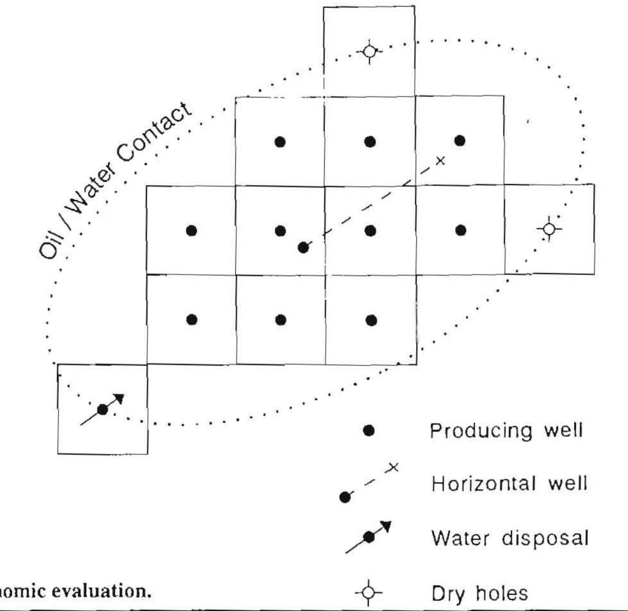

FIGURE 6: Oil play model for economic evaluation.

Increased Recovery Case

Almost half of the 25 small Lodgepole and Mission Canyon pools reviewed had recoverable reserves in excess of 100,000 m^3. An Increased Recovery Case was run assuming the same initial pool productivity, 43 m^3/d, and a 25% increase in recoverable reserves for the pool, from 76,900 to 96,400 m^3 (Table 6).

Horizontal Drilling Case

In order to demonstrate the attractiveness of horizontal drilling in Manitoba, a Horizontal Drilling Case was run assuming the pool was delineated by vertical wells and three producers in the Base Case were replaced by a horizontal well (Figure 6). The horizontal well has a 600 m horizontal section and is drilled and completed openhole for $500,000. In this case, initial pool productivity is 46 m^3/d, including horizontal well production of 16 m^3/d. The pool recoverable reserves are increased from 76,900 to 83,400 m^3 to account for improved reservoir drainage by the horizontal well (Table 6).

In 1994, the average posted price for light sour blend at Cromer was $130.55/$m^3$. For the purpose of this evaluation, the following conservative price forecast has been used: 1994 – $113.27/$m^3$, 1995 – $121.64/$m^3$, 1996 – $125.86/$m^3$, 1997 to the end of the evaluation – $130.07/$m^3$.

Assuming the discovery well is drilled 8 km from existing production, under the Manitoba Drilling Incentive Program, the well earns a holiday oil volume of 10,000 m^3. The development wells earn an average holiday oil volume of 1,816 m^3. The horizontal well earns a holiday oil volume of 10,000 m^3.

The flexibility provided by the holiday volume account allows the holiday oil volume earned by the dry holes and salt water disposal well to be allocated to the producing wells. Over the life of the project, the incentive effectively reduces the combined Crown royalty and freehold production tax burden to: Base Case 4.0%, Increased Recovery Case 4.9%, and Horizontal Drilling Case 3.8%.

The economic assumptions used for the three cases are listed in Table 6. Economic results both before and after tax using a discount rate of 12% are shown in Table 7.

Conclusions

Manitoba Energy and Mines has undertaken a number of initiatives to ensure barriers to petroleum investment in Manitoba are eliminated. The province offers a competitive and stable petroleum investment climate. Manitoba advantages include the availability of Crown land at comparatively low prices, drilling and exploration incentives, low drilling and completion costs and easy access to markets.

Development drilling opportunities exist for each of Manitoba's five producing formations: the sandstones of the Jurassic Melita and Amaranth formations and the Mississippian Bakken Formation and the carbonates of the Mississippian Lodgepole and Mission Canyon formations. Drilling density in southwestern Manitoba is low. Exploration opportunities exist not only in the traditional Jurassic and Mississippian targets but also in pre-Mississippian strata of Ordovician, Silurian and Devonian age. Manitoba's reservoirs are also amenable to horizontal drilling.

Economic indicators for sample economics run on three development scenarios modelled after a "typical" Manitoba oil play were favourable; ratio of undiscounted cash flow to capital investment (AIT) 0.54 to 0.82, rate of return (AIT) 25 to 37.3% and pay-out 2.6 to 3.2 years. The economics demonstrate the attractiveness of Manitoba's fiscal and regulatory regime.

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