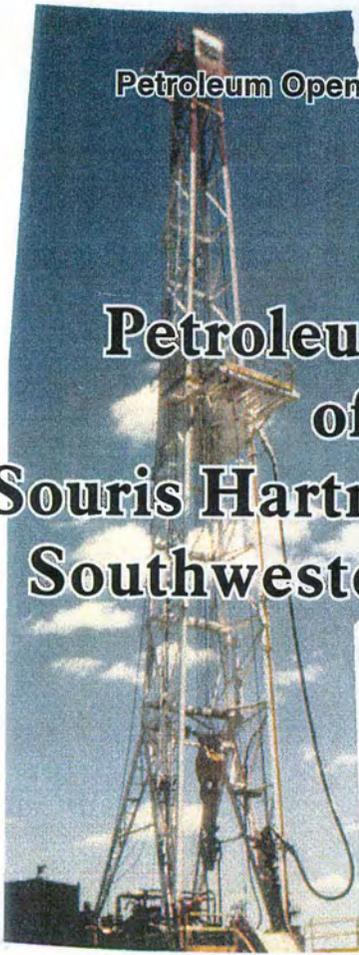


Petroleum Open File Report POF 16-97



Petroleum Geology of the Souris Hartney Field Area, Southwestern Manitoba

By

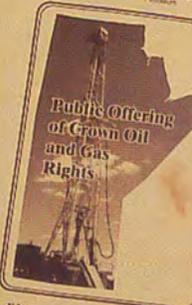
H.J. Klassen
and
J.N. Fox

Manitoba
Energy and Mines

David Newman
Minister



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Manitoba
Energy and Mines
Petroleum and Energy Branch

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**Petroleum Geology of the Souris Hartney
Field Area, Southwestern Manitoba**

by H.J. Klassen and J.N. Fox
Winnipeg, 1997

Energy and Mines

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INTRODUCTION

Located in Township 6, Range 22 WPM (Fig. 1), the Souris Hartney Field is part of a regional subcrop trend of the Mississippian Lodgepole Formation that encompasses fields from Virden to Lulu Lake. Production in the field is obtained from the oolitic limestones of the Upper Virden Member of Lodgepole Formation. The field was discovered in 1962 by Texaco Exploration Limited by the well at, 8-17-6-22 WPM. As of June 30, 1996, 26 wells had been drilled in the field; 9 active producers (including 3 horizontal wells), 7 abandoned producers, 1 water disposal well and 8 abandoned dry wells. The only designated pool in the field is the Lodgepole Virden A ("the A pool").

The purpose of this study is to outline the stratigraphy, lithology and factors controlling oil accumulation in the Upper Virden Member in the Souris Hartney Field. Reservoir parameters for the pool will be presented. A comparison will be made between vertical and horizontal producers.

A total of 11 cores were examined for this study. Select core descriptions are included in Appendix I.

REGIONAL GEOLOGICAL SETTING

Southwestern Manitoba lies along the northeast flank of the Williston Basin. A basinward thickening sedimentary wedge is formed by rocks of Paleozoic, Mesozoic and Cenozoic age that reach a total thickness of 2300 m in the extreme southwest corner of the province. Several unconformities truncate strata within the Mesozoic and Paleozoic section.

A major angular unconformity separates the Paleozoic from the Mesozoic strata, and may represent one or more periods of erosion that occurred from late Mississippian to early Jurassic time. During this interval, Paleozoic strata in the northeast portion of the basin were uplifted and differentially eroded, where as strata in the south part underwent relatively slight uplift (McCabe, 1959). Successively older Paleozoic strata were progressively truncated toward the basin margin. Deposition resumed during Mesozoic time when a thick sequence of Jurassic and Cretaceous strata was deposited on the eroded Paleozoic surface.

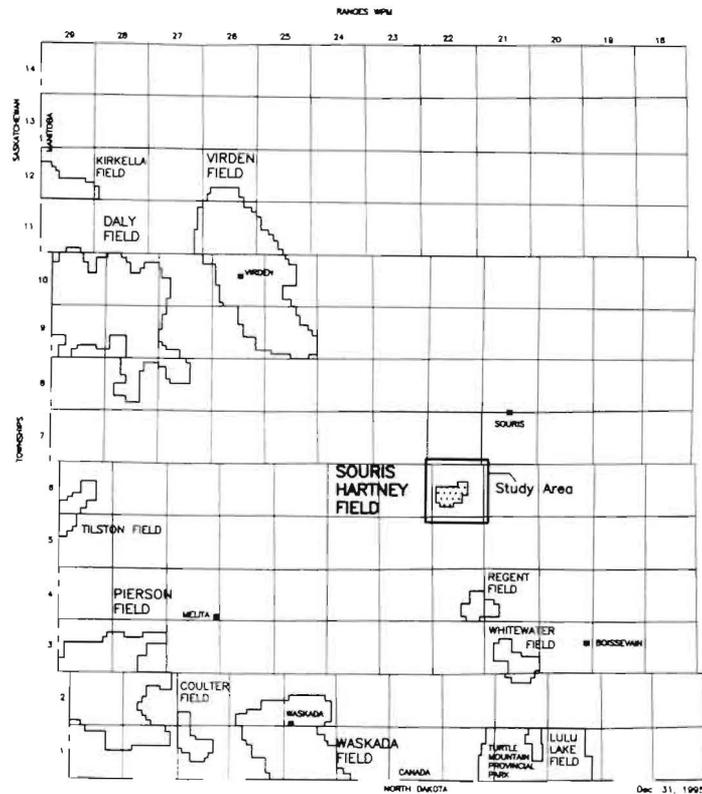


Figure 1: Index Map showing location of Souris Hartney Field and study area.

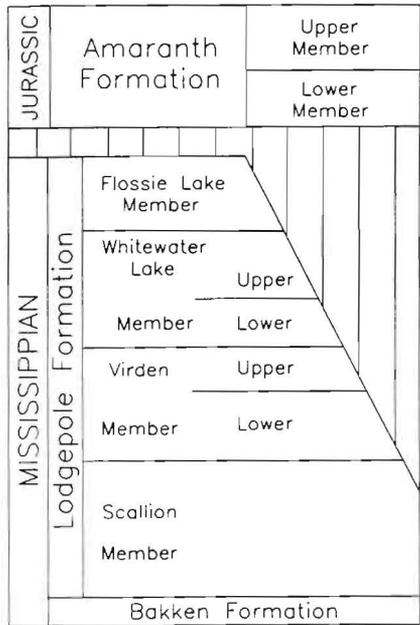


Figure 2: Stratigraphic column (after Martiniuk and Arbez, 1986b).

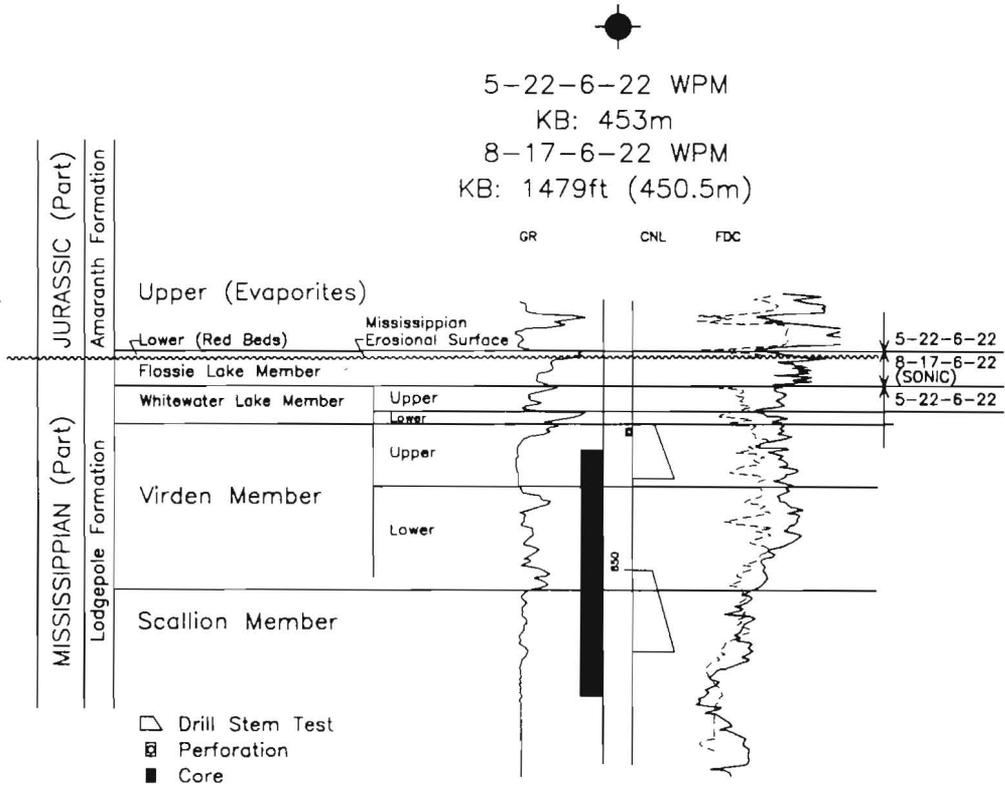


Figure 3: Souris Hartney composite reference well: 5-22-6-22 WPM and 8-17-6-22 WPM.

GENERAL STRATIGRAPHY

In southwest Manitoba, the Mississippian strata represents one major sedimentary marine transgressive-regressive cycle (McCabe, 1959). Mississippian strata are subdivided into the Bakken Formation and the Lodgepole Formation (Fig. 2).

During the initial major transgressive-regressive cycle, the Bakken Formation was deposited over the slightly eroded Devonian surface. The formation consists mainly of carbonaceous black shales of shallow water origin. Continued subsidence resulted in deposition of the argillaceous limestones of the Lodgepole Formation. The sedimentary rocks of this formation represent several minor cyclical transgressive-regressive episodes. Regression continued after Lodgepole time and the rate of subsidence decreased, producing a very shallow slope environment with progressively shallowing waters. Cyclical fluctuations in the regressing sea produced an interfingered carbonate-evaporite sedimentary rock sequence.

In the Souris Hartney area, the Lodgepole strata are truncated and overlain unconformably by the red beds of the Lower Amaranth Formation of Jurassic age. The Lodgepole is subdivided into four members. The basal unit, the Scallion member, lies unconformably above the Bakken Formation. It consists generally of white- to medium- grey, fine crystalline limestone with a granular or chalky texture and scattered fossil debris. The proposed depositional environment is an open marine shelf of shallow to moderate water depths.

Overlying the Scallion Member is the lower unit of the Virden Member. The Virden Member represents the first complete sedimentary cycle with the Lodgepole Formation. (Stanton, 1956). The Lower Virden Member is distinguished from the Scallion by an increase in argillaceous material. This change in sediment character can be observed on the spontaneous potential and radioactivity logs (Fig. 3). The lower unit is an interlaminated to bedded argillaceous, red and grey calcareous unit with few thin crinoidal and/or oolitic bands. In contrast, the Upper Virden Member is characterized as a clean fragmental limestone with few argillaceous bands. This unit is characterized by a blocky form in the spontaneous potential log and low radioactivity (Fig. 3).

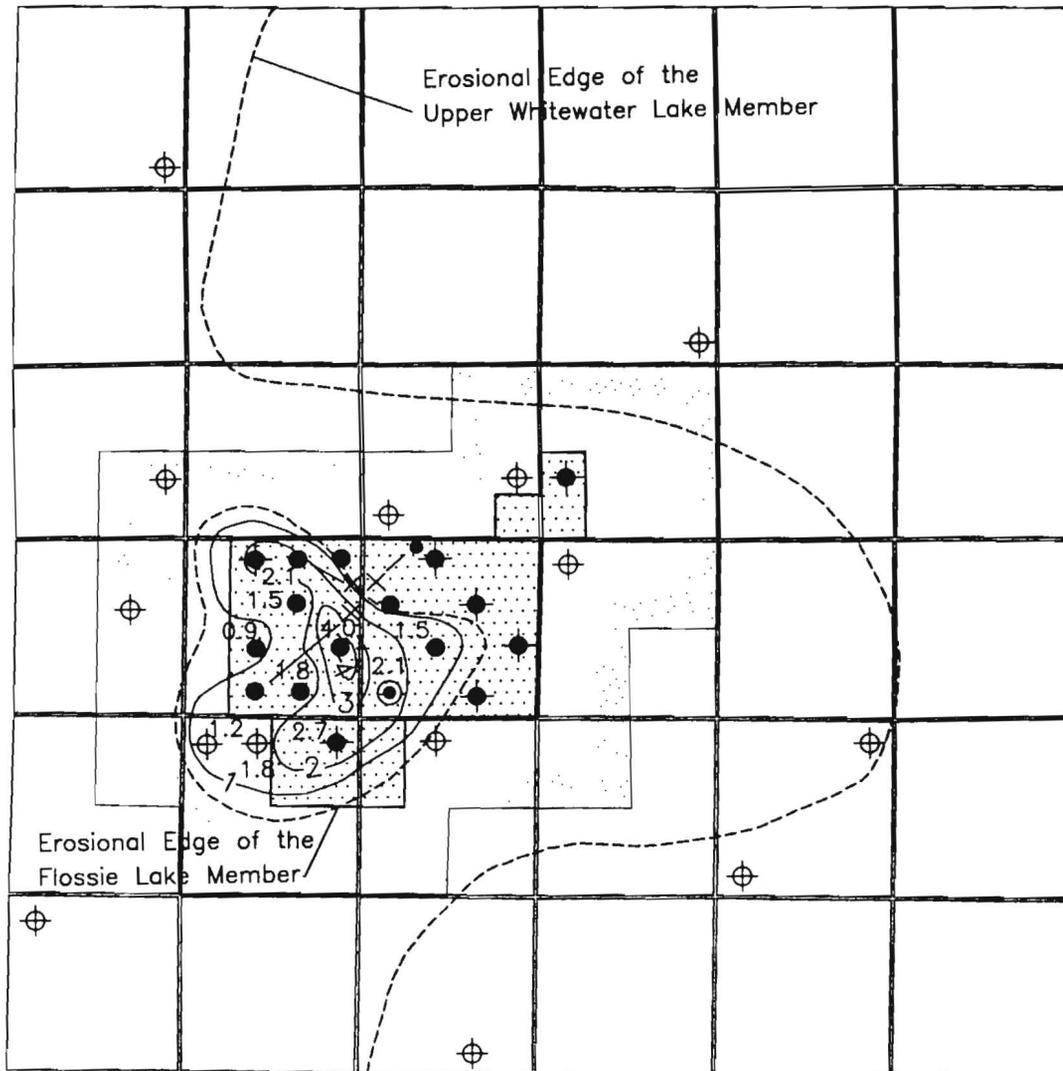
The Whitewater Lake Member represents the second sedimentary cycle developed in the study area. The abrupt change from a clean unit to an argillaceous unit is observed on the petrophysical logs (Fig. 3). Although similar in deposition to the Virden Member, the contrast between the lower and upper units is not as sharp. The Lower Whitewater Lake Member is defined as an interbedded oolitic to bioclastic limestone or argillaceous limestone and calcareous shale. The Upper Whitewater Lake, however, has only thin argillaceous bands within a fossiliferous, fragmental and oolitic limestone.

The Flossie Lake Member completes the Lodgepole sequence in the study area. This unit consists mainly of argillaceous limestone with strong secondary alteration (Stanton, 1956). The presence of this member in the study area is limited to the central portion of the Souris Hartney Field (Fig. 4).

Throughout the study area, Jurassic Lower Amaranth red beds lie unconformably above the Lodgepole Formation. This unit consists of siltstones and shales (Fig. 3). Secondary alteration in the uppermost beds of the Lodgepole Formation has been attributed to erosion prior to Lower Amaranth time.

R 22 WPM

T 6



Dec. 31, 1995

- ◆ Dry and abandoned
- Producer
- ◆ Abandoned producer
- C. I. = 1m
- Salt water disposal (former producer)
- ✕ Surface location - horizontal well
- Oil field - Souris Hartney Field
- ▨ Pool area

Figure 4: Isopach map-Flossie Lake Member (Upper Lodgepole).

LITHOLOGY

Lithologic and textural characteristics of the sedimentary rock of the Lodgepole Formation in the Souris Hartney Field were determined by examining 11 cores from the area. The core was described using the classifications of Dunham (1962) and Choquette and Pray (1970). Select core descriptions are presented in Appendix I.

SCALLION MEMBER

The Scallion Member is a light grey, fine crystalline, limy wackestone to packstone with lenses of white chalk (Appendix I). Intercrystalline and vuggy porosity is associated with patchy oil stain. Some crinoids and brachiopods are present.

LOWER VIRDEN MEMBER

The Lower Virden Member is predominantly mudstone to wackestone. Laminations of very fine to silt size limestone and shale characterize this unit. Bioturbation gives a mottled appearance to the unit. Colour ranges from light grey to dark grey, pink, green and brown. Dolomitization is present. Anhydrite is widespread, appearing as interbeds, nodules and fossil replacements. Silica occurs in this unit as fossil replacements. Porosity ranges from 0-3% and is commonly pinpoint vuggy in nature; however, medium size vuggy and fracture porosity is also evident. Few stylolites with concentrated zones of dark shale and hematite are present as well as some crinoids and brachiopods. Local interbeds of light grey-brown, medium crystalline, oolitic grainstone occur in the uppermost portion of the Lower Virden Member. Minor patches of oil stain are visible in the areas of the highest porosity grainstones.

UPPER VIRDEN MEMBER

The Upper Virden Member consists predominately of a light brown, fine- to -medium crystalline oolitic grainstone. In the producing wells, the upper unit displays very little secondary affects. In a few areas, the oolitic grainstone is limy and is affected by minor dolomitization. Anhydrite is scarce but where present it occurs as interoolitic fill. Crinoids and brachiopods are present with rare corals. The interoolitic porosity ranges from 6-20% with prominent oil staining. Calcareous mudstone beds and laminae occur above and below the oolitic grainstone unit. Both healed and open vertical fractures are present.

In abandoned producer wells, the Upper Virden Member is dominantly a limestone; but dolomitization has occurred with a concurrent reduction of permeability and to a lesser degree, porosity. The abundance of anhydrite, especially within pore spaces, also varies throughout. Beds and nodules of silica are present locally. A few thin beds or laminations of calcareous mudstone are interbedded with the oolitic grainstone. Due to varying amounts of anhydrite in the pore spaces, the pinpoint vuggy and interoolitic porosity ranges from 3-25%. Patchy and bedded oil staining is widespread.

In the dry and abandoned wells, the grainstones are interbedded with calcareous mud and the unit has been strongly dolomitized. Anhydrite is abundant and occurs as nodules, ooid replacements and infilling fractures and pore spaces. Silica has also been observed as ooid replacement. Pinpoint vuggy and interoolitic porosity varies from 0-12%. Oil staining is minor and patchy.

LOWER WHITEWATER LAKE MEMBER

The Lower Whitewater Lake Member is similar to the Lower Virden Member, but it is more highly dolomitized. It consists of grey green and dark grey laminae of hematite stained, argillaceous dolomitic mudstone. Anhydrite is abundant as interbeds, nodules and fracture filling. Visual porosity is rare, but when present occurs as pinpoint vugs or fracture porosity. Some interbeds of medium crystalline oolitic packstone were noted.

Upper Whitewater Lake Member

The Upper Whitewater Lake Member is commonly a wackestone to packstone in which strong dolomitization obliterates most textures. Within this light grey brown, fine- to -medium crystalline dolostone, few anhydrite and silica fossil replacements are preserved. Crinoids and brachiopods with some corals have been noted by Zakus (1967) in the Whitewater Lake Members. Anhydrite also occurs within the unit in bedform, nodules and fracture filling. Commonly, mudstone beds occur within the crystalline dolostone. Intrafossil and pinpoint vuggy porosity varies from 3-12%. Oil staining is minor and patchy.

FLOSSIE LAKE MEMBER (UPPER LODGEPOLE)

This unit has not been cored in the Souris Hartney Field in the Whitewater Field. It is restricted to the central portion of the field (Fig. 4) and appears to cap the Upper Whitewater Lake Member.

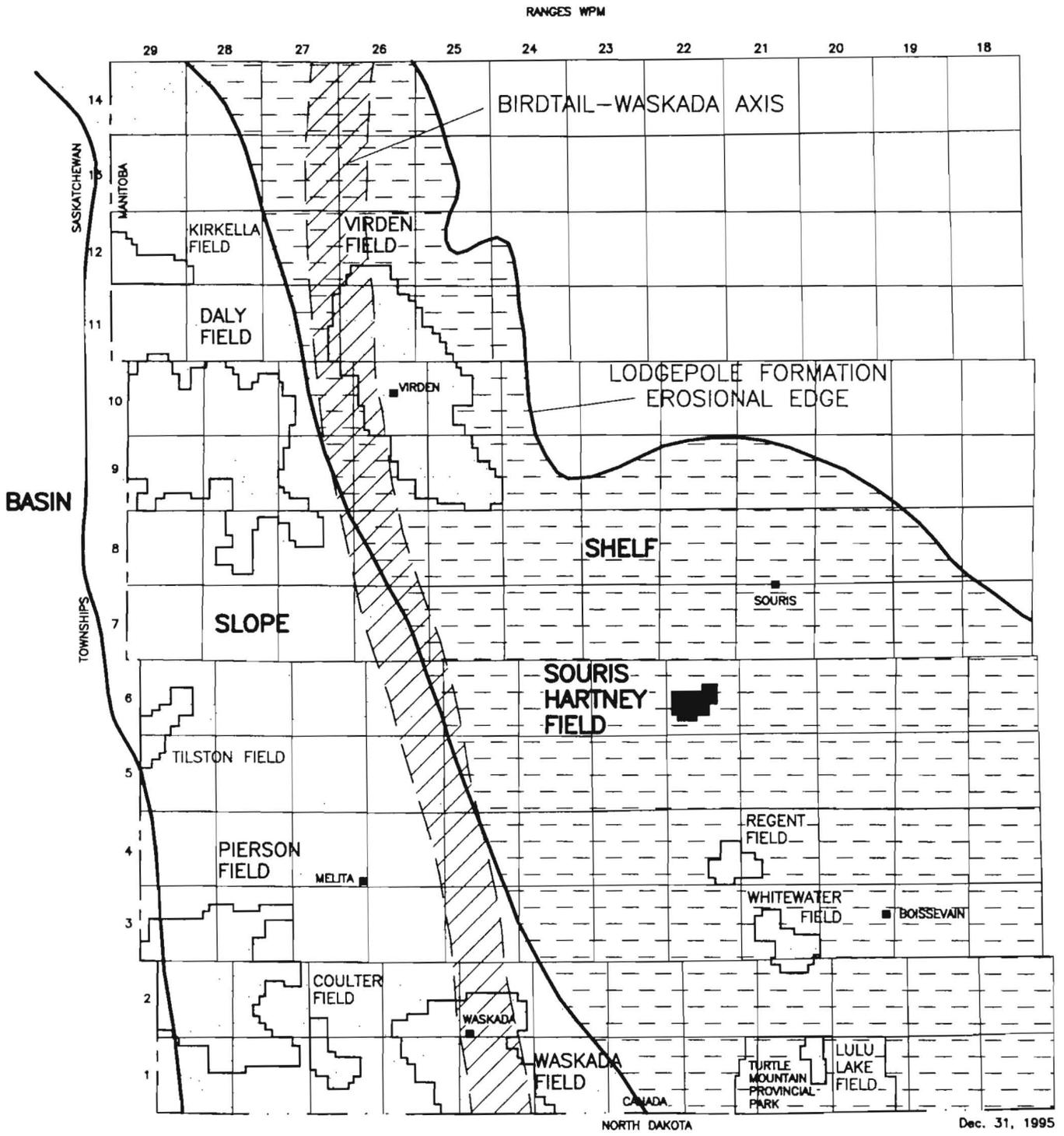


Figure 5: Map showing general distribution of Lodgepole Formation depositional environments (after Klassen, 1996).

DEPOSITIONAL ENVIRONMENT

The Virden and Whitewater Lake members represent cyclic deposition within a general regression of Lodgepole seas (McCabe, 1959). This cyclical nature is apparent from the textural character of the sediment deposited. The repetitive occurrence of argillaceous and clean sedimentary rocks of the Mississippian Lodgepole strata in the Souris Hartney area indicates fluctuating low to high energy conditions along a shallow marine, gently, sloping shelf (Fig. 5). The Scallion Member suggests an open marine shelf mode of deposition with shallow to moderate water depths (McCabe, 1959).

The argillaceous sediment of the Lower Virden Member indicates a low energy environment. In a detailed study of the Virden Member in southwestern Manitoba, Young (1973) observed an absence of mud cracks, algal stromatolites and other exposure features that indicate an environment with no subaerial exposure and suggesting a shallow marine environment. During periods of slightly increased water level, enough agitation would be present to winnow finer particles. The prominent maroon colour and presence of hematite in the Lower Virden Member may imply a strongly oxidizing environment; however, Young (1973), feels that due to textural relationships the hematite formation is post depositional. Young (1973) suggests a lagoonal low energy, quiet water environment above wave base, where wave or current agitation is only periodic.

The Upper Virden unit, characterized by irregular fine carbonate mud beds within a dominantly oolitic grainstone, demonstrates a variation in water agitation. The oolitic grainstone suggests a high energy environment; however, according to Young (1973), the Souris Hartney area is dominantly composed of calcareous, intraclastic-rich sedimentary rocks suggesting an environment of intermediate energy conditions. The decrease in argillaceous material within the low energy carbonate muds, relative to the Lower Virden Member, implies a lack of argillaceous terrigenous sediment supply. This lack of supply may be the result of a more stable shore or a deposition farther from shore. The Upper Virden Member appears to have been deposited in shoal areas with intermediate to high energy waters. Carbonate muds were deposited during fluctuations in sea levels when energy was decreased.

The Whitewater Lake Member display a cycle similar to that of the Virden Member with sedimentary rocks that have similar textural characteristics to that of the Virden Member (Zakus, 1967) and therefore, was deposited in comparable environments. The argillaceous content of the Lower Whitewater Lake Member suggests uplift and erosion to the north and east (Zakus, 1967).

R 22 WPM

T 6

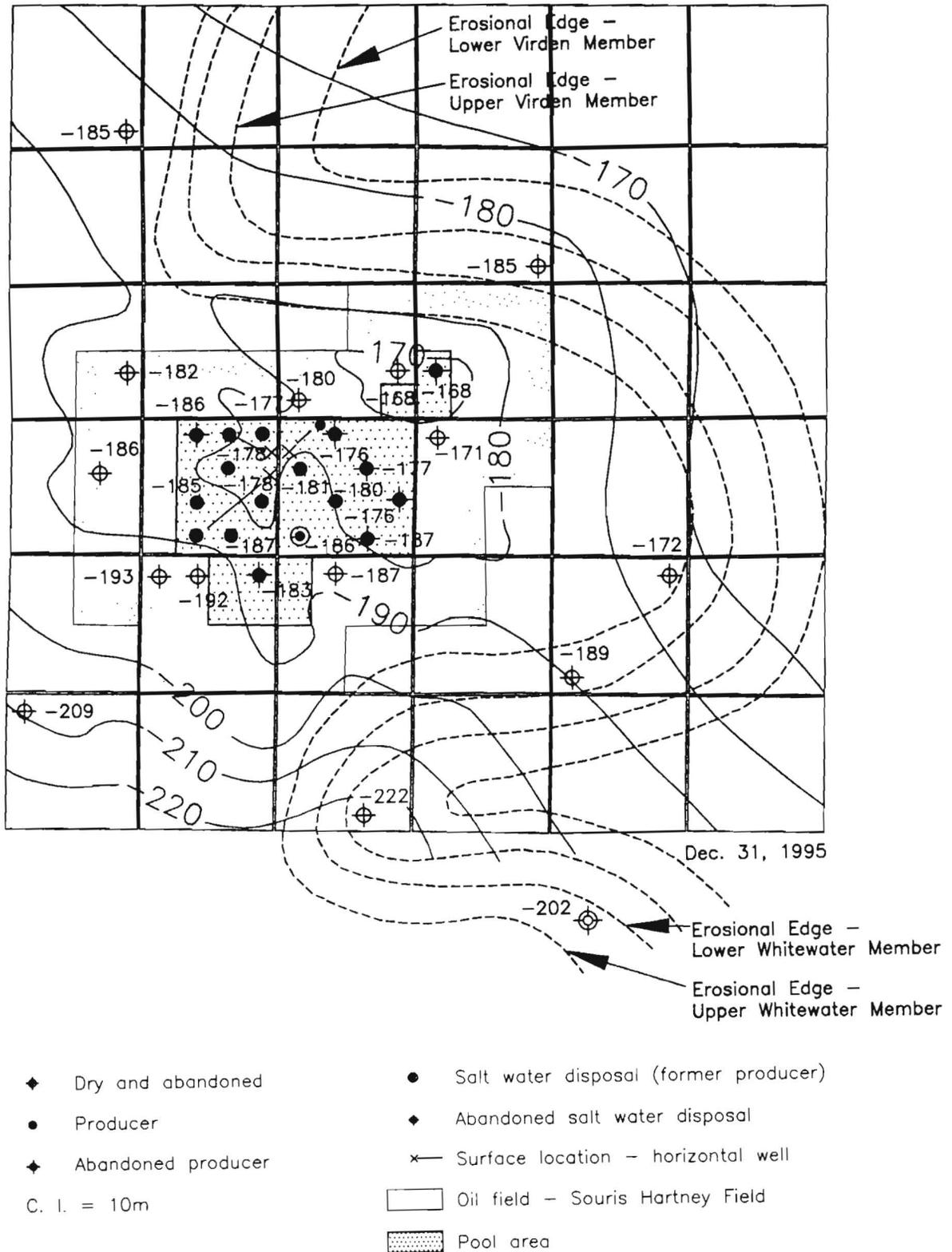


Figure 6: Structure map on the top of the Mississippian erosional surface.

ISOPACH AND STRUCTURE

In the field area, only 8 wells were drilled into the Scallion Member, but none have penetrated the base. Therefore mapping was focused on the Upper Virden, Upper Whitewater Lake and Flossie Lake members.

Along with regional dip to the southwest, the Mississippian erosional surface structure map (Fig. 6) displays the erosional edges of the Virden and Whitewater Lake members and a structural high covering the field area. Erosion and dolomitization has occurred on the flanks of this high. In general, the isopach of Lower Amaranth Formation (Red Beds) (Fig. 7) is a reflection of the Mississippian erosional topography with the Red Beds infilling lows on the erosional surface. The Lower Amaranth Formation thins over the wells 2-17 and 10-17 of the field area and around the well in 5-22-6-22 WPM, but it thickens to the south on the flank of the Souris Hartney field.

Although not mapped during this study, the Lower Virden Member ranges from 8 to 14.2 m.

All of the oil in Souris Hartney is produced from the Upper Virden Member (Fig. 8), which ranges from 3 to 9 m. The best production in the field occurs in wells where the thickness is between 6 and 6.5 m. Figure 9 displays the Upper Virden Member structure showing dip to the southwest and the well in 5-22-6-22 WPM as the Upper Virden Member structural high point.

The thickness of the Lower Whitewater Lake Member varies from 2.4 to 4.6 m, whereas the Upper Whitewater Lake Member ranges from 1.5 to 14.9 m with the thickest values present over the central portion of the field area (Fig. 10) The Flossie Lake Member, an erosional outlier (Fig. 4), which is restricted to the central portion of the field area, attains a maximum thickness of 4 m. The outline of the Flossie Lake Member appears to coincide with the better producing wells in the Souris Hartney field.

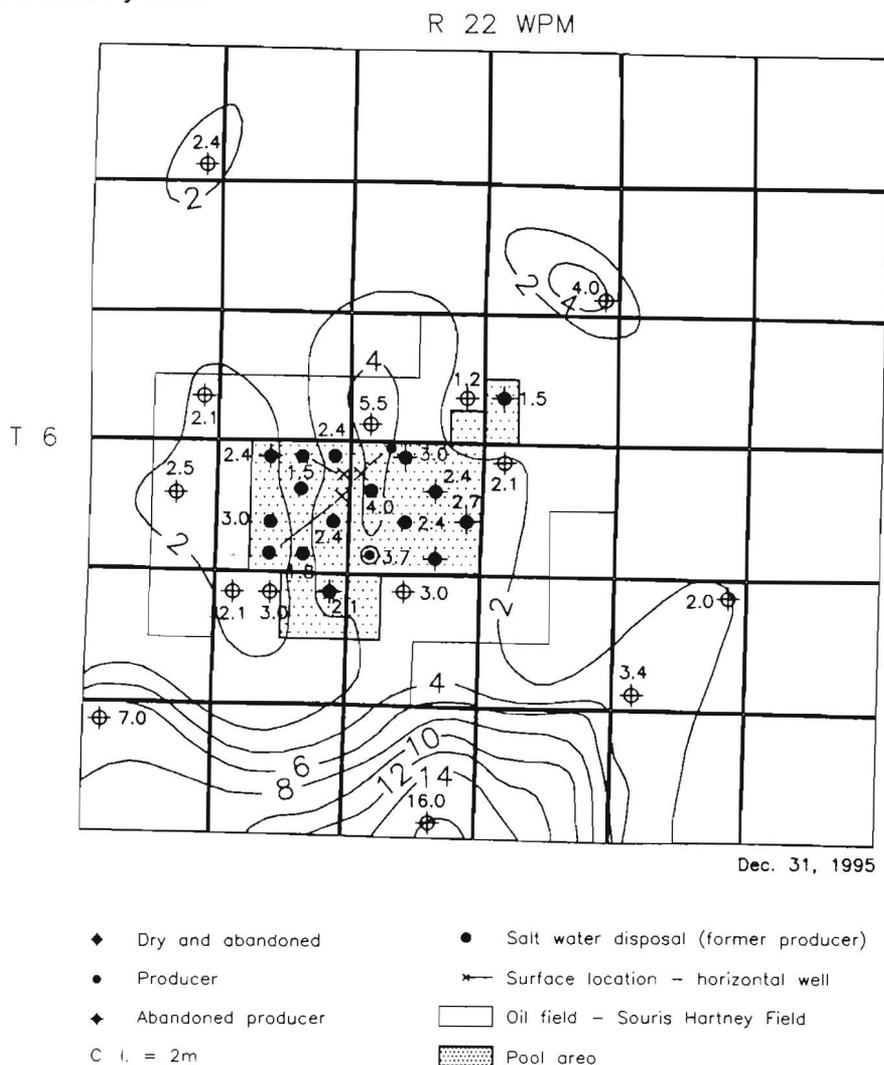
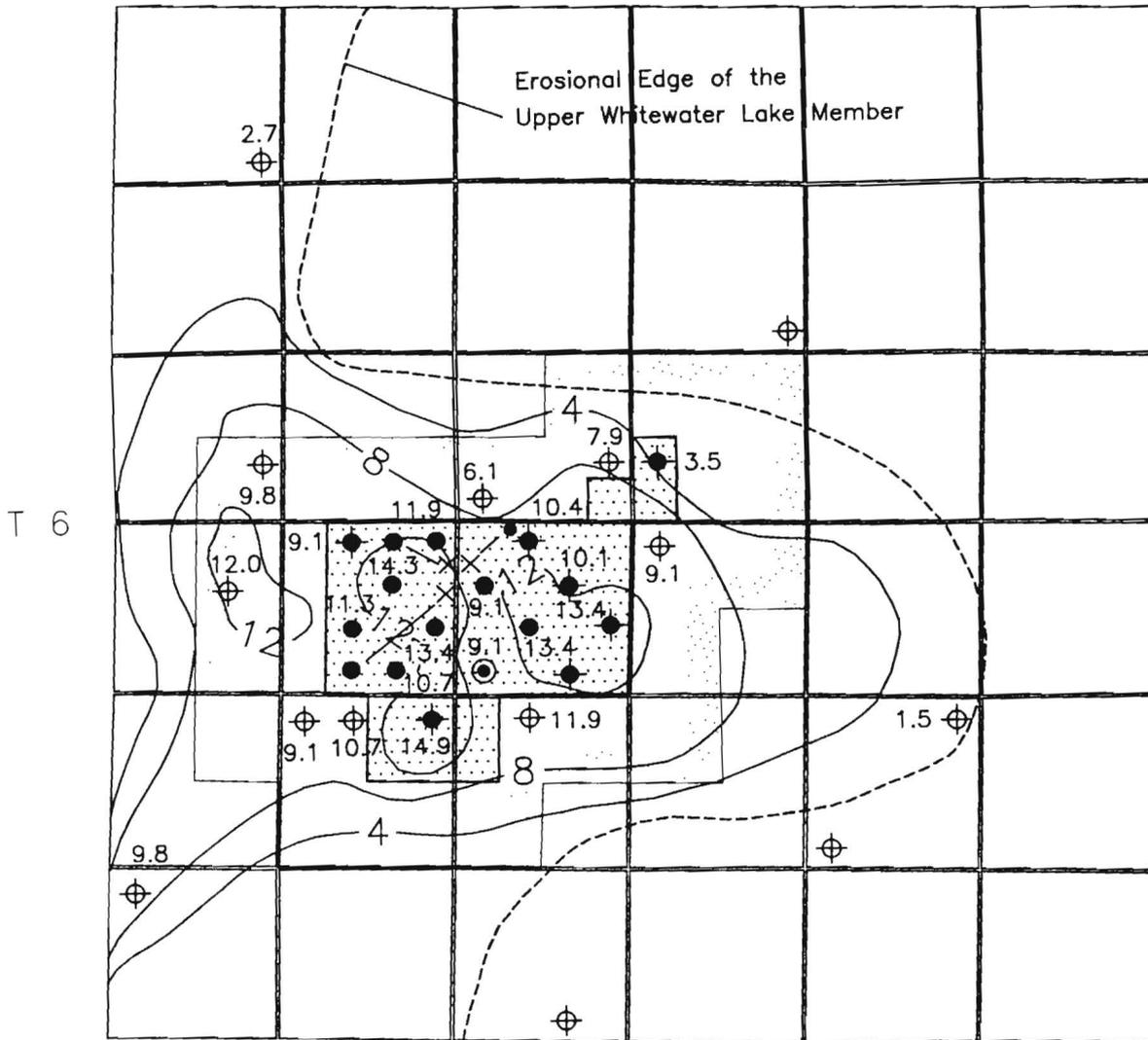


Figure 7: Isopach map of the Lower Amaranth Formation (Red Beds).

R 22 WPM



Dec. 31, 1995

- ◆ Dry and abandoned
- Producer
- ◆ Abandoned producer
- C. I. = 4m
- Salt water disposal (former producer)
- ✕ Surface location - horizontal well
- ▭ Oil field - Souris Hartney Field
- ▨ Pool area

Figure 10: Isopach map of the Upper Whitewater Lake Member.

TRAPPING MECHANISM

Souris Hartney lies along the subcrop trend of other Lodgepole Formation fields found within the shelf depositional setting (Table 1) such as Virden, Regent, Whitewater and Lulu Lake (Stanton, 1956; McCabe, 1963; Young, 1973; Potter, 1991; Martiniuk and Arbez, 1986a and b)(Fig. 5).

Oil accumulation in the Souris Hartney Field is related to an unconformity trap and a porosity-permeability trap. Cross sections A-A' and B-B' (Fig. 11, 12) illustrate the stratigraphic trapping. In southwest Manitoba, northeast truncation of the Mississippian strata resulted in an escarpment formed along the subcrop belts of the Virden and Whitewater Lake members (Potter, 1991; McCabe, 1959). Favourable conditions for oil accumulation occur in porous strata at or near this erosional surface due to updip migration. The Virden Member has been truncated just northeast of the Souris Hartney Field. Oil accumulation in this field is likely due to the updip migration of oil towards the unconformity surface through the relatively porous oolitic grainstones of the Upper Virden Member.

The nature of the Upper Virden Member and the overlying lower unit of the Whitewater Lake Member has affected the accumulation of oil in the Souris Hartney Field. The relatively porous and permeable oolitic grainstone of the Upper Virden Member provides the reservoir for the migration and accumulation of oil, which is sealed by the mudstones of the overlying Lower Whitewater Lake Member.

Table 1
General Reservoir Characteristics - Souris Hartney Field to June 30, 1996

Souris Hartney Field - Lodgepole Virden A Pool (10 53A)

Year of discovery		1962
Number of Wells	Capable of Oil Production	6 Vertical 3 Horizontal
	Previous Producers	7
	Service	1
Spacing		32 ha
Average Depth of Producing Zone		655m KB
Crude Oil Quality	Density	866 kg/m ³
	Sulphur Content	10.4 g/kg
Permeability (cut off: 1.0 mD)		79 mD
Initial Pressure (-201 m subsea)		6674 kPa
Current Pressure		Not Available
Recovery Mechanism:		Water Drive
Reserves Information:		
Production Area (A)		667 ha
Net Pay (h)		3.16 m
(cutoffs: Porosity = 7.5%, k = 1.0 mD)		
Porosity		12.2%
Connate Water Saturation (Sw)		51.6%
Shrinkage Factor (1/Boi)		0.94
Original Oil in Place		1 171 713 m ³
Current Recovery Factor		14.2%
Ultimate Recoverable reserves		213 800 m ³
Cumulative Production		166 432.1 m ³
(to June 30,1996)		
Remaining Recoverable Reserves		47 400m ³
(to June 30,1996)		

The abundance of secondary anhydrite and dolomite may also have affected oil accumulation in the Souris Hartney Field. Within the grainstone of the Upper Virden Member, the anhydrite, which infills pore spaces and fractures and as fossil and oolite replacements, has reduced porosity and permeability. Dolomitization may also have decreased permeability and porosity in the unit. The flanks of the field have reduced oil production and the lithology of the Upper Virden Member is dolostone.

Oil production along the flanks of the field, where the lithology of the Upper Virden Member is primarily a dolostone, is poorer than in the central portion of the field.

In the field, dolomitization occurs on the flanks of the trap and permeability is reduced. The effect of dolomitization can be seen at 5-22-6-22 WPM where the Upper Virden is mainly dolostone and the well was subsequently abandoned after producing only 24.9 m³. Anhydritization and dolomitization have more greatly affected the Upper Whitewater Lake Member creating a more dense rock and a barrier to updip and lateral oil migration. At Souris Hartney, the Flossie Lake Member occurs as a thin erosional outlier over the best producing wells (Fig. 4).

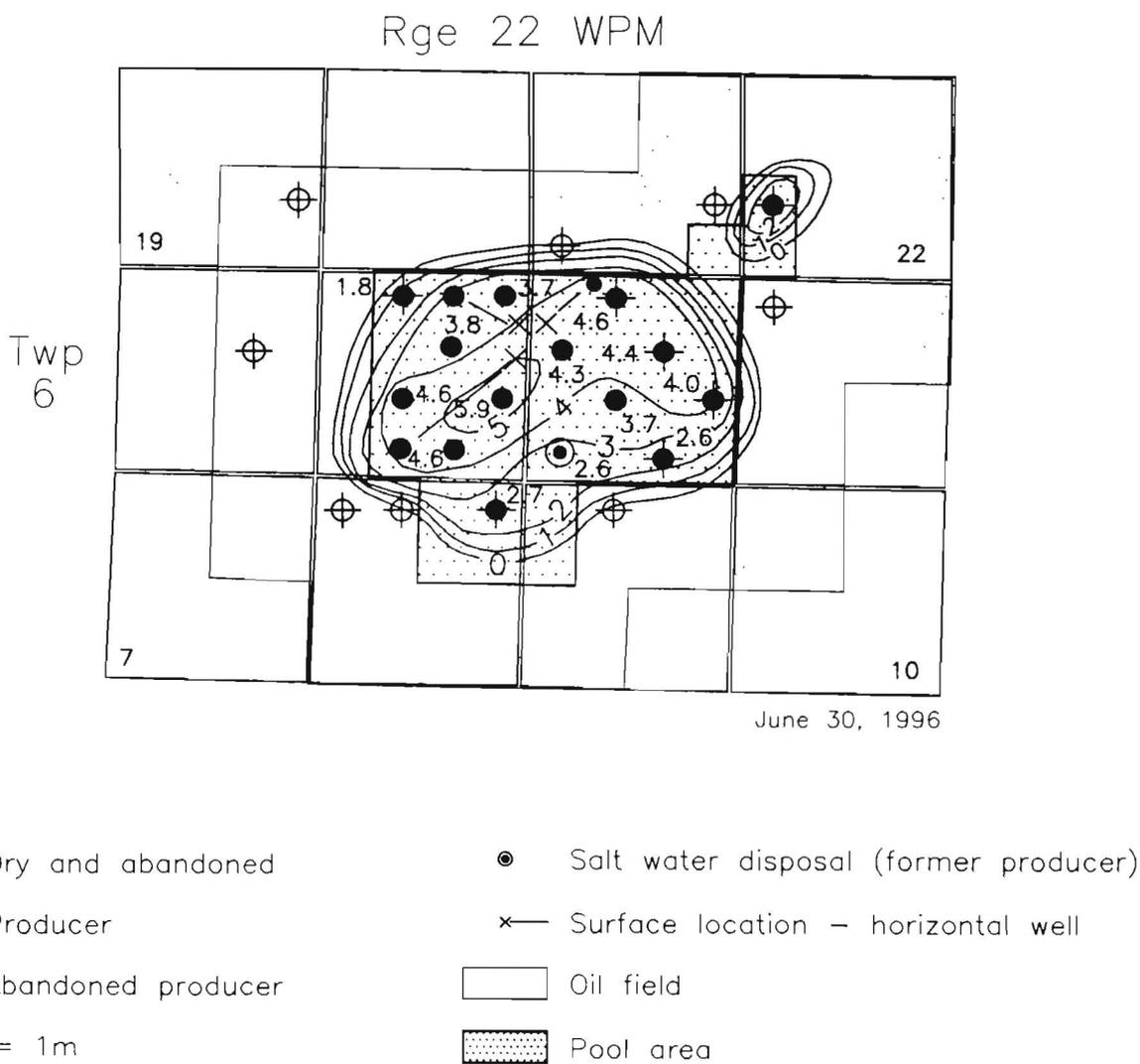


Figure 13: Net pay map of the Lodgepole Virden A Pool.

RESERVOIR AND PRODUCTION CHARACTERISTICS

RESERVOIR PARAMETERS

The productive area of the A Pool covers 667 ha. Production is limited updip by a change in reservoir facies from limestone to a low permeability dolostone. Downdip production is limited by an estimated oil/water contact at -208.8 m subsea.

Net pay in the A Pool ranges from 1.8 m to 5.9 m (Fig. 13). Net pay was determined primarily from core using a 1 mD permeability cut-off (Fig. 14). The average pay thickness is 3.16 m. The best producers in the pool have net pay in excess of 3.5 m.

Porosity in the productive limits of Upper Virden Member varies between 5% and 24% (Fig. 15). Lower porosity occurs where the reservoir facies has been dolomitized. The average porosity in the A Pool is 12.2%.

The estimated initial water saturation in the A Pool is 51.6%. Water saturations were calculated using the Archie equation with constants, $a = 1.0$ and $m = 2.0$. An R_w of 0.051 W^{-m} was used based on a reservoir temperature of 33.9°C. Of all the reservoir parameters the water saturation determination is the least reliable. Higher than expected recoveries in the central portion of the pool suggest the initial water saturation may be lower than estimated.

Crude oil from the A Pool has a density of 866 kg/m³ (32° API) and a sulphur content of 1.04%. The estimated GOR is 12.5 m³/m³. No PVT analysis is available for the A Pool. A formation volume factor of 1.06 m³/m³ has been used based on PVT analysis from the Whitewater WL B Pool which has similar crude oil properties.

The estimated original oil in place (OOIP) in the A Pool is 1171.7 10³m³. Oil in place was determined volumetrically using the average reservoir parameters listed in Table 1. The majority of reserves are in the central portion of the pool in the W/2 of Section 16 and the E/2 of Section 17.

PRODUCTION AND RESERVES

A comparison of cumulative oil production to December 31, 1995 from the Lodgepole Formation fields in the shelf depositional setting (Fig. 5) is shown in Table 2.

The pool was developed on 32 ha spacing with the majority of wells drilled by the end of 1963. At the end of 1992 there were six vertical producers in the pool with a combined production of 5.8 m³ OPD. In 1993, Corvair Oils Ltd. drilled two horizontal wells in the pool. In August 1995, after completion of a third horizontal well, production reached 32.5 m³ OPD, the highest total since December 1965.

Table 2
Comparison of Cumulative Production of Lodgepole Formation

Field	Cumulative Oil Production (1000 m ³) to December 31, 1995
Virden	21 012.7
Souris Hartney	162.5
Regent	39.1
Whitewater	238.4
Lulu Lake	71.8

There are currently six vertical and three horizontal producers in the pool. In June 1996, production averaged 20.6 m³ OPD at a WOR of 3.97 m³/m³. Cumulative production to June 30, 1996 totaled 166 432.1 m³ (Table 3). A plot of the pool production history is shown in Figure 16.

Wells in the A Pool can be divided into two groups, good producers and poor producers. The good producers are located in the central portion of the pool, in the W/2 of Section 16 and the E/2 of Section 17, where the reservoir facies is primarily limestone (Fig. 17). Along the updip edge of the pool, in the E/2 of Section 16, the reservoir facies changes to dolostone and the permeability decreases significantly. The kh map (Fig. 18) highlights the difference in permeability thickness between the limestone and dolostone facies. The average permeability where the reservoir facies is limestone is 131 mD, compared to 29 mD in the dolostone. Downdip to the southwest, production has been limited by proximity to the oil/water contact.

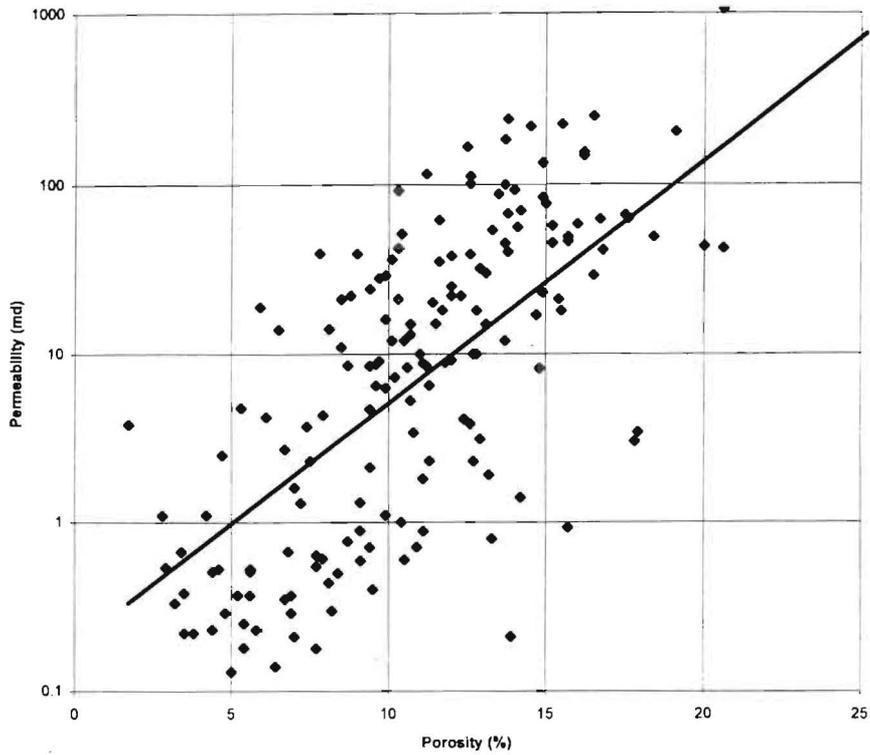


Figure 14: Permeability - Porosity cross plot showing 9 wells in Souris Hartney field.

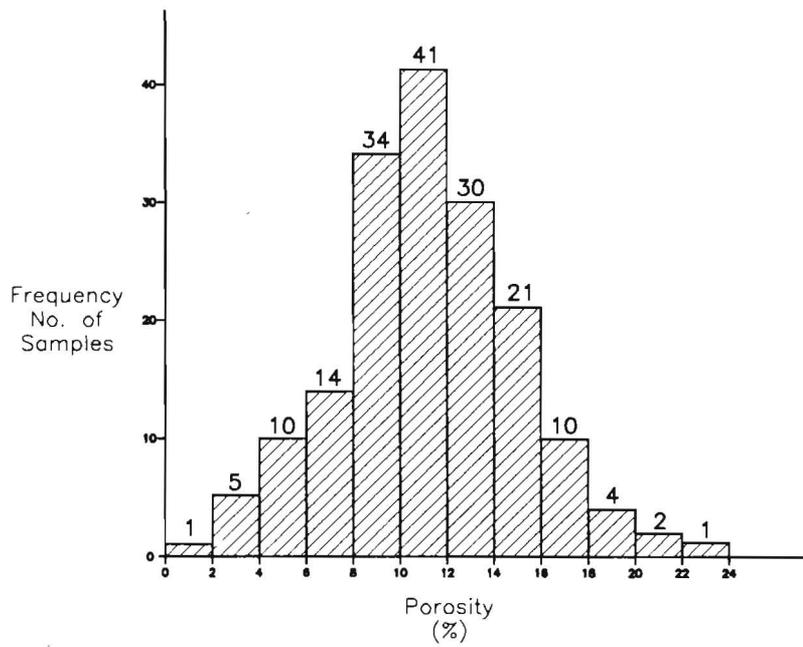


Figure 15: Core porosity distribution for Souris Hartney field.

The primary recovery mechanism in the A Pool is water drive. Pressure support is provided by water influx from the Upper Virden Member along the flanks of the pool. Water influx may also be occurring from the underlying wet Lower Virden Member through vertical fractures. The evidence of water influx is illustrated by the higher cumulative WOR's for wells located on the flanks of the pool (Fig. 19). The original reservoir pressure in the A Pool was 6674 kPa. Limited pressure data is available for the pool therefore material balance calculations are not possible. Additional pressure data would be useful for quantifying water influx, designing horizontal well drilling programs and optimizing the depletion strategy for the pool.

Current recovery from the A Pool is 14.2% OOIP. Individual well recoveries vary substantially, ranging as high as 41.3% OOIP at the 12-16 well (Fig. 20). The highest average current recovery is 27.2% OOIP in Section 17 and the lowest is 2.1% OOIP in Section 16, excluding the 12-16 well. The three horizontal wells drilled in the pool are located in the areas of highest recovery.

Ultimate recoverable reserves from the A Pool are estimated at 213.8 10^3m^3 or 18.2% OOIP. Remaining recoverable reserves are 47.4 10^3m^3 . The ultimate recovery in the central portion of the pool is estimated to exceed 28% OOIP. By comparison ultimate recoveries in other large water drive Lodgepole reservoirs range from 11.1% OOIP in the Whitewater Lodgepole WL B Pool to 22.8% OOIP in Routledge Unit No. 1 (Virden Lodgepole C Pool).

Table 3
Souris Hartney Field Production to June 30, 1996. Shows all wells in the Lodgepole Virden A (10 53A) Pool

Well (Lsd-Section)	Current Status	Cumulative Oil (m^3)	Cumulative Water (m^3)	Daily Oil (m^3) Average	First Month Production (year-month)	Last Month Production (year-month)
16-8	ABD P	145.7	413.0	0.9	63-11	63-11
2-16	ABD P	71.6	535.6	0.5	63-03	63-11
4-16	SWD	452.7	492.7	0.6	63-03	63-11
6-16	COOP	5130.4	56227.5	0.7	63-01	88-10
8-16	ABD P	189.1	1163.4	1.1	63-03	63-11
10-16	ABD P	82.2	407.0	1.3	69-06	69-10
12-16	COOP	31997.7	11545.5	3.0	63-11	96-06
14-16	ABD P	60.5	102.1	1.3	63-03	64-08
2-17	COOP	22690.2	68955.9	2.0	63-09	96-06
6-17	COOP	22178.9	91557.0	2.0	63-04	96-06
8-17	COOP	32540.0	11661.3	2.8	62-11	96-06
10-17	COOP	25762.9	72257.0	2.3	63-04	96-06
14-17	ABD P	133.0	115.6	0.7	63-06	64-10
16-17	COOP	10414.2	83548.5	1.0	63-10	96-06
5-22	ABD P	24.9			86-01	86-05
03-17 HZ	COOP	9595.5	15493.3	11.0	93-11	96-06
15-17 HZ	COOP	2854.6	18218.0	4.0	93-11	96-06
14-16 HZ	COOP	2108	4.8	6.5	96-06	96-06
TOTAL		166432.1	432698.2			

COOP = Capable of Production
ABD P = Abandoned Producer
SWD = Water Disposal

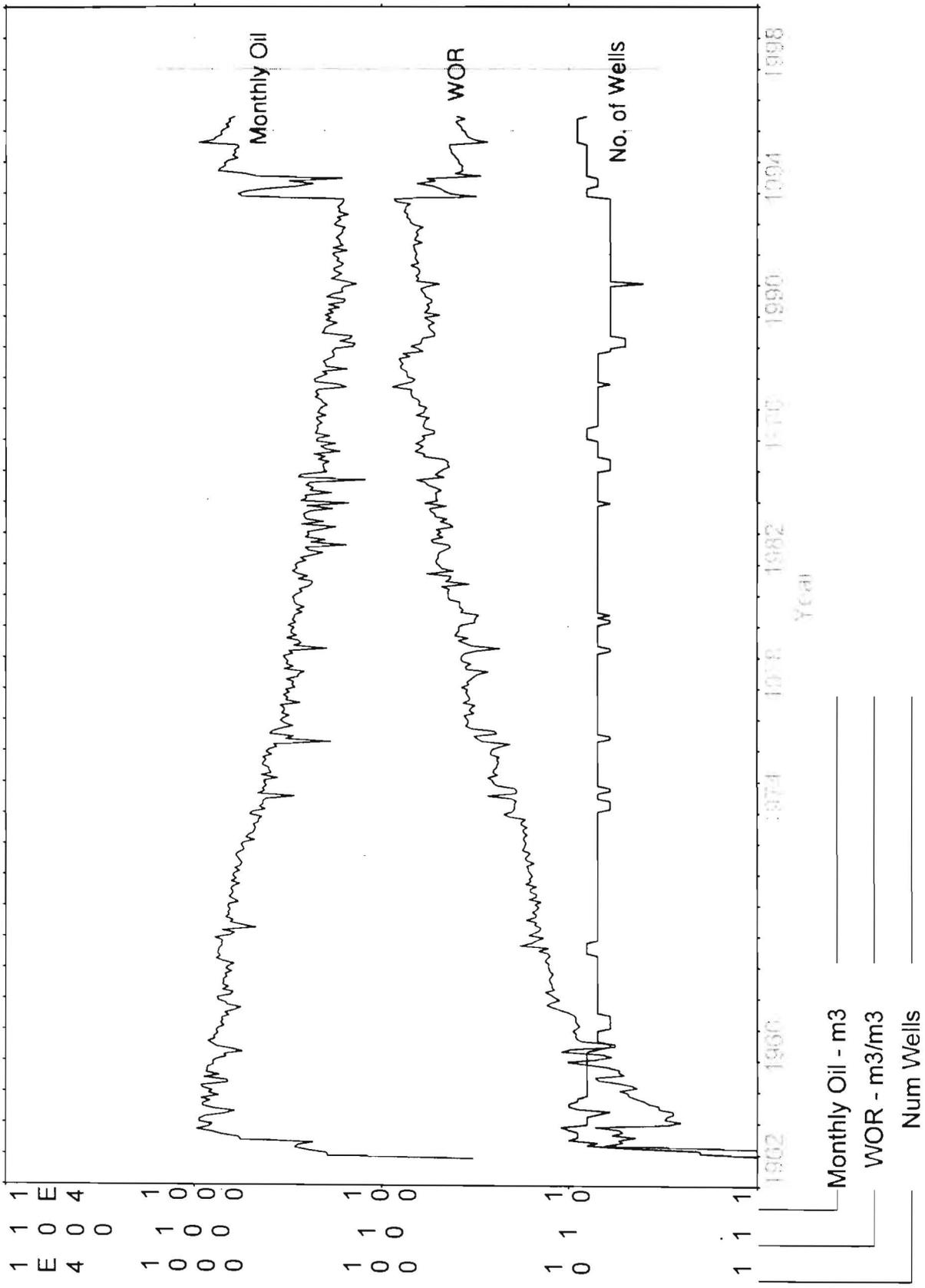


Figure 16: Pool production history plot.

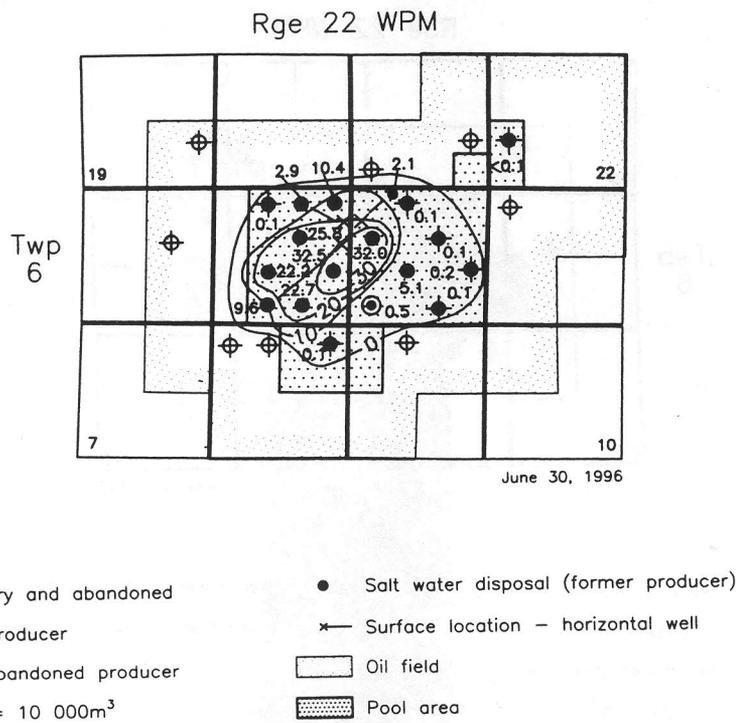


Figure 17: Cumulative production map to June 30, 1996.

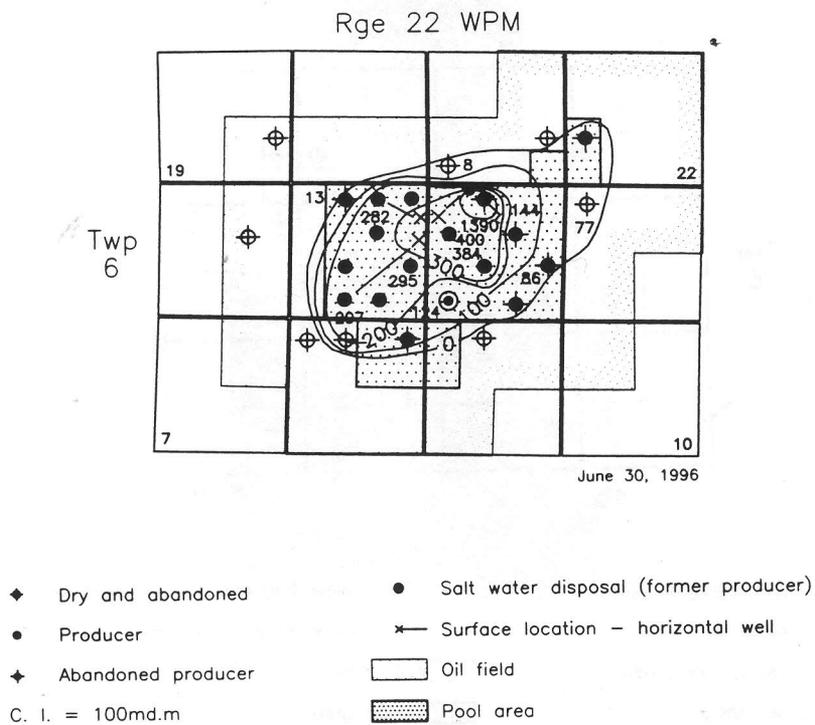
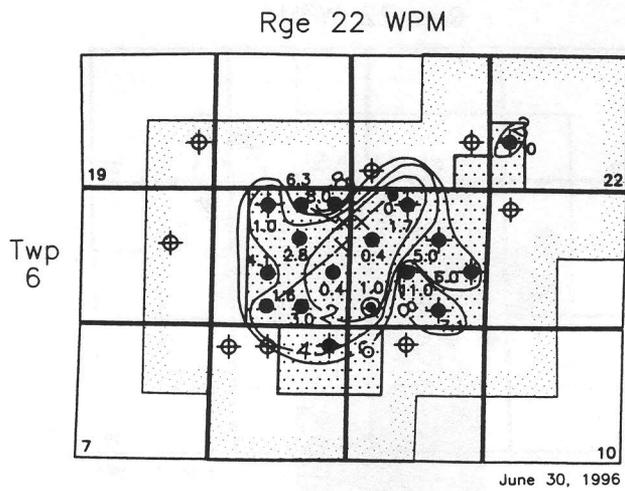
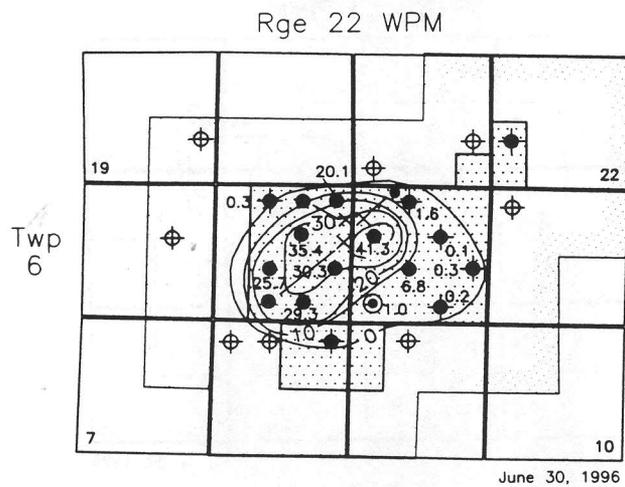


Figure 18: Permeability thickness map (Kh).



- | | |
|-----------------------------------|---|
| ◆ Dry and abandoned | ● Salt water disposal (former producer) |
| ● Producer | ✕ Surface location - horizontal well |
| ◆ Abandoned producer | □ Oil field |
| C. I. = $20\text{m}^3/\text{m}^3$ | ▨ Pool area |

Figure 19: Cumulative WOR map.



- | | |
|----------------------|---|
| ◆ Dry and abandoned | ● Salt water disposal (former producer) |
| ● Producer | ✕ Surface location - horizontal well |
| ◆ Abandoned producer | □ Oil field |
| C. I. = 10% | ▨ Pool area |

Figure 20: Current recovery map to June 30, 1996.

COMPARISON OF VERTICAL AND HORIZONTAL WELL PERFORMANCE

Horizontal drilling has rejuvenated the A Pool. During the first six months of 1996 horizontal wells accounted for 84% of the pool production. Horizontal wells averaged 6.1 m³ OPD at a WOR of 2.48 m³/m³, 8.8 times the average vertical well rate of 0.7 m³ OPD at a WOR of 10.82 m³/m³.

The three horizontal wells drilled in the A Pool were drilled using a gelled hydrocarbon-based drilling mud (Oildril 90™). Drilling mud weight ranged from 850-940 kg/m³ resulting in slightly underbalanced drilling of the horizontal section. The horizontal section lengths range from 612-781 m with orientations both parallel and perpendicular to the regional structural strike of the Lodgepole Formation. Table 4 summarizes the individual horizontal well drilling parameters.

Table 4
Horizontal Well Drilling and Production Data for Township 6, Range 22 WPM

Well	Surface	Horiz. Length (m)	Final Orientation Degrees	Max. TVD (m) (subsea)	Initial Production		Current Production		Cum. Prod. m ³
					Daily Oil m ³ /d	WOR m ³ /m ³	Daily Oil m ³ /d	WOR m ³ /m ³	
14-16	12C-16	634	54.96	-196.2	6.4	0	5.5	0.02	2108.0
3-17	9A-17	781	231.9	-205.6	10.8	1.46	10.8	2.34	9595.5
15-17	15-17	612	304.3	-203.2	4.8	4.88	4.8	10.91	2854.6

The three horizontal wells have very different production characteristics. Figures 21 to 23 are production plots for the three horizontal wells; 14-16-6-22, 3-17-6-22 and 15-17-6-22. The 3-17 well is the best producer averaging 11.0 m³OPD since going on production in November 1993. The other two horizontal wells have been disappointing with initial productivity (first year) of 6.4 m³OPD for 14-16 and 4.8 m³OPD for 15-17.

Normalized production plots were generated to compare the performance of vertical and horizontal wells. The normalized production plot of the best seven vertical wells in the pool is shown in Figure 24. The plot indicates an average initial productivity (1st year) of 5.5 m³OPD. Initially production declines very rapidly, eventually stabilizing at a decline rate of 3.9% p.a. (exponential). Water coning is observed immediately with the WOR increasing at a rate of 0.17 m³/m³ per 1000 m³ of oil produced. The average vertical well recovers 15.0 10³m³ over a 15 year period.

The normalized production plot for the three horizontal wells is shown in Fig. 25. The plot indicates an average initial horizontal well productivity (1st year) of 7.4 m³OPD, 1.3 times the initial vertical well rate. The initial horizontal well WOR was 1.75 m³/m³ (first year), compared to a first year vertical well WOR of 0.2 m³/m³. The higher initial WOR for horizontal wells is a function of reservoir depletion. The WOR increase observed in the horizontal wells is 0.165 m³/m³ per 1000 m³ of oil produced matching the rate experienced by the vertical producers. Based on the limited production history the horizontal well declines at a rate 26% p.a. (exponential) after the first year and recovers 11.7 10³m³ over a 7.7 year period based on an economic limit of 1.0 m³OPD. By comparison the best horizontal well in the pool, 3-17, has produced 9.6 10³m³ in 2.7 years and is currently producing 10.9 m³OPD.

At the stage of depletion of the A Pool, where vertical wells have declined to marginal rates, horizontal wells appear to offer a viable option for recovery of additional reserves.

Decline curve analysis for each of the horizontal wells indicates a combined horizontal well recovery of 40.9 10³ m³, an additional 3.5% OOIP. Almost 75% of the horizontal well recoverable reserves are attributed to the 3-17 well.

To determine whether horizontal well production in the A Pool is accelerated or incremental, the impact of horizontal well production on vertical well performance was reviewed. Each of the horizontal wells penetrates undrilled 16 ha tracts in the pool and also penetrates within 100-200 m of one or more vertical wells. Production testing of the vertical wells in the A pool occurs on average twice a year. A plot of vertical well production versus time (Fig. 26) shows no production interference between the vertical and horizontal producers in the pool during 1993-95. The rapid drop in vertical well production in 1996 is a result of vertical well production testing between January-June 1996. Additional vertical well production testing is required before a conclusion can be drawn regarding production interference from the horizontal wells. The WOR for horizontal producers averaged 2.48 m³/m³ between January 1996 to June 1996, compared to an average vertical well WOR of 10.82 m³/m³. This suggests that water coning near vertical wellbores may limit the area that can be effectively drained by a vertical well to less than the current 32 ha spacing. The evidence suggests that horizontal wells drilled between existing producers are primarily producing incremental reserves.

Based on the limited number of horizontal wells drilled in the A Pool it appears horizontal well productivity may be enhanced by orienting the wellbore in a NE-SW direction, parallel to the primary vertical fracture orientation observed in the Manitoba portion of the Williston Basin. Other factors that may help reduce water production are locating the horizontal section at the top of the Upper Virden Member and maximizing the interwell distance between the horizontal section and offsetting vertical wells.

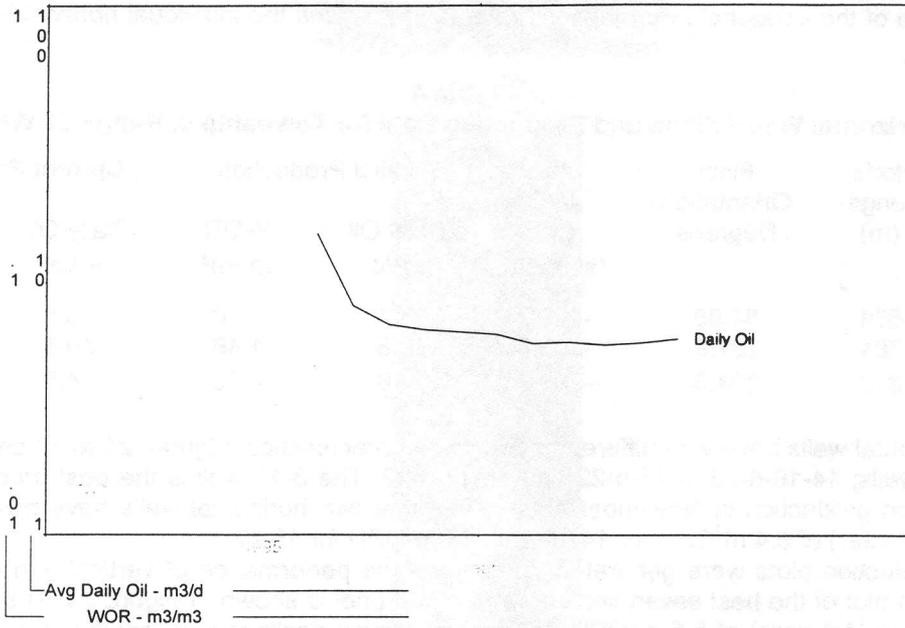


Figure 21: Production plot for Horizontal Well 14-16-6-22 WPM.

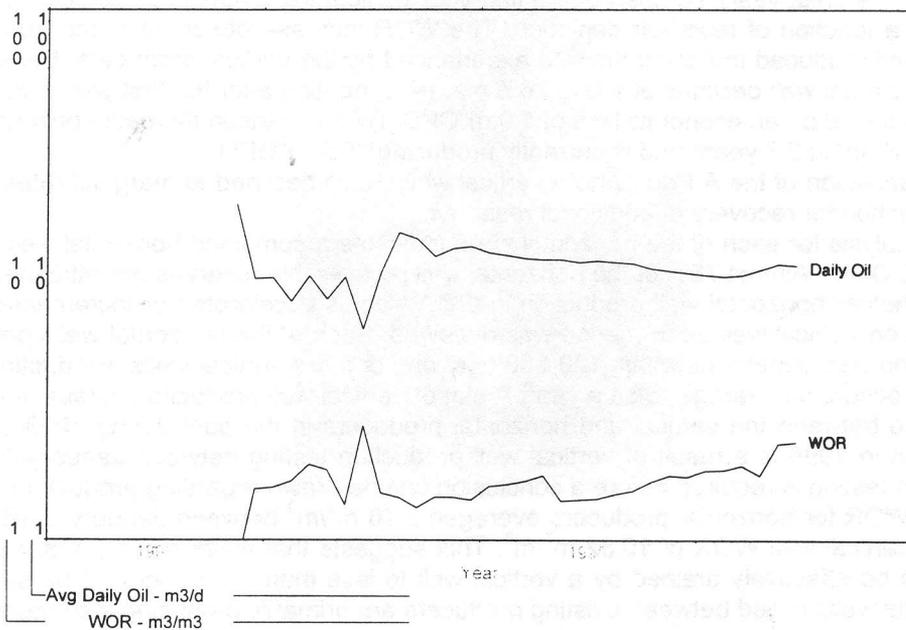


Figure 22: Production plot for horizontal well 3-17-6-22 WPM.

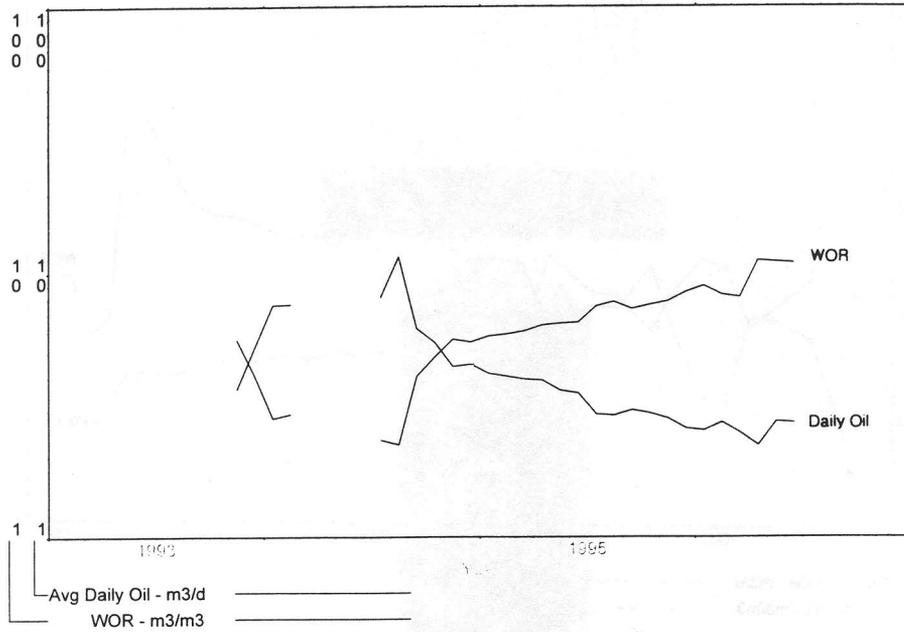


Figure 23: Production plot for Horizontal Well 15-17-6-22 WPM.

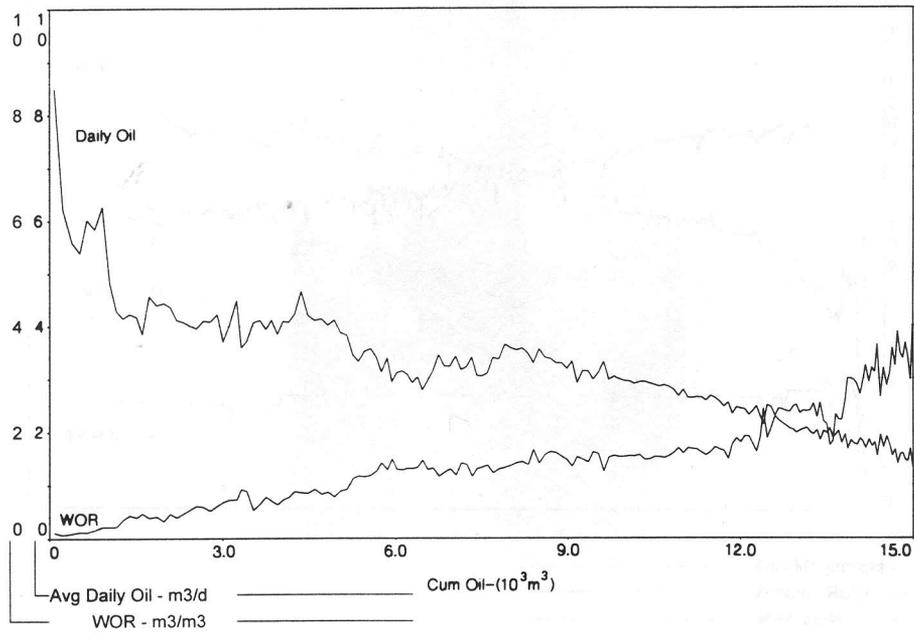


Figure 24: Normalized production plot of seven best vertical wells in the Pool (6-16, 12-16, 2-17, 6-17, 8-17, 10-17 and 16-17-6-22 WPM).

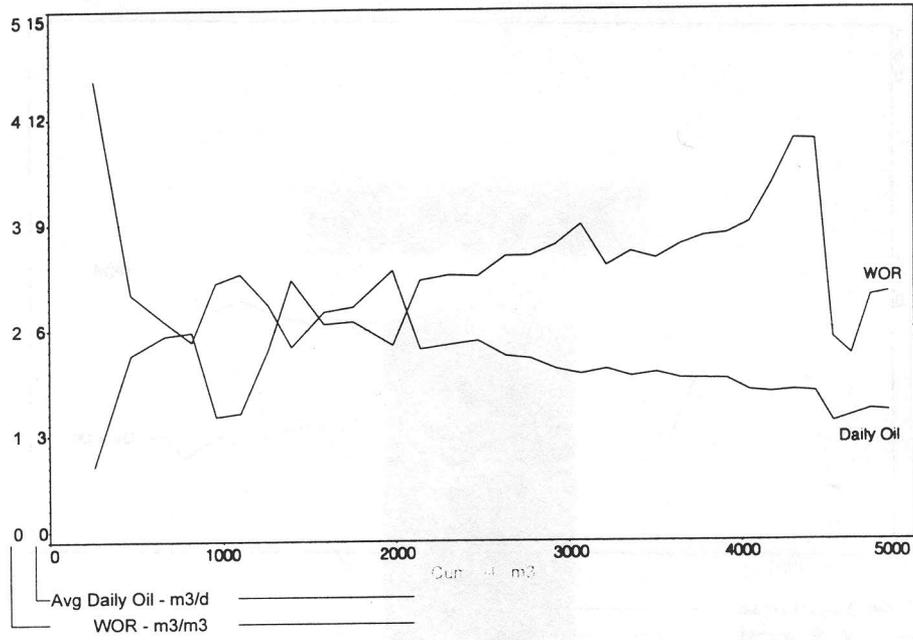


Figure 25: Normalized production plot of three horizontal wells.

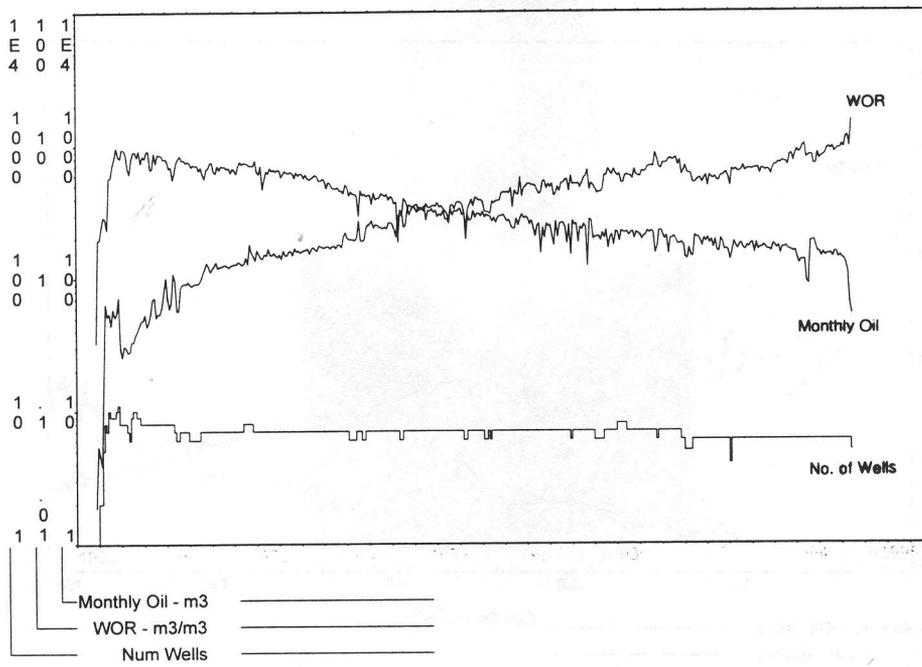


Figure 26: Vertical well production versus time plot.

CONCLUSIONS

The Virden and Whitewater Lake members of the Lodgepole Formation each represent one complete sedimentary cycle within a major Mississippian transgressive-regressive cycle.

Production in the Souris Hartney Field is from the oolitic grainstone of the Upper Virden Member that was deposited in an intermediate to high energy shoal environment. Mudstones and wackestones of the Virden and Whitewater Lake Members bracket this grainstone unit.

Oil accumulation in the Souris Hartney Field is stratigraphically trapped. The Upper Virden Member is truncated by the Mississippian erosional surface that created an unconformity trap. Preferential accumulation occurs within thickets of the Upper Virden Member. The porous and permeable nature of the grainstone produces good reservoir characteristics; however, lateral and vertical variation changes has created porosity and permeability pinchout traps.

The Souris Hartney Field consists of one pool; the Lodgepole A pool. Cumulative production (to June 30, 1996) is 166 432.1 m³ oil and 432 698.2 m³ water.

A detailed study of the Virden Member in southwestern Manitoba was completed by Young (1973) and Young and Greggs(1975). Lutz (1987) examined the diagenesis and porosity evolution of the Virden Member in the Souris Hartney Field. Future study of this field should be directed towards analysis of the reservoir characteristics; including calculation and mapping of the field porosity, permeability and water saturation variability, net pay thickness and oil-in-place estimates.

In order to determine the most appropriate depletion strategy to maximize economic recovery from the A pool, the following additional information is required:

- (a) a core fluid study to determine accurate end point oil and water saturations and the anticipated primary and secondary recovery;
- (b) additional reservoir pressure data in Sections 16 and 17, Township 6, Range 22 WPM; and,
- (c) a minimum of quarterly production testing for the vertical producers.

This information will help refine OOIP estimates, waterflood potential and assist in identifying additional horizontal well targets.

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APPENDIX I
Select Core Descriptions from Souris Hartney area

Texaco B. A. Souris I3-I5
I3-I5-6-22 WPM
KB: 1484 ft. (453.2 m)

Cored Interval:
2057.5-2117.8 ft. (627.2-645.5 m)

Interval (ft/m)	Thickness (ft/m)	Description
Upper Whitewater Lake Member		
2057.5-2069.3 ft. (627.2-630.7 m)	11.5 ft. (3.5 m)	<u>Packstone to Wackestone</u> : light grey-brown, dolomitic, anhydrite replaced shell fragments, fracture filling and bedding, 6-12% intraparticle and pinpoint vuggy porosity, oil staining along bedding planes.
2069.3-2070.4 ft. (630.7-631.1 m)	1.1 ft. (0.4 m)	<u>Mudstone</u> : dark grey and maroon, dolomitic shale, anhydrite bedding, hematite staining.
2070.4-2075.2 ft. (631.1-632.5 m)	4.8 ft. (1.4 m)	<u>Wackestone</u> : light brown to pink, dolomitic, fine- to -medium crystalline, shale laminae, anhydrite replaced shell fragments, fracture filling and bedding, 3-6% pinpoint vuggy porosity, minor patchy oil staining.
Lower Whitewater Lake Member		
2075.2-2088 ft. (632.5 (636.4 m)	12.8 ft. (1.9 m)	<u>Mudstone</u> : dark grey, green, and maroon, shale and dolomitic, inter-laminated, anhydrite as nodules and interbeds, hematite staining.
Upper Virden Member		
2088-2090.7 ft. (636.4-637.2 m)	2.7 ft. (0.8 m)	<u>Mudstone</u> : light brown to grey green, dolomitic, very fine crystalline, shale laminae, anhydrite interbeds, 0-3% pinpoint porosity.
2090.7-2107.9 ft. (637.2-642.5 m)	17.2 ft. (3.3 m)	<u>Wackestone to Packstone</u> : light brown, dolomitic, very fine- to -medium crystalline, patches of oolitic grainstone, anhydrite replaced ooids and as beds, silica replaced ooids, 6-12% interoolitic and pinpoint vuggy porosity, patchy oil staining. Note: 2.7 ft. (0.8 m) core missing.
2107.9-2111.4 ft. (642.5-643.6 m)	3.5 ft. (1.1 m)	<u>Wackestone</u> : light pink to brown dolomitic, shale stringers, anhydrite infilling and bedding, 3-6% pinpoint vuggy porosity, patchy oil staining.
Lower Virden Member		
2111.4-2117.8 ft. (643.6-645.5 m)	6.4 ft. (1.9m)	<u>Mudstone</u> : grey brown to dark brown, grey green and maroon, shale and dolostone interlaminated, bedded anhydrite, bioturbated, hematite staining, 0-3% pinpoint vuggy porosity.

Texaco Souris 6-16
6-16-6-22 WPM
KB: 1481 ft. (451.4 m)

Cored Interval:
2108.9-2159.9 ft. (642.8-658.3 m)

Upper Whitewater Lake
Member

2108.9-2112.3 ft. (642.8-643.8 m)	3.4 ft. (1.0 m)	<u>Packstone to Wackestone</u> : light brown, dolomitic, very fine crystalline, few shale laminae shell fragments, anhydrite as infilling, fracture fill, and beds, silica replaced fossils, 3-12% intrafossil and pinpoint vuggy porosity.
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2112.3-2113.6 ft. (643.8-644.2 m)	1.3 ft. (0.4 m)	<u>Mudstone</u> : maroon, dolomitic shale, anhydrite as beds, hematite staining.
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2113.6-2119.8 ft. (644.2-646.1 m)	6.2 ft. (1.9 m)	<u>Packstone to Wackestone</u> : as above
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Lower Whitewater Lake Member	2119.8 ft. (646.1 m)	
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2119.8-2132 ft. (646.1-649.8 m)	12.2 ft. (3.7 m)	<u>Mudstone</u> : grey green and maroon, dolomite and shale, anhydrite nodules and beds, hematite staining.
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2132-2134.6 ft. (649.8-650.6 m)	2.6 ft. (0.8 m)	<u>Mudstone</u> : grey green to brown, dolomitic, very fine to silt, shale laminae, anhydrite as infilling and nodules, silica infilling, hematite staining, 3-6% pinpoint vuggy porosity.
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2134.6-2135.4 ft. (650.6-650.9 m)	0.8 ft. (0.2 m)	<u>Grainstone</u> : light brown, oolitic dolomitic, few mud laminae, anhydrite infilling, 3-6% pinpoint vuggy porosity, patchy oil staining.
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2135.4-2152.3 ft. (650.9-656.0 m)	16.9 ft. (5.1 m)	<u>Grainstone</u> : light brown, oolitic limestone, medium crystalline, anhydrite infilling, 6-20% oomoldic, interoolitic and pinpoint porosity, oil staining.
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Lower Virden Member	2152.3 ft. (656 m)	
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2152.3-2157.9 ft. (656.0-657.7 m)	5.6 ft. (1.7 m)	<u>Mudstone</u> : grey brown and maroon, dolostone and shale, finely laminated and bedded, bioturbation, 0-3% pinpoint vuggy porosity, patchy oil staining.
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2157.9-2159.9 ft. (657.7-658.3 m)	2.0 ft. (0.6 m)	<u>Interbedded Grainstone to Mudstone</u> : light grey brown and maroon, oolitic limestone and shale, 0-3% pinpoint vuggy porosity, patchy oil staining.
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**Texaco Souris 8-16
8-16-6-22 WPM
KB: 1491 ft. (454.4 m)**

**Cored Interval:
2122-2150.9 ft. (646.8-655.6 m)**

**Lower Whitewater Lake
Member**

2122-2124 ft. (646.8-647.4 m)	2.0 ft. (0.6 m)	<u>Mudstone</u> : dark grey and maroon, dolomitic shale, base - grey green, shaly dolostone, anhydrite nodules, hematite staining, 0-3% pinpoint vuggy porosity.
Upper Virden Member		
2124-2125.2 ft. (647.4-647.8 m)	1.2 ft. (0.4 m)	<u>Wackestone to Mudstone</u> : light brown, dolostone grading to limestone, very fine crystalline, anhydrite infilling and nodules, 0-3% pinpoint vuggy porosity, patchy oil staining.
2125.2-2126.3 ft. (647.8-648.1 m)	1.1 ft. (0.3 m)	<u>Mudstone</u> : as above
2126.3-2128.8 ft. (648.1-648.9 m)	2.5 ft. (0.8 m)	<u>Wackestone to Packstone</u> : light brown, limestone, fine crystalline, patches of medium crystalline oolitic grainstone, anhydrite as infilling and nodules, 3-6% pinpoint vuggy porosity, patchy oil staining.
2128.8-2137.2 ft. (648.9-651.4 m)	8.4 ft. (2.5 m)	<u>Grainstone</u> : light brown, oolitic limestone, fine crystalline, anhydrite infilling, 3-12% pinpoint vuggy and interoolitic porosity, oil staining.
2137.2-2137.5 ft. (651.4-651.5 m)	0.3 ft. (0.1 m)	<u>Wackestone</u> : grey, silica, 0-3% pinpoint vuggy porosity.
2137.5-2138.2 ft. (651.5-651.7 m)	0.7 ft. (0.2 m)	<u>Grainstone</u> : as above.
2138.2-2140 ft. (651.7-652.3 m)	1.8 ft. (0.6 m)	<u>Wackestone to Packstone</u> : light pink to brown, limestone, fine crystalline, silica replaced shell fragments, stylolitic, 0-3% pinpoint vuggy porosity.
2140-2141.2 ft. (652.3-652.6 m)	1.2 ft. (0.3 m)	<u>Grainstone</u> : light brown, oolitic limestone, fine crystalline, anhydrite as infilling and nodules, 3-12% pinpoint vuggy porosity, oil staining.
Lower Virden Member		
2141.2-2146.9 ft. (652.6-654.4 m)	5.7 ft. (1.8 m)	<u>Mudstone</u> : grey brown, dark grey and maroon, dolostone and shale interbeds, finely laminated, hematite stained, 0-3% pinpoint vuggy porosity.
2146.9-2147.8 ft. (654.4-654.6 m)	0.9 ft. (0.2 m)	<u>Mudstone</u> : grey brown, dark grey, and maroon, shale laminations and interbeds, anhydrite nodules, hematite staining, 0-3% pinpoint vuggy porosity.

2147.8-2149.6 ft. (654.6-655.2 m)	1.8 ft. (0.6 m)	<u>Grainstone</u> : light grey, oolitic limestone, medium crystalline, stylolitic, 3-6% pinpoint to medium vuggy porosity, patchy oil staining.
2149.6-2150.9 ft. (655.2-655.6 m)	1.3 ft. (0.4 m)	<u>Mudstone</u> : light pink brown, limestone, few laminae, minor hematite staining, 0-3% pinpoint to medium vuggy porosity.
Texaco Souris 8-17		
8-17-6-22 WPM		
KB: 1478 ft. (450.5 m)		
Cored Interval:		
2106.3-2157.3 ft. (642.0-657.5 m)		
Upper Whitewater Lake Member		
2106.3-2110.5 ft. (642.0-643.3 m)	4.2 ft. (1.3 m)	<u>Packstone to Wackestone</u> : red brown to grey brown, dolomitic, fine crystalline, few interbeds of shale, anhydrite as fossil replacements, fracture filling and beds, hematite staining, 0-6% pinpoint vuggy porosity, minor oil staining.
2110.5-2114.4 ft. (643.3-644.5 m)	3.9 ft. (1.2m)	<u>Wackestone to Packstone</u> : grey brown, very fine crystalline, anhydrite as nodules and bedding, 6-12% pinpoint vuggy porosity, oil staining.
2114.4-2115.8 ft. (644.5-644.9 m)	1.4 ft. (0.4 m)	<u>Mudstone</u> : grey green and maroon, dolomitic shale, anhydrite nodules and beds, hematite staining, fractures.
2115.8-2120 ft. (644.9-646.2 m)	4.2 ft. (1.3 m)	<u>Wackestone to Packstone</u> : grey brown, dolomitic, very fine crystalline, anhydrite as fracture filling nodules and bedding, 6-12% pinpoint vuggy porosity.
Lower Whitewater Lake Member		
2120-2127.5 ft. (646.2-648.5 m)	7.5 ft. (2.3 m)	<u>Mudstone</u> : grey green and maroon, dolomitic anhydrite as nodules and beds, hematite staining, 3-6% pinpoint vuggy and fracture porosity.
2127.5-2127.9 ft. (648.5-648.6m)	0.4 ft. (0.1 m)	<u>Packstone</u> : pinkish brown, anhydritic ooids, dolostone and shale, anhydrite as fracture filling and beds, 3-6% pinpoint vuggy porosity.
2127.9-2133 ft. (648.6-650.1 m)	5.1 ft. (1.5 m)	<u>Mudstone</u> : as above.
Upper Virden Member		
2133-2134 ft. (650.1-650.4)	1.0 ft. (0.3 m)	<u>Mudstone</u> : grey brown, dolomitic, fine crystalline, few laminae and beds of grey green dolomitic shale, anhydrite nodules, 6-12% pin point vuggy and fracture porosity, patchy oil staining.
2134-2149.3 ft. (650.4-655.1m)	15.3 ft. (4.7 m)	<u>Grainstone</u> : light brown, oolitic, limestone, anhydrite as infilling and ooid replacement, pinpoint vuggy and interoolitic porosity, oil staining.
Note: 3.0 ft. (0.9 m) core missing		
2149.3-2152.3 ft. (655.1-656.0 m)	3.0 ft. (0.9 m)	<u>Wackestone</u> : grey brown, limestone, fine crystalline, few shale laminae, anhydrite as fossil replacement and nodules, 3-6% pinpoint vuggy porosity, patchy oil staining.

Lower Virden Member	2152.3 ft. (656 m)	
2152.3-2157.3 ft. (656.0-657.5 m)	5.0 ft. (1.5m)	<u>Mudstone</u> : grey to brown and maroon, dolostone and shale, finely laminated, bioturbated, hematite staining, 0-3% pinpoint vuggy porosity, patchy oil staining.
 Texaco Souris 14-17 14-17-6-22 WPM KB: 1483 ft. (452 m)		
Cored Interval: 2137.8-2165.8 ft. (651.6-660.1 m)		
Lower Whitewater Lake Member		
2137.8-2140 ft. (651.6-652.3m)	2.2 ft. (0.7 m)	<u>Mudstone</u> : dark grey and maroon, dolomitic to shaly dolostone toward base, anhydrite as nodules and beds, hematite staining.
Upper Virden Member		
	2140 ft. (652.3 m)	
2140-2141.9 ft. (652.3-652.9 m)	1.9 ft. (0.6 m)	<u>Mudstone to Wackestone</u> : light brown, dolomitic, fine- to very fine-crystalline, anhydrite replaced fossils and nodules, siliceous nodules(?), 3-6% pinpoint porosity and intrafossil porosity, patchy oil staining.
2141.9-2143.2 ft. (652.9-653.2 m)	1.3 ft. (0.3m)	<u>Packstone</u> : light pink brown, oolitic dolostone, medium crystalline, anhydrite nodules, 6-12% pinpoint to vuggy porosity, oil staining.
2143.2-2144.3 ft. (653.2-653.6m)	1.1 ft. (0.4m)	<u>Mudstone to Wackestone</u> : light brown, dolomitic limestone, anhydrite as infilling and nodules, stylolitic, minor hematite staining, 12-20% pinpoint to medium vuggy porosity, minor oil staining.
2144.3-2154.5 ft. (653.6-656.7m)	10.2 ft. (3.1m)	<u>Grainstone</u> : light pink to brown, oolitic limestone, medium crystalline, anhydrite nodules, siliceous beds, stylolitic, 6-25% pinpoint vuggy and interoolitic porosity, oil staining. Note 4.0 ft. (1.2m) core missing
Lower Virden Member		
	2154.5 ft (656.7 m)	
2154.5-2159.7 ft. (656.7-658.3m)	5.2 ft. (1.6m)	<u>Mudstone</u> : grey to brown and maroon, dolomitic and shale, laminations, 3-6% pinpoint vuggy porosity, minor oil staining.
2159.7-2165.8 ft. (658.3-660.1m)	6.1 ft. (1.8m)	<u>Mudstone to Wackestone</u> : grey brown and light dolomitic limestone, fine crystalline, anhydrite replaced fossils and nodules, stylolitic, 3-6% pinpoint to medium vuggy porosity.

Texaco Souris 8-19
8-19-6-22 WPM
KB: 1470 ft. (448 m)

Cored Interval:
2109-2139 ft. (642.8-652.0 m)

Whitewater Lake Member

2109-2113 ft. (642.8-644.0 m)	4.0 ft. (1.2 m)	<u>Mudstone:</u> grey and maroon, dolomitic shale, anhydrite as nodules and beds, hematite staining.
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Upper Virden Member	2113 ft. (644 m)	
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2113-2130.8 ft. (644.0-649.5m)	17.8 ft. (5.5m)	<u>Interbedded Grainstone to Mudstone:</u> light brown to pink and grey and maroon, dolomitic, oolitic, laminated, few shale laminae, anhydrite replaced fossils and as nodules, fracture filling, infilling and beds, hematite staining, 0-6% pinpoint vuggy porosity, minor oil staining.
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Lower Virden Member	2130.8 ft. (649.5 m)	
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2130.8-2139 ft. (649.5-652.0m)	8.2 ft. (2.5m)	<u>Interbedded Mudstone to Grainstone:</u> dark grey, maroon, and grey green, dolomitic shale, interbeds of dolostone, finely laminated, oolitic, anhydrite fossil replacements and as infilling, nodules and bedding, silica fossil replacements, bioturbated, stylolitic, hematite staining, 0-3% pinpoint vuggy and fracture porosity.
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Saskoil NCO Souris
Hartney 5-22
5-22-6-22 WPM
KB: 453 m

Cored Interval:
632-668.5 m

632-634.5m	2.5m	<u>Dolostone:</u> light grey to buff, oolitic grainstone, fine crystalline, some brachiopods, rare corals, some interbeds of grey anhydrite (10-15 cm), becoming packstone towards base.
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634.5-636 m	1.5m	<u>Dolostone:</u> light maroon, fine- to -medium crystalline, occasional "fossil hash" zones, some interbeds of light grey anhydrite (5-10 cm).
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636-639.5m	3.5m	<u>Dolostone:</u> light grey to light maroon, mottled, some brachiopods and crinoids, some interbeds of grey anhydrite (5 cm).
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639.5-642 m	2.5m	<u>Mudstone to Wackestone:</u> light maroon, dolomitic, some brachiopods and crinoids with anhydrite replacement.
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Lower Virden Member	642m	
642-645.34m	3.34m	<u>Mudstone</u> : maroon to light grey/green, very fine crystalline, some mottling, dolomitic, stylonitic, some crinoids and occasional very thin fossil hash zones, grey anhydrite as blebs and thin interbeds.
645.34-645.74 m	0.4m	<u>Grainstone</u> : light grey, fine crystalline, limy, crinoids, some anhydrite replacement.
645.74-647 m	1.26m	<u>Mudstone</u> : maroon, mottled, fossils include crinoids and brachiopods.
647-647.5 m	0.5m	<u>Grainstone</u> : grey to maroon, mottled, limy, crinoids.
647.5-649.6 m	2.1m	<u>Mudstone</u> : maroon, mottled, limy, abundant brachiopods
649.6-650 m	0.4m	<u>Mudstone</u> : as above, grey.
Scallion Member	650 m	
650-660 m	10m	<u>Wackestone to Packstone</u> : light grey, fine crystalline, limy, lenses of white chalk, some crinoids and brachiopods, some fair to good inter-crystalline and vuggy porosity associated with patchy oil staining in 20 cm thick beds.
660-668.5 m	8.5 m	As above, chalky.



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