EVALUATION OF SASKATCHEWAN'S

HEAVY OIL RESERVES

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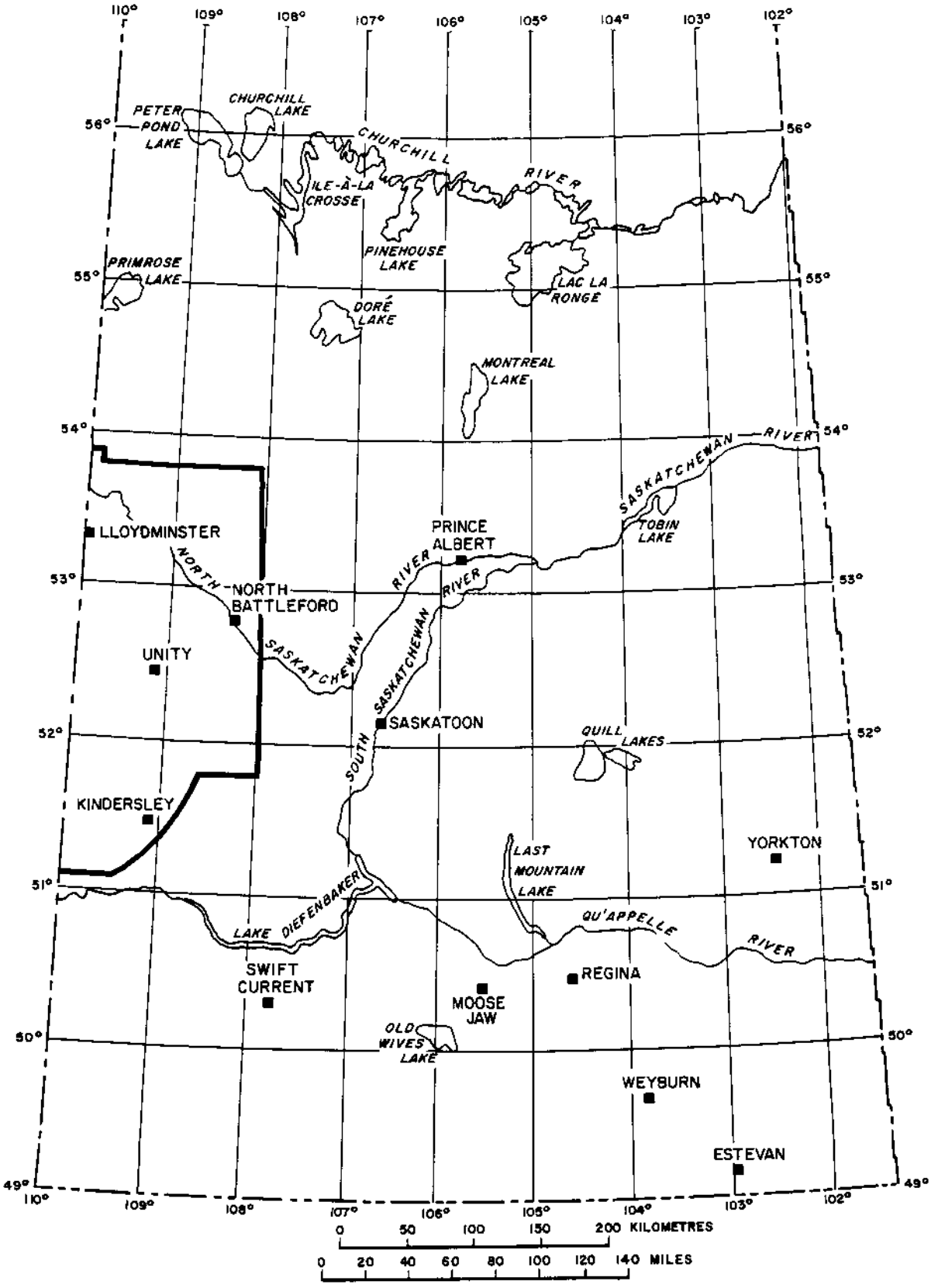
INTRODUCTION

The primary intent of this study is to provide a new estimate of Saskatchewan's reserves of heavy oil. Insofar as it is possible, the figures provided in this report refer only to reserves that are POTENTIALLY ECONOMIC rather than to ALL of Saskatchewan's reserves. In the opinion of the authors and their industry contacts, neither the low porosity zones nor the very thin heavy oil zones (in this case, defined as less than 1 m) are economic, at least for the forseeable future.

In Saskatchewan, the heavy oil is found in the sands of the Bakken Formation (Mississippian) and the Mannville Group (Lower Cretaceous). Geographically, these deposits lie in west-central Saskatchewan.

The study area encloses virtually all showings of heavy oil in the Bakken Formation and Mannville Group in Saskatchewan (Text-Fig. 1). This covers most of the lands bounded by Range 14 West of the Third Meridian and the Alberta border and extending from Townships 24 to 56. Areas within administrative pool boundaries were studied as well as those outside.

The method employed for this study involved the examination of available logs for virtually all wells within the area outlined in Text-Figure 1. Time limitations precluded anything but a cursory examination of core and samples in a few areas where stratigraphic determination from the logs was problematic.



Text-Figure 1 - Study area (the area outlined by heavy black line in west-central Saskatchewan).

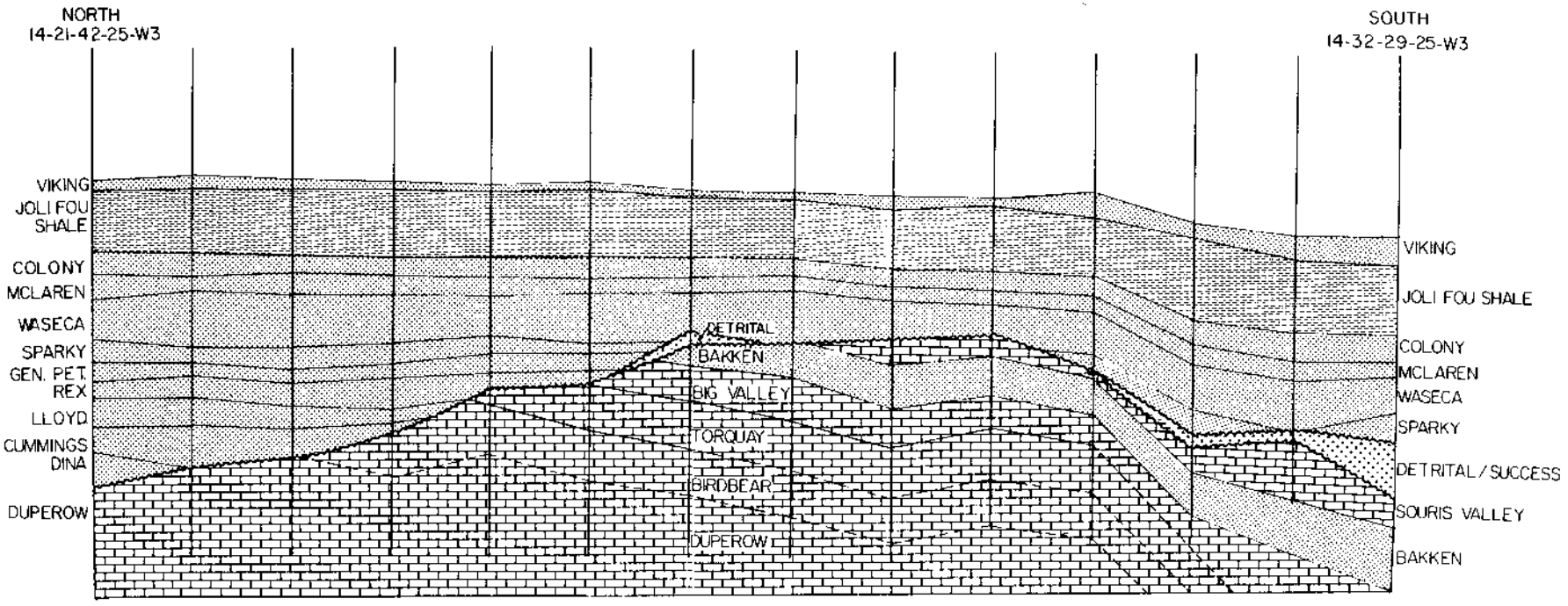
ACKNOWLEDGEMENTS

The authors wish to thank J. MacEachern for his assistance in examining some of the many thousands of logs looked at in this study. They would also like to thank E. Dancsok for obtaining some basic information and V. Harris for her assistance in gathering data and drafting maps. Finally, thanks to D. Paterson for his constructive criticism, helpful suggestions and moral support.

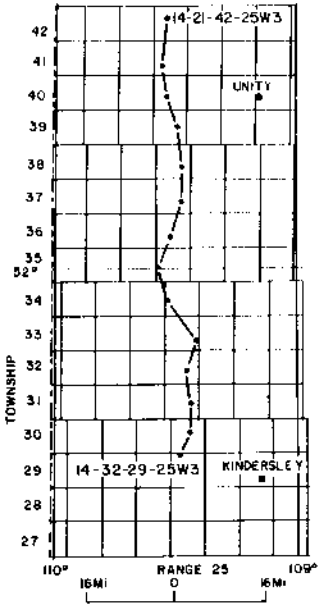
GEOLOGICAL FRAMEWORK

In the study area the Mannville Group, which contains the bulk of the oil, unconformably overlies rocks of Devonian and Mississippian age. These underlying units become progressively younger to the south (Text-Fig. 2), displaying a distinct pre-Mannville scarp against which the older Mannville units progressively pinch out. The regional dip is a gentle decline towards the southwest. This overall trend shows a reversal north and east of Lloydminster (with a southeasterly trend) caused by partial salt-solution of the underlying Prairie Evaporite Formation (Text-Fig. 3, modified from Meijer-Drees, 1985). The Bakken Formation appears only in the southern portion of the study area and, although an extremely widespread unit, it contains heavy oil only in this relatively small area of west-central Saskatchewan.

The Mannville Group is conformably(?) overlain by the shales of the Lower Colorado Group, a unit dominated by marine shales with some sandy units included within it (for example, the Spinney Hill and Viking sands).



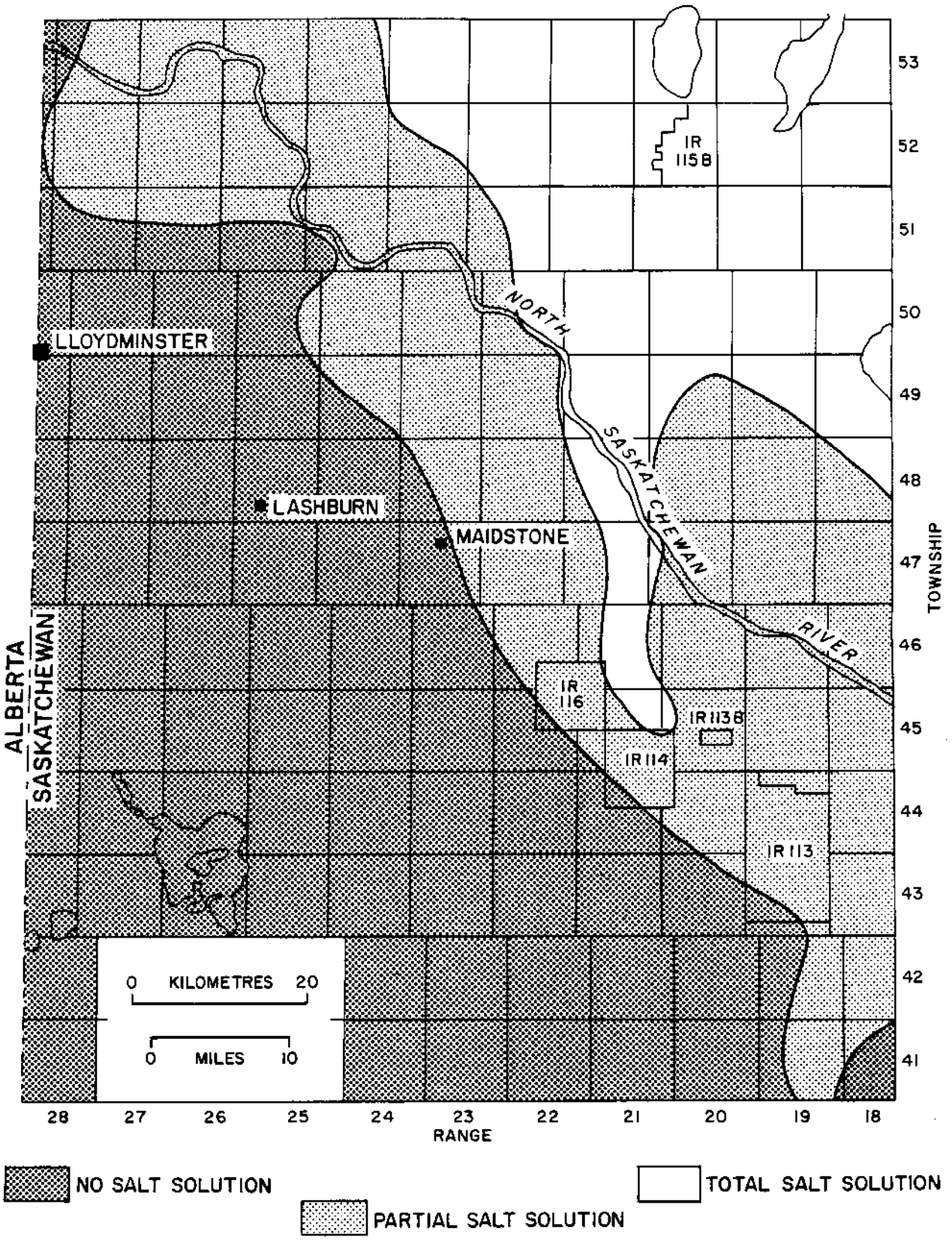
LOCATION MAP



WELLS ON SECTION
(in order from N to S)

14-21-42-25-W3
2- 8-41-25-W3
7-16-40-25-W3
8-23-39-25-W3
5-11-38-25-W3
08-11-37-25-W3
5- 9-36-25-W3
1-18-35-25-W3
12-18-34-25-W3
5-12-33-25-W3
8-15-32-25-W3
11-14-31-25-W3
10-22-30-25-W3
14-32-29-25-W3

Text-Figure 2 - North-south cross-section through the study area showing the progressively younger Palaeozoic units that subcrop at the pre-Mannville unconformity. Datum - top of Lower Colorado Group.



Text-Figure 3 - Area of partial removal of salt causing a collapse of the overlying beds, including the Mannville. To the southwest, the salt remains intact and to the northeast it is entirely missing (modified from Meijer-Drees, 1985).

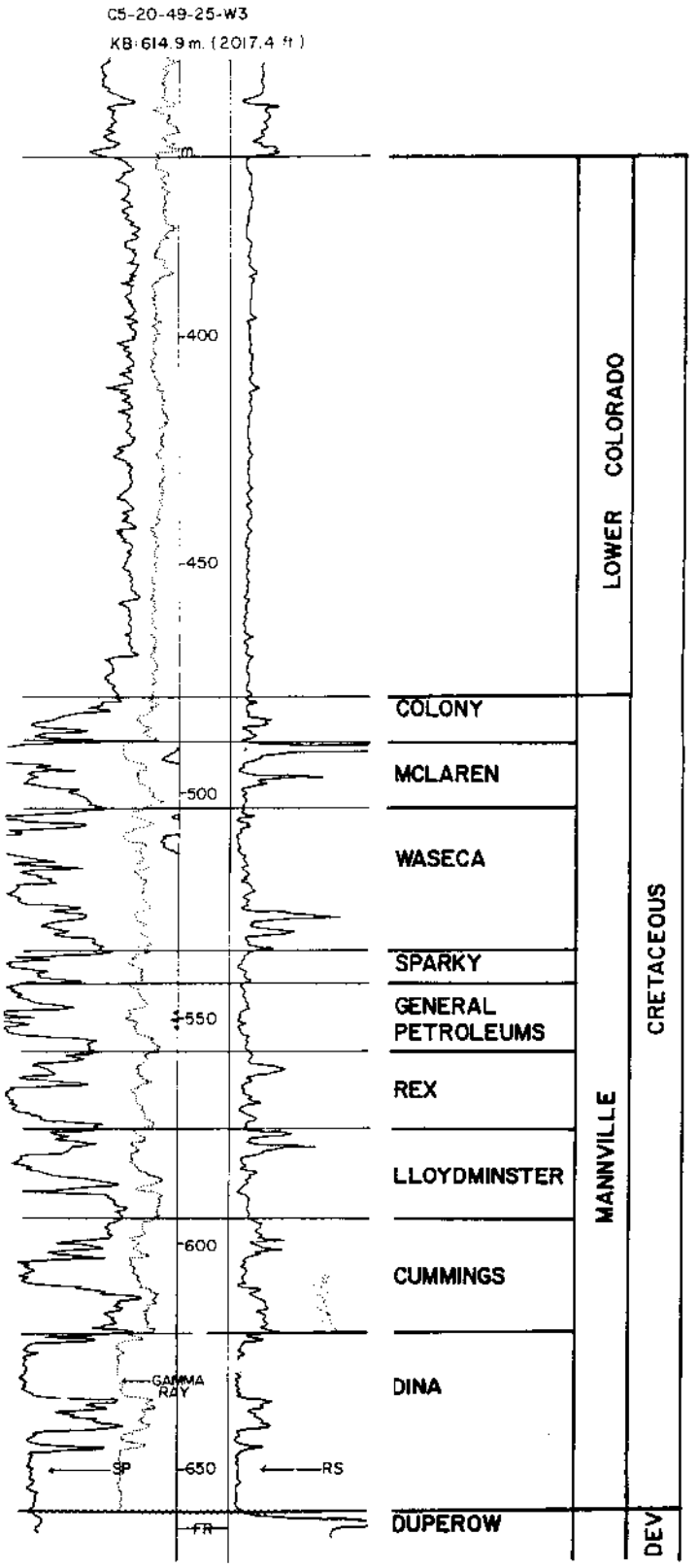
STRATIGRAPHY

The Mannville Group within the study area comprises a stacked sequence of interbedded sands and shales. The sands are frequently unconsolidated or weakly consolidated, with the matrix, where present, being argillaceous material. Occasionally they are calcite cemented. The sands are fine-grained quartz, the grain size falling in the coarse silt to medium sand range. Other minerals and rock fragments form only a small percentage of the total. Porosities and permeabilities are frequently high or even very high in the sands, with porosity values commonly in excess of 30% and permeabilities commonly exceeding 1 darcy in the oil-filled portions.

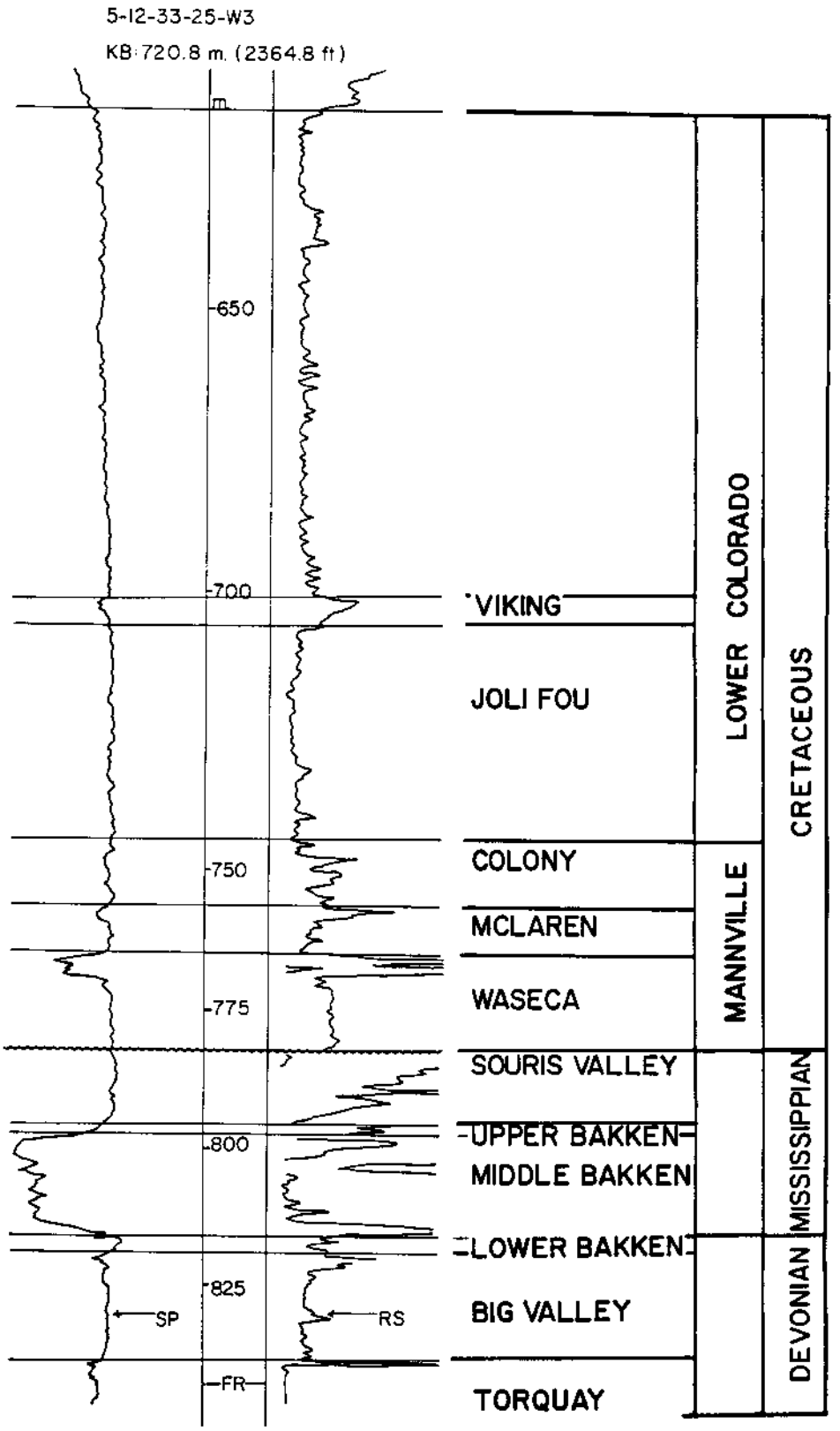
The sands and shales of the Mannville Group have been subdivided into nine stratigraphic units. They are illustrated in Text-Figure 4 plotted on a typical log from the northern part of the study area. This nomenclature has evolved over time, starting with the work of Nauss (1945), the use of drillers' terminology by Edmunds (1948), to the final nine subdivisions used by Fuglem (1970), Vigrass (1977) and Orr et al. (1977). The upper seven subdivisions, Lloydminster to Colony inclusive (oldest to youngest), remain as informal stratigraphic units. The lower two subdivisions were formally defined by Nauss (1945).

The stratigraphic relationships of the Bakken Formation, which is transitional across the Devonian/Mississippian boundary (Christopher, 1961), are shown in Text-Figure 5. The basal shale and middle sand units are laterally consistent within the southern portion of the study area, though over much of the area the Bakken Formation has been removed by erosion. The thin upper shale is rather less consistent, particularly towards the erosional edge.

For further information on the Mannville Group, please refer to **Lloydminster and Beyond, Geology of Mannville Hydrocarbons Reservoirs** edited by L.S. Beck, J.E. Christopher and D.M. Kent (1980), and **Oil and Gas in Saskatchewan** edited by J.A. Lorsong and M.A. Wilson (1984).



Text-Figure 4 - Stratigraphic subdivisions and relationships of the Mannville Group (Lower Cretaceous).



Text-Figure 5 - Stratigraphic subdivisions and relationships of the Bakken Formation (transitional Devonian/Mississippian).

For the Bakken, please refer to Saskatchewan Department of Mineral Resources Report 66 by J.E. Christopher (1961) and Geological Survey of Canada Open File 1123 by H.T. Hornford (1985).

METHOD

This study was completed using the available geophysical logs in the study area (Text-Fig. 1). As of June 1985, the study area includes within its limits the majority of heavy oil occurrences known to the authors. The limits of Bakken heavy oil were taken from the maps of Hornford (1985) and the geophysical logs re-examined.

The constraints applied in defining the pay zones were as follows:

1) **Presence of Oil** - This was determined using the deep resistivity curve on the Resistivity logs with a minimum value of 7.5 ohm-metres being necessary in areas of approximately 11^{o} - 16^{o} API gravity oil, 10 ohm-metres where the API gravity of the oil falls below 11^{o} and 5 ohm-metres where the API gravity exceeds 16^{o}. (The assumption was made that gravity and viscosity display a more-or-less linear relationship).

2) **Porosity** - A minimum of 24% porosity was considered necessary and was taken from the density - porosity curve on the Compensated Density - Compensated Neutron log.

3) **Water Saturation** - A maximum of 50% water saturation was used. This was calculated using the Rwa and Fr/Fs comparison method where the logs indicate that the oil saturation in the well might be too low.

4) **Thickness** - A minimum of 1 m of oil pay was deemed necessary for economic oil production.

These limits were arrived at in consultation with several industry geologists and are therefore considered to be reasonably close to those generally used.

In the numerous cases where a complete suite of logs was unavailable, a value judgement had to be made. Only electric logs were taken for many of the older wells, so only resistivity cut-offs could be used. In such

situations it is not always possible to determine cemented zones against oil-filled sand or some gas-filled sands.

The oil pays (not shown but available from Saskatchewan Energy and Mines in blueline format) were compiled for each stratigraphic unit, resulting in ten pay maps (Bakken sand and the nine subdivisions of the Mannville Group). Individual, or widely spaced, wells are displayed as oil shows only. When the calculations were made, these shows were arbitrarily assigned 16.2 ha (40 acres or one drainage unit). The thickness of the oil pay in the well was assumed to be the same throughout the 16.2 ha for the convenience of calculation.

Where wells are grouped and the structure map indicates that the wells are related, an attempt has been made to link the wells by contouring the pays and calculating the oil in place as a small pool. These calculations, and the calculations for reserves within some fields, were based on a map scale of 1:126,720 (1 inch = 2 miles) using a 10-acre grid pattern. For the pool areas, with potential pool extensions, a larger scale map was used. Here the area was calculated using a planimeter as well as a 10-acre (or occasionally less) grid pattern where the areas were too small for accurate planimetry.

Where the net oil pays could be contoured, the outer limit was taken as the 1-metre contour (net pay) line. This line, where possible, was based on structure contours. The use of a 10-metre contour interval on the structure maps (available from Saskatchewan Energy and Mines in blueline format) precludes the definition of the fine structural detail, as does the wide scatter of reference points outside the field boundaries, with the result that the outer oil limit is rather subjective. Subsequent contours can be considered as more accurate in most cases. It should be noted here that net pays for each stratigaphic subdivision may be composed of multiple pay zones. The multiple pays were simply added together for construction of the heavy oil in place maps. With the contours constructed and the areas summed, the pay for the area was calculated using the average for the contour interval (i.e., 1 m to 5 m averaged at 3 m, 5 m to 10 m averaged at 7.5 m, etc.). If the upper

limit was well below the next contour interval (i.e., 12.8 m), then this upper figure was taken as the limit and averaged (i.e., 12.8 m - 10 m = 2.8 m, average this at 1.4 m to give an average of 11.4 m for this area).

The figures for heavy oil in place were then calculated using average net pay, area, average porosity, average water saturation, and shrinkage factor on a pool-by-pool basis. For the purpose of calculating oil in place for the isolated wells, an average porosity, water saturation and shrinkage factor was determined for each stratigraphic unit using the figures taken from pools within that stratigraphic unit.

For oil with enhanced recovery potential, a minimum pay of six metres was used. This represents six metres for a single pay zone, or six metres of oil-filled sand with no significant (one metre or more) shale breaks.

The figures are given as cubic metres (m^3) of oil at the surface, with the equivalent in barrels given for totals. The conversion factor from cubic metres to barrels was taken, again as an average, as 6.3 (Levorsen, 1954).

RESULTS

Individual calculations are available from the authors. The generalized total calculations are given in Table I and are shown graphically in Text-Figure 6. The full results are given in Appendix A.

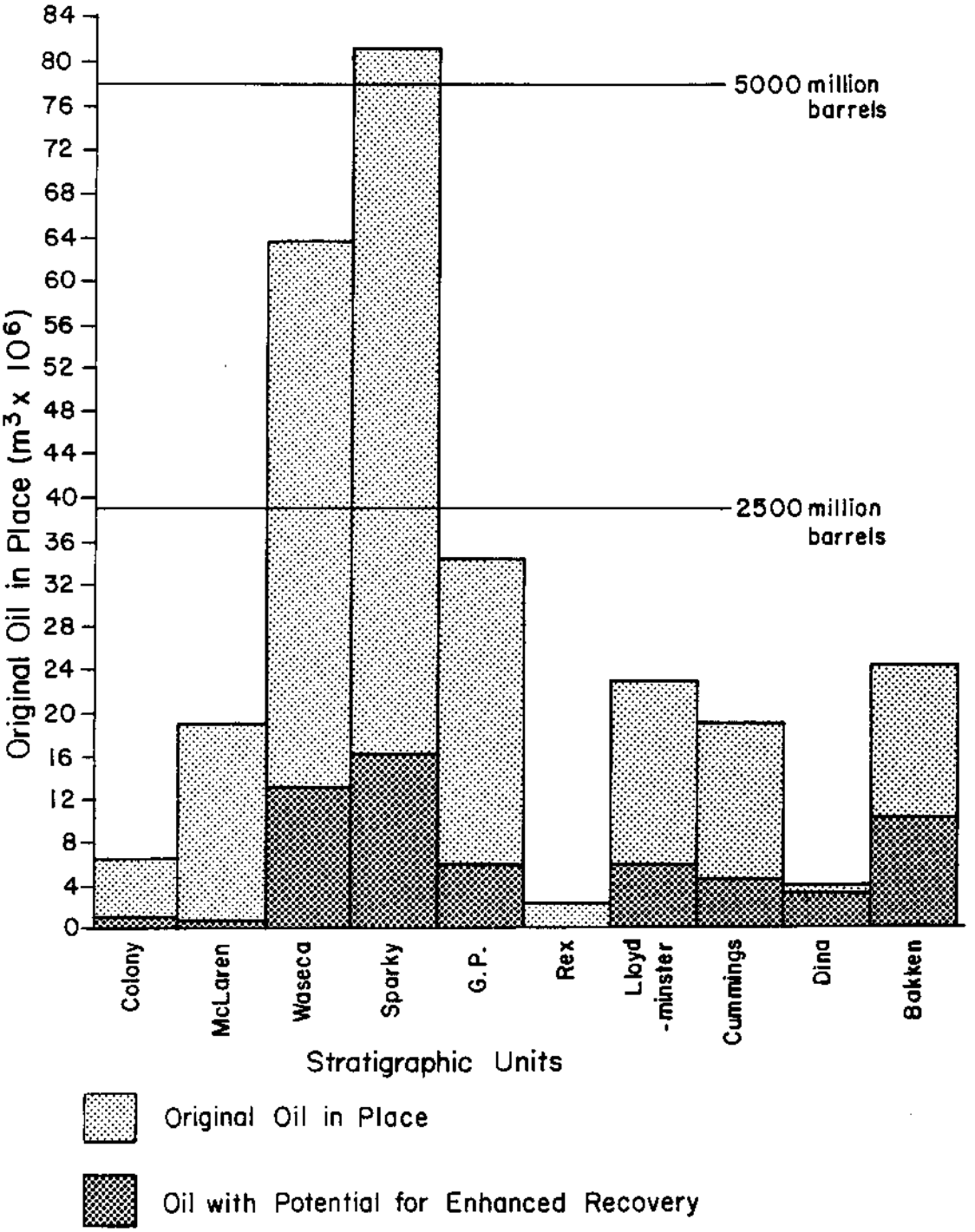
OOIP = Original Oil in Place, EOR = Enhanced Oil Recovery Potential.

In both cases this represents Heavy Oil that is potentially economically recoverable.

TABLE I

Stratigraphic Unit	OOIP ($m^3 x 10^6$)	EOR ($m^3 x 10^6$)
Colony	68.02	12.16
McLaren	191.48	8.45
Waseca	638.11	131.95
Sparky	812.76	165.35
G. P.	347.82	60.09
Rex	25.78	-
Lloydminster	236.02	60.41
Cummings	190.86	48.63
Dina	40.66	33.53
Mannville Total	2,551.51	520.57 (20.4%)
Bakken	245.60	101.51 (41.33%)
Overall Total	2,797.11	622.08 (22.24%)
	(17,621.79 x 10^6 barrels)	(3,919.13 x 10^6 barrels)

Saskatchewan has, therefore, approximately 2.8 billion cubic metres (18.0 billion barrels) of original oil in place with economic potential. The authors have discounted what they consider to be non-economic oil (thin pay zones and low porosity oil). To date, the oil with excessive bottom water has not been discounted; this may represent several percent



Text-Figure 6 - Visual representation of the original heavy oil in place in Saskatchewan, subdivision by stratigraphic unit.

of the total figure. That oil with potential for enhanced oil recovery amounts to 490 million cubic metres or 22.24% of the total oil. With recovery factors some 4 or 5 times that of primary recovery, this EOR oil has the potential to produce very significant quantities of oil in the future.

The maps and original worksheets used in this study are available for consultation at the Subsurface Geological Laboratory, Regina, by contacting the authors or, in blueline format, from the Publications Office of Saskatchewan Energy and Mines.

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APPENDIX A

The oil column gives figures for original oil in place with potential for economic recovery. The EOR oil column gives figures for oil with potential for enhanced recovery.

Stratigraphic Unit	Pool Field	Oil ($m^3 x 10^6$)	EOR Oil ($m^3 x 10^6$)
Colony	Miscellaneous Oil	68.02	12.16
McLaren	Miscellaneous Oil	99.90	1.87
	Aberfeldy	13.04	
	Big Gully	17.52	
	Coleville & Coleville South	19.83	6.59
	Golden Lake South	6.93	
	Landrose	6.60	
	Neilburg	4.90	
	Northminster	2.19	
	Northminster North	2.32	
	Tangleflags	19.99	
	Tangleflags West	1.16	
Waseca	Miscellaneous Oil	198.10	68.26+
	Big Gully	3.69	
	Celtic	120.21	15.63
	Dee Valley	19.56*	8.24
	Dee Valley East	5.22*	
	Delmas	7.85	
	Edam	28.47	11.69
	Edam West	11.19	
	Forest Bank	13.48	
	Golden Lake North	29.88	6.68
	Golden Lake South	29.73	
	Gully Lake	27.39	

APPENDIX A (cont.)

Stratigraphic Unit	Pool Field	Oil ($m^3 x 10^6$)	EOR Oil ($m^3 x 10^6$)
Waseca	Lashburn	33.23	2.53
	Lasburn South	17.65	
	Maidstone	2.15	
	Pikes Peak	29.16	11.82
	Rush Lake	11.02	0.80
	Standard Hill	19.53*	
	Tangleflags	12.31	
	Westhazel	18.30	

* figures from Petroleum and Natural Gas Division, Saskatchewan Energy and Mines

+ includes Delmas

Sparky	Miscellaneous Oil	122.15	2.70
	Aberfeldy	159.07	84.05
	Baldwinton	5.60	
	Big Gully	6.60	
	Celtic	53.62	6.80
	Dee Valley	4.13	
	Dee Valley East	5.00*	
	Dulwich	33.10	3.13
	Edam West	8.27	2.02
	Epping/Lone Rock	109.00	40.78
	Forest Bank	23.56	
	Freemont	5.15	
	Furness	18.22	4.74
	Golden Lake North	17.72	
	Golden Lake South	63.27	12.93
	Lashburn West	13.77	
	Lloydminster	4.69	
	Macklin	9.20*	
	Maidstone	2.50	
	Marsden	3.01	

APPENDIX A (cont.)

Stratigraphic Unit	Pool Field	Oil (m^3x10^6)	EOR Oil (m^3x10^6)
Sparky	Marsden South	11.95	6.79
	Northminster	31.08	
	Northminster North	9.21	
	Pikes Peak	2.28	
	Rush Lake	10.61	
	Silverdale	24.08	
	Tangleflags	23.34	
	Westhazel	32.60	1.41
General Petroleums	Miscellaneous Oil	70.57	4.54
	Aberfeldy	47.89	
	Celtic	43.28	24.20
	Dulwich	9.76	
	Edam West	16.19	5.52
	Epping/Lone Rock	42.24	
	Forest Bank	2.72	
	Furness	1.81	
	North Hoosier	4.29	
	Northminster	5.96	0.32
	Northminster North	3.27	
	Pikes Peak	2.99	
	Silverdale	3.38	
	Tangleflags	54.99	11.52
	Tangleflags West	7.74	
	Westhazel	30.75	13.99
Rex	Miscellaneous Oil	25.78	
Lloydminster	Miscellaneous Oil	42.78	4.02^{+}
	Buzzard	3.15	
	Cosine Lake	8.52	
	Northminster	12.43	
	Pikes Peak	1.56	

APPENDIX A (cont.)

Stratigraphic Unit	Pool Field	Oil (m^3x10^6)	EOR Oil (m^3x10^6)
Lloydminster	Salt Lake	10.17	2.95
	Senlac	15.06	
	Tangleflags	55.85	
	Tangleflags North	82.34	53.44
	Tangleflags West	4.16	
+ Delmas			
Cummings	Miscellaneous Oil	125.42+	7.08*
	Eyehill	27.49	18.29
	Macklin	10.80	3.73
	Tangleflags North	2.66	
	Winter	24.48	19.53
+ includes Onion Lake			
* Onion Lake			
Dina	Miscellaneous Oil	0.04	
	Onion Lake	40.61	33.53
Bakken	Miscellaneous Oil	45.11	12.21
	Buffalo Coulee	16.75	10.86
	Buffalo Coulee North	23.05	5.32
	Cactus Lake	34.33	12.22
	Coleville	35.08	16.96
	Coleville South	5.54	0.64
	Court	12.11	8.70
	Fusilier	5.52	1.39
	Hearts Hill	6.60	0.49
	Hoosier	10.66	2.53
	Luseland	18.29	12.17
	North Hoosier	19.23	7.18
	Plover Lake	13.35	10.84

APPENDIX B

The following table shows the conversion factors used for calculating the oil in place.

SF = Shrinkage Factor
Ø = Porosity
Sw = Water Saturation

Stratigraphic Unit	Pool Field	SF	Ø	1-Sw
Colony	Miscellaneous Oil	0.947	0.323	0.760
McLaren	Miscellaneous Oil	0.960	0.322	0.786
	Aberfeldy	0.983	0.350	0.870
	Big Gully	0.982	0.360	0.847
	Coleville & Coleville South	0.960	0.322	0.786
	Golden Lake South	0.987	0.350	0.820
	Landrose	0.950	0.300	0.800
	Neilburg	0.900	0.250	0.700
	Northminster	0.983	0.340	0.850
	Northminster North	0.900	0.250	0.700
	Tangleflags	0.978	0.350	0.743
	Tangleflags West	0.978	0.350	0.743
Waseca	Miscellaneous Oil	0.963	0.328	0.790
	Big Gully	0.982	0.360	0.847
	Celtic	0.992	0.350	0.760
	Dee Valley	0.985	0.350	0.840
	Dee Valley East	0.985	0.350	0.840
	Delmas	0.963	0.350	0.750
	Edam	0.900	0.250	0.700
	Edam West	0.900	0.300	0.750
	Forest Bank	0.985	0.350	0.840
	Golden Lake North	0.985	0.350	0.840

APPENDIX B (cont.)

Stratigraphic Unit	Pool Field	SF	Ø	1-Sw
	Golden Lake South	0.985	0.350	0.840
	Gully Lake	0.968	0.357	0.840
	Lashburn	0.970	0.300	0.790
	Lashburn South	0.983	0.350	0.850
	Maidstone	0.900	0.250	0.700
	Pikes Peak	0.980	0.330	0.850
	Rush Lake	0.900	0.250	0.700
	Standard Hill	0.985	0.340	0.800
	Tangleflags	0.978	0.350	0.743
	Westhazel	0.971	0.350	0.730
Sparky	Miscellaneous Oil	0.954	0.327	0.788
	Aberfeldy	0.983	0.350	0.870
	Baldwinton	0.900	0.250	0.700
	Big Gully	0.982	0.360	0.847
	Celtic	0.992	0.350	0.760
	Dee Valley	0.985	0.350	0.840
	Dee Valley East	0.985	0.350	0.840
	Dulwich	0.896	0.340	0.850
	Edam West	0.900	0.300	0.750
	Epping/Lone Rock	0.965	0.340	0.840
	Forest Bank	0.985	0.350	0.840
	Freemont	0.950	0.350	0.800
	Furness	0.983	0.340	0.850
	Golden Lake North	0.991	0.350	0.800
	Golden Lake South	0.988	0.350	0.820
	Lashburn West	0.900	0.250	0.700
	Lloydminster	0.983	0.350	0.870
	Macklin	0.968	0.350	0.770
	Maidstone	0.900	0.250	0.700
	Marsden	0.950	0.350	0.800
	Marsden South	0.950	0.350	0.800
	North Hoosier	0.953	0.280	0.730

APPENDIX B (cont.)

Stratigraphic Unit	Pool Field	SF	Ø	1-Sw
Sparky	Northminster	0.983	0.340	0.850
	Northminster North	0.900	0.250	0.700
	Pikes Peak	0.950	0.350	0.700
	Rush Lake	0.900	0.250	0.700
	Silverdale	0.950	0.340	0.800
	Tangleflags	0.973	0.350	0.700
	Westhazel	0.992	0.350	0.760
General Petroleums	Miscellaneous Oil	0.958	0.336	0.789
	Aberfeldy	0.983	0.350	0.870
	Celtic	0.992	0.350	0.760
	Dulwich	0.896	0.340	0.850
	Edam West	0.900	0.300	0.750
	Epping/Lone Rock	0.980	0.350	0.820
	Forest Bank	0.985	0.350	0.840
	Furness	0.983	0.340	0.850
	Northminster	0.983	0.340	0.850
	Northminster North	0.900	0.250	0.700
	Pikes Peak	0.950	0.350	0.700
	Silverdale	0.950	0.340	0.800
	Tangleflags	0.980	0.350	0.780
	Tangleflags West	0.980	0.350	0.780
	Westhazel	0.950	0.350	0.700
Rex	Miscellaneous Oil	0.947	0.323	0.760
Lloydminster	Miscellaneous Oil	0.955	0.327	0.750
	Buzzard	0.900	0.250	0.700
	Cosine Lake	0.955	0.327	0.750
	Northminster	0.983	0.340	0.850
	Pikes Peak	0.960	0.350	0.750
	Salt Lake (averaged value)	0.955	0.327	0.750
	Senlac	0.900	0.300	0.750

APPENDIX B (cont.)

Stratigraphic Unit	Pool Field	SF	Ø	1-Sw
	Tangleflags	0.980	0.350	0.750
	Tangleflags North	0.980	0.350	0.700
	Tangleflags West	0.980	0.350	0.750
Cummings	Miscellaneous Oil	0.900	0.300	0.680
	Eyehill	0.970	0.340	0.840
	Macklin	0.968	0.350	0.770
	Tangleflags North	0.980	0.350	0.700
	Winter	0.900	0.250	0.700
Dina	Miscellaneous Oil	0.900	0.300	0.680
	Onion Lake	0.900	0.300	0.680
Bakken	Miscellaneous Oil	0.950	0.285	0.750
	Buffalo Coulee	0.900	0.230	0.750
	Buffalo Coulee North	0.930	0.295	0.750
	Cactus Lake	0.950	0.294	0.750
	Coleville	0.928	0.241	0.690
	Coleville South	0.928	0.241	0.690
	Court	0.950	0.294	0.750
	Fusilier	0.938	0.254	0.780
	Hearts Hill	0.950	0.285	0.750
	Hoosier	0.928	0.315	0.780
	Luseland	0.950	0.285	0.750
	North Hoosier	0.950	0.305	0.780
	Plover Lake	0.950	0.315	0.750