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# OIL RESOURCES OF WESTERN CANADA

By

P.J. Lee

Geological Survey of Canada (Calgary), 3303 - 33 Street N.W.
Calgary, Alberta T2L 2A7

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# OIL RESOURCES OF THE WESTERN CANADA SEDIMENTARY BASIN

P. J. Lee[1]

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[1]Perspective Information Inc., P.O. Box 81133, 755 Lake Bonavista Drive S.E., Calgary, Alberta T2J 0N0

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# OIL RESOURCES OF THE WESTERN CANADA SEDIMENTARY BASIN

## Executive Summary

The 7,142 oil pools identified in the Western Canada Basin have been edited and classified into 69 established and 25 immature plays. These plays were analyzed by the geological and statistical computer-assisted system, PETRIMES, to derive the potential of each play and geological system. From this analysis, the potential of immature and conceptual plays was also estimated.

The oil potential, in established mature plays of the basin, ranges (90% chance) from 4,400 to 6,648 x $10^6 m^3$ (28 to 42 B bbl) with a mean of 5,488 x $10^6 m^3$ (35 B bbl) of in-place volume, whereas the expected potential of immature and conceptual plays is 1,470 x $10^6 m^3$ (9.2 B bbl).

The potential of the established Devonian plays ranges from 631 to 1,627 x $10^6 m^3$ (4 to 10 B bbl). The Nisku Shelf and the Middle Devonian clastic plays provide the greatest potential for oil in the Devonian system. The potential of immature and conceptual plays ranges from 127 to 3,033 x $10^6 m^3$ (0.80 to 19 B bbl). The potential of the largest Devonian immature or conceptual play ranges from 117 to 163 x $10^6 m^3$ (734 to 1,025 MM bbl) of in-place volume. The Devonian System offers great opportunity for exploring conceptual plays.

The potential of the Carboniferous and Permian systems ranges from 478 to 1,577 x $10^6 m^3$ (3 to 10 B bbl) of in-place volume. The Mississippian subcrop play contains the greatest potential for oil in this system.

The potential of the Triassic plays ranges from 150 to 580 x $10^6 m^3$ (944 to 3,648 MM bbl). The Charlie Lake carbonates play contains the greatest potential in the Triassic system.

The potential of the Jurassic plays ranges from 108 to 243 x $10^6 m^3$ (679 to 1,528 MM bbl).

The light and medium oil potential from the Lower Cretaceous Mannville Group ranges from 297 to 602 x $10^6 m^3$ (1.9 to 3.8 B bbl), whereas the heavy oil potential ranges from 1,075 to 2,512 x $10^6 m^3$ (7 to 16 B bbl).

The potential of the Upper Cretaceous Colorado Group plays ranges from 274 to 903 x $10^6 m^3$ (1.7 to 5.6 B bbl). The Viking Transgressive play contains the greatest potential for oil in this system.

The potential of the Upper Cretaceous Belly River Group plays ranges from 87 to 270 x $10^6 m^3$ (547 to 1,698 MM bbl). The Belly River Cycle 2 marine play contains the greatest potential for oil in this system.

# INTRODUCTION

## Purpose

Estimates of the conventional (light and medium) oil resources of the Western Canada Sedimentary Basin were prepared by the Geological Survey of Canada (Podruski et al., 1988). Since then, a total of 2,324 x $10^6m^3$ of light and medium oil has been discovered in the basin. An updated oil resource assessment of the Western Canada Sedimentary Basin is therefore required.

This report contains a detailed assessment of the light, medium and heavy oil resources estimated to exist in the Western Canada Sedimentary Basin, based on reserve data available in 1995. The objectives of this study were threefold: (1) to estimate the total amount of light, medium and heavy oil in the Devonian, Carboniferous, Permian, Triassic, Jurassic, and Cretaceous systems, regardless of whether the oil will ever be discovered or be economically exploitable if discovered; (2) to outline the principal geological oil plays in the basin so that industry can use the estimates and the associated reservoir data for exploration; and (3) to provide the necessary geological and resource potential information to allow industry and government agencies to undertake economic viability studies on exploration, producibility and marketability.

## Terminology

The term *light and medium oil* is defined by Alberta Energy and Utilities Board (1995) as "A mixture mainly of pentanes and heavier hydrocarbons that may be contaminated with sulphur compounds, that is recovered or is recoverable at a well from an underground reservoir, and that is liquid at the conditions under which its volume is measured or estimated, and includes all other hydrocarbon mixtures so recovered or recoverable except raw gas, condensate or crude bitumen." The term *heavy crude oil* is defined as "crude oil will be deemed to be heavy crude oil if it has a density of 900 kg/m$^3$ or greater, but the Board, in a particular case, may classify crude oil otherwise than in accordance with this criterion, having regard to its market utilization and purchasers' classification". The term *light and medium crude oil* is defined as "crude oil will be deemed to be light-medium crude oil if it has a density of less than 900 kg/m$^3$, but the Board, in a particular case, may classify crude oil otherwise than in accordance with this criterion, having regard to its market utilization and purchasers' classification". In this study, the oil within the Lloydminster area is classified as heavy oil, whereas all other oils are classified as heavy or light-medium oil based on the density of the crude oil.

The terms *resource*, *reserve* and *potential,* as defined by the Geological Survey of Canada (Podruski et al., 1988), are retained in this study. *Resource* is defined as all hydrocarbon accumulations that are known, or are inferred, to exist. *Reserves* are that portion of the resource that has been discovered, and the term *potential* describes that portion of the resource that is inferred to exist but is not yet discovered. The terms *potential* and *undiscovered resources* are synonymous and may be used interchangeably. The terms *pool, field,* and *play* have the following designated meanings in this study. A *pool* is defined as a discovered accumulation of oil, typically within a single stratigraphic interval, that is hydrodynamically separate from another oil accumulation. Any number of discrete pools, at varying stratigraphic levels, may exist within a *field.* A *play* consists of a family of pools and/or prospects that share a common history of hydrocarbon generation, migration, reservoir development and trap configuration (Energy, Mines, and Resources Canada, 1977).

## Scope

The assessment of the oil resources has two essential components: geological play analysis and statistical analysis. The play definitions used in this study are adopted from the work on gas resource assessments of the Devonian (Reinson et al., 1993), the Triassic (Bird et al., 1994a), the Carboniferous (Barclay et al., 1997), the Mannville Group (Warters et al., 1997), the Colorado Group (Reinson et al., 1995), the Post-Colorado Group (Hamblin and Lee, 1995, 1997), and Foothills (Osadetz et al., in prep.) strata. The method for estimating undiscovered resources was developed by the Geological Survey of Canada and is described in detail under Methods for Estimating Undiscovered Resources.

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## METHODS FOR ESTIMATING UNDISCOVERED RESOURCES

### Introduction

The statistical methods used in this study have been developed by the Geological Survey of Canada during the past 15 years (Lee and Wang, 1983a, 1983b, 1984, 1985, 1986, 1990; Lee and Tzeng, 1993, 1995; Lee, 1993a, 1993b; Lee and Lee, 1994). The results obtained from existing tools were checked using new tools, such as the finite population discovery process model (Bickel et al., 1992) and the Bayesian discovery process model (Lee, 1997). All these models have been implemented in the HP computer system and PC system (Lee and Tzeng, 1993) as **PETRIMES** (**P**etroleum **R**esource **I**nformation **M**anagement and **E**valuation **S**ystem). Since the early 1980s, the system has been applied to evaluate plays from various worldwide basins. Some of the assessment results have been verified by actual discoveries.

Comparisons with the output from the geochemical material balance method were discussed by Coustau et al. (1988). Validations by historical data sets were studied by Lee and Tzeng (1995). Comparisons with other methods were discussed by Lee et al. (1995) and Lee and Gill (in prep.). Applications for evaluating plays from various basins can be found in Barclay et al. (1997), Bird et al. (1994a, 1994b); Hamblin and Lee (1997), Warters et al. (1997), Olsen-Heise et al. (1995), Lee and Singer (1994), Reinson and Lee (1993), Reinson et al. (1993), Podruski et al. (1988). Methods related to PETRIMES can be found in Lee et al. (1988), Lee and Price (1991), Kaufman and Lee (1992), and Lee and Lee (1994).

The following sections describe the basic statistical principles employed by PETRIMES. The disadvantages of the methods are also discussed here.

### Sources and preparation of reservoir data

The reservoir data used for this assessment include the electronic data files provided by the Alberta Energy and Utilities Board (1995), British Columbia Ministry of Energy, Mines and Petroleum Resources Division (1995), and Saskatchewan Energy and Mines (1995). The raw data was edited by the following procedures:

1) Pools divided by project area in British Columbia were combined and viewed as one single geological pool.

2) Pools divided by unit in Saskatchewan were also combined into one single geological pool.

3) The discovery date of each pool was chosen from the oldest well among all producing wells or abandoned wells of the same pool. In this case, the date was expressed by year, month and day. The discovery date chosen was also checked against the discovery date assigned by the provincial government. If there was a major discrepancy between the two discovery dates, then the one assigned by the provincial government was used. In that case, the date was expressed by year only.

4) The following data was reformatted and stored into PETRIMES' database: unique identification of the discovery well, pool operator, pool status, trap type, latitude and longitude of the discovery well, pool area, net pay, reservoir temperature and pressure, porosity, water saturation, average depth of the pool, gas and oil ratio, formation volume factor, surface loss (for gas), density and its unit of measurement, Kelly Bushing of the discovery well, gas deviation factor, in-place volume, produced volume, primary recovery factor, secondary recovery factor, primary and secondary reserves, cumulative production of the pool, average depths of gas/oil, oil/gas, and gas/water contacts of the pool, discovery and initial production dates. For gas reservoirs, the average values of all gas components analyses were also stored.

5) The above raw data was stored in the PETRIMES' Reservoir Database (R-database).

6) After the play definitions were established, oil pools were assigned to each play. The reservoir data was then retrieved from the R-database and stored in the Play Database (PD-database) where it was ready for evaluation modules to retrieve, analyze and display graphically.

### Estimating number of pools

Oil or gas pool sizes can be plotted with their discovery dates to produce a time series, or discovery sequence (Fig. 1) — a result of the exploration process. The vertical axis (Fig. 1) represents the pool size in millions of cubic metres (plotted on a logarithmic scale), and the horizontal axis shows the discovery date. This set of oil or gas discoveries is the sample used in the petroleum resource assessment. Note the general decline of pool size over time. This trend indicates that the exploration process produces a biased sample in a statistical sense. That is, larger pools are discovered relatively early in the petroleum play's exploration history.

The biased sample causes a statistical problem, because normal statistical procedure assumes a random sample. One must, therefore, create a new statistical model which can handle biased samples in order to estimate the pool populations. On the other hand, the biased sample does contain information that can be extracted for estimating undiscovered resources.

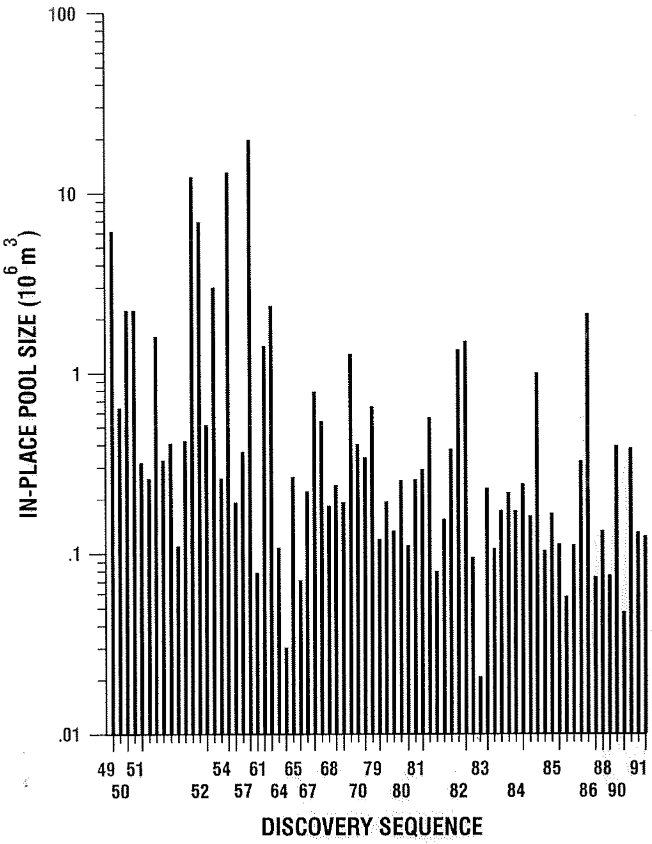


***Figure 1.*** *Discovery sequence for the Leduc–Bashaw play.*

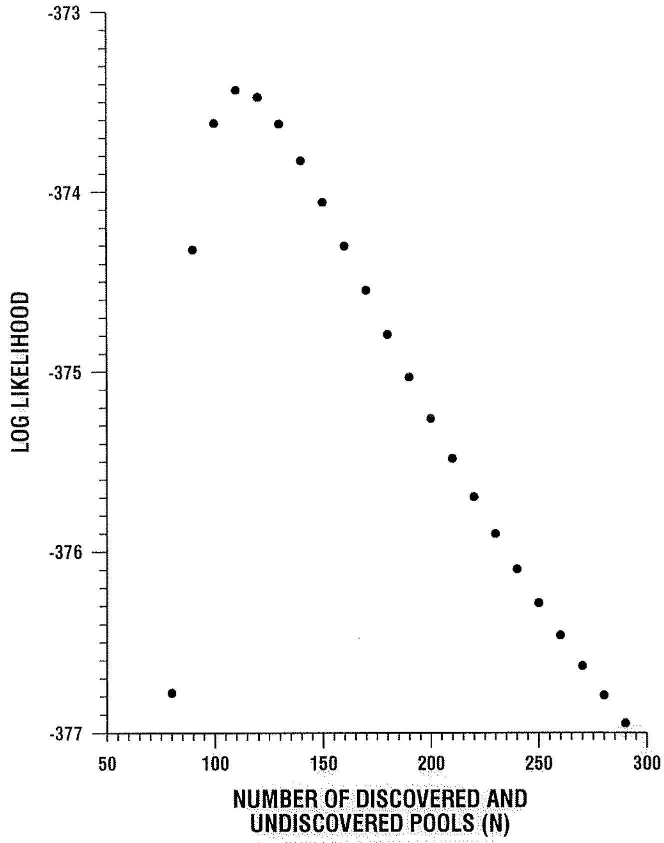


***Figure 2.*** *Lognormal discovery process model plot for the Leduc–Bashaw play of the estimated number of pools, N, that might exist in a play.*

The present method adopts the following statistical assumptions: (1) the probability of discovering a pool is proportional to its size or other pool parameters; and (2) a pool can be discovered only once. These two assumptions are verified by observing discovery sequences from various plays in sedimentary basins around the world. Because of the biased nature of the sample contained in the discovery sequence, these sequences contain vital information for resource evaluation, i.e., the number of pools that might exist in a play, and its corresponding pool size probability distribution. The mathematical treatment of the discovery sequence is called the discovery process model (Lee and Wang, 1985, 1986, 1990; Lee, 1993a).

In PETRIMES, there are two discovery models: one adopts a lognormal pool size assumption and the other takes the nonparametric approach. Both of these models were used to validate each other.

Figure 2 is the result of the lognormal discovery process model. The vertical axis represents the log likelihood value and the horizontal axis indicates the total number of discovered and undiscovered pools in a play, N. The higher the log likelihood value, the more plausible the value of N. In Figure 2, the most likely number of pools is 140. The nonparametric discovery process model yields almost the same result (Fig. 3). Both models were executed for every play. The results from these two models were then compared. If both models did not yield a compatible N value, the output from the nonparametric discovery process model was used if the sample size was large (e.g., number of discoveries, n greater than 30). However, if the sample size was small (n less than 30), the output of the lognormal discovery process model was used. The finite population and the Bayesian discovery models were also used to cross check the results.

## Estimating pool size probability distribution

After estimating the N value, the corresponding pool size distribution was used. The $\mu$ and $\sigma^2$ were used to generate the pool size distribution of a play if the lognormal discovery process model was adopted, whereas the empirical pool size distribution was used if the nonparametric distribution was taken. Distribution A of Figure 4 shows the lognormal pool size distribution, whereas distribution B of Figure 4 shows the empirical pool size probability distribution of the same play. The following sections discuss how to use the N value and its corresponding pool size distribution to estimate the probability distributions for the play resource and potential, and individual pool sizes.

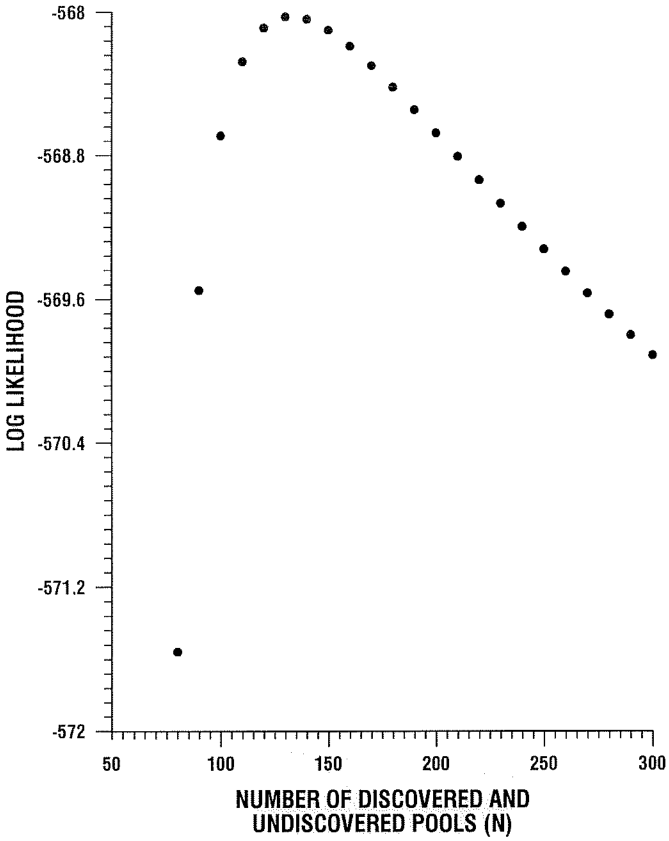


*Figure 3.* *Non-parametric discovery process model plot for the Leduc–Bashaw play, of the estimated number of pools, N, that might exist in a play.*

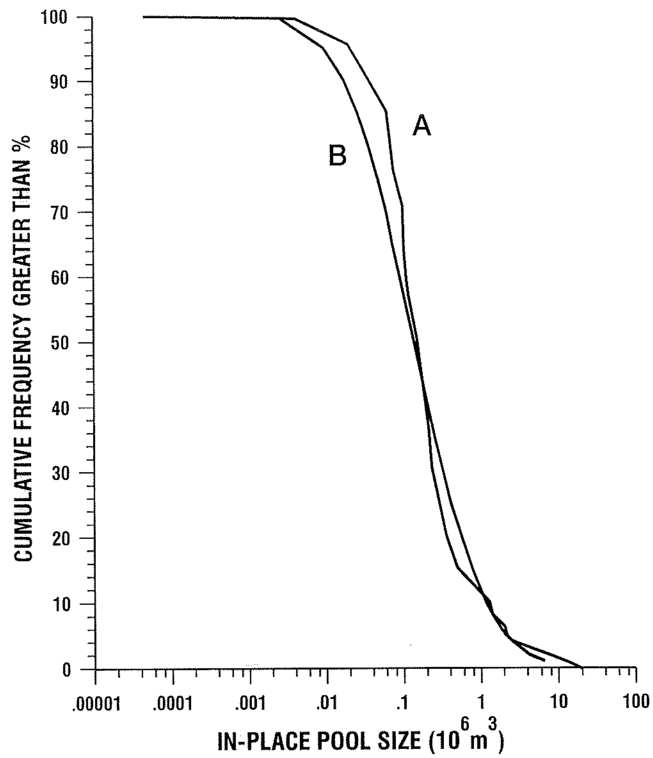


*Figure 4.* *Pool size distribution estimated by the non-parametric discovery process model (A), and by the lognormal discovery process model (B) for the Leduc–Bashaw play.*

Both of the discovery process models contain an unknown variable, the exploration efficiency coefficient, β, which is estimated from the discovery sequence. The discovery process is proportional to the magnitude of the pool size, as well as other factors (e.g., commercial objectives, land availability, pool depth, and exploration techniques). The use of a single parameter, β to account for all these factors may seem oversimplified. Nevertheless, the example presented by Lee and Singer (1994) demonstrates that a simple, but logical approach can approximate reality, at least for the purposes of resource assessment. The β value for each play is recorded under the heading "Exploration History".

## Estimating play potential distribution

A play resource distribution (Distribution A in Fig. 5) can be estimated from the N value and the pool size distribution (either lognormal or nonparametric distribution) (Lee and Wang, 1983a). Furthermore, a play potential distribution (Distribution B of Fig. 5) can be derived from the play resource distribution, given that the sum of all discoveries of the play is used as a condition.

The potential values of the 95th and 5th upper percentiles and the expected values are used in this report as a 0.9 probability prediction interval.

## Estimating conceptual and immature play potential

The number and size of conceptual plays that may exist in an established basin can be estimated by the nonparametric discovery process model. Thus, after compiling the expected values of the play potential for each established play and their respective discovery dates (the discovery date of the first pool in each play), a play resource discovery sequence is generated for all the established plays (Fig. 6). The play discovery sequence for each basin is analyzed by the same procedure as the discovery sequence for each play. The play resource distribution can then be derived.

## Uncertainties in estimates

All estimates contain uncertainties, which can be evaluated and expressed in terms of probabilities. In this section, we shall discuss the uncertainties in estimates derived by PETRIMES in two ways: expressed in terms of probability distribution and evaluated by comparing with historical discoveries.

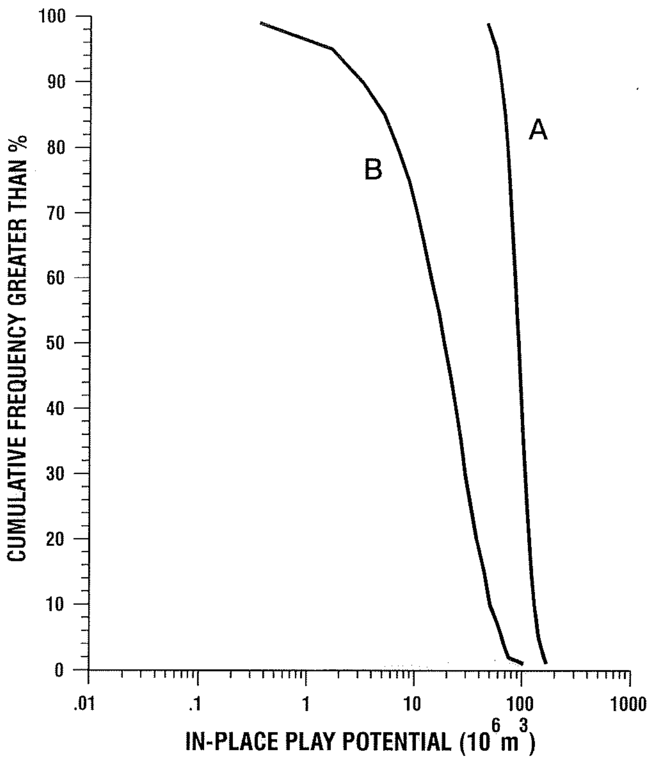


*Figure 5. Play resource distribution (A) and conditional play potential distribution (B) for the Leduc–Bashaw play.*

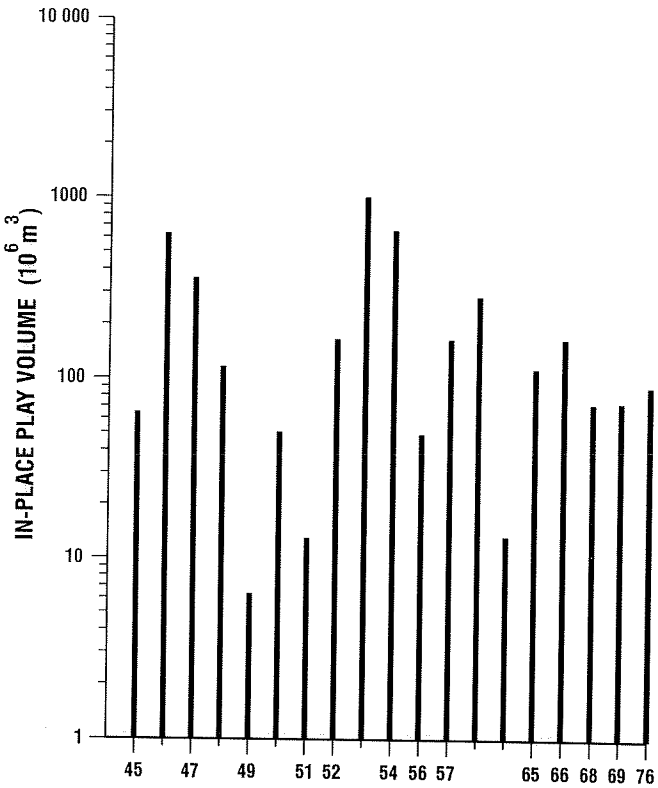


*Figure 6. Play resource discovery sequence for the Devonian system.*

### *Uncertainty expressed in terms of probability distribution*

PETRIMES adopts the probabilistic approach and expresses estimation uncertainty in terms of probability distribution. The following estimates, e.g., play potential, individual pool size for undiscovered pools and basin potential are all expressed by probability distribution. All these distributions are derived by formal statistical procedures.

### *Uncertainty evaluated by historical discoveries*

Certain types of uncertainty cannot be expressed quantitatively, but can be evaluated using historical discoveries. This approach allows users to assess the pitfalls or limitations of the evaluation tools. The following paragraphs describe this.

The Jumping Pound Rundle gas play of the Western Canada Sedimentary Basin (Osadetz et al., 1995) was chosen for this study. The following procedure was used:

1) The play data, consisting of 94 discoveries in the 1991 database, were divided into three time windows; pre-1966 (Fig. 7A, 15 discoveries); pre-1974 (Fig. 7B, 25 discoveries); pre-1991 (Fig. 7C, 94 discoveries).

2) The data sets for the three windows were evaluated. The pool reserves used in the study were the values reported by the Alberta Energy Resources Conservation Board (ERCB) at the end of 1965 (ERCB, 1966), 1973 (ERCB, 1974), and 1991 (ERCB, 1991).

3) The following estimates from the three time windows were compared: (1) number of pools in the play; (2) largest yet-to-be discovered pool size; (3) play resource distribution; and (4) play potential distribution.

4) This approach allows us to examine the limitations of PETRIMES when it is applied to a play that has gone through the immature to established exploration stages. The following conclusions were reached:

5) The most severe impact on resource assessments due to a small number of discoveries is evident in estimating of the total number of pools, N.

6) The effect of small sample size on the resource distribution estimation is minimal, as can be observed from the similarity in the resource distributions for all time windows. (Fig. 8 and Table 1). The sum of the discovered and expected potential values is almost the same for all time windows. If the sums are compared to the 1991 value, the maximum difference is 16% for the 1966 time window and 3% for the 1974 time window.

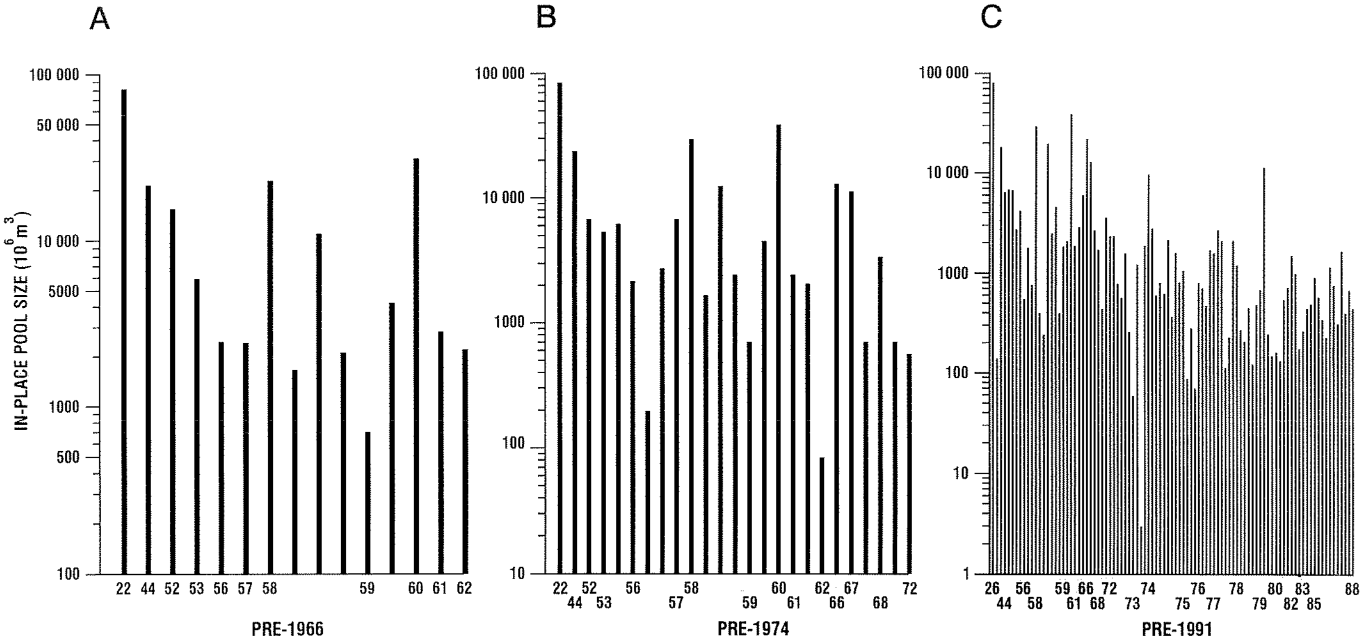


***Figure 7.** Discovery sequences for the Jumping Pound play. A, pre-1966 data set; B, pre-1974 data set; C, pre-1991 data set.*

The two largest pools predicted by the 1966 time window data set are the Quirk Creek Rundle A pool and the Clearwater Rundle A pool. The former was discovered in 1967 and the latter pool was discovered in 1980. Since then, no pools larger than these two pools have been discovered. However, several pools with sizes smaller than the Clearwater Rundle A but larger than the eighth rank (Fig. 9) have been discovered in subsequent years.

It can be summarized from the above retrospective study that the number of discoveries (sample size) used in the assessment is the most important factor affecting the estimation of the number of pools and the corresponding pool size distribution.

The total number of pools might be underestimated because of the small sample size. However, the play resource distribution and conditional play potential distribution are the most reliable estimates to be used. The estimated potential should not be considered as the ultimate resource and should be updated periodically.

**Reservoir parameters**

Reservoir parameter data, namely pool area, net pay, porosity, water saturation and recovery factor are plotted in Appendices A (Devonian), B (Carboniferous and Permian), C (Triassic), D (Jurassic), E (Mannville Group), F (Colorado Group) and G (Belly River Group). This data represents sample distributions, rather than probability distributions. The 95 and 5 upper percentiles are reported in the text. In the case of insufficient data, or for other reasons, the minimum (min) and maximum (max) values are reported.

Cross plots of pool size versus pool area for all of the established plays are given in the appendices. These plots are used to obtain a pool area if the pool size is given. All these plots provide essential information for prospect analysis of a specific prospect of a play.

The discovery sequences and the cumulative in-place reserve graphs are also provided. This type of graph summarizes the results of the exploration history and provides a future outlook without any statistical analysis. Information from these plots and the predictions for each play can be used to identify the best plays to explore.

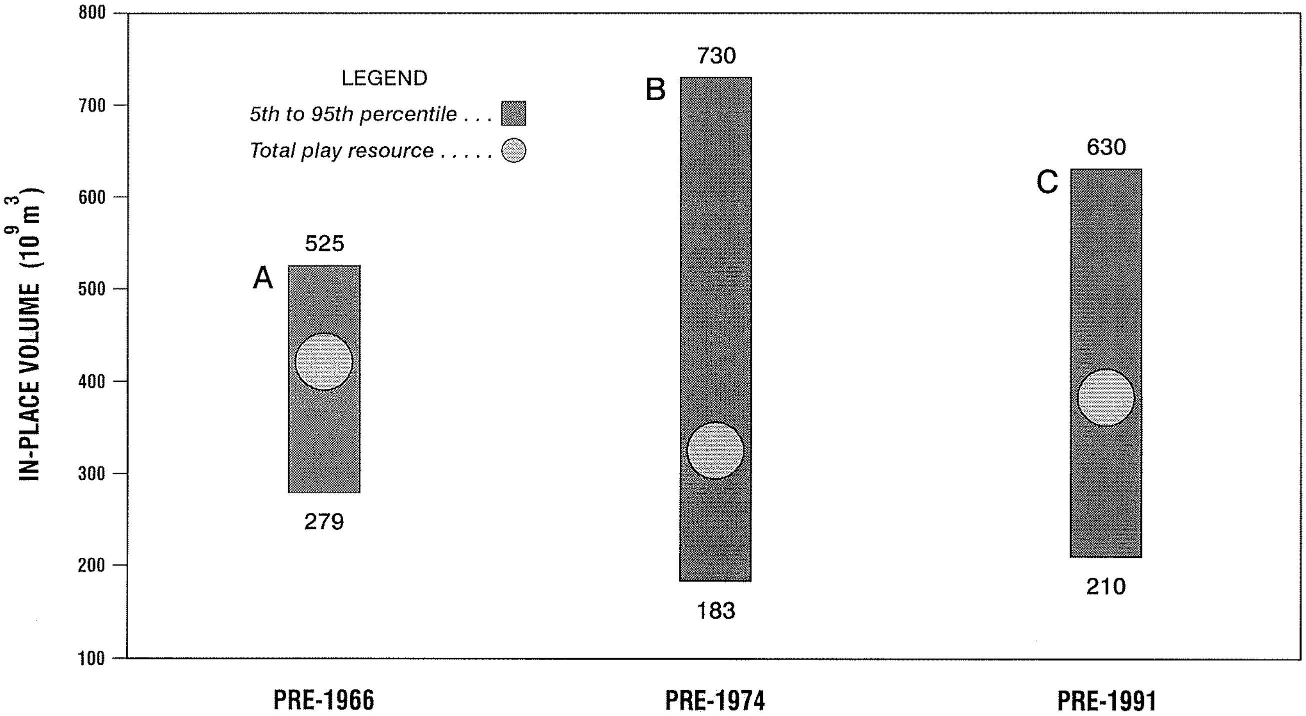


***Figure 8.*** *Play resource distribution for the Jumping Pound play. A, pre-1966 data set; B, pre-1974 data set; C, pre-1991 data set.*

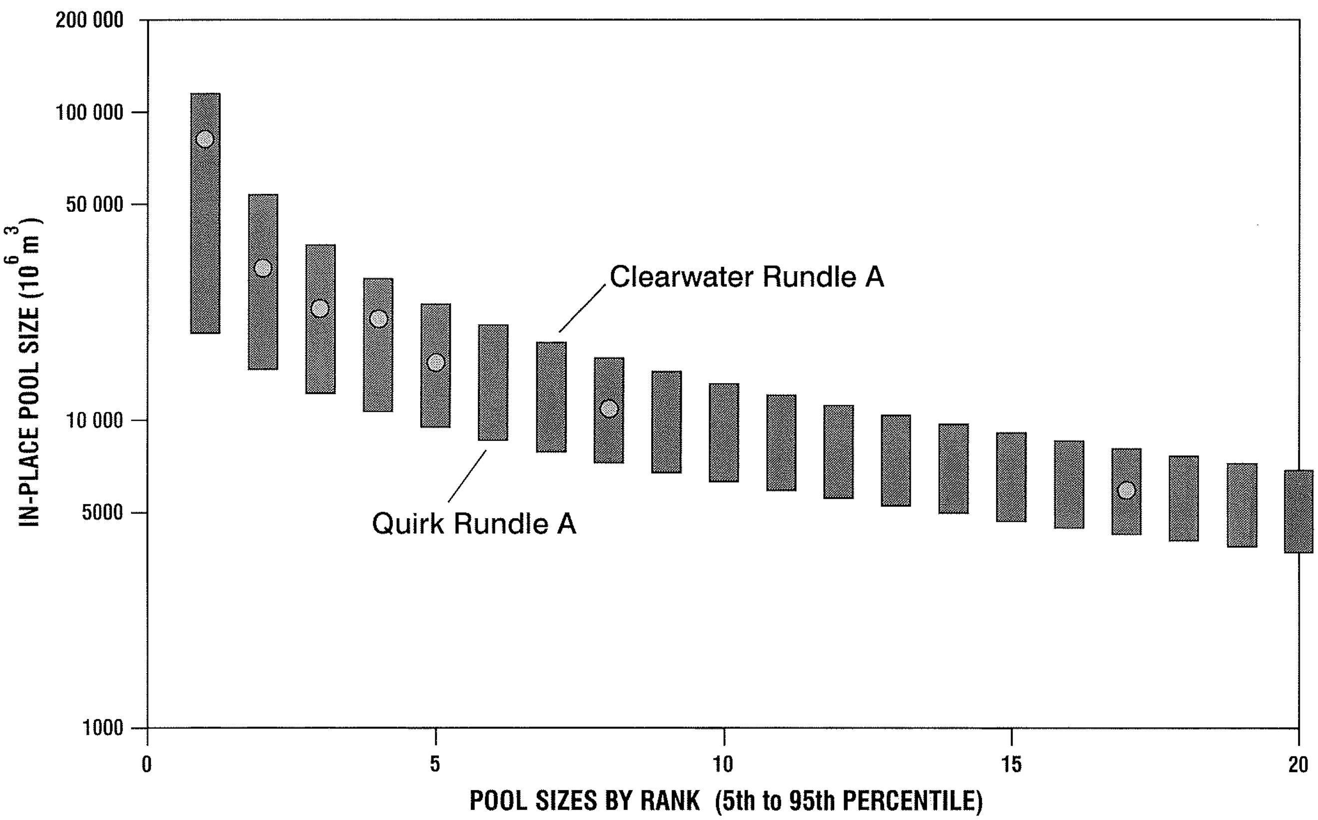


***Figure 9.*** *Pool size by rank predicted by the pre-1966 data set.*

**Table 1**

**Summary of the retrospective study for the Jumping Pound play**

| Time window | Total number of pools estimated | Booked resource at the end of time window ($10^9m^3$) | Expected potential ($10^9m^3$) | 5th and 95th upper percentiles of the play resource distribution ($10^9m^3$) | Mean of the play resource distribution ($10^9m^3$) |
|---|---|---|---|---|---|
| Pre-1966 | 100 | 208 | 213 | 279 - 525 | 382 |
| Pre-1974 | 100 | 262 | 63 | 183 - 730 | 376 |
| Pre-1991 | 173 | 355 | 28 | 210 - 630 | 366 |

## DEVONIAN SYSTEM

### Geological framework

The Western Canada Sedimentary Basin occupies an area of 1.4 x $10^6$ $km^2$, and encompasses southwestern Manitoba, southern Saskatchewan, Alberta, northeastern British Columbia, and the southwestern corner of the District of Mackenzie (Fig. 10). The portion of the basin extending into the United States occupies an additional area of 0.3 x $10^6$ $km^2$. The basin consists of a wedge of sedimentary rocks that tapers from zero thickness in the east to greater than 6 km thick, west of Calgary. This sedimentary succession, which represents geological history of more than 600 million years, lies on the westward extension of the PreCambrian continental craton (Porter et al., 1982). The basin is bounded on the north by the Tathlina Arch, on the east by the Canadian Shield, on the south by the Transcontinental, Sioux, and Central Montana arches, and on the west by the edge of folded and faulted thrust belts.

Moore (1988, 1989) divided the Devonian of Western Canada into five major sequences bounded by discontinuities, and referred to them as the Delorme, Bear Rock, Hume–Dawson, Beaverhill–Saskatchewan, and Palliser (Figs. 11 and 12). The Devonian strata constitute the transgressive part of the Kaskaskia sequence of Sloss (1963), but the transgression was pulsatory as it inundated eastward over the craton. The Devonian is discussed below in terms of the seven depositional cycles shown in Figure 12, and illustrated in Figures 13 and 14.

### *Lower Elk Point (Cycles 1 and 2)*

Rocks of the Lower Elk Point consist of interbedded redbeds, evaporites, shallow-marine clastics, and minor carbonates. The cycles include the succession from the Basal Red Beds to the base of the Keg River Formation (Fig. 10). This succession was deposited within a restricted, shallow, epicontinental sea that terminated in the south at the Meadow Lake Escarpment. The basin and arch paleotopography is

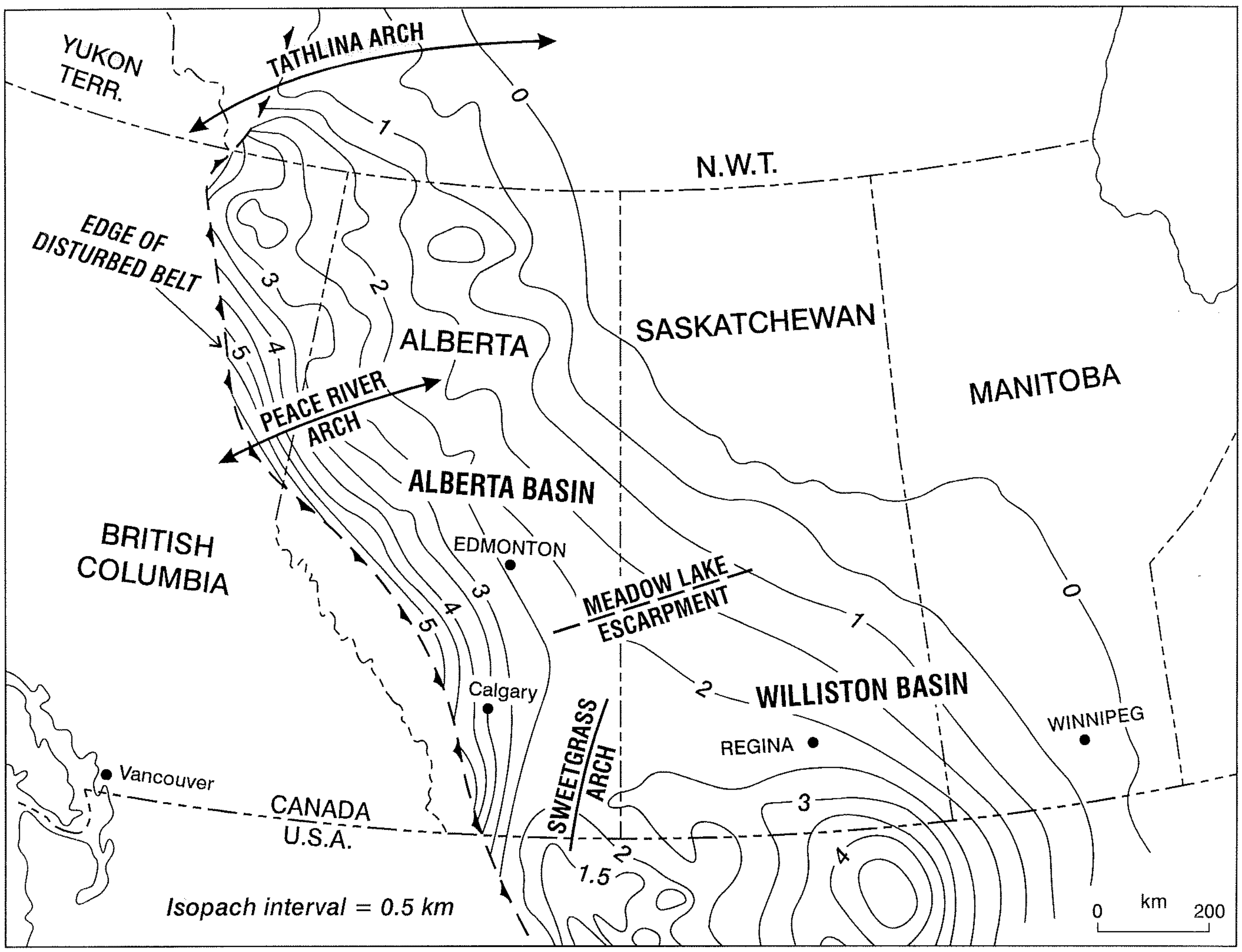


*Figure 10. Basin-fill map, Western Canada Sedimentary Basin (after Porter et al., 1982).*

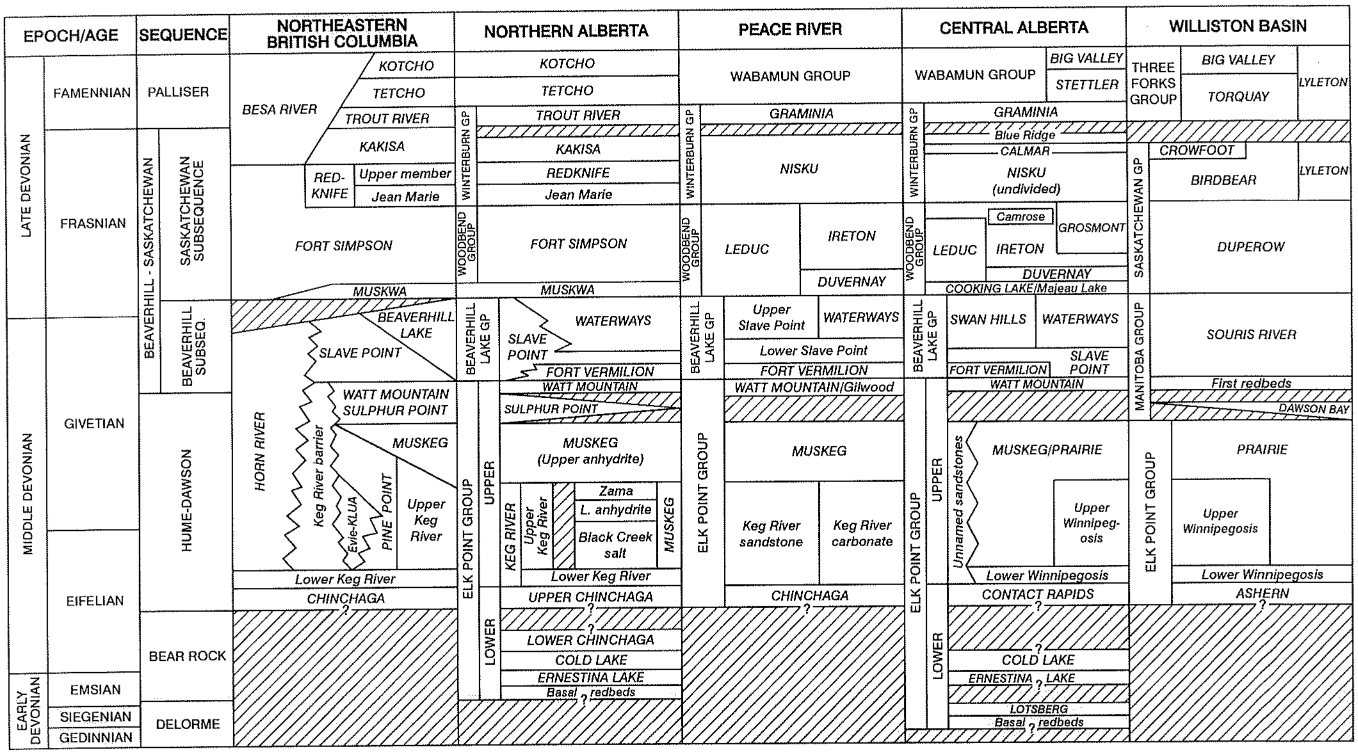


***Figure 11.*** *Table of Devonian formations of the Western Canada Sedimentary Basin (after Reinson et al., 1993).*

well illustrated by the distribution of Lotsberg Salt (Moore, 1989) and the isopach map of the Cold Lake Salt (Meijer Drees, 1986). Within the sub-basins, Lower Elk Point deposits attain thicknesses of 300 m, but thin through depositional onlap to nearly zero over the Tathlina Arch, Peace River Arch, and Western Alberta Ridge. No oil or gas occurrences have been found within these two cycles.

### *Upper Elk Point Group (Cycle 3)*

The transition from Lower to Upper Elk Point deposits is marked by an abrupt change from the restricted evaporites, dolostones, and siliciclastic rocks of the Chinchaga Formation to the relatively open-marine, fossiliferous carbonates of the Lower Keg River Member. This change accompanied a major transgression that gave rise to basinwide deposition of these carbonates in a ramp-to-platform setting.

| Devonian stage | Discontinuity-bounded sequences (from Moore, 1989) | Lithostratigraphic nomenclature (Podruski et al., 1988) | Depositional cycle (this paper) |
|---|---|---|---|
| Famennian | Palliser | Wabamun | $C_7$ |
| Late Givetian to early Frasian | Saskatchewan-Beaverhill Lake | Winterburn<br>Woodbend<br>Beaverhill Lake | $C_6$<br>$C_5$<br>$C_4$ |
| Eifelian to early Givetian | Hume-Dawson | Upper Elk Point | $C_3$ |
| Emsian to early Eifelian | Bear Rock | Lower Elk Point (Ernestina Lake, Cold Lake) | $C_2$ |
| Lochkovian to Pragian | Delorme | Lower Elk Point (Lotsberg) | $C_1$ |

***Figure 12.*** *Relationship between major Devonian sequences and established lithostratigraphy in the Western Canada Sedimentary Basin (after Reinson et al., 1993).*

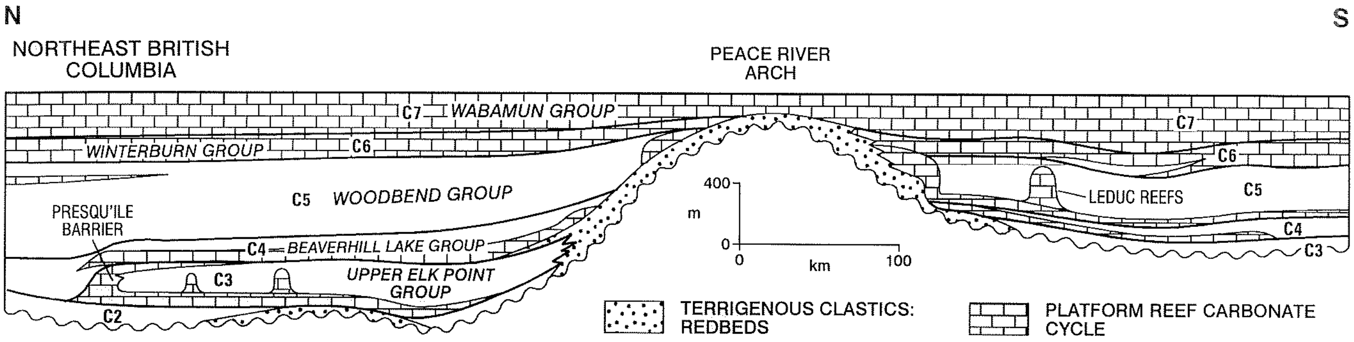


***Figure 13.** North–south cross section illustrating the major depositional cycles in the Devonian of the Western Canada Sedimentary Basin (modified from Moore, 1989).*

With continued subsidence and marine transgression, an extensive upper Keg River barrier-reef complex (Pine Point Formation of Presqu'ile Barrier Complex) developed near the northern limit of the basin in northern British Columbia and the southern District of Mackenzie (Fig. 13). Southeast of the barrier, isolated pinnacle reefs and reef mounds of the upper Keg River developed on a lower Keg River platform. In the Rainbow-Zama area hundreds of pinnacle reefs, up to 250 m thick, grew in discrete sub-basins.

Within the central and southern part of the basin, reefoid mounds and banks up to 60 m thick developed over lower Keg River platform deposits. These buildups extend from north-central Alberta into southeastern Saskatchewan (Winnipegosis Formation).

Following the upper Keg River phase, normal marine sedimentation was confined to the region north of the Presqu'ile Barrier Complex. In the Rainbow–Zama basins of northern Alberta, evaporitic deposition occurred as halite, anhydrite, and evaporitic dolostone of the Muskeg Formation. Southeastward, increasingly evaporitic conditions resulted in abundant halite deposits, which predominate in the Muskeg and Prairie Evaporite formations.

Near the end of Upper Elk Point deposition, a minor marine incursion in northwestern Alberta resulted in the deposition of peritidal to shallow-marine carbonates of the Sulphur Point Formation. Upper Elk Point deposition was terminated by a pronounced base-level drop that resulted in the widespread occurrence of the coastal-marine and continental shales and sandstones of the Watt Mountain Formation. A total of 231 x $10^9 m^3$ of natural gas (Reinson et al., 1993; Osadetz et al., in prep.) and 895 x $10^6 m^3$ of oil have been discovered in this cycle.

### *Beaverhill Lake Group (Cycle 4)*

Beaverhill Lake Group sedimentation began with gradual marine transgression over the relatively flat surface of the Watt Mountain Formation. Throughout most of Alberta, the initial deposits of the Beaverhill Lake Group were peritidal anhydrites and carbonates of the Fort Vermilion Formation. This formation is only a few metres thick in central and southern Alberta, but thickens north and northwest to more than 50 m in northern Alberta.

The Fort Vermilion Formation is overlain by open-marine platform carbonates of the Slave Point Formation. Along the flanks of the Alberta Ridge and the Peace River Arch, the Slave Point carbonates form a widespread coral- and stromatoporoid-bearing, shallow-marine platform ranging from 20 to 35 m thick. To the east of this platform the Slave Point thins and changes to deeper water facies. North and northwest of the Peace River Arch, the Slave Point thickens progressively to 150 m near the Presqu'ile Barrier Complex (Fig. 13).

Further marine transgression over the Slave Point surface resulted in the development in west-central Alberta of an extensive reef-rimmed carbonate platform and the atoll-like reef complexes of the Swan Hills Formation (Fig. 14). Basinal shale and argillaceous limestone of the Waterways Formation overlie the Swan Hills reef complexes. In southern Alberta, the Waterways interfingers with shelf carbonates and evaporites of the Southern Alberta Shelf Complex. In northern Alberta, the Waterways onlaps Slave Point reef complexes that fringe the Peace River Arch. The total resources discovered from this cycle are 524 x $10^9 m^3$ of natural gas (Reinson et al., 1993) and 1,106 x $10^6 m^3$ of oil.

### *Woodbend Group (Cycle 5)*

The transition from the Beaverhill Lake Group to the overlying Woodbend Group is conformable and resulted from renewed marine transgression and deepening of the entire basin. It appears that maximum marine incursion of the craton occurred sometime during this cycle. In contrast, the last two cycles (Winterburn and Wabamun) are characterized by regressive conditions and widespread basin filling (Stoakes, 1988).

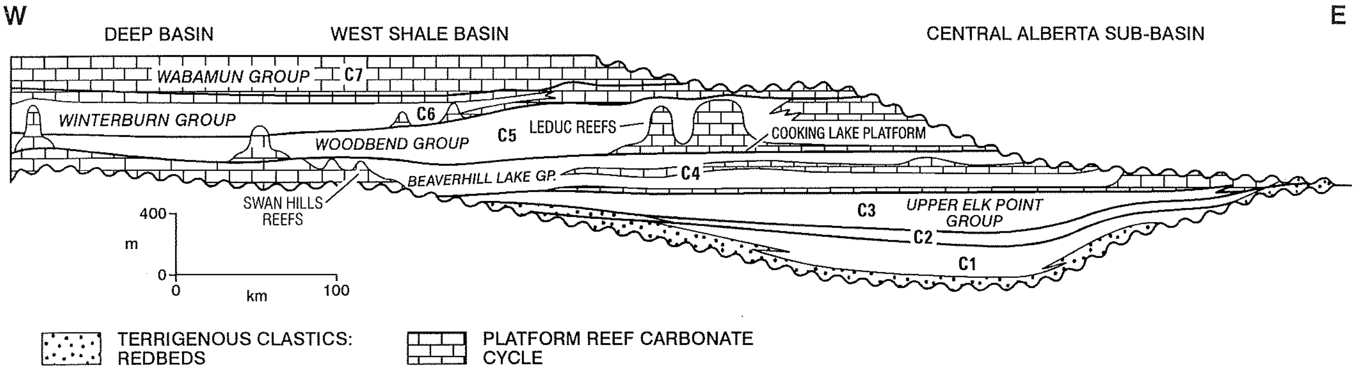


***Figure 14.*** *East–west cross section illustrating the major depositional cycles in the Devonian of the Western Canada Sedimentary Basin (modified from Moore, 1989).*

Over the central and northern parts of Alberta, shelf limestones of the upper Waterways Formation are overlain by deep-water, organic-rich limestones and shales of the Duvernay, Majeau Lake and Muskwa formations (Fig. 11). Across southern and southeastern Alberta, extensive platform carbonates of the Cooking Lake Formation, up to 100 m thick, comprise shallow-water equivalents of the Majeau Lake and basal Duvernay formations. Equivalents of these platform carbonates also overlie Swan Hills shelf deposits and reef complexes situated along the Western Alberta Ridge.

Ongoing marine incursion eventually resulted in drowning of the Cooking Lake platform in northern and north-central Alberta. In southern and southeastern Alberta, however, shallow-water and evaporitic carbonate deposition of the Leduc Formation and equivalents kept pace with sea-level rise, producing an extensive reef-rimmed shelf complex (Southern Alberta Shelf Complex). In the "Deep Basin" area of Alberta, isolated Leduc reef complexes up to 250 m thick developed on the Cooking Lake and Beaverhill Lake platforms (Fig. 14). Woodbend reefs also formed an arcuate fringe around the Peace River Arch.

The upper Woodbend cycle began with sequential infilling of the basin by Ireton shales, progressing from the northeast toward the south and southwest. Ireton fine-grained clastic deposition successively engulfed the stratigraphically younger Leduc reefs in the 'East Shale Basin' (Stoakes, 1988). The Grosmont shelf-platform reef complex developed over the prograding Ireton shales in northeastern Alberta.

During Ireton deposition, organic-rich shales and limestones of the Duvernay Formation were accumulating in deeper water basinal environments. In northwestern Alberta, the Ireton interval is represented by the Muskwa Formation (Burrowes and Krause, 1987). The Muskwa Formation is overlain by thick upper Woodbend Group shales of the Fort Simpson Formation. At the end of Ireton-Fort Simpson deposition the Ireton basin in central Alberta was nearly filled, and the remaining clinoform slopes formed the Cynthia basin, which was the site of pinnacle reef development during later Winterburn Group deposition. A total of 502 x $10^9 m^3$ of natural gas (Reinson et al., 1993; Osadetz et al., in prep.) and 822 x $10^6 m^3$ of oil has been discovered from this cycle.

### *Winterburn Group (Cycle 6)*

Winterburn Group rocks were deposited during shallowing conditions even though overall inundation of the craton was continuing. The regressive sedimentation patterns during Woodbend time resulted in widespread shelf carbonates of the Nisku Formation. To the north, carbonates were silty and argillaceous, but in eastern and southeastern Alberta, and rimming the Cynthia basin, fossiliferous shelf and reef carbonates were widespread. Numerous small pinnacle reefs developed in the west Pembina area, along the southeastern flank of the Cynthia basin (Watts, 1987).

Nisku sedimentation was terminated by a major regression marked by terrigenous deposits of the Calmar Formation. Subsequently, shallow-marine incursion resulted in deposition of shelf carbonates of the Blue Ridge Member, which pinches out to the southeast, but thickens to over 50 m in western Alberta. A second major regression, which occurred at the close of Winterburn deposition, deposited a northwestward-thickening wedge of terrigenous clastics known as the Graminia Silt. The Graminia Silt marks the Frasnian-Famennian boundary. A total of 90 x $10^9 m^3$ of natural gas (Reinson et al., 1993; Osadetz et al., in prep.) and 408 x $10^6 m^3$ of oil has been discovered.

### *Wabamun Group (Cycle 7)*

The transgression that initiated Wabamun deposition occurred over a broad, flat surface, resulting in an extensive, low-gradient, prograding carbonate ramp (Stoakes, 1988). This carbonate ramp covered most of central and northern Alberta and northeastern British Columbia. With continued ramp accretion, intertidal-supratidal conditions evolved in southeastern Alberta. Wabamun Group strata average 300 m in thickness in western Alberta, conformably overlie Winterburn deposits, and consist mainly of shallow-marine to peritidal platform carbonates. In southeastern Alberta, these carbonates interfinger with evaporites of the Stettler Formation. In northeastern British Columbia, deeper water shale equivalents occur within the Besa River Formation.

Two transgressive episodes are recognized in the prograding Wabamun ramp-platform. The first transgression resulted in the shoal carbonates of the Crossfield member, which forms a lenticular wedge that pinches out into evaporites of the Stettler Formation (Eliuk and Hunter, 1987). The second transgressive episode, near the end of Wabamun deposition, formed the open-marine, fossiliferous limestone deposits of the Big Valley Formation. A total of 289 x $10^9m^3$ of natural gas (Reinson et al., 1993; Osadetz et al., in prep.) and 50 x $10^6m^3$ has been discovered.

The play definitions of the Devonian System were adopted from previous work on resource assessment of oil (Podruski et al., 1988) and of gas (Reinson et al., 1993; Osadetz et al., in prep.).

## Resource assessment

### *Devonian system potential*

The potential predicted from the established Devonian plays ranges from 631 to 1,627 x $10^6m^3$. The mean (or expected value) of the potential distribution is 1,066 x $10^6$ $m^3$. The Nisku shelf play contains the greatest potential for oil in the Devonian system.

New plays are still available for exploration. The largest immature or conceptual play ranges from 117 to 163 x $10^6m^3$. The potential from the immature and conceptual plays ranges from 127 to 3,033 x $10^6m^3$ with a mean of 1,230 x $10^6m^3$. The Devonian System offers a great opportunity for conceptual play exploration.

The in-place volume has increased from 2,854 x $10^6m^3$ to 3,278 x $10^6m^3$ since the GSC's 1987 assessment. A total of 78 x $10^6m^3$ of in-place volume was discovered between 1990 and 1994. The pools discovered and the sizes of the ten largest pools discovered between 1990 and 1994 are listed in Tables 2 and 3.

### *Northern Alberta region*

Five established mature plays, Rainbow, Zama, and Shekilie sub-basins, Zama and Muskeg, and Bistcho are located within this region.

*Keg River shelf basins, Rainbow, Zama and Shekilie sub-basin plays*

*Play definition.* These plays include all oil and gas pools in patch and pinnacle reefs, and reef complexes, of Keg River age that occur within the Rainbow, Zama, and Shekilie shelf basins (Fig. 15). Although resource evaluations were undertaken separately, the underlying geological controls defining these three sub-basin plays are interrelated, and are therefore discussed collectively.

*Geology.* The principal stratigraphic traps in this play are Keg River pinnacle reefs and bank-margin reef buildups that accumulated in small, deep basins, which were subsequently filled by Muskeg evaporites (McCamis and Griffith, 1967; Langton and Chin, 1968; Barss et al., 1970). The Keg River reefs, which developed on Lower Keg River ramp-platform carbonates, range up to 200 m in thickness, yet occupy areas much smaller than a section (one square mile). The Muskeg evaporites form an ideal seal for these high-porosity reef buildups, which consist dominantly of dolomitized coral-stromatoporoid floatstone and bindstone capped by algal-rich grainstone-packstone shoal deposits.

*Exploration history for the three plays.* The in-place volume has increased from 340 to 396 x $10^6m^3$ since the GSC's 1987 assessment. New discoveries have contributed mainly to the increase. The reservoirs and potentials of each play are described in the following paragraphs.

**Table 2**

**Devonian oil pools discovered**

| Pool size class ($10^6m^3$) | Pools discovered up to 1989 | Pools discovered between 1990 and 1994 |
|---|---|---|
| < 0.1 | 395 | 74 |
| 0.1 - 1 | 1306 | 167 |
| 1 - 10 | 201 | 9 |
| 10 - 100 | 33 | 0 |
| 100 - 1,000 | 8 | 0 |
| Total number of pools | 1943 | 250 |
| In-place volume | 3,200 x $10^6m^3$ | 78.018 x $10^6m^3$ |

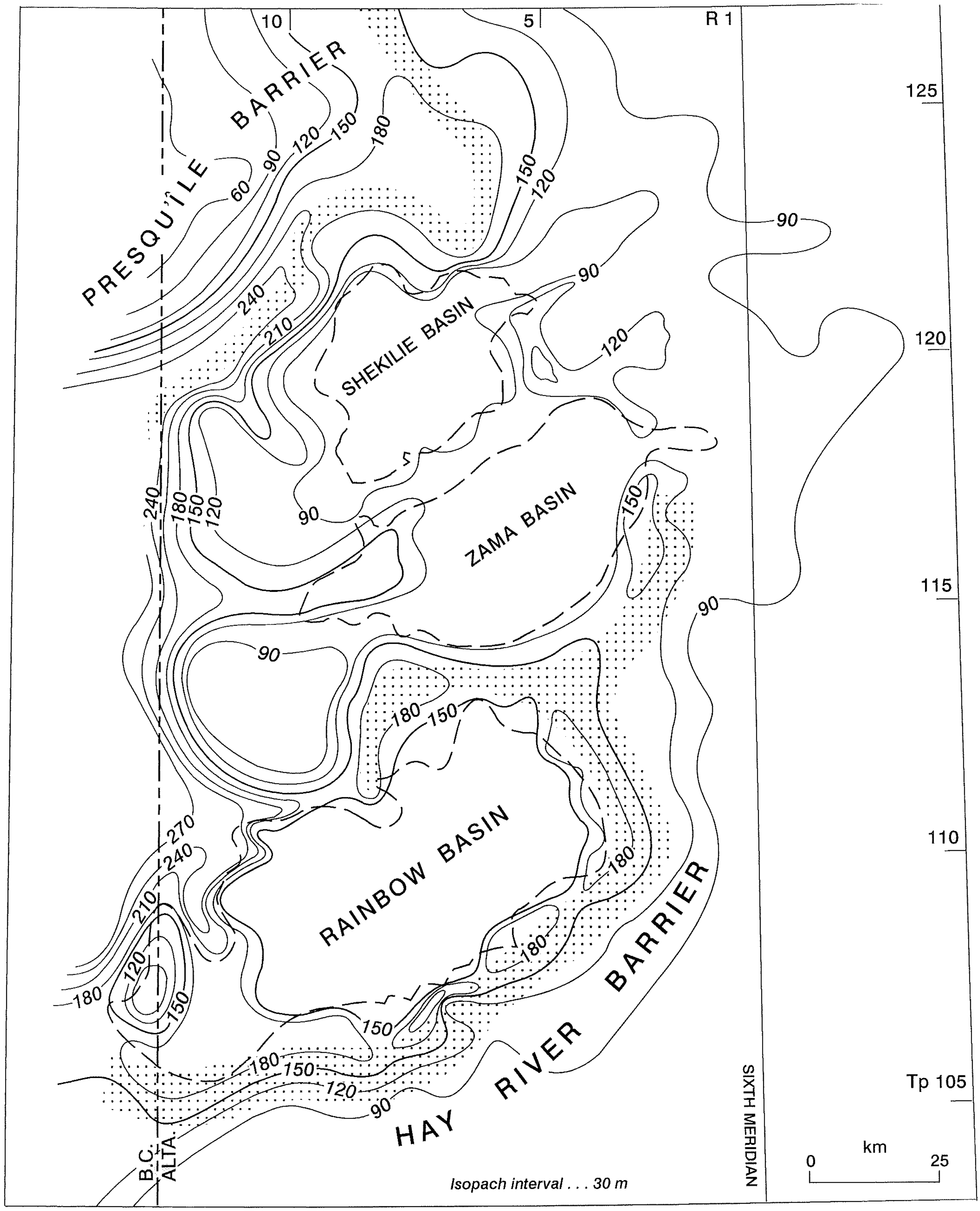


***Figure 15.*** *Isopach map of the Keg River Formation, showing the Rainbow, Zama and Shekilie shelf basins.*

*Exploration history of the Rainbow sub-basin.* The discovery sequence ($\hat{\beta}=1.0$) and the cumulative in-place volume discovered are graphically displayed in Appendix A (Figs. A1.1 and A1.2). The cumulative in-place graph shows a moderately upward increase. The potential and discoveries are summarized in Tables 4 and 5.

*Reservoir parameters of the Rainbow sub-basin.* Reservoirs have pool areas from 16 to 300 ha; net pay from 10 to 74 m; porosity from 1.2 to 9.5%; water saturation from 10 to 44%; and a recovery factor from 0.3 to 60%. The parameters are also graphically displayed in Appendix A (Figs. A1.3 to A1.8).

*Exploration history of the Zama sub-basin.* The discovery sequence ($\hat{\beta}=0.6$) and the cumulative in-place volume discovered are graphically displayed in Appendix A (Figs. A2.1 and A2.2). The cumulative in-place graph shows a very strong upward increase. The potential and discoveries are summarized in Tables 6 and 7.

*Reservoir parameters of the Zama sub-basin.* Reservoirs have pool areas from 5 to 33 ha; net pay from 16 to 80 m; porosity from 4 to 12%; water saturation from 10 to 30%; and a recovery factor from 1.6 to 40%. The parameters are also graphically displayed in Appendix A (Figs. A2.3 to A2.8).

*Exploration history of the Shekilie sub-basin.* The discovery sequence ($\hat{\beta}=0.8$) and the cumulative in-place volume discovered are graphically displayed in Appendix A (Figs. A3.1 and A3.2). The cumulative in-place graph shows a very strong upward increase. The potential and discoveries are summarized in Tables 8 and 9.

*Reservoir parameters of the Shekilie sub-basin.* Reservoirs have pool areas from 4 to 30 ha; net pay from 12 to 93 m; porosity from 4 to 12%; water saturation from 10 to 25%; and a recovery factor from 0.3 to 40%. The parameters are also graphically displayed in Appendix A (Figs. A3.3 to A3.8).

### *Zama and Muskeg*

*Play definition.* This play is defined to include all oil and gas pools of the Zama Member and thin dolomite beds of the Muskeg Formation where they drape over remnants of the Black Creek salt or Keg River reefs. It covers the play areas of the Rainbow, Zama, and Shekilie sub-basins.

*Geology.* Traps formed by structural drape occur in the Zama Member, which represents deposition during marine incursion into the Muskeg evaporite basin (McCamis and Griffith, 1967). The Zama Member is present primarily in the Zama Basin, to a lesser extent in the Shekilie Basin, and is absent in the Rainbow Basin. Porosity in the Zama Member is best developed over Keg River reefs, where higher energy conditions resulted in the formation of biostromal grainstones and packstones; dolomitization further enhanced the reservoirs.

Thin dolostone beds (less than 20 m) in the thick Muskeg evaporite section are commonly porous and form drape traps over underlying remnants of Black Creek Salt.

*Exploration history.* The discovery sequence ($\hat{\beta}=0.7$) and the cumulative in-place volume discovered are graphically displayed in Appendix A (Figs. A4.1 and A4.2). The in-place volume has increased from 28 to 48 x $10^6 m^3$ since the GSC's 1987 assessment. New discoveries and appreciation of existing pools have mainly contributed to the increase. The largest pools predicted by the GSC's 1987 assessment have been discovered. The cumulative in-place graph shows a very strong upward increase. The potential and discoveries are summarized in Tables 10 and 11.

*Reservoir parameters.* Reservoirs have pool areas from 5 to 300 ha; net pay from 3.5 to 55 m; porosity from 4 to 10%; water saturation from 9 to 30%; and a recovery factor from 0.4 to 36%. The parameters are also graphically displayed in Appendix A (Figs. A4.3 to A4.8).

### *Bistcho (Sulphur Point)*

*Play definition.* This play is defined to include all oil and gas pools in stratigraphic traps of the carbonate shelf facies of the Sulphur Point Formation. The play extends northeast from Zama and Shekilie across the Alberta–Northwest Territories border to the northern edge of the Muskeg anhydrite (Fig. 16).

*Geology.* The Sulphur Point Formation consists of a shelf carbonate, 5 to 80 m thick, which disconformably overlies (and is laterally equivalent to) Muskeg evaporites. It is unconformably overlain by the Watt Mountain Shale (Williams, 1981). Detailed correlations of uppermost Muskeg anhydrite and dolomite cycles with adjacent Sulphur Point carbonates suggest that a facies relationship exists between the formations (McCamis and Griffith, 1967). McCamis and Griffith proposed the name Bistcho Member to be used in place of Sulphur Point Formation.

Sulphur Point lithotypes range from dolomitic mudstone and grainstone in the lower part, to lime mudstone in the upper part. The hydrocarbon reservoirs are formed from porous dolomitic grainstone or packstone that was deposited in peritidal channel environments. The reservoirs are sealed laterally by supratidal lime mudstone or anhydrite, and vertically by lime mudstone deposited in less restricted environments.

## Table 3

**The ten largest Devonian pools discovered between 1990 and 1994**

| Field, pool | In-place volume ($10^6 m^3$) |
|---|---|
| Macoun, Winnipegosis | 7.258 |
| Edgerton, Woodbend A | 5.403 |
| Simonette, Beaverhill Lake A | 3.721 |
| Bashaw, D-2 G | 3.308 |
| Enchant, Arcs AAA | 2.512 |
| Shekilie, Keg River I2I | 1.815 |
| Red Earth, Granite Wash X2X | 1.259 |
| Gift, Gilwood M | 1.110 |
| Widewater, Gilwood A | 1.008 |
| Bashaw, D-2 L | 0.954 |

## Table 4

**Pools discovered and predicted for the Rainbow Sub-basin play**

| Pool size class ($10^6 m^3$) | Pools discovered up to 1989 | Pools discovered between 1990 and 1994 | Pools yet to be discovered |
|---|---|---|---|
| < 0.1 | 35 | 3 | 116 |
| 0.1 - 1 | 79 | 8 | 42 |
| 1 - 10 | 32 | 0 | 1 |
| 10 - 100 | 4 | 0 | 0 |
| Total number of pools | 150 | 11 | 159 |
| In-place volume | $231.053 \times 10^6 m^3$ | $1.919 \times 10^6 m^3$ | $4 - 134 \times 10^6 m^3$ |

## Table 5

**The five largest pools of Table 4 discovered between 1990 and 1994**

| Field, pool | In-place volume ($10^6 m^3$) |
|---|---|
| Rainbow South, Keg River Y | 0.342 |
| Rainbow, Keg River V3V | 0.303 |
| Rainbow, Keg River S3S | 0.235 |
| Rainbow, Keg River R3R | 0.190 |
| Sousa, Keg River T | 0.80 |

## Table 6

**Pools discovered and predicted for the Zama sub-basin play**

| Pool size class ($10^6 m^3$) | Pools discovered up to 1989 | Pools discovered between 1990 and 1994 | Pools yet to be discovered |
|---|---|---|---|
| < 0.1 | 53 | 5 | 81 |
| 0.1 - 1 | 347 | 23 | 132 |
| 1 - 10 | 8 | 0 | 1 |
| Total number of pools | 408 | 28 | 214 |
| In-place volume | $122.182 \times 10^6 m^3$ | $7.967 \times 10^6 m^3$ | $27 - 46 \times 10^6 m^3$ |

**Table 7**

**The five largest pools of Table 6 discovered between 1990 and 1994**

| Field, pool | In-place volume ($10^6m^3$) |
|---|---|
| Virgo, Keg River F5F | 0.723 |
| Zama, Keg River I7I | 0.709 |
| Zama, Keg River M7M | 0.669 |
| Virgo, Keg River D5D | 0.624 |
| Virgo, Keg River B5B | 0.578 |

**Table 8**

**Pools discovered and predicted for the Shekilie sub-basin play**

| Pool size class ($10^6m^3$) | Pools discovered up to 1989 | Pools discovered between 1990 and 1994 | Pools yet to be discovered |
|---|---|---|---|
| < 0.1 | 11 | 1 | 89 |
| 0.1 - 1 | 83 | 6 | 147 |
| 1 - 10 | 1 | 1 | 1 |
| Total number of pools | 95 | 8 | 237 |
| In-place volume | 27.956 x $10^6m^3$ | 4.546 x $10^6m^3$ | 35 - 47 x $10^6m^3$ |

**Table 9**

**The five largest pools of Table 8 discovered between 1990 and 1994**

| Field, pool | In-place volume ($10^6m^3$) |
|---|---|
| Shekilie, Keg River I2I | 1.815 |
| Shekilie, Keg River J2J | 0.690 |
| Shekilie, Keg River M2M | 0.674 |
| Shekilie, Keg River O2O | 0.614 |
| Shekilie, Keg River Q2Q | 0.257 |

**Table 10**

**Pools discovered and predicted for the Zama and Muskeg play**

| Pool size class ($10^6m^3$) | Pools discovered up to 1984 | Pools discovered between 1985 and 1992 | Pools yet to be discovered |
|---|---|---|---|
| < 0.1 | 26 | 8 | 301 |
| 0.1 - 1 | 81 | 8 | 266 |
| 1 - 10 | 8 | 0 | 2 |
| Total number of pools | 115 | 16 | 569 |
| In-place volume | 45.831 x $10^6m^3$ | 2.614 x $10^6m^3$ | 48 - 87 x $10^6m^3$ |

*Exploration history*. The discovery sequence ($\hat{\beta}=1.4$) and the cumulative in-place volume discovered are graphically displayed in Appendix A (Figs. A5.1 and A5.2). The in-place volume has increased from 5.5 to 9.8 x $10^6m^3$ since the GSC's 1987 assessment. New discoveries and the appreciation of existing pools have contributed to the increase. The cumulative in-place graph shows a strong upward increase. The potential and discoveries are summarized in Tables 12 and 13.

**Table 11**

**The five largest pools of Table 10 discovered between 1985 and 1992**

| Field, pool | In-place volume ($10^6m^3$) |
|---|---|
| Zama, Muskeg AAA | 0.556 |
| Zama, Muskeg L | 0.365 |
| Zama, Muskeg GG | 0.365 |
| Zama, Muskeg XX | 0.204 |
| Zama, Muskeg WW | 0.200 |

**Table 12**

**Pools discovered and predicted for the Bistcho play**

| Pool size class ($10^6m^3$) | Pools discovered up to 1984 | Pools discovered between 1985 and 1989 | Pools yet to be discovered |
|---|---|---|---|
| < 0.1 | 4 | 0 | 46 |
| 0.1 - 1 | 13 | 4 | 11 |
| 1 - 10 | 1 | 0 | 1 |
| Total number of pools | 18 | 4 | 58 |
| In-place volume | $9.054 \times 10^6m^3$ | $0.695 \times 10^6m^3$ | $0.2 - 10.5 \times 10^6m^3$ |

**Table 13**

**The four largest pools of Table 12 discovered between 1985 and 1989**

| Field, pool | In-place volume ($10^6m^3$) |
|---|---|
| Zama, Sulphur Point T | 0.261 |
| Rainbow, Sulphur Point R | 0.162 |
| Amber, Sulphur Point D | 0.158 |
| Zama, Sulphur Point U | 0.114 |

*Reservoir parameters.* Reservoirs have pool areas from 9 to 193 ha; net pay from 3 to 26 m; porosity from 3.5 to 12%; water saturation from 9 to 36%; and a recovery factor from 0.03 to 20%. The parameters are also graphically displayed in Appendix A (Figs. A5.3 to A5.8).

*Immature plays*

The plays, Keg River and Slave Point on the shelf, were considered to be conceptual plays in the GSC's 1987 assessment. These patch and pinnacle reefs developed on a carbonate shelf, but outside the Rainbow, Zama, and Shekilie sub-basins.

Slave Point drape traps outside the Rainbow, Zama, and Shekilie sub-basins contain four pools with $0.672 \times 10^6m^3$ of oil in-place.

The Keg River Formation immature play includes patch and pinnacle reefs developed within the carbonate shelf or barrier complex and shelf-edge reefs. This play was considered to be a conceptual play in the GSC's 1987 assessment, but six oil pools with about $1.5 \times 10^6m^3$ of oil in-place have been discovered.

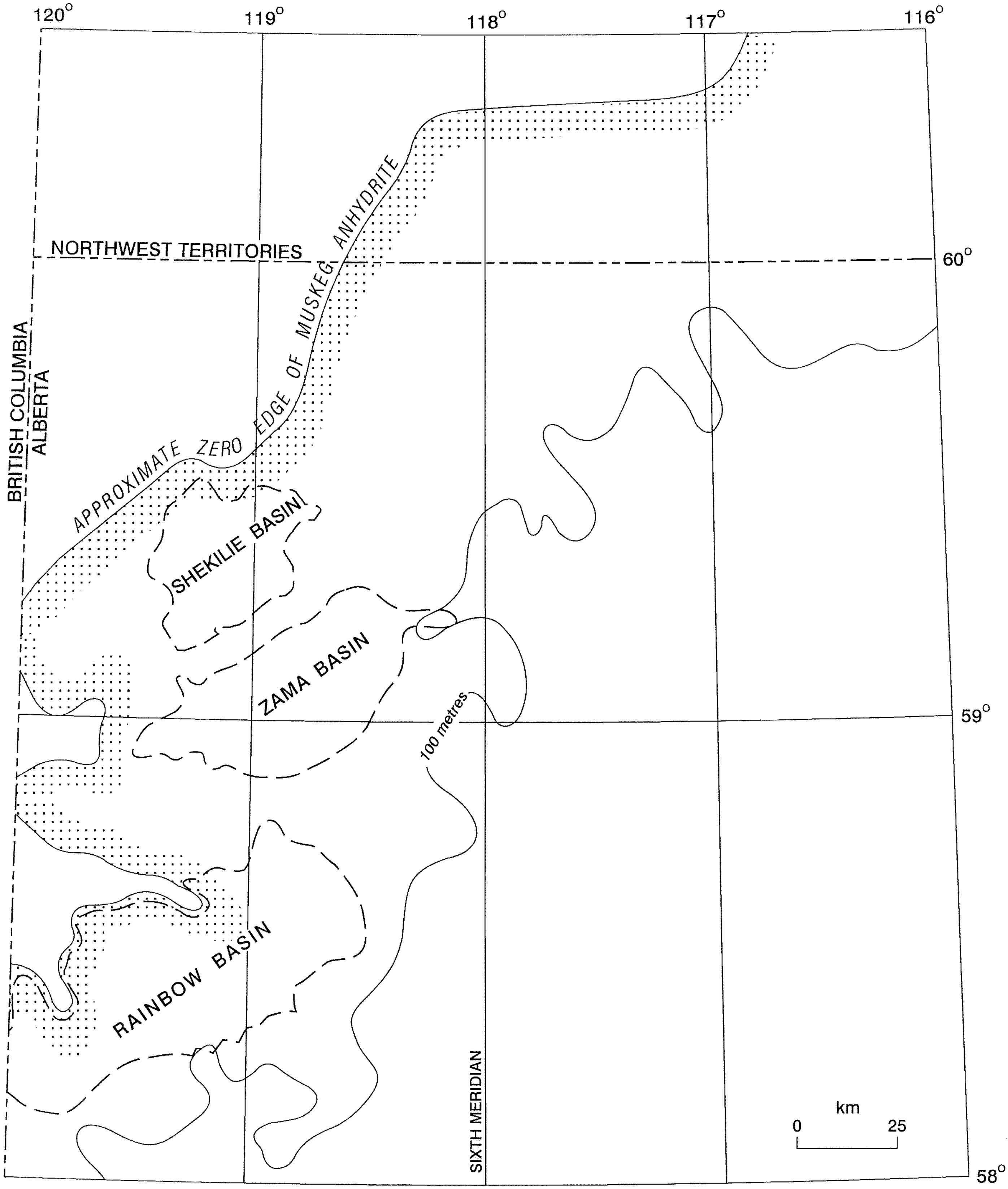


*Figure 16.* *Sulphur Point platform facies (Bistcho) play (with zero and 100 m isopach lines of Muskeg anhydrite).*

### *Peace River Arch region*

Five established plays, Middle Devonian clastics, Slave Point, Keg River–Senex, Leduc–Nisku fringing reef and Wabamun, are located within this region.

#### *Middle Devonian clastics*

*Play definition.* This play includes all oil and gas pools in structural and stratigraphic traps in Middle Devonian sandstone and conglomerate reservoirs that flank the Peace River Arch and feather-out away from it (Figs. 17, 18).

*Geology.* Middle Devonian clastics, particularly the Granite Wash and Gilwood sandstones, are primarily oil-bearing reservoirs. The geology has been described by Shawa (1969), Alcock and Benteau (1976), and Chevron Canada Resources (1990). Regional relations of these Middle Devonian clastics to the Peace River Arch, and the enclosing onlapping carbonate-evaporite strata have been discussed by Jansa and Fischbuch (1974), Rottenfusser and Oliver (1977), Trotter and Hein (1988), and Podruski et al. (1988).

This play includes three distinct clastic wedges (Gilwood, Keg River and Chinchaga sandstones), which pinch out updip into associated shale and evaporitic sequences. The depositional environments of these clastic reservoirs ranged from alluvial and coastal plain to fan delta and shallow marine. The Middle Devonian sequence thins onto the Peace River Arch, and as the cyclical carbonate-evaporite units disappear, the clastic deposits amalgamate and cannot be differentiated from each other; these are collectively referred to as Granite Wash. The Granite Wash overlies the Precambrian and its distribution appears to have been controlled mainly by structural movements of the basement (Fig. 18).

Hydrocarbon traps were formed by updip depositional pinch-out of the sandstone clastic wedges. Basement block-faulting also contributed to the formation of traps by controlling the occurrence of locally thick sandstone deposits and by influencing the overall depositional pattern relative to updip closure. Reservoirs are generally of good to excellent quality as they consist of fine- to coarse-grained conglomeratic, arkosic sandstones.

*Exploration history.* The discovery sequence ($\hat{\beta}=1.0$) and the cumulative in-place discovered volume are graphically displayed in Appendix A (Figs. A6.1 and A6.2). The in-place volume has increased from 318 to 360 x $10^6 m^3$ since the GSC's 1987 assessment. New pools have mainly contributed to this increase. The cumulative in-place volume shows a moderate upward increase. The potential and discoveries are summarized in Tables 14 and 15. Note, the pool size distribution of this play has a long tail toward the large pool sizes because of the presence of two much larger discovered pools: Gilwood and Mitsue. The expected value, taken from the 90th upper percentile is 68 x $10^6 m^3$.

**Table 14**

**Pools discovered and predicted for the Middle Devonian clastics play**

| Pool size class ($10^6 m^3$) | Pools discovered up to 1984 | Pools discovered between 1985 and 1989 | Pools yet to be discovered |
|---|---|---|---|
| < 0.1 | 28 | 29 | 273 |
| 0.1 - 1 | 89 | 96 | 163 |
| 1 - 10 | 13 | 1 | 3 |
| 10 - 100 | 2 | 0 | 0 |
| 100 - 1,000 | 2 | 0 | 0 |
| Total number of pools | 134 | 126 | 440 |
| In-place volume | 332.924 x $10^6 m^3$ | 27.143 x $10^6 m^3$ | 35 - 648 x $10^6 m^3$ |

**Table 15**

**The five largest pools of Table 14 discovered between 1985 and 1989**

| Field, pool | In-place volume ($10^6 m^3$) |
|---|---|
| Loon, Granite Wash E | 1.864 |
| McLeans Creek, Gilwood A | 0.985 |
| High Prairie, Gilwood F | 0.783 |
| Shadow, Gilwood C | 0.756 |
| High Prairie, Gilwood B | 0.603 |

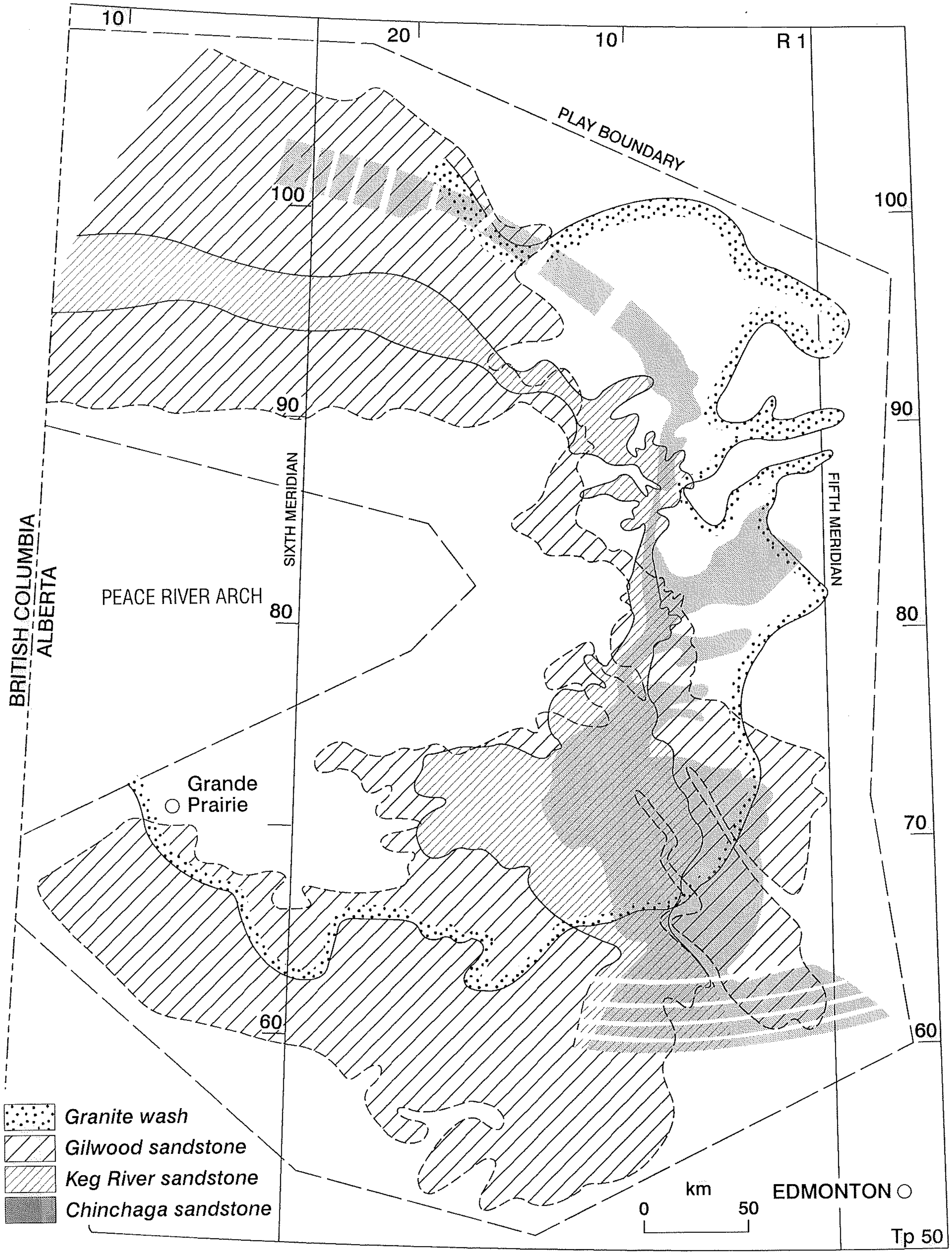


***Figure 17.*** *Middle Devonian clastics play map. Depositional limits of the Gilwood, Keg River and Chinchaga formations, and Granite Wash sandstones are shown (after Reinson et al, 1993).*

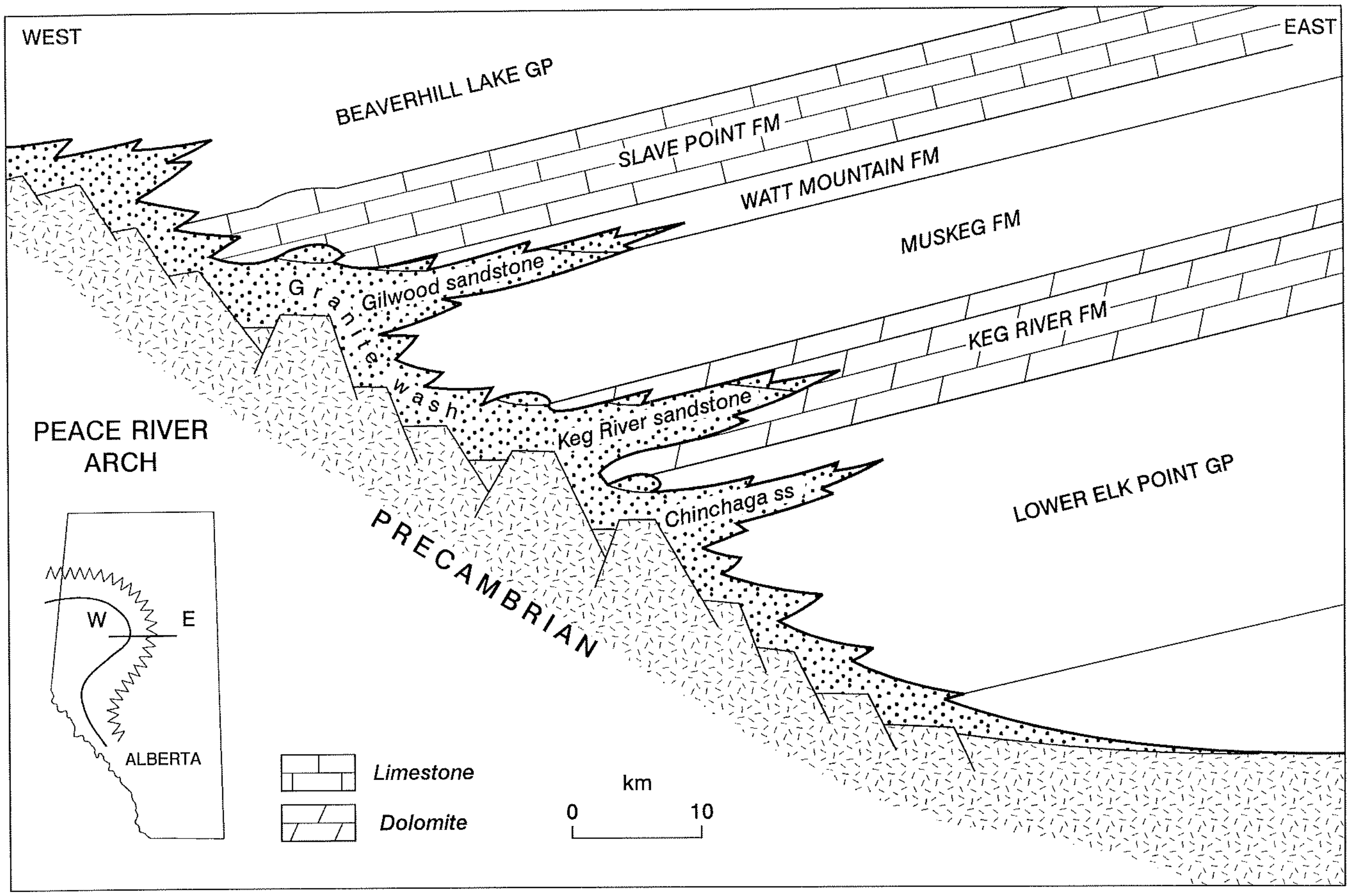


***Figure 18.*** *Schematic cross section of Middle Devonian clastic units illustrating their relationship to the Peace River Arch (from Barclay et al., 1985).*

*Reservoir parameters.* Reservoirs have pool areas from 63 to 490 ha; net pay from 1.2 to 5.8 m; porosity from 9.5 to 21%; water saturation from 20 to 50%; and a recovery factor from 0.3 to 30%. Permeabilities may be up to 4000 md (Alcock and Benteau, 1976; Rottenfusser and Oliver, 1977). The reservoir parameters are graphically displayed in Appendix A (Figs. A6.3 to A6.8).

*Slave Point*

*Play definition.* This play is defined to include all oil and gas pools in the Slave Point reef complexes that occur in an arcuate trend around the north and east flanks of the Peace River Arch, and as isolated buildups within the widespread carbonate platform that extends northward into the southern Northwest Territories (Fig. 19).

*Geology.* The Beaverhill Lake Group in the Peace River Arch area includes, in ascending stratigraphic order, the Fort Vermilion, Slave Point, and Waterways formations (Leavitt and Fischbuch, 1968). The Beaverhill Lake Group records an overall transgressive depositional cycle comprising shallow-water evaporite and carbonate of the Fort Vermilion and Slave Point formations and basin-filling shale and limestone of the overlying Waterways Formation.

The Fort Vermilion Formation consists of interbedded anhydrite, dolostone, limestone and shale representative of peritidal and shallow, restricted shelf environments. Anhydrite and evaporitic carbonate characterize the Fort Vermilion east of the sixth meridian, but westward, platform carbonates are more prevalent and not easily distinguishable from carbonates of the overlying Slave Point. In the oil-bearing areas east of the Peace River Arch (Red Earth, Loon, Otter), the Fort Vermilion is dominated by anhydrite and evaporitic dolostone, in contrast to the peritidal shelf carbonate of the overlying lower Slave Point Formation.

The Slave Point is a widespread, shallow-marine carbonate formation that extends from the central Alberta Basin southeast of the Peace River Arch northward to its type area near Great Slave Lake in the Northwest Territories. The Slave Point Formation is thickest near 60º latitude in northeast British Columbia and northwest Alberta, and thins progressively southward to a zero edge where it onlaps the

Peace River Arch. Reef facies are developed at several stratigraphic levels around the margins of the Peace River Arch, reflecting a step-like sea-level rise and transgressive onlap of the Arch. Slave Point buildups occur in arcuate patterns around the flanks of the Arch (Podruski et al., 1988), and individual discontinuous reef complexes form isolated hydrocarbon reservoirs (Dunham et al., 1983; Craig, 1987; Tooth and Davies, 1988).

Several of the better producing oil pools, such as Evi, Golden, Slave and Seal, occur within the dolomite halo that surrounds the Peace River Arch. One of the major gas pools, Hamburg, is also, in part, a dolomitized reef complex. However, this play is facies controlled, according to whether dolomitization has occurred. Hydrocarbons are produced from skeletal stromatoporoid and interparticle matrix porosity of reef and backreef limestones in the Cranberry and Chinchaga gas pools, and in the Red Earth, Swan and Loon oil pools. The lateral and upper seal rocks for these Slave Point reservoirs are Waterways shaly limestone and calcareous shale.

*Exploration history.* The discovery sequence ($\hat{\beta}=0.8$) and the cumulative in-place volume discovered are graphically displayed in Appendix A (Figs. A7.1 and A7.2). The in-place volume has increased from 63 to 111 x $10^6 m^3$ since the GSC's 1987 assessment. New discoveries and the appreciation of existing pools have contributed to the increase. The largest two pools predicted by the GSC's assessment have been discovered. The cumulative in-place volume graph increases moderately upward. The potential and discoveries are summarized in Tables 16 and 17.

*Reservoir parameters.* Reservoirs have pool areas from 17 to 1,225 ha; net pay from 2 to 14 m; porosity from 5 to 11%; water saturation from 16 to 49%; and a recovery factor from 0.06 to 30%. The parameters are also graphically displayed in Appendix A (Figs. A7.3 to A7.8).

*Keg River–Senex*

*Play definition.* This play is defined to include all oil and gas pools in Keg River patch reefs on local and regional structural culminations in an arcuate trend on the east flank of the Peace River Arch (Fig. 20).

*Geology.* Pools are trapped in excellent reservoir rocks contained in reefal depositional facies with tectonic-diagenetic enhancement of porosity and permeability. The reefs are commonly developed over eroded PreCambrian basement highs.

*Exploration history.* The discovery sequence ($\hat{\beta}=1.0$) and the cumulative in-place volume discovered are graphically displayed in Appendix A (Figs. A8.1 and A8.2). The in-place volume has increased from 10 to 56 x $10^6 m^3$ since the GSC's 1987 assessment. New discoveries and the appreciation of existing pools have contributed to the increase. The largest pools predicted by the GSC's 1987 assessment have been discovered.

**Table 16**

**Pools discovered and predicted for the Slave Point play**

| Pool size class ($10^6 m^3$) | Pools discovered up to 1989 | Pools discovered between 1990 and 1994 | Pools yet to be discovered |
|---|---|---|---|
| < 0.1 | 30 | 2 | 199 |
| 0.1 - 1 | 78 | 8 | 152 |
| 1 - 10 | 19 | 0 | 2 |
| 10 - 100 | 2 | 0 | 0 |
| Total number of pools | 129 | 10 | 361 |
| In-place volume | 108.408 x $10^6 m^3$ | 2.548 x $10^6 m^3$ | 12 - 99 x $10^6 m^3$ |

**Table 17**

**The five largest pools of Table 16 discovered between 1990 and 1994**

| Field, pool | In-place volume ($10^6 m^3$) |
|---|---|
| Seal, Slave Point G | 0.520 |
| Otter, Slave Point B | 0.457 |
| Dawson, Slave Point P | 0.409 |
| Otter, Slave Point C | 0.257 |
| Evi, Slave Point W | 0.219 |

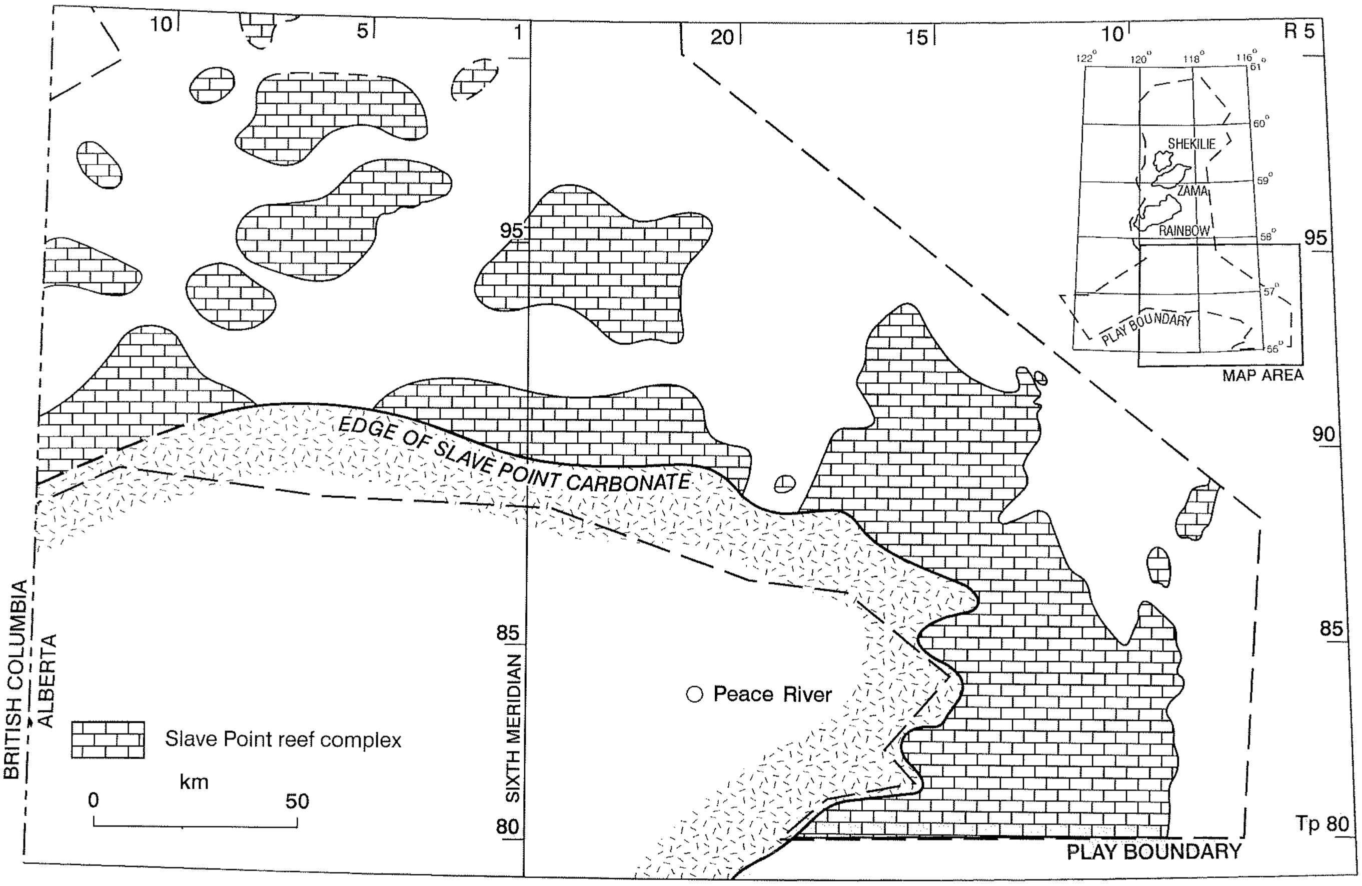


***Figure 19.*** *Slave Point reef complexes, Peace River Arch region.*

The cumulative in-place graph shows a moderate upward increase. The potential and discoveries are summarized in Tables 18 and 19.

*Reservoir parameters.* Reservoirs have pool areas from 32 to 500 ha; net pay from 2 to 15 m; porosity from 4 to 10%; water saturation from 22 to 45%; and a recovery factor of 0.2 to 34%. The parameters are also graphically displayed in Appendix A (Figs. A8.3 to A8.8).

**Table 18**

**Pools discovered and predicted for the Keg River–Senex play**

| Pool size class ($10^6 m^3$) | Pools discovered up to 1987 | Pools discovered between 1988 and 1994 | Pools yet to be discovered |
|---|---|---|---|
| < 0.1 | 20 | 0 | 105 |
| 0.1 - 1 | 74 | 8 | 65 |
| 1 - 10 | 14 | 14 | 0 |
| Total number of pools | 108 | 22 | 170 |
| In-place volume | 52.847 x $10^6 m^3$ | 3.204 x $10^6 m^3$ | 4 - 31 x $10^6 m^3$ |

**Table 19**

**The five largest pools of Table 18 discovered between 1988 and 1994**

| Field, pool | In-place volume ($10^6 m^3$) |
|---|---|
| Kidney, Keg River SS | 0.428 |
| Kidney, Keg River TT | 0.352 |
| Kidney, Keg River WW | 0.278 |
| Panny, Keg River AA | 0.235 |
| Kidney, Keg River MM | 0.193 |

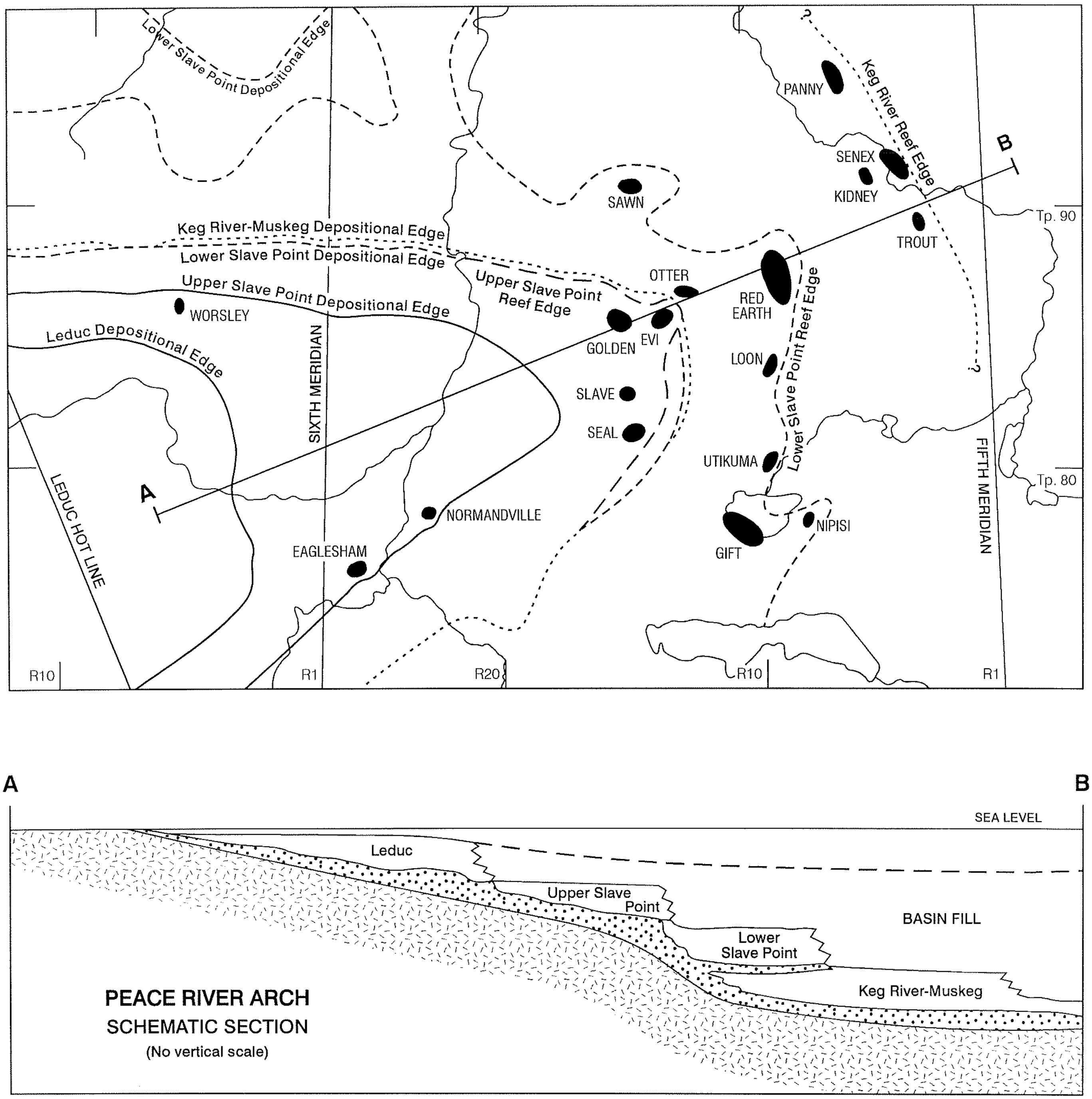


***Figure 20.*** *Devonian transgressive phase reef plays, Peace River Arch region. Areas for Keg River, Slave Point, and Leduc plays lie between the outer edge of patch or barrier reef development and the inner depositional limit.*

*Leduc–Nisku fringing reef*

*Play definition.* This play includes all oil and gas pools occurring in upthrown fault blocks of the Leduc fringing and Nisku reef complex that rims the Peace River Arch (Fig. 21).

*Geology.* The Leduc reef chain forms the shelf margin of a carbonate-siliciclastic platform complex. The complex is a wedge-shaped body up to 250 m thick that thickens basinward from the Peace River Arch landmass to the shelf margin (Belyea, 1964; Bassett and Stout, 1967).

The marginal reef chain is relatively narrow, ranging from 2 to 6 km wide, and separates basin-fill mudstone facies from landward, shelf-interior facies consisting of sandstone and dolomitic mudstone. Three main carbonate sequences are defined for the Leduc complex: the lowest sequence represents carbonate ramp development, the middle sequence is a locally rimmed shelf, and the uppermost sequence is a muddy carbonate ramp that grades into the overlying Winterburn Group (Dix, 1990).

Granite Wash arkosic, conglomeratic sandstone blankets the Peace River Arch landmass and forms the innermost part of the shelf complex (Fig. 21). This sandstone underlies and interfingers with shelf-interior carbonate and fringing reef carbonate. The shelf-interior carbonate consists of nodular, brecciated, dolomitic mudstone and dolomitic floatstone containing fragments of corals, crinoids, brachiopods, tabular stromatoporoids, and dendroid stromatoporoids. Fine-crystalline dolostone with vugs and fenestral fabric occurs as a minor rock type in the shelf-interior facies.

The shelf margin facies that forms the reservoir is composed of dolomitic floatstone, which consists of 10 to 30% coral fragments and a minor amount of tabular and dendroid stromatoporoid fragments in a matrix of dolomitic mudstone. Dissolution of the large fossil fragments coupled with pervasive matrix dolomitization appears to have controlled development of vuggy and biomoldic porosity in this facies.

The Leduc–Nisku fringing reef complex is dissected by numerous fault blocks produced by pre-, syn- and post-reef movements on basement-rooted normal faults. The faults have acted to displace reef blocks upward and laterally against the shaly carbonate seal rocks of the Winterburn Group and Nisku Formation.

*Exploration history.* The discovery sequence ($\hat{\beta}$=2.2) and the cumulative in-place volume discovered are graphically displayed in Appendix A (Figs. A9.1 and A9.2). The in-place volume has increased from 1.9 to 4 x $10^6 m^3$ since the GSC's 1987 assessment. The increase is mainly a result of the new discoveries. The cumulative in-place graph shows a strong upward increase. The potential and discoveries are summarized in Tables 20 and 21.

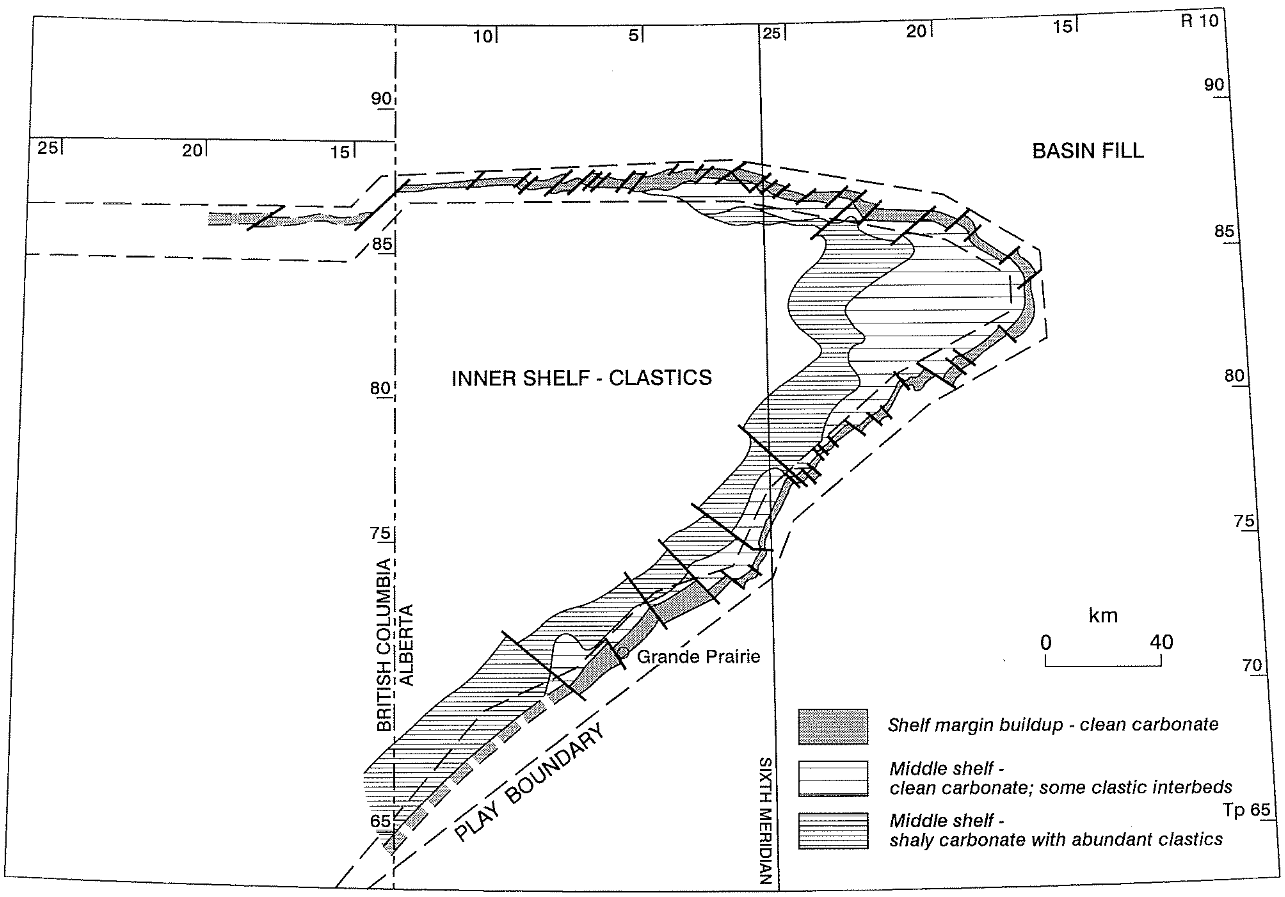


***Figure 21.*** *Facies distribution of the Leduc fringing reef complex that rims the Peace River Arch.*

**Table 20**

**Pools discovered and predicted for the Leduc–Nisku fringing reef play**

| Pool size class ($10^6m^3$) | Pools discovered up to 1989 | Pools discovered between 1990 and 1994 | Pools yet to be discovered |
|---|---|---|---|
| < 0.1 | 0 | 0 | 4 |
| > 0.1 | 10 | 1 | 15 |
| Total number of pools | 10 | 1 | 19 |
| In-place volume | $3.665 \times 10^6m^3$ | $0.241 \times 10^6m^3$ | $0.6 - 4 \times 10^6m^3$ |

**Table 21**

**The largest pool of Table 20 discovered between 1990 and 1994**

| Field, pool | In-place volume ($10^6m^3$) |
|---|---|
| Normandville, D-3 C | 0.241 |

*Reservoir parameters.* Reservoirs have pool areas from 10 to 450 ha (min-max); net pay from 1 to 21 m (min-max); porosity from 1 to 15% (min-max); water saturation from 10 to 56% (min-max); and a recovery factor of 0.1 to 48% (min-max). The parameters are also graphically displayed in Appendix A (Figs. A9.3 to A9.8).

*Wabamun*

*Play definition.* This play includes diagenetic-structural traps in the upper Wabamun Group and stratigraphic-structural traps in the middle Wabamun Group of northwest Alberta and northeast British Columbia (Fig. 22).

*Geology.* The Wabamun Group consists of a sequence of shallow-water carbonates that were deposited in two major depositional settings: a broad carbonate ramp that extends across most of Alberta and into northeast British Columbia; and a restricted shallow-water carbonate platform that fringed the Peace River Arch (Packard et al., 1990; Stoakes and Foellmer, 1987). The Wabamun Group grades laterally west-northwest into basinal shales of the Kotcho Formation and limestone-shale of the Tetcho Formation.

The Wabamun Group in the Peace River Arch area ranges up to 250 m in thickness. The lower and middle portions consist of a series of progradational platform carbonates that fringe the Arch. Small stromatoporoid patch reefs occur within the middle Wabamun Group (i.e., the Normandville area). The upper Wabamun Group consists of deep-water crinoidal wackestone and mudstone deposited in a distal ramp setting. The upper Wabamun is a transgressive sequence overlain by the basinal anoxic shale of the Exshaw Formation (Stoakes, 1987; Stoakes and Foellmer, 1987; Halbertsma and Meijer Drees, 1987).

There are two distinct reservoir types in the Wabamun of the Peace River Arch area. The first consists of partly dolomitized grainstone zones and stromatoporoid patch reefs in the middle Wabamun (i.e., Normandville). Dolomitization appears to have been an early diagenetic process but is not extensive (Halbertsma and Meijer Drees, 1987). The second reservoir type occurs in dolomitized distal ramp deposits of the upper Wabamun Group, such as at Tangent and Eaglesham North. These dolomitized zones occur in irregular, laterally discontinuous, vertically oriented pods (Packard et al., 1990). This type of dolomitization is commonly associated with fault-generated breccia units that filled cavities created by hydrothermal fluid dissolution along fault zones. The breccia units range from 2 to 50 m in thickness and are present at various levels within the Upper Wabamun and overlying Exshaw Formation.

*Exploration history.* The discovery sequence ($\hat{\beta}=1.2$) and the cumulative in-place volume discovered are graphically displayed in Appendix A (Figs. A10.1 and A10.2). The in-place volume has increased from 16 to 35 x $10^6m^3$ since the GSC's 1987 assessment. New discoveries have contributed mainly to the increase. The cumulative in-place graph shows a very strong upward increase. The potential and discoveries are summarized in Tables 22 and 23.

*Reservoir parameters.* Reservoirs have pool areas from 16 to 63 ha; net pay from 6 to 90 m; porosity from 1.3 to 8%; water saturation from 15 to 40%; and a recovery factor of 0.3 to 35%. The parameters are also graphically displayed in Appendix A (Figs. A10.3 to A10.8).

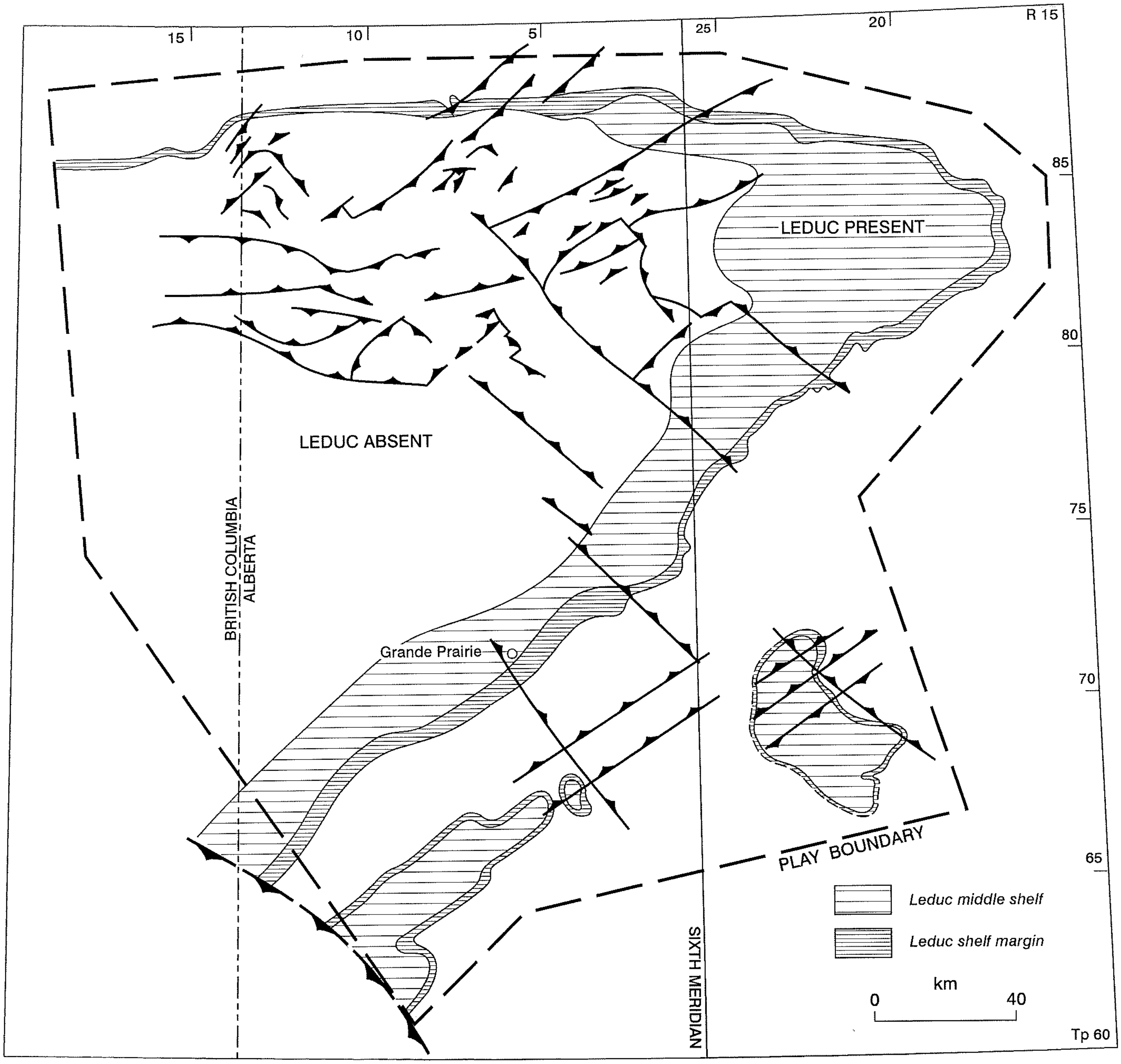


***Figure 22.*** *Wabamun structural and stratigraphic play. Distribution of faults derived from Richards et al. (1984).*

**Table 22**

**Pools discovered and predicted for the Wabamun–Peace River Arch play**

| Pool size class ($10^6m^3$) | Pools discovered up to 1989 | Pools discovered between 1990 and 1994 | Pools yet to be discovered |
|---|---|---|---|
| < 0.1 | 20 | 15 | 116 |
| 0.1 - 1 | 80 | 36 | 49 |
| 1 - 10 | 1 | 0 | 1 |
| Total number of pools | 103 | 51 | 166 |
| In-place volume | 27.456 x $10^6m^3$ | 7.628 x $10^6m^3$ | 9 - 19 x $10^6m^3$ |

**Table 23**

**The five largest pools of Table 22 discovered between 1990 and 1994**

| Field, pool | In-place volume ($10^6m^3$) |
|---|---|
| Culp, Wabamun I | 0.431 |
| Belloy, D-1 T | 0.392 |
| Normandville, D-1 G | 0.336 |
| Culp, Wabamun F | 0.330 |
| Tangent, D-1 XX | 0.275 |

### *Central Alberta region*

Seven established mature plays: Beaverhill Lake, Leduc — "Deep Basin", Leduc — isolated reef, Leduc — Bashaw, Nisku — West Pembina, Nisku shelf and Wabamun eroded edge, are located within this region.

#### *Beaverhill Lake*

*Play definition.* This play is defined to include all oil pools in Beaverhill Lake age reefs and reef complexes that grew on the Slave Point platform in west central Alberta. The play area is bounded to the southwest by the Beaverhill Lake "hot line", to the north by the southern limit of the Peace River Arch, and to the east and south by the edge of the Slave Point platform (Fig. 23).

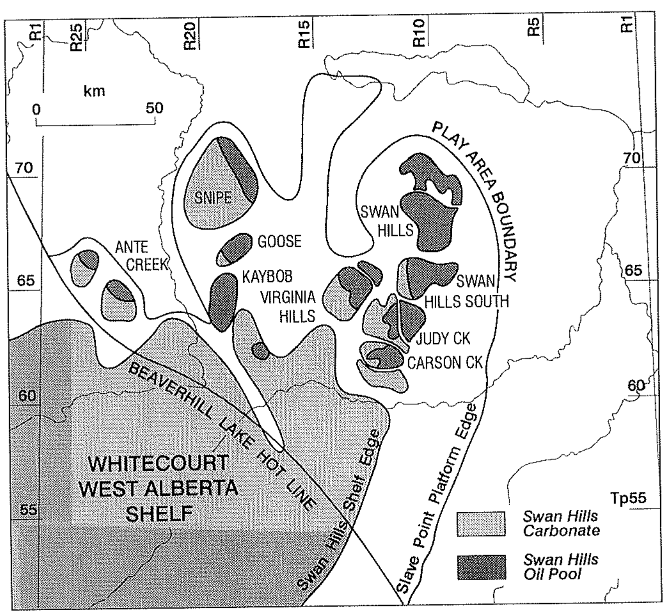


***Figure 23.*** *Beaverhill Lake play map.*

*Geology.* The reefs are limestone, with complicated internal stratigraphy and facies distribution (Fischbuch, 1968; Viau, 1983). The reef reservoirs are encased in Waterways carbonate and shales, which were deposited as regressive phase basin-fill sediment (Sheasby, 1971).

*Exploration history.* The discovery sequence ($\hat{\beta}=0.6$) and the cumulative in-place volume discovered are graphically displayed in Appendix A (Figs. A11.1 and A11.2). The in-place volume has increased from 967 to 995 x $10^6m^3$ since the GSC's 1987 assessment. The Swan Hills Beaverhill A & B was depreciated from 303 x $10^6m^3$ at the time of the GSC's 1987 assessment to 290 x $10^6m^3$ at the present time, but the net increase is due to new discoveries and appreciation of existing pools. The cumulative in-place graph shows a slight upward increase. The potential and discoveries are summarized in Tables 24 and 25.

*Reservoir parameters.* Reservoirs have pool areas from 64 to 16,000 ha; net pay from 1.5 to 19 m; porosity from 3.5 to 11%; water saturation from 0.9 to 40%; and a recovery factor of 0.2 to 46%. The parameters are also graphically displayed in Appendix A (Figs. A11.3 to A11.8).

#### *Leduc — "Deep Basin"*

*Play definition.* This play is defined to include all oil pools in Leduc age reef complexes that grew on Swan Hills platforms in west-central Alberta. The play area is defined by the Rimbey–Meadowbrook Cooking Lake platform edge to the southeast, the Grosmont Shelf edge to the northeast, the southern limit of the Peace River Arch to the north, and the Leduc hot line to the southwest (Fig. 24).

*Geology.* Reef reservoirs are intensively altered to dolomite with vuggy, intercrystalline, and fracture porosity. Vugs were formed by solution of reef-building fossil remains, and are partially filled with secondary anhydrite, dolomite, calcite, sulphur, and pyrobitumen.

*Exploration history.* The discovery sequence ($\hat{\beta}=1.2$) and the cumulative in-place volume discovered are graphically displayed in Appendix A (Figs. A12.1 and A12.2). The in-place volume has increased from 90 to 104 x $10^6m^3$ since the

### Table 24

**Pools discovered and predicted for the Beaverhill Lake play**

| Pool size class ($10^6m^3$) | Pools discovered up to 1989 | Pools discovered between 1990 and 1994 | Pools yet to be discovered |
|---|---|---|---|
| < 0.1 | 5 | 1 | 18 |
| 0.1 - 1 | 18 | 1 | 14 |
| 1 - 10 | 6 | 1 | 0 |
| 10 - 100 | 7 | 0 | 0 |
| 100 - 1000 | 4 | 0 | 0 |
| Total number of pools | 40 | 3 | 32 |
| In-place volume | 990.509 x $10^6m^3$ | 3.994 x $10^6m^3$ | 12 - 613 x $10^6m^3$ |

GSC's 1987 assessment. The increase is due mainly to the new discoveries. The cumulative in-place graph shows a slight upward increase. The potential and discoveries are summarized in Tables 26 and 27.

*Reservoir parameters.* Reservoirs have pool areas from 17 to 5,875 ha; net pay from 2.5 to 29 m; porosity from 5 to 10%; water saturation from 11 to 17%; and a recovery factor of 0.9 to 54%. The parameters are also graphically displayed in Appendix A (Figs. A12.3 to A12.8).

### Table 25

**The three largest pools of Table 24 discovered between 1990 and 1994**

| Field, pool | In-place volume ($10^6m^3$) |
|---|---|
| Simonette, Beaverhill Lake A | 3.721 |
| Sturgeon Lake South, Beaverhill Lake A | 0.208 |
| Girouxville East, Beaverhill Lake A | 0.065 |

### Table 26

**Pools discovered and predicted for the Leduc — "Deep Basin" play**

| Pool size class ($10^6m^3$) | Pools discovered up to 1989 | Pools discovered between 1990 and 1994 | Pools yet to be discovered |
|---|---|---|---|
| < 0.1 | 3 | 1 | 138 |
| 0.1 - 1 | 12 | 2 | 85 |
| 1 - 10 | 3 | 0 | 2 |
| 10 - 100 | 4 | 0 | 0 |
| Total number of pools | 22 | 3 | 225 |
| In-place volume | 102.405 x $10^6m^3$ | 1.212 x $10^6m^3$ | 5 - 160 x $10^6m^3$ |

### Table 27

**The three largest pools of Table 26 discovered between 1990 and 1994**

| Field, pool | In-place volume ($10^6m^3$) |
|---|---|
| Simonette, D-3 D | 0.890 |
| Simonette, D-3 E | 0.262 |
| Windfall, D-3 H | 0.060 |

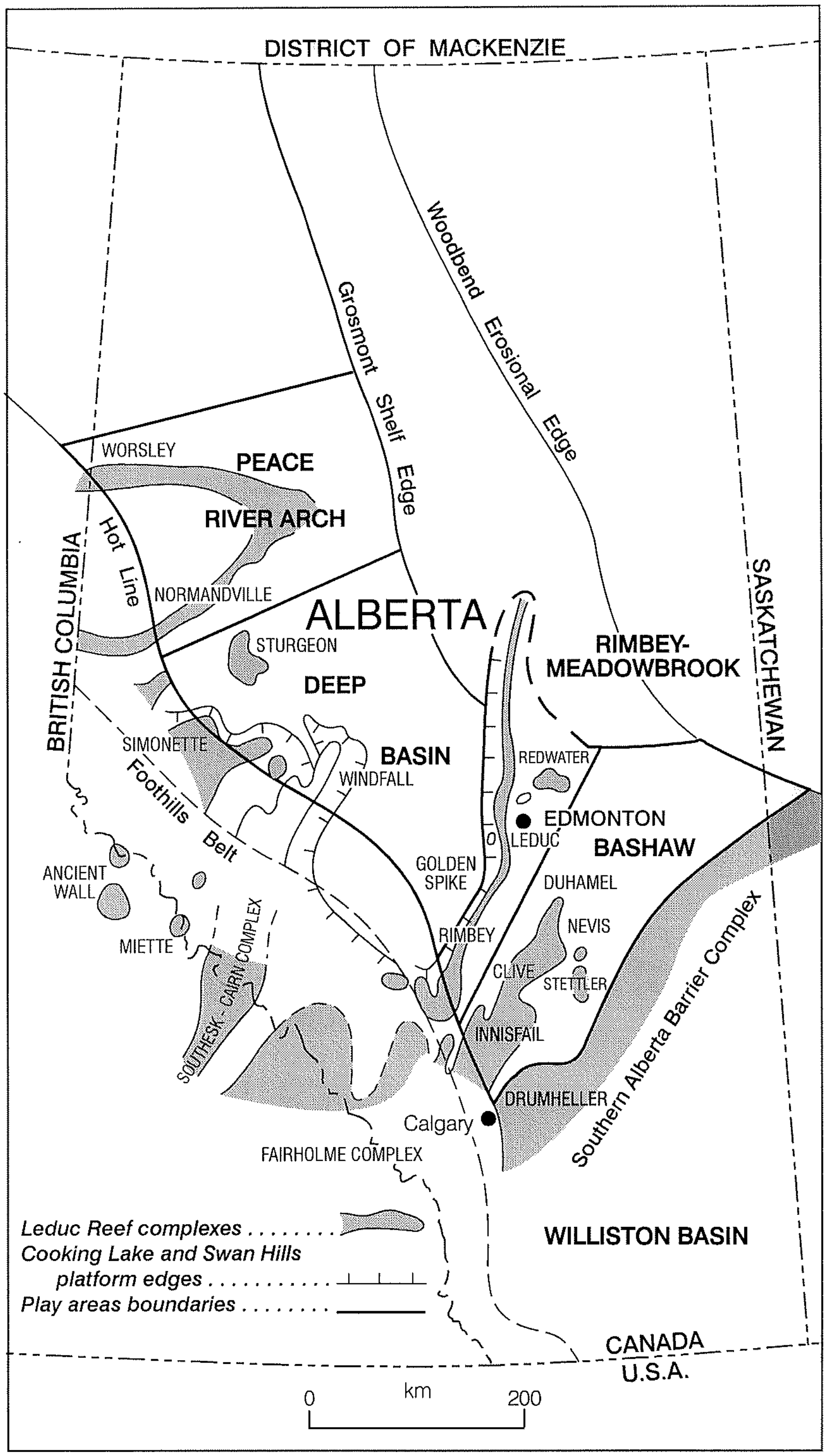


***Figure 24.*** *Leduc play areas (after Podruski et al, 1988).*

*Leduc — isolated reef*

*Play definition.* This play includes all oil and gas pools involving reservoirs in Leduc reef complexes that developed near or on the western margin of the Cooking Lake platform. Reef bodies ranging from large complexes to small patch reefs form a linear north-northeast trend (Ricinus–Meadowbrook) that extends across central Alberta (Fig. 25).

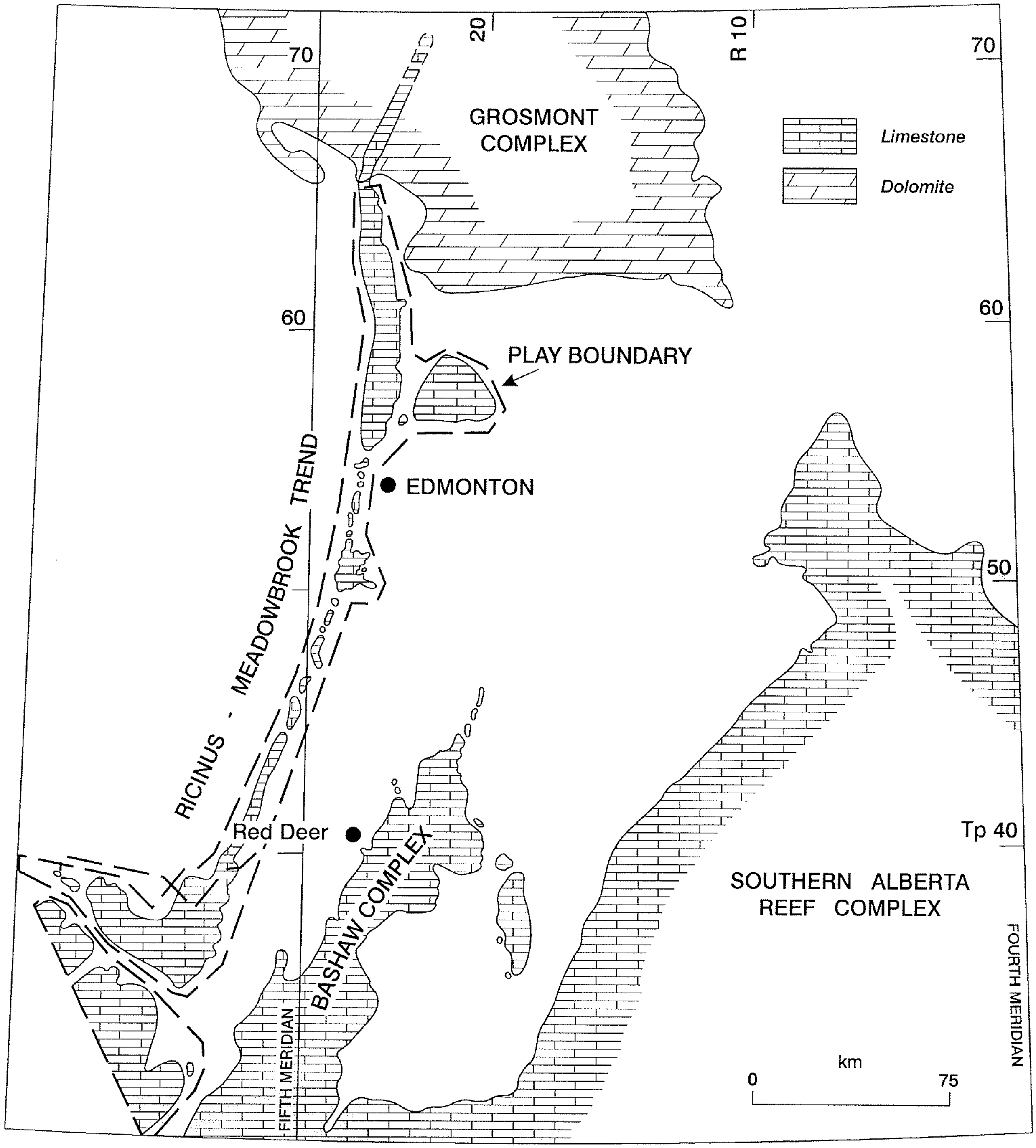


***Figure 25.*** *Leduc — isolated reef play.*

*Geology.* This play is bounded on the southwest by the eastern margin of the disturbed belt and on the north by the overlying Grosmont Formation. The Leduc Formation is a thick, commonly dolomitized reefal development in the Upper Devonian Woodbend Group. In addition to the Leduc Formation, the Woodbend Group includes the Ireton, Duvernay, Cooking Lake and Grosmont formations. Leduc carbonates developed as fringing reef complexes, linear chains of reefs, and isolated atolls and pinnacles. In the subsurface of central Alberta these buildups overlie the regional platform facies of the Cooking Lake Formation. The Cooking Lake Formation generally consists of shallow-marine limestone. However, in the vicinity of the western margin of the Cooking Lake, partial to complete dolomitization is encountered. Consequently, the Cooking Lake and the overlying Leduc carbonates are in direct communication and form a common aquifer. This interconnected reservoir has acted as a conduit through which hydrocarbons were distributed throughout the Leduc Ricinus–Meadowbrook trend.

In central Alberta, the Leduc Formation is typically encased and sealed by the impermeable shale and argillaceous limestone of the Duvernay and Ireton formations. In contrast, the reefs to the northeast are capped by, and are in hydrodynamic communication with, carbonates of the Grosmont Formation.

The Ricinus–Meadowbrook reef trend separates the eastern and western sectors of the Ireton shale basin. The Ireton Formation was laid down as basin fill during Woodbend deposition, and followed Leduc reef development and subsequent Duvernay shale and bituminous limestone deposition. The Duvernay shales, and to a lesser extent the Ireton Formation, are the primary source rocks for the hydrocarbons present in the Leduc reef complexes.

*Exploration history*. The discovery sequence ($\hat{\beta}$ =0.6) and the cumulative in-place volume discovered are graphically displayed in Appendix A (Figs. A13.1 and A13.2). The in-place volume has increased from 576 to 621 x $10^6 m^3$ since the GSC's 1987 assessment. The increase is a result of appreciation of existing pools, and new discoveries. The cumulative in-place graph shows a gradual upward increase. The potential and discoveries are summarized in Tables 28 and 29.

*Reservoir parameters*. Reservoirs have pool areas from 17 to 5,250 ha; net pay from 2 to 58 m; porosity from 6 to 13%; water saturation from 6 to 30%; and a recovery factor of 0.05 to 75%. The parameters are also graphically displayed in Appendix A (Figs. A13.3 to A13.8).

### *Leduc — Bashaw*

*Play definition*. This play includes all oil and gas pools within the Leduc Formation of the Bashaw reef complex. This complex lies between the Ricinus–Meadowbrook reef trend on the west and the broad Southern Alberta shelf complex to the southeast (Fig. 26).

*Geology*. Porous Leduc reefs up to 275 m thick grew on the Cooking Lake regional platform facies. The Leduc Formation typically is encased and sealed by impermeable shales of the Duvernay and Ireton formations. Stratigraphic and combined structural-stratigraphic traps associated with the Bashaw complex contain both gas and oil. Traps occur at the updip terminations of the large reef complex (Nevis), downdip of re-entrants in the reef complex (Clive), and in minor isolated atolls and pinnacles. In the larger reef bodies, differential compaction between back-reef lagoonal carbonates, off-reef shales, and the more rigid dolomitized periphery of the buildups, commonly gives the larger features a broadly atoll-like shape, resulting in drape of overlying beds. Isolated reef pinnacles and atolls are more oil prone.

*Exploration history*. The discovery sequence ($\hat{\beta}$ =0.7) and the cumulative in-place volume discovered are graphically displayed in Appendix A (Figs. A14.1 and A14.2). The in-place volume has decreased from 97 to 92 x $10^6 m^3$ since the GSC's 1987 assessment, but there are additions contributed by new discoveries. The cumulative in-place graph shows a moderate upward increase. The potential and discoveries are summarized in Tables 30 and 31.

*Reservoir parameters*. Reservoirs have pool areas from 11 to 1,956 ha; net pay from 2.4 to 55 m; porosity from 4 to 13%; water saturation from 10 to 28%; and a recovery factor of 0.14 to 70%. The parameters are also graphically displayed in Appendix A (Figs. A14.3 to A14.8).

### *Nisku — West Pembina*

*Play definition*. This play includes all oil and gas pools in the downslope Zeta Lake Member reefs of the Nisku Formation in west-central Alberta (Fig. 27).

*Geology*. The Nisku Formation of west-central Alberta consists of the Lobstick, Bigoray, Cynthia, Dismal Creek, Wolf Lake and Zeta Lake members. The Lobstick Member is 25 to 50 m thick on the Nisku shelf margin (Anderson and Machel, 1988). The Lobstick Member consists of a shallowing-upward sequence of subtidal ramp carbonates, and is overlain by subtidal ramp deposits of the Bigoray Member.

The Bigoray Member is up to 20 m thick and is divided into two units: a basal unit consisting of siltstones and minor carbonates, and an upper unit comprising silty, bioclastic carbonates. Near the end of Bigoray deposition, there was a change in the profile of the basin from a ramp to a reef-rimmed shelf. This shelf is represented in Figure 27 as the outer shelf of the Nisku Formation.

The Dismal Creek Member represents the shelf interior sediments that were deposited behind the shelf margin (Machel, 1985). The Cynthia Member contains a lower carbonaceous shale unit thought to be basinal, and an upper, fossiliferous, bioturbated carbonate unit thought to represent gradation to a deep ramp environment (Anderson, 1985). Machel (1985) found that both the Dismal Creek and Cynthia members interfingered with shelf margin Zeta Lake reef facies, and interpreted the Dismal Creek as being equivalent to the Cynthia Member. The Dismal Creek and Cynthia members grade upward into tidal flat carbonates of the Wolf Lake Member (12 m thick), which is overlain by the Calmar Formation.

**Table 28**

**Pools discovered and predicted for the Leduc — isolated reef play**

| Pool size class ($10^6m^3$) | Pools discovered up to 1989 | Pools discovered between 1990 and 1994 | Pools yet to be discovered |
|---|---|---|---|
| < 0.1 | 5 | 0 | 11 |
| 0.1 - 1 | 28 | 1 | 21 |
| 1 - 10 | 10 | 0 | 1 |
| 10 - 100 | 6 | 0 | 0 |
| 100 - 1000 | 2 | 0 | 0 |
| Total number of pools | 51 | 1 | 33 |
| In-place volume | 621 x $10^6m^3$ | 0.140 x $10^6m^3$ | 2 - 8 x $10^6m^3$ |

**Table 29**

**The largest pool of Table 28 discovered between 1990 and 1994**

| Field, pool | In-place volume ($10^6m^3$) |
|---|---|
| Leduc-Woodbend, D-3 O | 0.140 |

**Table 30**

**Pools discovered and predicted for the Leduc — Bashaw play**

| Pool size class ($10^6m^3$) | Pools discovered up to 1989 | Pools discovered between 1990 and 1994 | Pools yet to be discovered |
|---|---|---|---|
| < 0.1 | 9 | 1 | 29 |
| 0.1 - 1 | 46 | 4 | 35 |
| 1 - 10 | 12 | 0 | 1 |
| 10 - 100 | 3 | 0 | 0 |
| Total number of pools | 70 | 5 | 65 |
| In-place volume | 91.090 x $10^6m^3$ | 1.067 x $10^6m^3$ | 2 - 65 x $10^6m^3$ |

**Table 31**

**The five largest pools of Table 30 discovered between 1990 and 1994**

| Field, pool | In-place volume ($10^6m^3$) |
|---|---|
| Haynes, D-3 B | 0.389 |
| Chigwell North, D-3 C | 0.377 |
| Chigwell North, D-3 B | 0.130 |
| Wood River, D-3 C | 0.124 |
| Chigwell North, D-3 D | 0.048 |

The isolated reefs of the Zeta Lake Member developed at different levels on the downslope portion of the Lobstick and Bigoray ramps. They form the reservoirs in this play and the Cynthia Member and Calmar Formation act as the lateral and vertical seals. The source for the hydrocarbons in the Nisku isolated reef play is likely the Cynthia Member or the underlying Ireton Formation (Chevron Standard Limited, 1979; Machel, 1985).

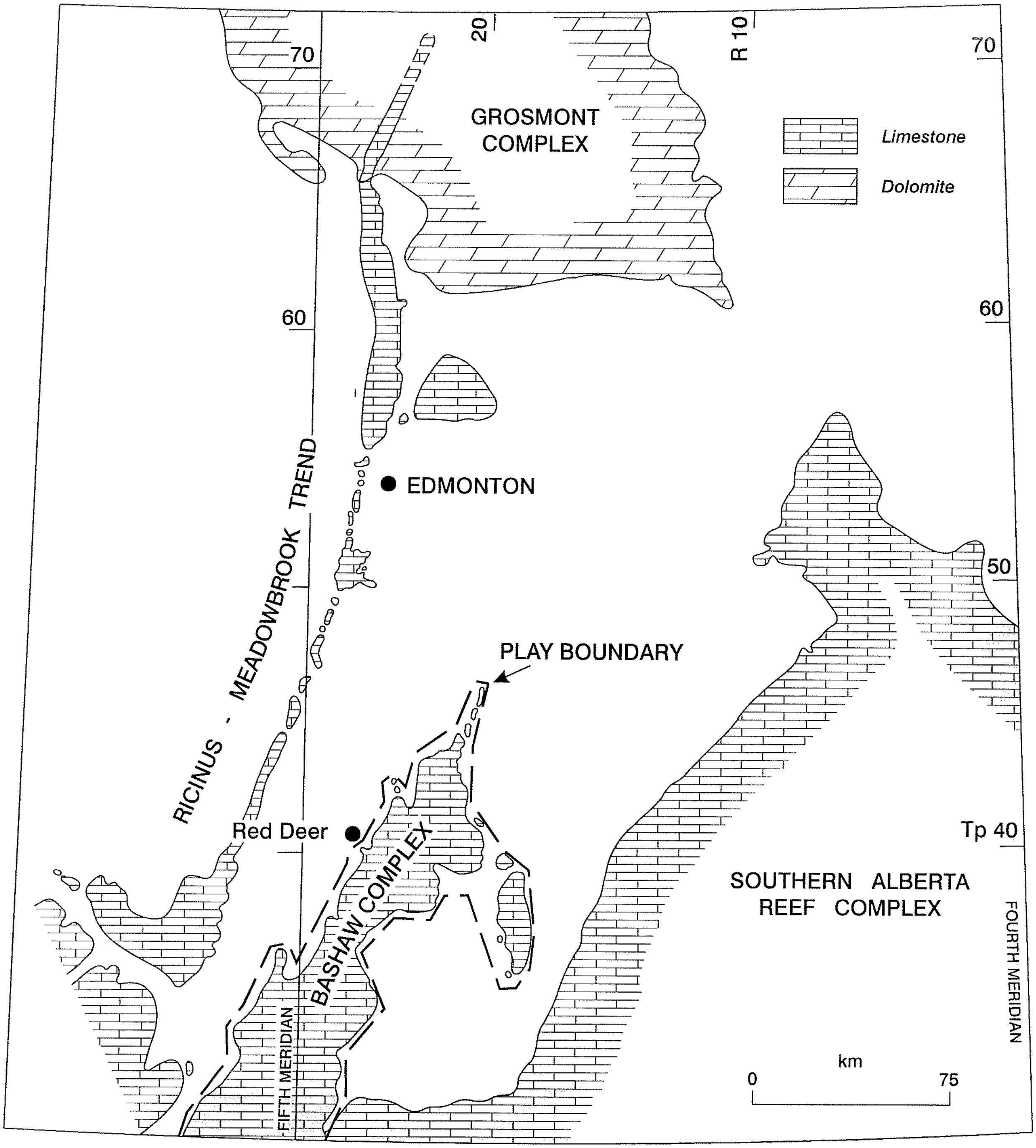


***Figure 26.*** *Leduc — Bashaw reef play.*

There is a marked change in the diagenetic history of the Zeta Lake reefs along the depositional strike. The amount of dolomitization decreases from the southwest, where the reefs have been extensively dolomitized, to the northeast, where the reefs are predominantly limestone. Limestone reefs have porosities ranging from 3 to 5% and permeabilities from 300 to 1000 md. Dolomitized reefs have porosities ranging from 5 to 11% and permeabilities of 1000 md or greater (Anderson and Machel, 1988).

*Exploration history.* The discovery sequence ($\hat{\beta}=0.8$) and the cumulative in-place volume discovered are graphically displayed in Appendix A (Figs. A15.1 and A15.2). The total in-place volume has not changed since GSC's 1987 assessment. However, there are additions contributed by new discoveries. The cumulative in-place graph shows a gradual upward increase in the past few years. The potential and discoveries are summarized in Tables 32 and 33.

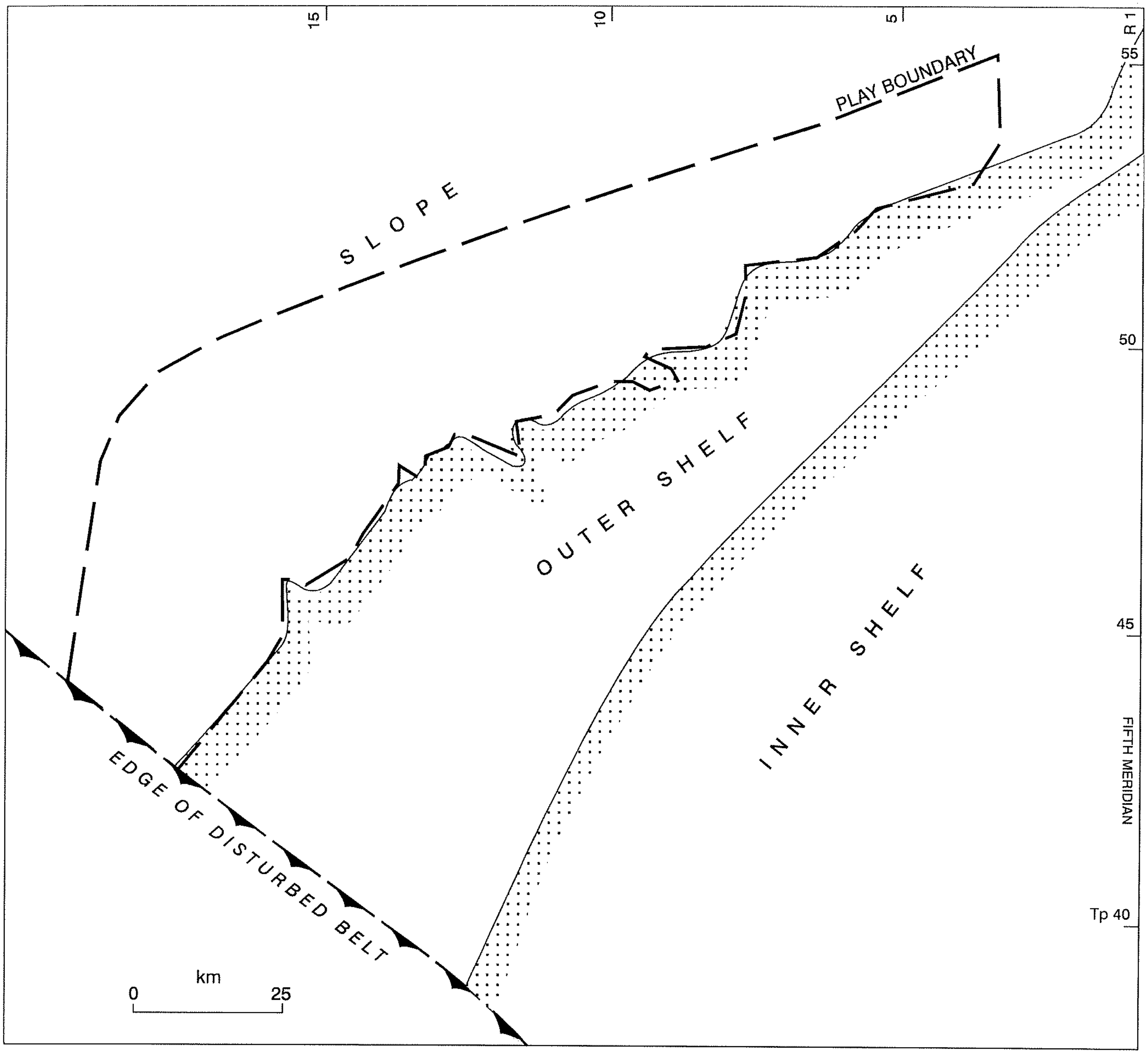


***Figure 27.*** *Nisku–West Pembina play.*

*Reservoir parameters.* Reservoirs have pool areas from 17 to 193 ha; net pay from 2.6 to 73 m; porosity from 5 to 13%; water saturation from 7 to 28%; and a recovery factor from 10 to 80%. The parameters are also graphically displayed in Appendix A (Figs. A15.3 to A15.8).

*Nisku shelf*

*Play definition.* This play includes all oil and gas pools in the porous regressive-phase Nisku shelf carbonate that occur principally in drape structures over Leduc reef complexes (including the Ricinus–Meadowbrook reef trend and the Bashaw reef complex) in west-central Alberta (Fig. 28).

*Geology.* The reservoir rock overlying the Ricinus–Meadowbrook trend consists of fine- to coarse-grained dolostone with intercrystalline and vuggy porosity. Reservoirs draped over the Bashaw reef trend consist of carbonate muds, bioclastic carbonate banks and evaporites.

*Exploration history.* The discovery sequence ($\hat{\beta}=0.8$) and the cumulative in-place volume discovered are graphically displayed in Appendix A (Figs. A16.1 and A16.2).

## Table 32

**Pools discovered and predicted for the Nisku — West Pembina play**

| Pool size class ($10^6m^3$) | Pools discovered up to 1989 | Pools discovered between 1990 and 1994 | Pools yet to be discovered |
|---|---|---|---|
| < 0.1 | 6 | 1 | 19 |
| 0.1 - 1 | 15 | 0 | 7 |
| 1 - 10 | 27 | 0 | 0 |
| Total number of pools | 48 | 1 | 26 |
| In-place volume | 81.410 x $10^6m^3$ | 0.091 x $10^6m^3$ | 1 - 24 x $10^6m^3$ |

## Table 33

**The Nisku pool of Table 32 discovered between 1990 and 1994**

| Field, pool | In-place volume ($10^6m^3$) |
|---|---|
| Pembina, Nisku X | 0.098 |

## Table 34

**Pools discovered and predicted for the Nisku shelf play**

| Pool size class ($10^6m^3$) | Pools discovered up to 1989 | Pools discovered between 1990 and 1994 | Pools yet to be discovered |
|---|---|---|---|
| < 0.1 | 18 | 2 | 166 |
| 0.1 - 1 | 58 | 10 | 109 |
| 1 - 10 | 20 | 1 | 12 |
| 10 - 100 | 4 | 0 | 0 |
| Total number of pools | 100 | 13 | 287 |
| In-place volume | 232.911 x $10^6m^3$ | 7.776 x $10^6m^3$ | 12 - 289 x $10^6m^3$ |

## Table 35

**The five largest pools of Table 34 discovered between 1990 and 1994**

| Field, pool | In-place volume ($10^6m^3$) |
|---|---|
| Bashaw, D-2 G | 3.308 |
| Bashaw, D-2 L | 0.954 |
| Bashaw, D-2 H | 0.850 |
| Bashaw, D-2 I | 0.503 |
| Fenn West, D-2 G | 0.495 |

The in-place volume has increased from 210 to 241 x $10^6m^3$ since the GSC's 1987 assessment. The increase is due to the new discoveries and appreciation of existing pools. The cumulative in-place graph shows a moderate upward increase. The potential and discoveries are summarized in Tables 34 and 35.

*Reservoir parameters.* Reservoirs have pool areas from 17 to 2,888 ha; net pay from 2.6 to 24 m; porosity from 3 to 11%; water saturation from 10 to 40%; and a recovery factor from 0.3 to 60%. The parameters are also graphically displayed in Appendix A (Figs. A16.3 to A16.8).

### *Wabamun eroded edge*

*Play definition.* This play is defined to include all oil and gas pools in traps developed against the unconformity where the Wabamun shelf carbonates subcrop beneath Cretaceous rocks. The play is bounded to the south by the facies change from Wabamun carbonate to Stettler evaporite. The north boundary is set at the southern limit of the Wabamun–Peace River Arch play. The western limit is set approximately at the subcrop edge (Fig. 29).

*Geology.* The trapping mechanism is a combination of Cretaceous shale above the unconformity and structural drape over Leduc reefs. The Wabamun Group in Alberta consists of a sequence of shallow-water carbonates that were deposited on a broad carbonate ramp/platform. Reservoirs commonly are partly dolomitized peloidal grainstones that occur at different levels within the Wabamun platform succession.

*Exploration history.* The discovery sequence ($\hat{\beta}=0.8$) and the cumulative in-place volume discovered are graphically displayed in Appendix A (Figs. A17.1 and A17.2). The in-place volume has increased from 5 to 7.154 x $10^6 m^3$ since the GSC's 1987 assessment. The increase is a result of new discoveries and appreciation (minus depreciation) of existing pools. The cumulative in-place graph shows a moderate upward increase. The potential and discoveries are summarized in Tables 36 and 37.

*Reservoir parameters.* Reservoirs have pool areas from 17 to 259 ha; net pay from 1 to 29 m; porosity from 3 to 20%; water saturation from 19 to 53%; and a recovery factor from 0.1 to 20%. The parameters are also graphically displayed in Appendix A (Figs. A17.3 to A17.8).

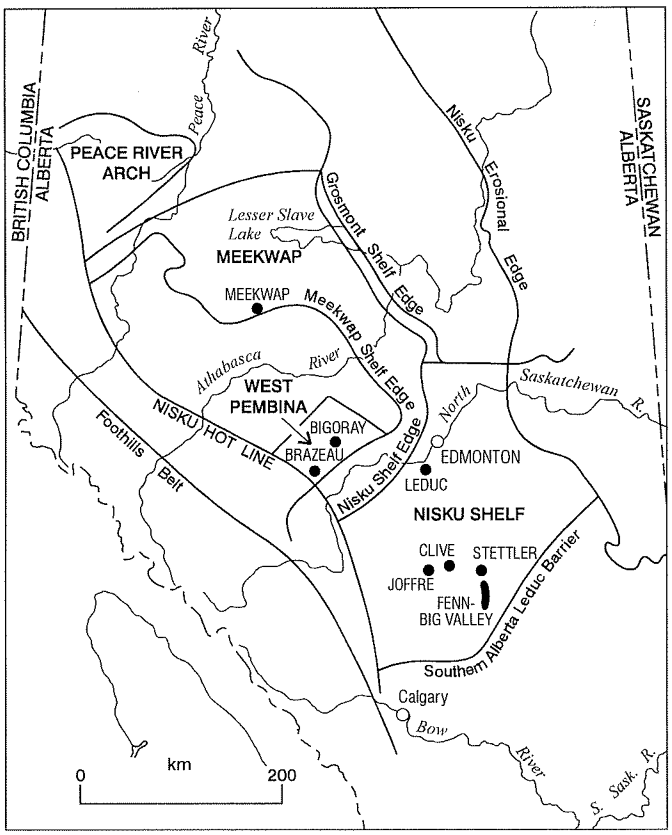


**Figure 28.** *Nisku play areas, central Alberta.*

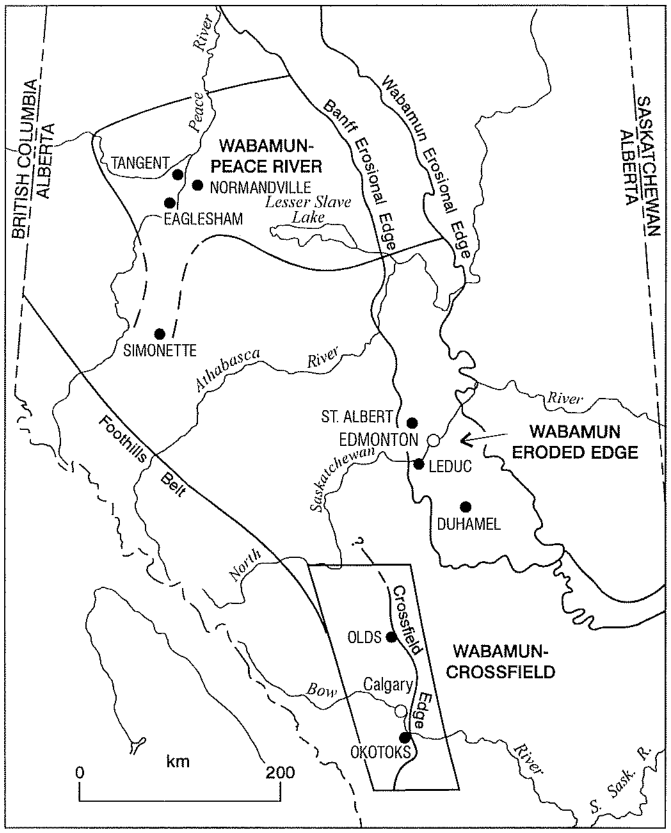


**Figure 29.** *Wabamun play areas.*

## *Immature plays*

*Blue Ridge play.* This play is defined to include all oil and gas pools in stratigraphic traps within the Blue Ridge Member (the lowest member of the Graminia Formation) in west-central Alberta. The Blue Ridge Member consists of a sequence of intertidal carbonate and siltstone. Hydrocarbon accumulations occur in stratigraphic traps in the intertidal carbonate of the Blue Ridge Member. This play has 21 gas pools and five oil pools containing 2.276 x $10^6 m^3$ of oil in-place.

*Nisku — Meekwap play.* This play is defined to include all oil pools in reef reservoirs developed at or near the regressive phase Upper Nisku or Meekwap shelf edge in west-central Alberta. The play extends along an arcuate, approximately 20 km wide, corridor centred on the shelf edge (Fig. 28). Reservoirs for this play include shelf margin reefs isolated by channels, and patch reefs developed landward within lagoonal shelf sediments. Reservoir rocks include both fossiliferous limestone and dolostone, with vuggy, intercrystalline, and fracture porosity. Dolomitization has enhanced the reservoir properties (Cheshire and Keith, 1977). Six oil pools have been discovered. The in-place

**Table 36**

**Pools discovered and predicted for the Wabamun — eroded edge play**

| Pool size class ($10^6 m^3$) | Pools discovered up to 1989 | Pools discovered between 1990 and 1994 | Pools yet to be discovered |
|---|---|---|---|
| < 0.1 | 15 | 0 | 60 |
| 0.1 - 1 | 14 | 1 | 18 |
| 1 - 10 | 2 | 0 | 0 |
| Total number of pools | 31 | 1 | 78 |
| In-place volume | 6.976 x $10^6 m^3$ | 0.110 x $10^6 m^3$ | 2 - 9 x $10^6 m^3$ |

volume has increased from 9.7 to 13.9 x $10^6 m^3$ mainly as a result of the appreciation of existing pools.

*Cooking Lake play.* This play has been recognized for a long time since the discovery of the Skaro pool. Only one oil pool has been discovered since the Skaro discovery. The total in-place volume of the Cooking Lake play is 0.638 x $10^6 m^3$ of oil.

*Ireton play.* This play has been recognized for a long time, but only two oil pools have been discovered to date containing a total volume of 0.742 x $10^6 m^3$ of in-place oil.

*Wabamun — Crossfield play.* This play is a relatively mature sour gas play in south-central Alberta that contains four oil pools with total reserves of 7.239 x $10^6 m^3$ of in-place oil (Fig. 29).

*Winnipegosis — Central Alberta play.* Only one Winnipegosis oil pool has been discovered to date in central Alberta. This pool in the Rich field contains about 0.1 x $10^6 m^3$ of in-place oil.

**Table 37**

**The largest pool of Table 36 discovered between 1990 and 1994**

| Field, pool | In-place volume ($10^6 m^3$) |
|---|---|
| Atim, Wabamun A | 0.110 |

***Williston Basin region***

Two established mature plays, Leduc-Nisku Southern Alberta and Arcs structural, are located within this region.

*Leduc–Nisku Southern Alberta*

*Play definition.* This play is defined to include all oil pools in thick reef carbonates along the Leduc Formation barrier reef, and those in the Camrose Member and Nisku carbonate shelves where they are draped over Leduc topographical features with positive relief (Fig. 30).

*Geology.* The Leduc barrier reef is developed above the Cooking Lake platform. Variations in thickness, possibly due to inter-reef channels and isolated buildups immediately basinward of the barrier edge, create stratigraphic trapping configurations. Reservoirs consist of reefal dolomite with vuggy, intercrystalline, and fracture porosity, and good permeability.

*Exploration history.* The discovery sequence ($\hat{\beta}$=0.5) and the cumulative in-place volume discovered are graphically displayed in Appendix A (Figs. A18.1 and A18.2). The in-place volume has increased from 20 to 35 x $10^6 m^3$ since the GSC's 1987 assessment. The largest pool predicted by the GSC's 1987 assessment has been discovered. The increase is a result of new discoveries and appreciation of existing pools. The cumulative in-place graph shows a strong upward increase with a jump in recent years. The potential and discoveries are summarized in Tables 38 and 39.

*Reservoir parameters.* Reservoirs have pool areas from 17 to 1,000 ha; net pay from 2.5 to 10 m; porosity from 5 to 18%; water saturation from 12 to 56%; and a recovery factor from 0.2 to 50%. The parameters are also graphically displayed in Appendix A (Figs. A18.3 to A18.8).

*Arcs structural*

*Play definition.* This play includes all oil pools in the structural and/or stratigraphic traps in the Arcs Member (Nisku correlative) of southern Alberta (Fig. 30).

*Geology.* Belyea (1957, 1964) considered the Arcs Member of the Southesk Formation in the subsurface of southern Alberta to be equivalent to the upper Nisku Formation in central Alberta, and the underlying Grotto Member to be equivalent to the Camrose Dolomite, also in central Alberta. The Arcs Member is a relatively thin (6 to 12 m) widespread unit, but locally it can be up to 45 m in thickness. The type subsurface section, in Lsd. 1-2-30-21 W4M (West Drumheller oil field) is 34 m thick. The Arcs Member consists of light coloured, fine- to coarse-grained crystalline dolostone with bands of brown, granular dolomite and minor anhydrite. The porosity is vugular and intercrystalline with minor oblique fractures.

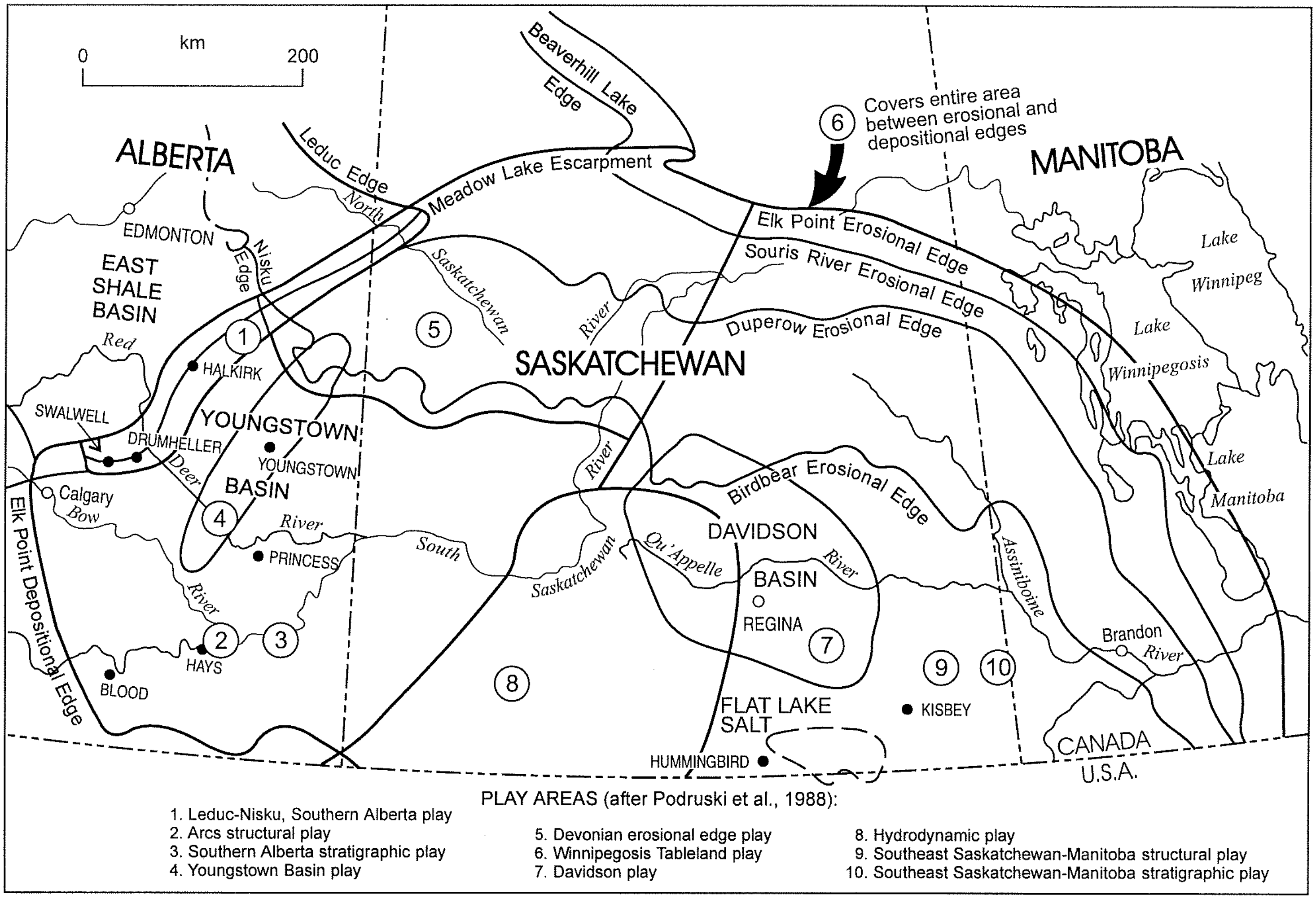


***Figure 30.*** *Williston Basin Devonian play areas (after Podruski et al., 1988).*

In the Hays area (Fig. 30), the Arcs Member can be divided into two reservoir units separated by a thin shale bed. Dolomite, with interbeds of anhydrite, is the dominant lithotype, and reflects a restricted peritidal to supratidal environment. Hydrocarbons are trapped in porous dolostone in structurally high closures. The structures are believed to be a result of salt solution in older Upper Devonian carbonate-evaporite sequences (Slingsby and Aukes, 1989). The Arcs is relatively uniform in thickness over the entire Hays region, indicating that structural deformation occurred after Arcs deposition. In addition, the isopach thickness of the Wabamun-to-Grotto interval indicates depositional thins over highs on the Arcs Member, suggesting that deformation occurred shortly after the Arcs carbonate was deposited.

*Exploration history.* The discovery sequence ($\hat{\beta}=0.4$) and the cumulative in-place volume discovered are graphically displayed in Appendix A (Figs. A19.1 and A19.2). This play was considered an immature play by the GSC's 1987 assessment. The cumulative in-place graph shows a strong upward increase with a jump in recent years. The potential and discoveries are summarized in Tables 40 and 41.

**Table 38**

**Pools discovered and predicted for the Leduc–Nisku Southern Alberta play**

| Pool size class ($10^6 m^3$) | Pools discovered up to 1989 | Pools discovered between 1990 and 1994 | Pools yet to be discovered |
|---|---|---|---|
| < 0.1 | 9 | 2 | 51 |
| 0.1 - 1 | 22 | 1 | 43 |
| 1 - 10 | 8 | 1 | 3 |
| Total number of pools | 39 | 4 | 97 |
| In-place volume | 28.924 x $10^6 m^3$ | 5.669 x $10^6 m^3$ | 2 - 34 x $10^6 m^3$ |

**Table 39**

**The four largest pools of Table 38 discovered between 1990 and 1994**

| Field, pool | In-place volume ($10^6m^3$) |
|---|---|
| Edgerton, Woodbend A | 5.403 |
| Red Willow, Camrose H | 0.147 |
| West Drumheller, D-3 B | 0.097 |
| Red Willow, Camrose F | 0.022 |

**Table 40**

**Pools discovered and predicted for the Arcs structural play**

| Pool size class ($10^6m^3$) | Pools discovered up to 1989 | Pools discovered between 1990 and 1994 | Pools yet to be discovered |
|---|---|---|---|
| < 0.1 | 2 | 2 | 16 |
| 0.1 - 1 | 31 | 6 | 62 |
| 1 - 10 | 6 | 1 | 4 |
| Total number of pools | 39 | 9 | 82 |
| In-place volume | 28.054 x $10^6m^3$ | 4.756 x $10^6m^3$ | 15 - 40 x $10^6m^3$ |

**Table 41**

**The five largest pools of Table 40 discovered between 1990 and 1994**

| Field, pool | In-place volume ($10^6m^3$) |
|---|---|
| Enchant, Arcs AAA | 2.512 |
| Enchant, Arcs MM and NN | 0.596 |
| Enchant, Arcs KK and FFF | 0.531 |
| Enchant, Arcs LL | 0.455 |
| Enchant, Arcs RR and SS | 0.200 |

*Reservoir parameters.* Reservoirs have pool areas from 17 to 566 ha; net pay from 3 to 16 m; porosity from 8 to 18%; water saturation from 11 to 39%; and a recovery factor from 0.1 to 30%. The parameters are also graphically displayed in Appendix A (Figs. A19.3 to A19.8).

*Immature plays*

There are two immature plays in the Williston Basin region. They are the Winnipegosis–Tableland play, and the southeast Saskatchewan–Manitoba structure play (Fig. 30). Figure 30 also shows the possible conceptual plays in the Williston Basin.

The four pools from the Winnipegosis Formation in the Tableland area contain about 23.829 x $10^6m^3$ of in-place oil.

The Southeast Saskatchewan–Manitoba structure play is defined to include all oil pools in the Dawson Bay, Souris River, Duperow, and Birdbear carbonate shelves in structural traps. The play occurs in southern Saskatchewan and southwestern Manitoba, in the area between the fresh water recharge zone and the erosional edge of the basin. Three types of structure occur in the region: tectonic, related to one or several stages of epeirogenic movement; salt solution, formed during multi-stage collapse of the Prairie Evaporite (De Mille et al., 1964; Smith and Pullen, 1967); and meteorite impact structures (Sawatzky, 1975). Two pools have been discovered to date containing 2.6 x $10^6m^3$ of in-place oil.

*Conceptual play analysis*

Several plays which were considered as conceptual plays by the GSC's 1987 assessment are now immature plays [e.g., Keg River and Slave Point (outside shelf basins), Ireton, and Winnipegosis platform–central Alberta plays].

Figure 31 displays the play discovery sequence from which the potential of immature and conceptual plays can be estimated. From the conceptual play analysis there are 40 Devonian plays in the Western Canada Sedimentary Basin. Among these 40 plays (Fig. 32), 19 are considered to be mature plays, 10 are immature, and 11 conceptual plays are thought to occur. The potential of the sum of immature and conceptual plays ranges from 127 to 3,033 x $10^6 m^3$ of oil in-place (with an expected value of 1,230 x $10^6 m^3$).

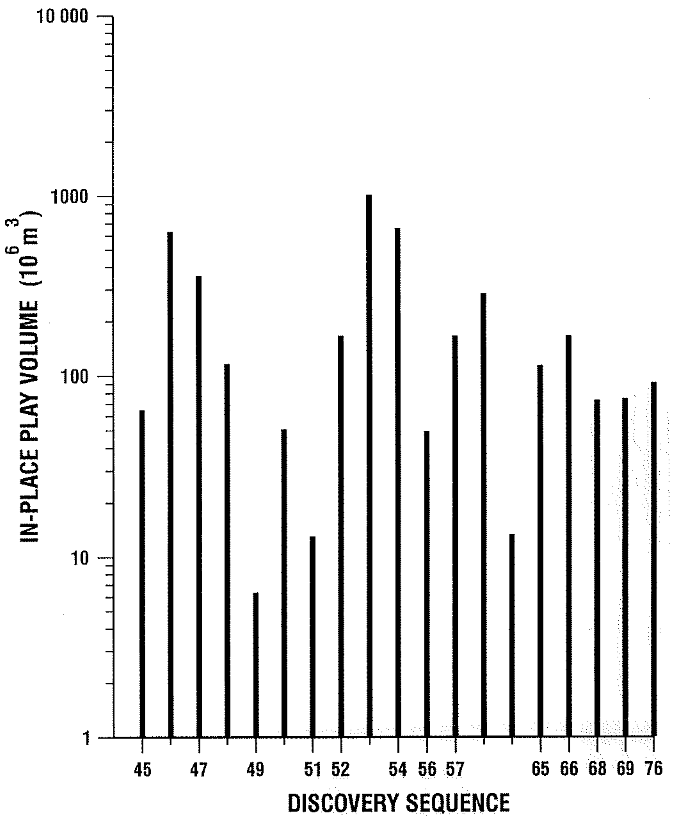


***Figure 31.*** *Devonian play discovery sequence.*

The largest and the second largest immature or conceptual play has an in-place volume ranging from 93 to 245 x $10^6 m^3$ and 72 to 166 x $10^6 m^3$, respectively (Fig. 32). The smallest plays might contain several pools.

The natural gas potential was converted into oil equivalent (using the conversion factor 0.95 x $10^6 ft^3$ of gas = 165 x $10^6$ barrels of oil). Figure 33 is a pie diagram showing the proportions of the potential from mature oil plays (29%), immature and conceptual oil plays (25%), from mature gas plays (13%), and from immature and conceptual gas plays (33%).

The result of this conceptual play analysis is very encouraging for future oil and/or gas exploration in the Devonian system.

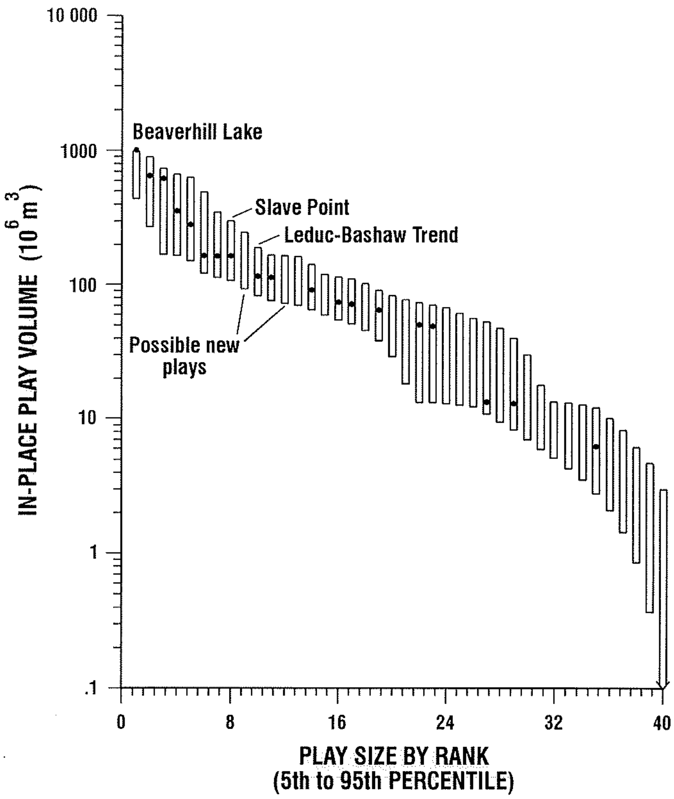


***Figure 32.*** *Play size by rank of the Devonian plays.*

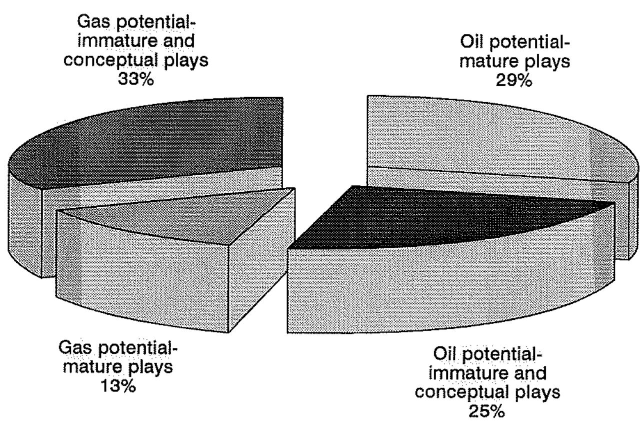


***Figure 33.*** *Proportions of undiscovered resources obtained from mature, immature and conceptual oil and gas plays.*

## CARBONIFEROUS AND PERMIAN SYSTEMS

### Geological framework

The subsurface Western Canada Sedimentary Basin contains two depocentres of Carboniferous rocks. The two — the Peace River Embayment and the Williston Basin — are separated by the Alberta Shelf (Fig. 34). Permian rocks are widespread in the Peace River Embayment. These depocentres merge westward with the Prophet Trough (Carboniferous) and Ishbel Trough (Permian) (Richards, 1989; 1993; Richards et al., 1993; 1994) and into the Alberta Shelf. Both depocentres progressively shrank in size during the Carboniferous with accompanying expansion of adjacent shelf areas. These shelves contain shallow-water deposits that were interrupted by episodic erosional events.

The initial development and subsequent restriction of the basinal regions was achieved through regional downwarp and local block faulting during several tectonic events from the Late Devonian to the Permian. Superposition of several marine transgressions on this evolving basin geometry during carbonate and clastic sedimentation resulted in a great diversity in facies patterns.

The Carboniferous succession has been divided on the basis of lithotype and depositional history into the lower, middle, and upper depositional units (Fig. 34). The Carboniferous stratigraphic column is shown in Figure 35. The lower unit consists of two shallowing-upward cycles, separated by a minor disconformity, that represent two transgressive–regressive events. The middle unit was deposited during multiple transgressive-regressive cycles. In the shelf deposits, many cycles begin with high energy bioclastic or oolitic grainstone.

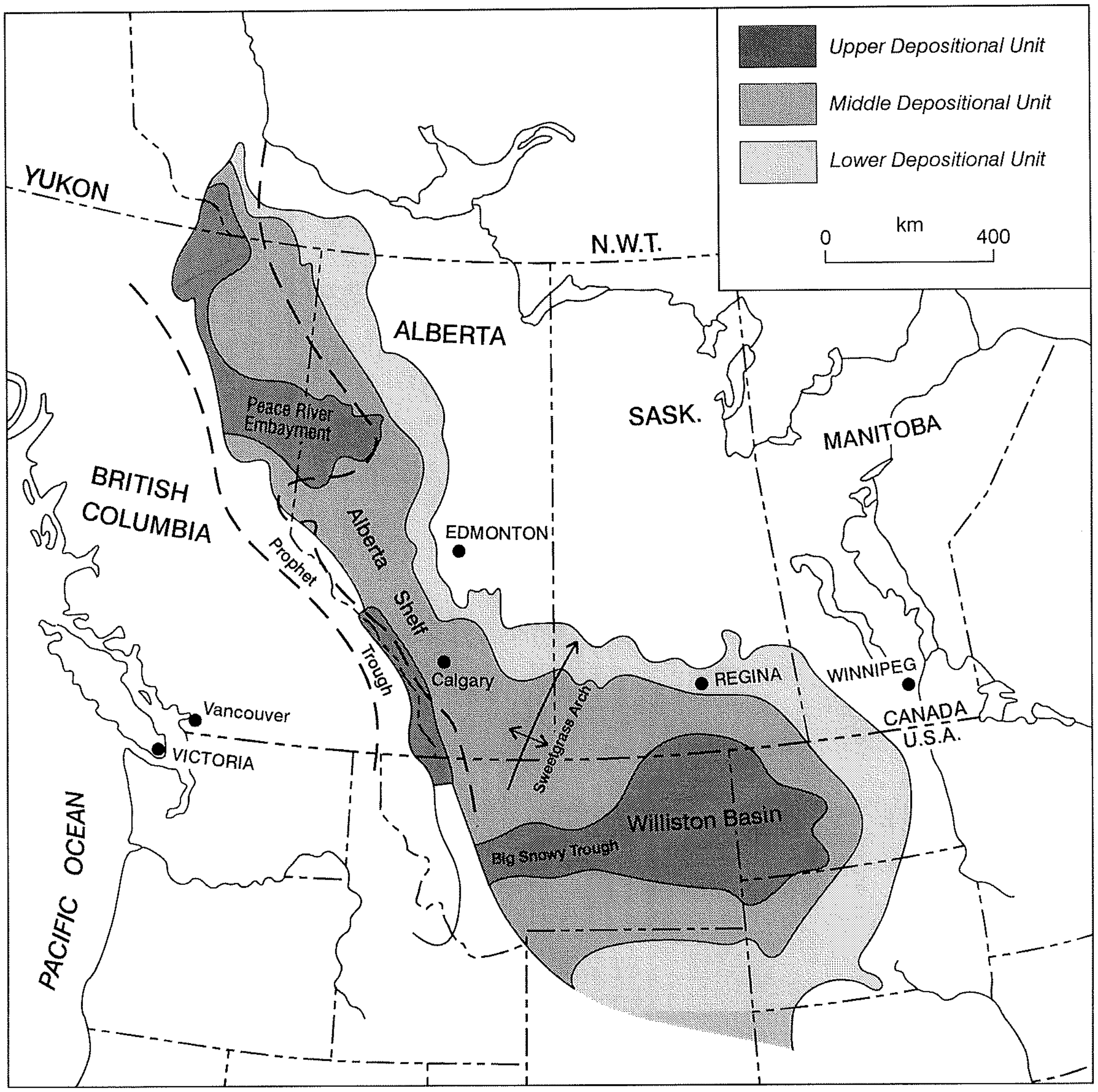


*Figure 34. Distribution of Carboniferous rocks, Western Canada Sedimentary Basin. Dashed line shows approximate and assumed position of the Prophet and Peace River embayment in the Upper Tournaisian (after Richards et al., 1993).*

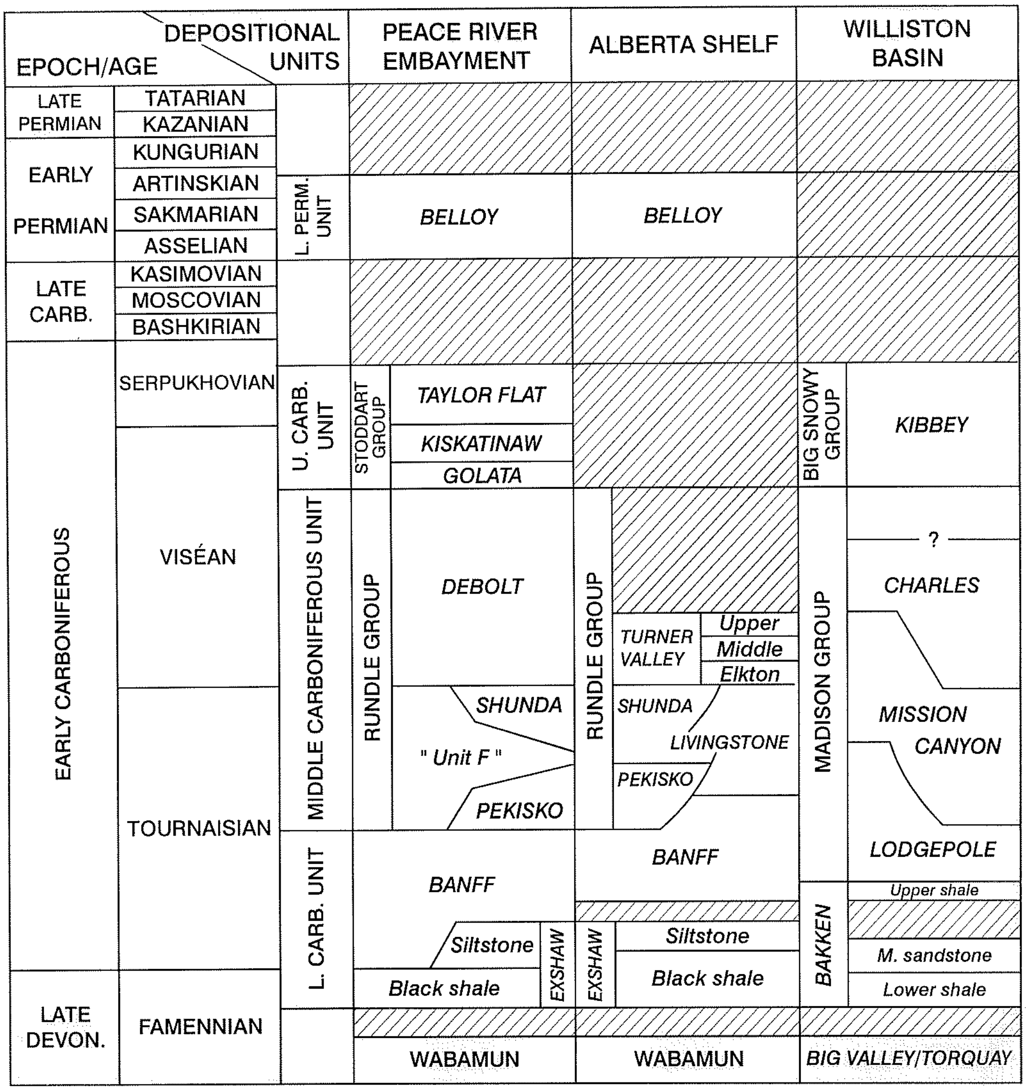


***Figure 35.*** *Table of Carboniferous and Permian formations, subsurface of Western Canada Sedimentary Basin.*

These basal deposits generally grade upward into lagoonal to supratidal carbonate, shale, and evaporite. In the Williston Basin, the shelf deposits prograde over and intertongue with slope deposits of the Lodgepole Formation. In the Peace River Embayment, they either overlie the Banff Formation or intertongue with slope facies of the Prophet Formation. The upper unit does not occur on most of the extensive Alberta Shelf, because of either non-deposition or erosion.

The Permian is represented by the Belloy Formation in the subsurface of the Peace River Arch Embayment. The Belloy Formation is separated from the Carboniferous by an erosional unconformity, and is, in turn, unconformably overlain by Triassic or Jurassic rocks.

Most of the oil is trapped below unconformities in southeast Saskatchewan, southwestern Manitoba, and central Alberta. These traps are formed at the northeast truncation of shelf carbonate reservoir beds as well as in outliers immediately beyond the truncation zone (Fig. 36). Reservoirs are typically grainstone and packstone that were dolomitized during several late Paleozoic and Mesozoic periods of erosion. Continental and marine Mesozoic seals are present above and surrounding the reservoirs. Seals are also formed by cementation at the unconformity between the Carboniferous and Mesozoic. Restricted-marine subtidal to supratidal carbonate and evaporite beds that cap each transgressive-regressive Carboniferous cycle commonly form seals (Kent, 1984).

Structural traps are of secondary importance in the Carboniferous and Permian systems. They include Laramide compressional folds, block faults, and meteorite impact structures (Sawatzky, 1972).

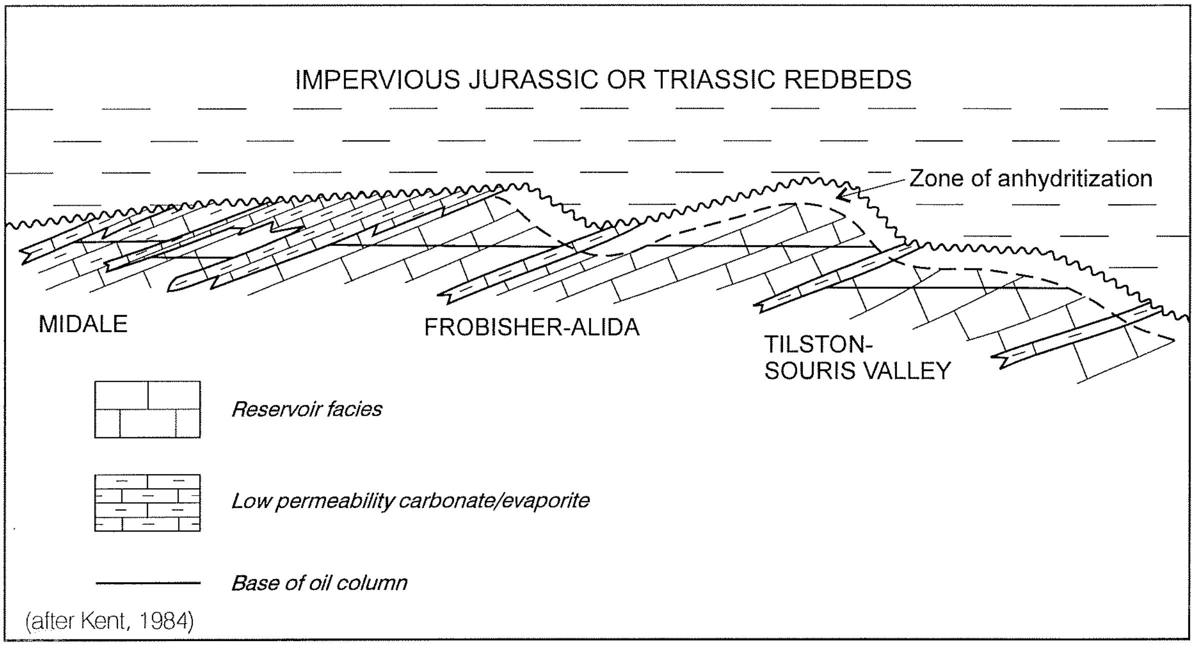


***Figure 36.*** *Schematic section of unconformity traps, Williston Basin.*

The regional geology and geological play definitions of Carboniferous and Permian plays are similar to those outlined by Podruski et al. (1988) and Barclay et al. (1997) with additional information available in the following publications: Barclay (1988), Barclay et al. (1990) Davies et al. (1989), Edwards (1988), Henderson (1989), Henderson et al. (1993), Richards, (1989, 1993) and Richards et al. (1993, 1994).

**Resource assessment**

***Carboniferous and Permian potential***

The potential of the Carboniferous and Permian systems ranges from 478 to 1,577 x $10^6 m^3$. The mean (or expected value) of the potential distribution is 973 x $10^6 m^3$. The Mississippian subcrop Play contains the greatest potential for oil in the Carboniferous and Permian.

The in-place volume has increased from 1,446 x $10^6 m^3$ to 1,996 x $10^6 m^3$ since the GSC's 1987 assessment. A total of 32 x $10^6 m^3$ of in-place volume was discovered between 1990 and 1994. The number of pools discovered and the sizes of the largest 10 pools discovered between 1990 and 1994 are listed in Tables 42 and 43.

***Peace River Arch region***

Two established mature plays, the Belloy and Debolt, are located within this region.

*Belloy*

*Play definition.* This play is defined to include oil and gas pools in fault-bounded structural and stratigraphic traps in the Belloy Formation deposited in the Peace River Embayment. The play area is defined by the Belloy erosional edge to the north and east, the Peace River structural deformation limit to the south and the disturbed belt to the west (Fig. 37).

*Geology.* The Belloy Formation consists of sandy dolomite, fine-grained, poorly sorted calcareous, glauconitic sandstone and quartz sandstone. The formation is usually phosphatic with some carbonaceous material. Thickness of the formation increases from zero edge in the east to more than 183 m near the Foothills south of Fort St. John. The clastic material is dominantly quartz. Chert nodules are also common in the formation. The sand distribution has been affected by Post-Permian faulting as in the Gordondale area. Bedded chert occurs with other rock types. Phosphatic rocks decrease from east to west across the embayment. Evidence indicates that the Belloy sediments were deposited in a low energy, wide and shallow continental shelf environment. The source of oil is probably from the overlying Triassic or the underlying Carboniferous rocks. Oil likely migrated in Laramide or post-Laramide time. Oil accumulations are therefore closely related to the structural and stratigraphic components of the area. Main references for the Permian system include Henderson (1989), Chung (1993), Chung and Henderson (1993a, b), Naqvi (1969, 1972), and Burton et al. (1990).

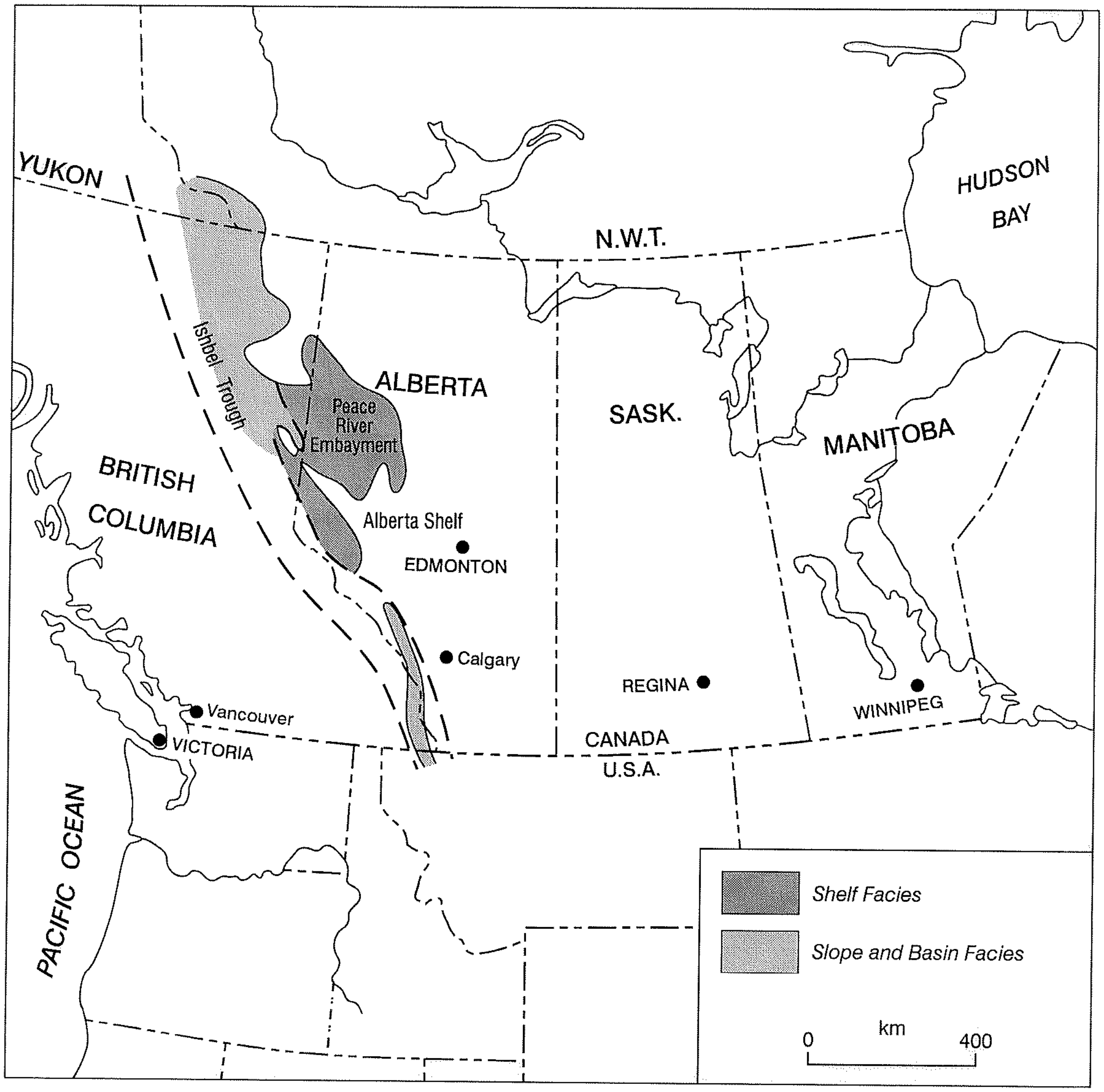


***Figure 37.*** *Distribution of Permian rocks, Western Canada Sedimentary Basin. Dashed line is approximate and shows assumed position of Ishbel Trough (after Henderson et al., 1993).*

**Table 42**

**Carboniferous and Permian oil pools discovered**

| Pool size class ($10^6 m^3$) | Pools discovered up to 1989 | Pools discovered between 1990 and 1994 |
|---|---|---|
| < 0.1 | 98 | 16 |
| 0.1 - 1 | 256 | 31 |
| 1 - 10 | 141 | 11 |
| 10 - 100 | 38 | 0 |
| 100 - 1,000 | 4 | 0 |
| Total number of pools | 537 | 58 |
| In-place volume | 1,964.122 x $10^6 m^3$ | 31.697 x $10^6 m^3$ |

**Table 43**

**The ten largest Carboniferous and Permian pools discovered between 1990 and 1994**

| Field, pool | In-place volume ($10^6 m^3$) |
|---|---|
| Buffalo Head, Frobisher - Alida | 2.725 |
| Notting North, Tilston | 2.670 |
| Ceylon, Bakken Sand | 2.512 |
| St Anne, Banff | 2.500 |
| Hazelwood South, Tilston | 2.400 |
| Bender Central, Tilston | 2.116 |
| Union Jack, Midale | 1.988 |
| Moose Valley South, Tilston | 1.368 |
| Workman South, Frobisher | 1.354 |
| Willmar West, Frobisher | 1.236 |

*Exploration history.* The discovery sequence ($\hat{\beta}$=0.6) and the cumulative in-place volume discovered are graphically displayed in Appendix B (Figs. B1.1 and B1.2). The in-place volume has increased from 40 to 57 x $10^6 m^3$ since the GSC's 1987 assessment. The increase is mainly the result of appreciation of the four largest discovered pools. The cumulative in-place volume shows a slight upward increase. This play likely contains a large number of small pools. The potential and discoveries are summarized in Tables 44 and 45.

*Reservoir parameters.* Reservoirs have pool areas from 30 to 2,100 ha; net pay from 1.3 to 6.3 m; porosity from 8 to 18%; water saturation from 18 to 45%; and a recovery factor from 0.1 to 50% (min-max). The parameters are also graphically displayed in Appendix B (Figs. B1.3 to B1.8). Reservoir permeability generally decreases with an increase of dolomitic cement in rocks.

### *Debolt*

*Play definition.* This play is defined to include all oil and gas pools in the carbonates of the Debolt Formation. Trap type is structural-stratigraphic associated with fault-bounded structures in the Peace River region. The play area is defined by the limits of the deformed belt to the west and Peace River Embayment structural deformation to the north, east and south approximately at the edge of the Dawson Creek Graben Complex (Barclay et al., 1990).

*Geology.* Dolomite reservoirs are associated with horst blocks and grabens. Secondary porosity development occurred in carbonates, which were fractured by faulting and folding or exposed at an unconformity surface and, in either case, subjected to diagenetic processes. Many intra- and inter-formational unconformities exist. Primary porosity may also occur in packstone or grainstone. Gas pools occur in the Banff, Pekisko, Shunda, and Taylor Flat formations, but no oil pools have been found in them.

*Exploration history.* The discovery sequence ($\hat{\beta}$=0.9) and the cumulative in-place volume discovered are graphically displayed in Appendix B (Figs. B2.1 and B2.2). This play was considered to be an immature play in the GSC's 1987 assessment. The cumulative in-place graph shows a very strong upward increase. The potential and discoveries are summarized in Tables 46 and 47.

**Table 44**

**Pools discovered and predicted for the Belloy–Peace River Arch play**

| Pool size class ($10^6m^3$) | Pools discovered up to 1989 | Pools discovered between 1990 and 1994 | Pools yet to be discovered |
|---|---|---|---|
| < 0.1 | 6 | 1 | 55 |
| 0.1 - 1 | 7 | 2 | 23 |
| 1 - 10 | 3 | 0 | 1 |
| 10 - 100 | 2 | 0 | 0 |
| Total number of pools | 18 | 3 | 79 |
| In-place volume | 57.273 x $10^6m^3$ | 0.399 x $10^6m^3$ | 1.3 - 53 x $10^6m^3$ |

**Table 45**

**The three largest pools of Table 44 discovered between 1990 and 1994**

| Field, pool | In-place volume ($10^6m^3$) |
|---|---|
| Flatrock, Belloy A | 0.334 |
| Pica, Belloy A | 0.108 |
| Airport, Belloy A | 0.065 |

*Reservoir parameters.* Reservoirs have pool areas from 10 to 100 ha (min-max); net pay from 1 to 8.5 m (min-max); porosity from 1 to 29% (min-max); water saturation from 10 to 45% (min-max); and a recovery factor from 1 to 15% (min-max). Parameters are also graphically displayed in Appendix B (Figs. B2.3 to B2.8).

*Immature and conceptual plays*

The Debolt structural–Blueberry play is restricted to the western part of the district where Laramide deformation characteristics of the Foothills extend under the Plains region. Its reservoir consists of dolomitized shelf grainstone and packstone that lie near the pre-Mesozoic unconformity. A total of 11.990 x $10^6m^3$ has been discovered from three pools.

The Kiskatinaw play is defined by the limits of the Rocky Mountain Thrust Belt to the west and the Kiskatinaw Formation erosional edge to the north, east and south. Three discoveries have been found with a total in-place volume of 0.344 x $10^6m^3$.

Conceptual plays include the structural and stratigraphic traps in the shelf carbonate units of the Banff Formation. Unit F (Richards et al., 1993) may also have potential. The Debolt shelf carbonates present opportunities for traps. The Mattson Formation in British Columbia may also have oil potential.

***Alberta shelf region***

Three established plays, Sweetgrass, Mississippian subcrop and Turner Valley, are located within this region.

*Sweetgrass Arch*

*Play definition.* This play is defined to include all oil and gas pools in the carbonates of the Rundle Group. Oil is found in both structural and stratigraphic-structural combination traps in the play. The play area extends from the Sweetgrass Arch to the Foothills disturbed belt and the subcrop edge of the Pekisko Formation (Fig. 38).

*Geology.* The shelf carbonates were faulted, deformed and fractured as a result of post-Paleozoic tectonics. Structural traps with good porosity induced by tectonics are developed on the Sweetgrass Arch. Traps are sealed by the overlying impermeable beds. Oil migration is facilitated by the fracture system. Exshaw and/or Bakken shales are likely the main oil source. Most of the pools in the play contain heavy oil.

*Exploration history.* The discovery sequence ($\hat{\beta}=1.0$) and the cumulative in-place volume discovered are graphically displayed in Appendix B (Figs. B3.1 and B3.2). The in-place volume has increased from 5 to 17 x $10^6m^3$ since the GSC's 1987 assessment. The increase is a result of new discoveries and appreciation of existing pools. The cumulative in-place graph shows a strong upward increase. The potential and discoveries are summarized in Tables 48 and 49.

**Table 46**

**Pools discovered and predicted for the Debolt–Peace River Arch play**

| Pool size class ($10^6m^3$) | Pools discovered up to 1989 | Pools discovered between 1990 and 1994 | Pools yet to be discovered |
|---|---|---|---|
| < 0.1 | 1 | 0 | 13 |
| > 0.1 | 8 | 2 | 21 |
| Total number of pools | 9 | 2 | 34 |
| In-place volume | 1.532 x $10^6m^3$ | 0.426 x $10^6m^3$ | 2 - 4 x $10^6m^3$ |

**Table 47**

**The two largest pools of Table 46 discovered between 1990 and 1994**

| Field, pool | In-place volume ($10^6m^3$) |
|---|---|
| Normandville, Mississippian F | 0.214 |
| Normandville, Mississippian E | 0.212 |

**Table 48**

**Pools discovered and predicted for the Sweetgrass Arch play**

| Pool size class ($10^6m^3$) | Pools discovered up to 1989 | Pools discovered between 1990 and 1994 | Pools yet to be discovered |
|---|---|---|---|
| < 0.1 | 16 | 8 | 152 |
| 0.1 - 1 | 32 | 7 | 61 |
| 1 - 10 | 3 | 0 | 1 |
| Total number of pools | 51 | 15 | 214 |
| In-place volume | 14.019 x $10^6m^3$ | 2.819 x $10^6m^3$ | 14 - 24 x $10^6m^3$ |

**Table 49**

**The five largest pools of Table 48 discovered between 1990 and 1994**

| Field, pool | In-place volume ($10^6m^3$) |
|---|---|
| Herronton, Turner Valley B | 0.778 |
| Herronton, Turner Valley C | 0.677 |
| Jenner, Pekisko G | 0.234 |
| Jenner, Pekisko M | 0.196 |
| Princess, Pekisko G | 0.187 |

*Reservoir parameters.* Reservoirs have pool areas from 16 to 120 ha; net pay from 2.3 to 26 m; porosity from 3.5 to 23%; water saturation from 15 to 63%; and a recovery factor from 0.16 to 20%. The parameters are also graphically displayed in Appendix B (Figs. B3.3 to B3.8).

*Mississippian subcrop*

*Play definition.* This play was defined to include all oil and gas pools in the unconformity traps at the erosional subcrop edges of the Banff, Pekisko, Shunda, Elkton, and Debolt formations. The play area includes these erosional edges and outliers extending from the southwestern Northwest Territories to southern Alberta, between the edge of the Banff Formation to the east and north, and the Foothills to the west (excluding central parts of the Peace River

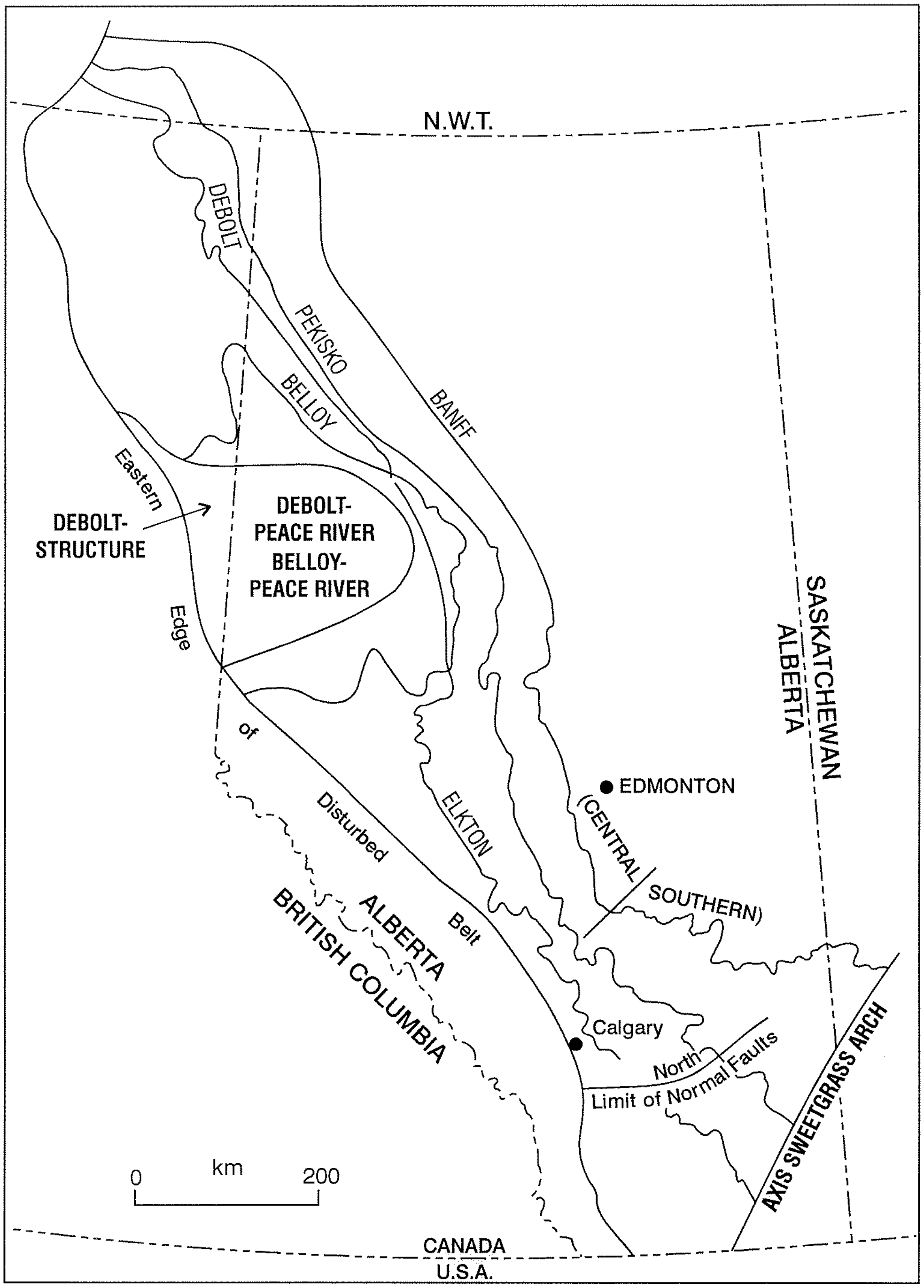


***Figure 38.*** *Carboniferous erosional edges and play areas, Alberta Shelf and Peace River regions. Mature play areas are along the erosional edges of each reservoir unit.*

Embayment, which lacks major subcrop edges and is dominated by subcrop plays) (Fig. 38). In the GSC's 1987 assessment, this play was divided into four plays: Banff Edge — Southern Alberta, Banff Edge — Central Alberta, Pekisko Edge, and Elkton Edge plays (Podruski et al., 1988). The present play definition is adopted from the GSC's gas assessment project (Barclay et al., 1997).

*Geology.* The Banff Formation in southern Alberta (south of township 45) can be divided into three depositional units. The lower unit consists mainly of argillaceous limy mudstone and shale. The middle unit, representative of a higher energy environment, includes limy wackestone, packstone and grainstone. The upper unit contains shallow-water limy wackestone and shale. Along the subcrop edge, the middle unit is a good reservoir.

In central Alberta, the lithofacies of the Banff Formation consist of limy mudstone, shale, wackestone, packstone and grainstone. Porous dolomites of the Banff Formation at the updip edge of the subcrop form excellent oil traps. These porous dolomites are known locally as "Clarke's member". The oil pools generally occur in paleotopographic highs.

The lateral and top seal rocks are non-porous Banff limestone and/or Mesozoic shale. Possible oil source rocks are Exshaw, Banff and Mesozoic shales. Some of the Banff pools contain heavy oil.

The Pekisko Formation consists of medium- to coarse-grained crystalline pelletoidal, crinoidal limestone and fine-grained sucrosic, medium-grained crystalline dolomite. To the north of the Peace River Arch, the Pekisko changes its facies from crinoidal limestone to shale, argillaceous limestone and silty dolomite. Pekisko carbonates were deposited on a marine shelf in locally developed, high-energy environments. They are usually well cemented, but good porosity development occurs near the erosional subcrop edge. Traps were formed in Pekisko erosional remnants and permeable lenses near the erosional edge with overlying Jurassic and Cretaceous impermeable strata acting as seals. Lateral seals include the impermeable channel clay fill along the irregular erosional edge and argillaceous or well-cemented carbonate. The source for hydrocarbons is likely within Jurassic or Lower Cretaceous strata.

The Elkton Formation consists of high-energy marine shelf packstone, wackestone and grainstone containing coarse-grained crinoidal and bryozoan fragments. Hydrocarbon traps were formed at the pre-Mesozoic unconformity and in erosional channel fills with overlying Mesozoic shales and dense upper Elkton strata acting as seals. Vuggy, pinpoint and intercrystalline porosity was formed from diagenesis.

The Debolt Formation extends from Alberta into northeastern British Columbia. Lateral and vertical facies variations from porous reservoir rocks to well cemented carbonate form stratigraphic-depositional traps. The reservoir rock and traps are similar to those of the Pekisko Formation. Fine- to medium-grained crystalline Debolt dolomite with vuggy and/or intercrystalline porosity is sealed at the updip erosional edge by overlying impervious Jurassic or Cretaceous strata. Porous dolomite truncated by the Pre-Mesozoic unconformity forms stratigraphic-erosional subcrop traps with overlying Mesozoic seal beds. The Debolt Formation is stratigraphically and lithologically equivalent to the Mount Head and Turner Valley formations in the Foothills and south-central Alberta. Pre-Laramide tectonic events created faulting, horst, graben and other tectonic structures that in some cases involve the complete stratigraphic column. The porosity and permeability are generally poor, except where faulting dominates. The decrease of porosity mainly results from diagenetic changes. The oil is heavy to medium crude. The lack of a natural drive mechanism or permeability or infill of pyrobitumen may account for fair to poor recovery in these pools.

Sixty-seven out of the 293 pools discovered contain heavy oil. The Banff and Pekisko formations contain 54 of the 67 heavy oil pools.

*Exploration history.* The discovery sequence ($\hat{\beta}=0.8$) and the cumulative in-place volume discovered are graphically displayed in Appendix B (Figs. B4.1 and B4.2). The in-place volume has increased from 368 to 448 x $10^6 m^3$ since the GSC's 1987 assessment. The increase is a result of both appreciation of existing pools and new discoveries. The cumulative in-place volume graph shows a moderate upward increase. The potential and discoveries are summarized in Tables 50 and 51.

**Table 50**

**Pools discovered and predicted for the Mississippian subcrop play**

| Pool size class ($10^6 m^3$) | Pools discovered up to 1989 | Pools discovered between 1990 and 1994 | Pools yet to be discovered |
|---|---|---|---|
| < 0.1 | 70 | 6 | 400 |
| 0.1 - 1 | 161 | 10 | 197 |
| 1 - 10 | 38 | 1 | 10 |
| 10 - 100 | 6 | 0 | 0 |
| 100 - 1,000 | 1 | 0 | 0 |
| Total number of pools | 276 | 17 | 607 |
| In-place volume | 442.275 x $10^6 m^3$ | 5.301 x $10^6 m^3$ | 103 -957 x $10^6 m^3$ |

**Table 51**

**The five largest pools of Table 50 discovered between 1990 and 1994**

| Field, pool | In-place volume ($10^6 m^3$) |
|---|---|
| St Anne, Banff K | 2.500 |
| Gilby, Rundle R | 0.601 |
| Gilby, Rundle S | 0.583 |
| Sylvan Lake, Elkton - Shunda H | 0.316 |
| Sylvan Lake, Pekisko X | 0.216 |

*Reservoir parameters*. Reservoirs have pool areas from 16 to 1,600 ha; net pay from 2 to 20 m; porosity from 4 to 20%; water saturation from 17 to 50%; and a recovery factor from 0.07 to 21%. The parameters are also graphically displayed in Appendix B (Figs. B4.3 to B4.8).

*Rundle — Turner Valley*

This play consists of three pools with a total in-place volume of 159.617 x $10^6 m^3$. Most of the reserve is contained in the Turner Valley Rundle A pool. This structural play, located in the Foothills region, represents the eastern component of Laramide compressional deformation that created the Rocky Mountains. The play area includes a number of southwest dipping imbricate listric thrust slices and related fold structures. This immature play is not evaluated.

***Williston Basin region***

The stratigraphic relationships in Williston Basin are shown in Figure 39 and the areal extent of the Lodgepole, Souris Valley–Tilston, Frobisher–Alida, Midale, and Ratcliffe plays are shown in Figure 40. Additional information can be found in Edie (1958), Hansen (1972), Kent (1984, 1987), Lake (1989), Grassby and Pelletier (1990), and Christopher (1961).

Six established plays, Lodgepole, Souris Valley–Tilston, Frobisher–Alida, Midale, Ratcliffe, and Bakken, are located within this region.

*Lodgepole*

*Play definition*. This play is defined to include all oil pools within the Virden, Whitewater Lake, and the Scallion members of Manitoba, the unnamed upper Lodgepole of Manitoba, and the undivided Lodgepole of eastern Saskatchewan and westernmost Manitoba. The play area is limited by the arcuate trend of the Lodgepole subcrop edge to the north, the International Boundary to the south, and the zone of low salinity formation water to the west (Fig. 40).

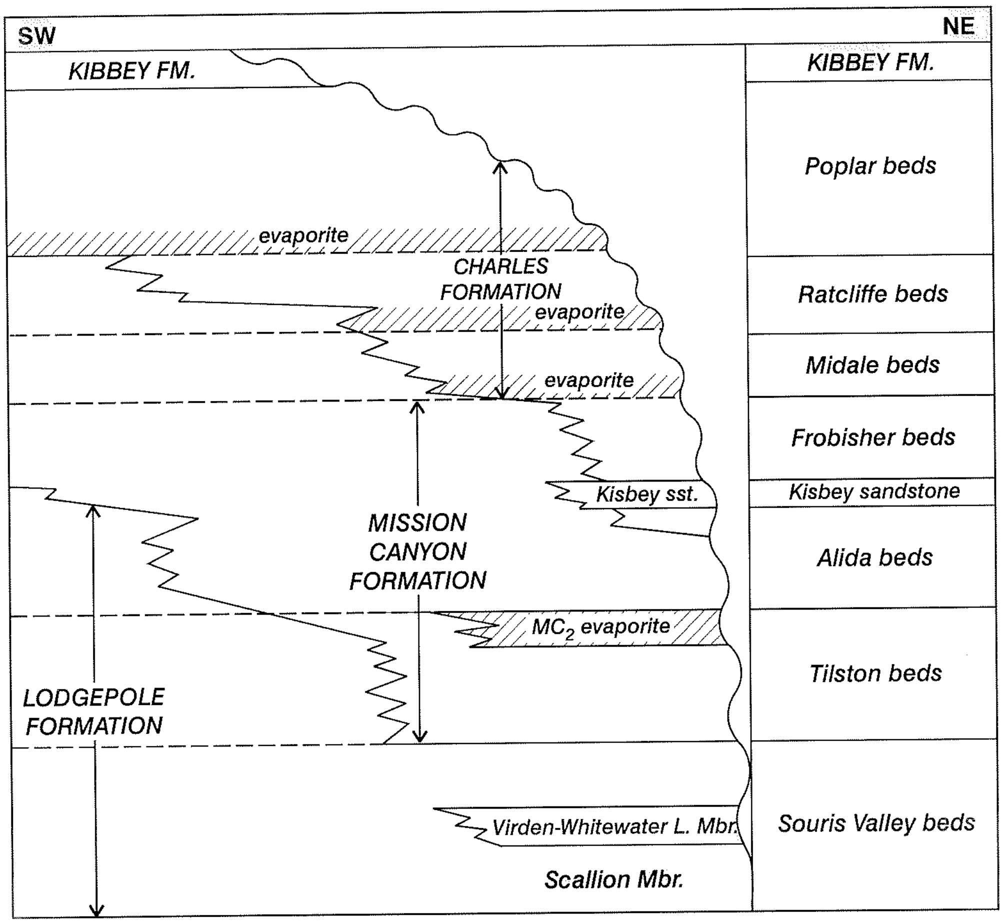


***Figure 39.*** *Stratigraphic relationships — Madison Group, Williston Basin.*

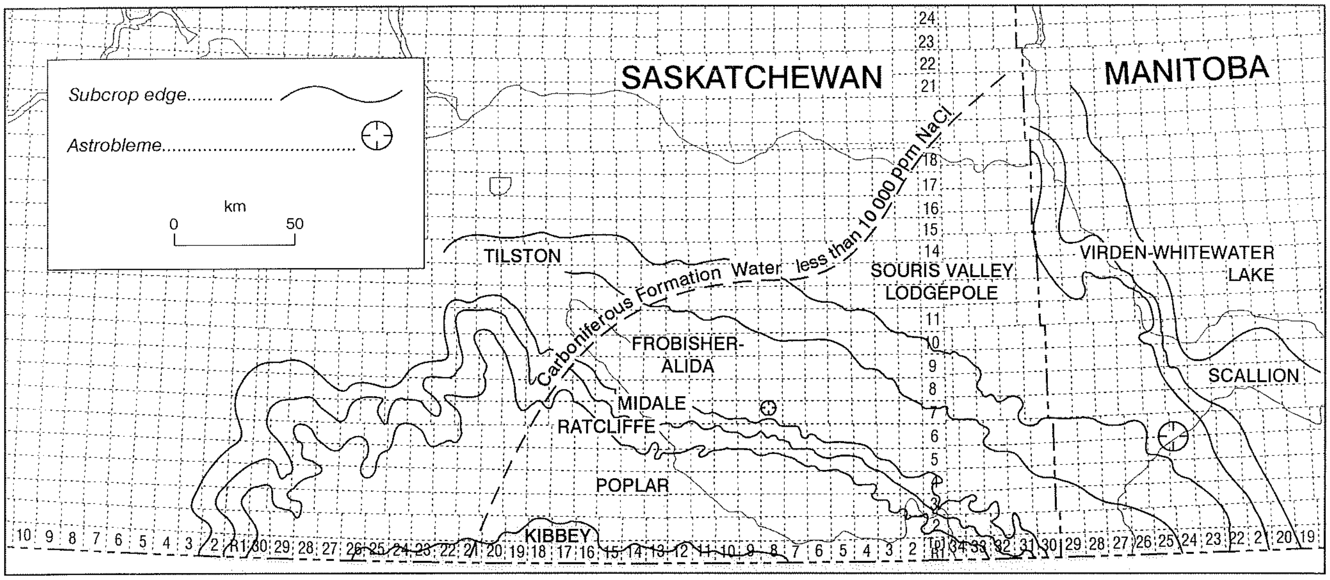


***Figure 40.*** *Carboniferous plays, Williston Basin. Play areas lie between the international border to the south, the zone of low salinity formation water to the northwest, and the erosional edges of each reservoir unit to the northeast.*

Oil pools in Waulsortian-type carbonate mud mounds in the Lodgepole Formation in North Dakota have been discovered (Burke and Diehl, 1993; Montgomery, 1996). Since 1966, 13 fields have been discovered. The most significant include the Dickinson Field (24 million barrels in-place), discovered in 1993, and the Eland Field (21 million barrels in-place), discovered in 1994 (Diehl, pers. comm., 1996). These oil accumulations in North Dakota represent a separate exploration petroleum play to the Lodgepole subcrop play in Canada, and are not evaluated in this report.

*Geology.* The Lodgepole Formation is underlain conformably by the Bakken shale. The lower Lodgepole Formation includes carbonate consisting of cherty, argillaceous limestone with poor to moderate porosity. The Lodgepole Formation grades upward to dolomitic marlstone with sponge spicules and chert. The dominant lithofacies in the formation are carbonates and fine-grained siliciclastics. The lower Lodgepole deposits are interpreted as shallow marine, whereas late Lodgepole deposition indicates an unstable to restricted shallow water environment. Diagenesis of the carbonate facies results in vuggy to fracture porosity.

*Exploration history.* The discovery sequence ($\hat{\beta}=1.2$) and the cumulative in-place volume discovered are shown graphically in Appendix B (Figs. B5.1 and B5.2). The in-place volume has not increased since the GSC's 1987 assessment. The cumulative in-place volume graph shows a moderate upward increase since 1982. The potential and discoveries are summarized in Table 52.

*Reservoir parameters.* Reservoirs have pool areas from 100 to 9,500 ha (min-max); net pay from 1 to 17 m (min-max); porosity from 1 to 12% (min-max); water saturation from 10 to 52% (min-max); and a recovery factor from 1 to 43% (min-max). The parameters are also shown graphically in Appendix B (Figs. B5.3 to B5.8).

**Table 52**

**Pools discovered and predicted for the Lodgepole play**

| Pool size class ($10^6 m^3$) | Pools discovered up to 1958 | Pools discovered between 1959 to 1994 | Pools yet to be discovered |
|---|---|---|---|
| < 0.1 | 0 | 0 | 5 |
| 0.1 - 1 | 10 | 0 | 16 |
| 1 - 10 | 7 | 0 | 0 |
| 10 - 100 | 2 | 0 | 0 |
| Total number of pools | 19 | 0 | 21 |
| In-place volume | $56.250 \times 10^6 m^3$ | 0 | $1.4 - 47 \times 10^6 m^3$ |

*Souris Valley–Tilston*

*Play definition.* This play is defined to include all oil pools in the Souris Valley (Lodgepole Formation) and the Tilston beds (Mission Canyon Formation) in southeastern Saskatchewan and southwestern Manitoba. The play area is defined by the arcuate northwesterly trend of the subcrops of these two formations from the international boundary to the zone of low salinity formation water in the west (Fig. 40).

*Geology.* The Souris Valley Beds are stratigraphically equivalent to the Banff Formation in Alberta; they conformably overlie the Bakken Shale (equivalent of the Exshaw Shale). The Souris Valley Beds consist of dark grey, thin-bedded, argillaceous limestone, limy shales and chert. The Tilston beds are divided into two unnamed units: $MC_1$ and $MC_2$. $MC_1$ consists of crinoidal oolitic grainstone and packstone and dense, cherty crystalline limestone. Unit $MC_2$ consists of argillaceous, silty to dolomitic limestone.

Top seals are either impermeable beds of the overlying Watrous Formation, or porosity pinchout at the unconformity surface. The Souris Valley beds at the type section are 176 m thick; the Tilston varies in thickness from 49 m to 80 m. Source rocks are either the Madison Formation or the organic-rich Bakken Shale.

*Exploration history.* The discovery sequence ($\hat{\beta}=1.0$) and the cumulative in-place volume discovered are shown graphically in Appendix B (Figs. B6.1 and B6.2). The in-place volume has increased from 41 to 102 x $10^6 m^3$ since the GSC's 1987 assessment. The increase is a result of new discoveries and appreciation of existing pools. The cumulative in-place volume graph shows a moderate upward increase. This play was under-evaluated in the GSC's 1987 assessment. The potential and discoveries are summarized in Tables 53 and 54.

*Reservoir parameters.* Reservoirs have pool areas from 49 to 1,000 ha; net pay from 4 to 15 m; porosity from 8 to 17%; water saturation from 13 to 40%; and a recovery factor from 1.6 to 45%. The parameters are also shown graphically in Appendix B (Figs. B6.3 to B6.8).

*Frobisher–Alida*

*Play definition.* This play is defined to include all oil pools in the Frobisher–Alida beds (Mission Canyon Formation) in reservoirs related to the subcrop unconformity. The play area is defined by the arcuate trend of the erosional edge of the Frobisher and Alida beds, from the International Boundary in southwestern Manitoba to the zone of low salinity formation water in southwestern Saskatchewan (Fig. 40).

*Geology.* The Frobisher–Kisbey–Alida beds overlie $MC_2$ evaporite of the Mission Canyon Formation and are, in turn, overlain by the Frobisher Evaporite of the Charles Formation. The carbonate consists of algal, oolitic-pisolitic limestone with fragmental fossils. Structural traps form along a series of topographic highs on the erosional surface of Paleozoic rocks sealed by the overlying tight strata, e.g., impermeable evaporite or structures at or near the subcrop edges of the Frobisher, Kisbey and Alida beds. The unit can attain a gross thickness of 123 m. The source of the oil is believed to be the carbonate of the Madison Group or the Bakken Shale.

*Exploration history.* The discovery sequence ($\hat{\beta}=0.5$) and the cumulative in-place volume discovered are shown graphically in Appendix B (Figs. B7.1 and B7.2). The in-place volume has increased from 253 to 453 x $10^6 m^3$ since the GSC's 1987 assessment. The increase is the result of new discoveries and appreciation of existing pools. The cumulative in-place volume graph shows a strong upward increase. This play was under-evaluated by the GSC's 1987 assessment. The potential and discoveries are summarized in Tables 55 and 56.

*Reservoir parameters.* The bioclastic reservoirs have pool areas from 32 to 4,300 ha; net pay from 4 to 15 m; porosity from 7 to 17%; water saturation from 25 to 45%; and a recovery factor from 2 to 42%. Higher recovery factors of pools might be possible from secondary recovery schemes, or pool development by horizontal drilling. The parameters are also shown graphically in Appendix B (Figs. B7.3 to B7.8).

*Midale*

*Play definition.* This play is defined to include all oil pools in the carbonate shelf Midale beds of the Charles Formation, in traps at and immediately downdip of the Midale subcrop edge. The play area is bounded by the Midale erosional subcrop edge, the International Boundary and the low salinity formation water zone (Fig. 40).

*Geology.* The Midale Beds consist of two distinct lithofacies: marine shelf carbonates and supratidal evaporites. Midale carbonates include skeletal, oolitic-pisolitic grainstone and packstone with good to excellent vuggy porosity and dolomitic wackestone with intercrystalline porosity. The carbonates lie between the impervious, layered and nodular Frobisher and Midale evaporites. Stratigraphic traps include the typical unconformity-edge trap sealed by overlying Mesozoic shales and a variant where the seal is the Carboniferous Midale evaporite. The source rocks are likely the Madison Group and organic-rich Bakken shale (Osadetz and Snowdon, 1986).

## Table 53

**Pools discovered and predicted for the Souris Valley play**

| Pool size class ($10^6m^3$) | Pools discovered up to 1989 | Pools discovered between 1990 to 1994 | Pools yet to be discovered |
|---|---|---|---|
| < 1 | 7 | 3 | 23 |
| 1 - 10 | 16 | 5 | 5 |
| 10 - 100 | 1 | 0 | 0 |
| Total number of pools | 24 | 8 | 28 |
| In-place volume | 91.059 x $10^6m^3$ | 11.336 x $10^6m^3$ | 2 - 76 x $10^6m^3$ |

## Table 54

**The five largest pools of Table 53 discovered between 1990 and 1994**

| Field, pool | In-place volume ($10^6m^3$) |
|---|---|
| Nottingham North, Tilston | 2.670 |
| Hazelwood South, Tilston | 2.400 |
| Bender Central, Tilston | 2.116 |
| Moose Valley South, Tilston | 1.368 |
| Big Marsh Lake, Tilston | 1.130 |

## Table 55

**Pools discovered and predicted for the Frobisher–Alida play**

| Pool size class ($10^6m^3$) | Pools discovered up to 1989 | Pools discovered between 1990 and 1994 | Pools yet to be discovered |
|---|---|---|---|
| < 0.1 | 0 | 1 | 6 |
| 0.1 - 1 | 26 | 4 | 17 |
| 1 - 10 | 43 | 3 | 4 |
| 10 - 100 | 16 | 0 | 0 |
| Total number of pools | 85 | 8 | 27 |
| In-place volume | 446.391 x $10^6m^3$ | 6.249 x $10^6m^3$ | 4 - 143 x $10^6m^3$ |

## Table 56

**The five largest pools of Table 55 discovered between 1990 and 1994**

| Field, pool | In-place volume ($10^6m^3$) |
|---|---|
| Buffalo Head, Frobisher–Alida | 2.725 |
| Workman South, Frobisher | 1.354 |
| Willmar West, Frobisher | 1.236 |
| Morrisview West, Frobisher–Alida | 0.330 |
| Arcola North, Frobisher | 0.268 |

*Exploration history.* The discovery sequence ($\hat{\beta}$ =0.8) and the cumulative in-place volume are graphically displayed in Appendix B (Figs. B8.1 and B8.2). The in-place volume has increased from 450 to 678 x $10^6m^3$ since the GSC's 1987 assessment. The increase is the result of new discoveries and appreciation of existing pools. The cumulative in-place volume graph shows a generally slight upward increase with a sharp increase in recent years. This play was under-evaluated by the GSC's 1987 assessment. The potential and the pools discovered are listed in Tables 57 and 58.

**Table 57**

**Pools discovered and predicted for the Midale play**

| Pool size class ($10^6m^3$) | Pools discovered up to 1989 | Pools discovered between 1990 and 1994 | Pools yet to be discovered |
|---|---|---|---|
| < 0.1 | 0 | 0 | 3 |
| 0.1 - 1 | 9 | 0 | 52 |
| 1 - 10 | 19 | 1 | 26 |
| 10 - 100 | 7 | 0 | 0 |
| 100 - 1,000 | 3 | 0 | 0 |
| Total number of pools | 38 | 1 | 81 |
| In-place volume | 675.769 x $10^6m^3$ | 1.988 x $10^6m^3$ | 15 - 560 x $10^6m^3$ |

**Table 58**

**The Midale pool of Table 57 discovered between 1990 and 1994**

| Field, pool | In-place volume ($10^6m^3$) |
|---|---|
| Union Jack, Midale | 1.988 |

*Reservoir parameters.* Reservoirs have pool areas from 30 to 17,300 ha; net pay from 2 to 20 m; porosity from 9 to 25%; water saturation from 22 to 54%; and a recovery factor from 0.7 to 39%. The parameters are also graphically displayed in Appendix B (Figs. B8.3 to B8.8).

*Ratcliffe*

*Play definition.* This play is defined to include all oil pools in the Ratcliffe beds (Charles, and Mission Canyon formations) that are on structural features in the central portion of the Williston Basin in southern Saskatchewan, and in stratigraphic traps resulting from updip porosity pinchout. The play area is bounded to the northeast near the Ratcliffe erosional subcrop edge, the international boundary to the south, and the estimated boundary of the low salinity zone to the northwest (Fig. 40).

*Geology.* The Ratcliffe shelf carbonates consist of calcareous mudstone and dense to oolitic dolomitized carbonate. These beds are interbedded with three evaporitic beds: Midale Evaporite at the base, Oungre Evaporite in the middle and an unnamed evaporite bed at the top. The Ratcliffe truncated subcrop edge forms an arcuate pattern in southeastern and south-central Saskatchewan. Ratcliffe beds attain a thickness of about 46 m. Structural traps were formed as a result of the collapse of the underlying Prairie Evaporite; the uppermost evaporite bed acts as a cap rock to the reservoir. Stratigraphic traps were formed by lateral facies and diagenetic changes in lithology.

*Exploration history.* The discovery sequence ($\hat{\beta}$ =2.3) and the cumulative in-place volume discovered are shown graphically in Appendix B (Figs. B9.1 and B9.2). The in-place volume has increased from 50 to 54 x $10^6m^3$ since the GSC's 1987 assessment. The increase is the result of appreciation in existing pools. No new pools have been discovered since the GSC's 1987 assessment. Although the cumulative in-place volume graph shows a strong upward increase pattern, the potential is rather limited. The potential and discoveries are summarized in Table 59.

*Reservoir parameters.* Reservoirs have pool areas from 100 to 3,500 ha (min-max); net pay from 2 to 20 m; porosity from 10 to 24% (min-max); water saturation from 10 to 47% (min-max); and a recovery factor from 10 to 39% (min-max). The parameters are shown graphically in Appendix B (Figs. B9.3 to B9.8).

*Bakken*

*Play definition.* This play is defined to include all oil and gas pools in structural-stratigraphic and unconformity-related traps in the Bakken sandstones in southeast Alberta, western Saskatchewan and southwestern Manitoba. The play area is bounded by the trend of the Carboniferous subcrop edge, the international boundary to the south and the Sweetgrass Arch (Fig. 34).

*Geology.* The Bakken Formation consists of calcite-cemented, shallow marine sandstone and/or siltstone and black, highly radioactive, organic-rich shale. In Alberta, basal sandstones and black shale form Exshaw Formation. It varies in thickness from a minimum of about 3 to 40 m. Oil production is primarily at the unconformity edge and in structure-stratigraphic, and unconformity-related traps. In

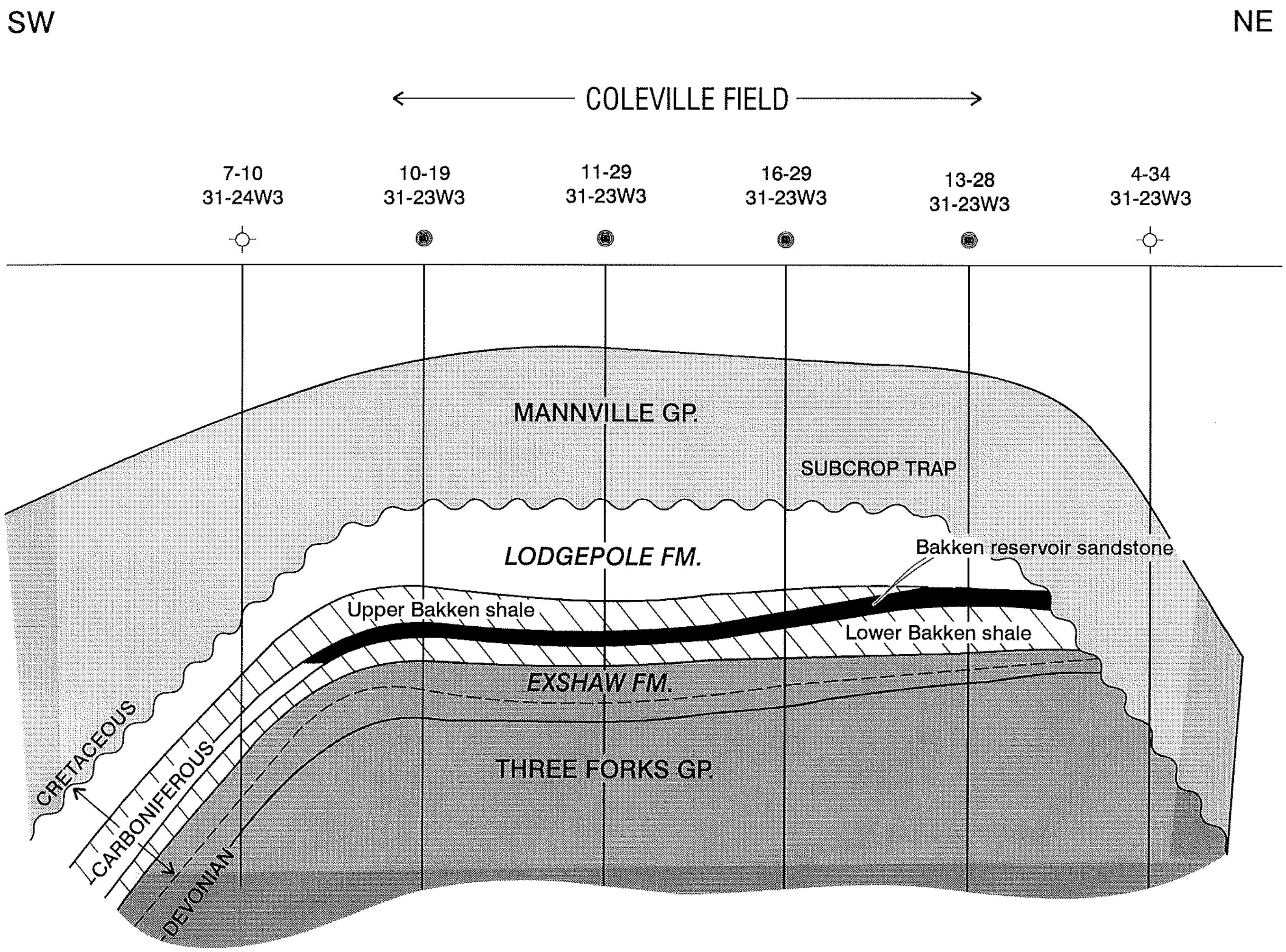


***Figure 41.*** *Cross section of the Coleville Field (after Grassby and Pelletier, 1990).*

the Coleville Bakken oil pool (Grassby and Pelletier, 1990) in western Saskatchewan, for example, oil was structurally trapped in a mild fold trending east and west (Fig. 41). Bakken oil pools are scattered throughout southeast Alberta and Saskatchewan. Reservoir quality in the formation is limited and most pools contain heavy oil. The source of the oil in Bakken reservoirs lies more than 375 km downdip in the Alberta/Montana trough. The oil owes its high density to pervasive light and medium biodegradation (Osadetz et al., 1994).

*Exploration history.* The discovery sequence ($\hat{\beta}=0.1$) and the cumulative in-place volume discovered are shown graphically in Appendix B (Figs. B10.1 and B10.2). The in-place volume has increased from 2.6 to 179 x $10^6 m^3$ since the GSC's 1987 assessment. The increase is the result of new discoveries. The cumulative in-place volume graph shows a gradual upward increase. The potential is promising. The potential and the pools discovered are listed in Tables 60 and 61.

*Reservoir parameters.* Reservoirs have pool areas from 17 to 2,900 ha; net pay from 2 to 12 m; porosity from 9 to 32%; water saturation from 23 to 37%; and a recovery factor from 0.33 to 24%. The relatively low recovery is likely attributable to the heavy crude component (12.5 API). The parameters are also shown graphically in Appendix B (Figs. B10.3 to B10.8).

## Table 59

**Pools discovered and predicted for the Ratcliffe play**

| Pool size class ($10^6 m^3$) | Pools discovered up to 1969 | Pools discovered between 1970 and 1994 | Pools yet to be discovered |
|---|---|---|---|
| < 1 | 0 | 0 | 3 |
| 1 - 10 | 7 | 0 | 19 |
| 10 - 100 | 1 | 0 | 0 |
| Total number of pools | 8 | 0 | 22 |
| In-place volume | $54.323 \times 10^6 m^3$ | 0 | $27 - 78 \times 10^6 m^3$ |

## Table 60

**Pools discovered and predicted for the Bakken play**

| Pool size class ($10^6 m^3$) | Pools discovered up to 1989 | Pools discovered between 1990 and 1994 | Pools yet to be discovered |
|---|---|---|---|
| < 0.1 | 2 | 0 | 141 |
| 0.1 - 1 | 3 | 0 | 25 |
| 1 - 10 | 11 | 1 | 12 |
| 10 - 100 | 5 | 0 | 0 |
| Total number of pools | 21 | 1 | 178 |
| In-place volume | $176.390 \times 10^6 m^3$ | $2.512 \times 10^6 m^3$ | $5 - 158 \times 10^6 m^3$ |

## Table 61

**The Bakken pool of Table 60 discovered between 1990 and 1994**

| Field, pool | In-place volume ($10^6 m^3$) |
|---|---|
| Ceylon, Bakken Sand | 2.512 |

## TRIASSIC SYSTEM

### Geological framework

The areal distribution of the Triassic sediments in the Western Canada Sedimentary Basin is displayed in Figure 42 and its stratigraphic nomenclature is illustrated in Figure 43. The strata are subdivided into three main assemblages, which in most areas coincide with three major regional transgressive-regressive marine cycles (Podruski et al., 1988; Gibson and Barclay, 1989; Barclay, 1993). These assemblages are: (1) Lower Triassic Montney Formation shelf and shoreline sandstones; (2) Middle to lower Upper Triassic Doig, Halfway, and Charlie Lake formation shelf and shoreline sandstone, evaporite and carbonate; and (3) Upper Triassic Baldonnel and Pardonet formation nearshore to distal shelf carbonate. Each major cycle appears to be asymmetrical with a short transgressive phase being followed by prolonged overall regression (Embry, 1988).

#### *Assemblage 1. Lower Triassic Montney Formation*

The transgressive part of the assemblage rests on the smoothly bevelled surface of the Permian Belloy Formation. A basal transgressive sandstone containing phosphate and chert pebbles commonly occurs at the contact. This sandstone is overlain by very thin bedded, dark grey calcareous shale and mudstone virtually devoid of fauna. These sediments are interpreted as having been deposited in a distal shelf or basinal setting. Eastward toward the margin of the basin, fine-grained glauconitic sandstone with interbedded shales represent proximal shelf facies (Gibson and Barclay, 1989).

The strata deposited in the regressive phase consist of light coloured dolomitic to calcareous siltstone, and micritic and bioclastic limestone and sandstone, with minor shale beds, deposited in a proximal shelf setting. Porous sandstone and coquina, producing oil and gas in the Sturgeon-Kaybob areas represent marked progradations of shoreline facies within the overall regressive pattern (Miall, 1976).

#### *Assemblage 2. Middle to lower Upper Triassic Doig, Halfway and Charlie Lake formations*

In the subsurface, the base of Assemblage 2 is marked by a radioactive phosphatic zone at the contact of the Montney and Doig formations. The lower part of the Doig Formation consists of grey phosphatic and calcareous siltstone, grading upward into calcareous siltstone, bituminous shale and argillaceous siltstone, representing deposition in a shelf to distal shoreface setting (Armitage, 1962).The Upper Doig Formation marks the beginning of the regressive phase of this assemblage and consists of a coarsening-upward sequence of shale near the base, grading upward through fine-grained sandstone to coarse-grained sandstone at the top (Gibson, 1968; Aukes and Webb, 1986). These strata are characterized by sandy siltstone and fine-grained, phosphatic, calcareous sandstone, bioturbation, shell fragments, and acritarchs (Armitage, 1962). These shelf deposits are overlain by shoreface sandstone, commonly dolomitic and coquinoid, as well as siltstone, shale and occasionally limestone.

Although the regional nature of the Halfway-Doig contact is controversial (Armitage, 1962; Barss et al., 1964), progressive truncation is evident from the regressive pattern of Doig Formation shelf sediments coarsening upward into shallow-marine and shoreline sandstones of the Halfway Formation, which in turn, grade into overlying sabkha sediments of the basal Charlie Lake Formation. The Halfway sandstone–Charlie Lake contact is distinct in the eastern subsurface, but becomes less so westward where the Charlie Lake is dominated by shallow marine sandstone (Barss et al., 1964; Armitage, 1962). The overall coarsening-upward pattern of the Halfway and Doig formation succession is locally interrupted by coquinas and sandstones thought to have been deposited in tidal inlets and channels (Cant, 1986; Barclay and Leckie, 1986; Horne et al., 1985; Munroe and Moslow, 1990). Halfway Formation lithofacies represent deposition in shoreface, barrier island, and sabkha settings. This pattern is complicated by possible intermittent relative sea-level falls during Halfway Formation deposition, causing multiple shorelines and perhaps initiating multiple erosional events (Hunt and Ratcliffe, 1959; Campbell et al., 1989). To the west of the shoreline units, the Halfway is a laterally extensive blanket deposit of fine-grained sandstone representing lower shoreface to shelf deposition (Armitage, 1962; Clark, 1961).

In the eastern parts of the Peace River Embayment, Charlie Lake Formation lithofacies include anhydrite and evaporitic dolomitic mudstone, shale and siltstone redbeds, stromatolitic and skeletal carbonate, dissolution breccias, sandstone, and salt (Barss et al., 1964; Gibson, 1974, 1975; Aukes and Webb, 1986; Higgs, 1990). Reservoir lithofacies occur mainly in stromatolitic skeletal carbonate and sandstone. These facies represent deposition in supratidal to intertidal environments, such as restricted lagoons and salt pans, tidal flats, aeolian dunes, barrier bars and beach shoals (Gibson, 1975; Edwards et al., 1994), and tidal channels belonging to flat, arid coastal plains. In western parts of the Peace River Embayment, carbonate and clean sandstone intercalated with the eastern facies represent slightly deeper marine environments. Most oil and gas resources occur within this assemblage.

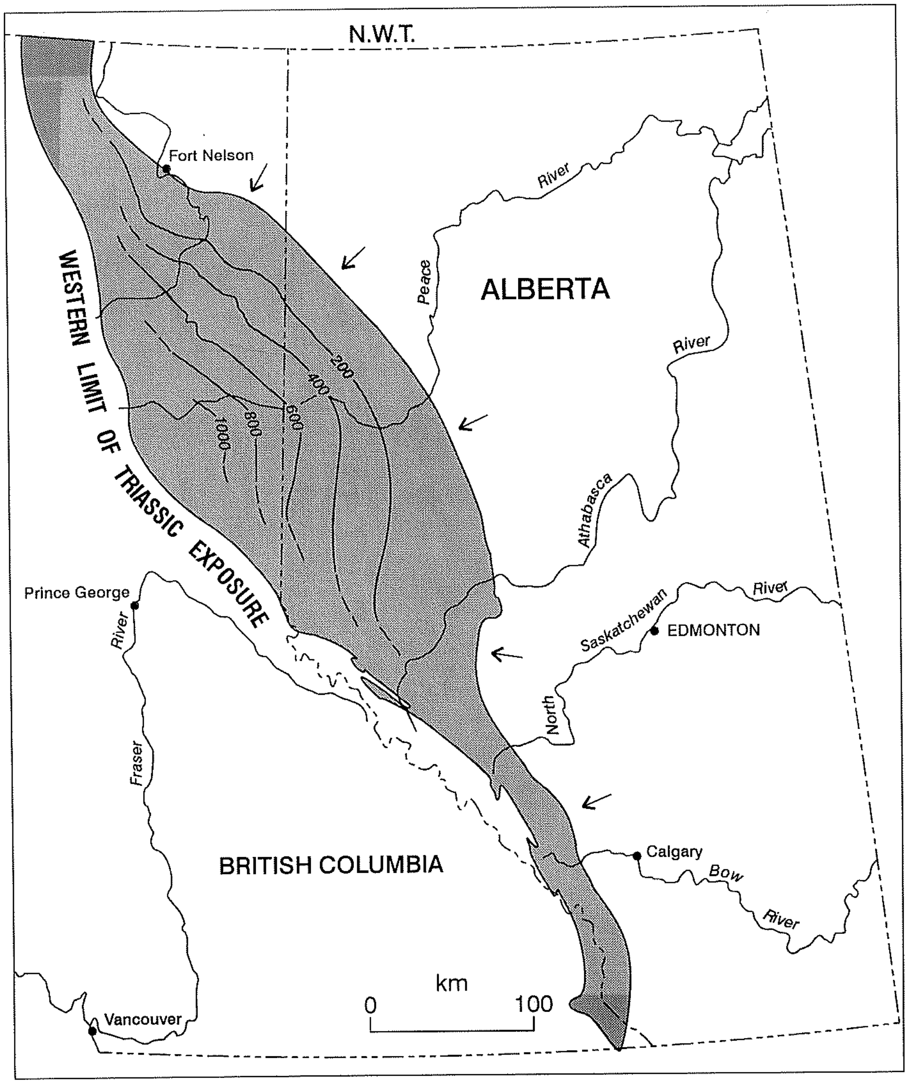


***Figure 42.*** *Isopach map of Triassic sediments in Alberta. The eastern edge is defined by the Montney subcrop. The western margin is defined by the limit of Triassic outcrops. Arrrows show probable direction of sediment transport (modified from Edwards et al., 1994; Barss et al., 1964).*

### *Assemblage 3. Upper Triassic Baldonnel and Pardonet formations*

Marine limestone, siltstone and dolostone of the Baldonnel and Pardonet formations represent a return to transgressive shallow marine conditions. In Assemblage 3, transgressive lower Baldonnel carbonate conformably overlies Charlie Lake evaporite. The base of Assemblage 3 is considered to begin above the last occurrence of anhydrite beds (Hunt and Ratcliffe, 1959; Barss and Montandon, 1981). Lithofacies in this assemblage include dolomitic mudstone to grainstone, very fine grained sandstone and argillaceous siltstone (Hunt and Ratcliffe, 1959; Gibson, 1975; Bever and McIlreath, 1984). Facies are interpreted to represent deposition in shoreface to shoreline environments.

The Pardonet Formation represents the final phase of transgressive deposition in Assemblage 3. It rests conformably on the uppermost Baldonnel Formation (Armitage, 1962; Gibson, 1975, 1993a, b).

In the western parts of the Peace River Embayment, a lower Pardonet unit consisting of dark dolomitic and argillaceous siltstone represents transgressive deposition over the upper Baldonnel Formation (Barss and Montandon, 1981). The upper Pardonet Formation is dominated by sandy, pelletal, oolitic bioclastic and intraclastic limestone and dolomite.

The stratigraphic column of the Triassic system is shown in Figure 43. Additional information about the regional geology can be found in Mossop and Shetsen (1994).

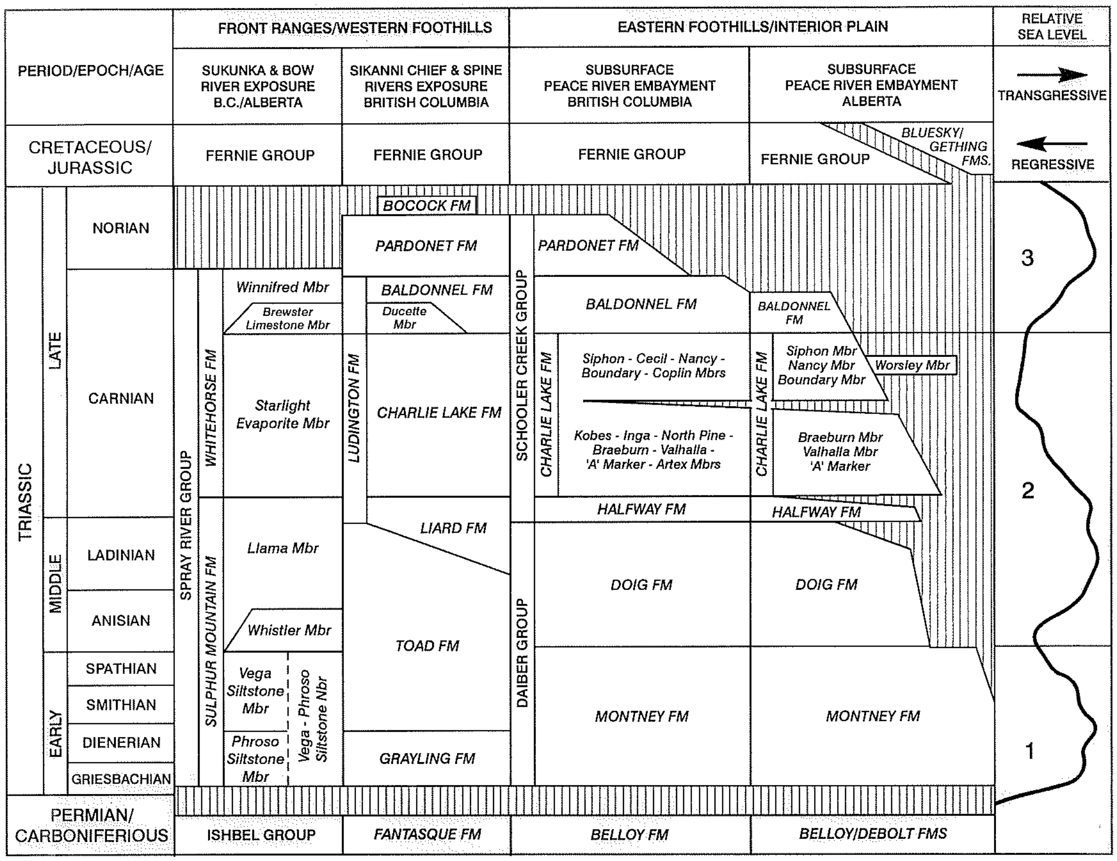

*Figure 43. Table of Triassic formations, subsurface and surface of the Western Canada Sedimentary Basin (modified from Gibson and Barclay, 1989).*

All Triassic trap types can be classified into stratigraphic and structural traps. Stratigraphic traps include lithofacies pinchouts and unconformity-related traps, whereas structural traps are differentiated based on geometry, location, and timing of controlling tectonic events. The first group involves underlying Peace-River-Arch-related Paleozoic structures, while a second group consists of folded reservoirs associated with the Laramide Orogeny. More information about trap types can be found in Campbell et al. (1989), and Forbes et al. (1991). The oil sources have been discussed by Creaney and Allan (1990) and Riediger et al. (1990). The contact of the Triassic with overlying Jurassic formations is unconformable throughout the region.

The Triassic oil play definitions are based on the framework established for gas resource assessments (Bird et al., 1994a).

## Resource assessment

### *Triassic system potential*

The potential of the Triassic System ranges from 150 to 580 x $10^6 m^3$. The mean (or expected value) of the potential distribution is 345 x $10^6 m^3$. The Charlie Lake carbonates play contains the greatest potential for oil in the Triassic system.

The in-place volume has increased from 262 x $10^6 m^3$ to 469 x $10^6 m^3$ since the GSC's 1987 assessment. A total of 33 x $10^6 m^3$ of in-place volume was discovered between 1990 and 1994. The number of discoveries and the ten largest pools discovered between 1990 and 1994 are listed in Tables 62 and 63.

### *Peace River embayment region*

Eight established mature plays: Montney subcrop, Halfway–Doig shore zone–Peace River Arch, Halfway–Doig shore zone, Halfway–Doig shelf–Peace River Arch, Halfway–Doig shelf, Charlie Lake clastics–Inga, Charlie Lake clastics–Peace River Arch, Charlie Lake carbonates, and one immature play, Baldonnel subcrop, are located within this region.

### Table 62

### Triassic oil pools discovered

| Pool size class ($10^6m^3$) | Pools discovered up to 1989 | Pools discovered between 1990 and 1994 |
|---|---|---|
| < 0.1 | 93 | 16 |
| 0.1 - 1 | 197 | 56 |
| 1 - 10 | 51 | 7 |
| 10 - 100 | 8 | 0 |
| Total number of pools | 349 | 79 |
| In-place volume | 436.128 x $10^6m^3$ | 32.552 x $10^6m^3$ |

### Table 63

### The ten largest Triassic pools discovered between 1990 and 1994

| Field, pool | In-place volume ($10^6m^3$) |
|---|---|
| Worsley, Charlie Lake H and J | 5.440 |
| Valhalla, Montney B | 2.592 |
| Boundary Lake South, Triassic N | 2.352 |
| Woking, Halfway B | 1.756 |
| Flatrock West, Halfway G | 1.316 |
| Bonanza, Doig B | 1.021 |
| Bonanza, Doig C | 1.020 |
| Buick Creek, Lower Halfway E | 0.922 |
| Valhalla, Boundary M | 0.897 |
| Valhalla, Doig F | 0.787 |

### Table 64

### Pools discovered and predicted for the Montney play

| Pool size class ($10^6m^3$) | Pools discovered up to 1989 | Pools discovered between 1990 and 1994 | Pools yet to be discovered |
|---|---|---|---|
| < 0.1 | 3 | 2 | 31 |
| 0.1 - 1 | 4 | 4 | 10 |
| 1 - 10 | 3 | 1 | 1 |
| 10 - 100 | 1 | 0 | 0 |
| Total number of pools | 11 | 7 | 42 |
| In-place volume | 46.083 x $10^6m^3$ | 3.886 x $10^6m^3$ | 1 - 53 x $10^6m^3$ |

### Table 65

### The five largest pools of Table 64 discovered between 1990 and 1994

| Field, pool | In-place volume ($10^6m^3$) |
|---|---|
| Valhalla, Montney B | 2.592 |
| Valhalla, Montney A | 0.460 |
| Valhalla, Montney C | 0.360 |
| Flood, Montney A | 0.269 |
| Normandville, Montney A | 0.102 |

*Montney subcrop*

*Play definition.* This play is defined to include all oil and gas pools in stratigraphic traps in the Montney sandstone and coquina reservoirs. Hydrocarbons are trapped in erosional truncations at the eastern subcrop edge, by structural drape over underlying Paleozoic features, in facies pinchouts, and combinations of the previous three types. The play area forms a belt up to 130 km wide, limited to the east by the Montney erosional edge, to the west and south by the depositional edge of reservoir facies sandstones, and to the northwest by the northern limit of Peace River Arch structural influence (Fig. 44). Unlike the gas plays (Bird et al., 1994), oil has not been found in the two Montney immature plays: Montney Distal shelf- Glacier and Montney subcrop North-Ring.

*Geology.* Reservoirs occur in several sandstone and bioclastic dolomite units, representing progradational pulses of shoreface sediments that are interbedded with distal to proximal shelf deposits. Less productive reservoirs include very fine- to fine-grained, quartzose sandstone cemented with carbonate (Metherell, 1966; Miall, 1976). Erosional truncation is a common trapping mechanism. Enhancement of porosity by the leaching of soluble grains at or near the erosional surface is likely to occur anywhere along the subcrop zone. The presence of fracturing is also an important control on reservoir distribution and quality. Drape of reservoir facies and differential compaction over buried Leduc reef topography is the trapping mechanism for the Sturgeon Lake South pool. Facies pinchout traps are caused by the lateral termination of sandstone and coquina reservoir facies, where they change to siltstone and shale.

*Exploration history.* The discovery sequence ($\hat{\beta}$=0.6) and the cumulative in-place volume discovered are shown graphically in Appendix C (Figs. C1.1 and C1.2). The in-place volume has increased from 44 to 50 x $10^6 m^3$ since the GSC's 1987 assessment. The increase in volume is a result of new discoveries. The cumulative in-place volume graph shows a gradual upward increase with a sharp increase in 1993. The potential and discoveries are summarized in Tables 64 and 65.

*Reservoir parameters.* Reservoirs have pool areas from 10 to 8,700 ha (min-max); net pay from 1 to 10 m (min-max); porosity from 1 to 20% (min-max); water saturation from 1 to 65% (min-max); and a recovery factor from 0.01 to 51% (min-max). The parameters are shown graphically in Appendix C (Figs. C1.3 to C1.8).

*Halfway–Doig shore zone–Peace River Arch*

*Play definition.* This play is defined to include all oil and gas pools in facies change traps in nearshore sandstones and coquinas of the Halfway and Doig formations. Although this play is dominantly a stratigraphic play, it includes a large area that was influenced by an intermittent structural disturbance associated with the Peace River Arch. The eastern limit of the play is defined by the erosional edges of the Halfway and Doig formations (Fig. 45). The western edge of the play is delineated by a westward change from isolated shoreline and shoreface sandbodies to a broad, continuous shelf sandstone. The northern and southern limits of the play are established by the extent of Peace River Arch tectonic effects as defined in O'Connell et al. (1990).

*Geology.* The Halfway and Doig formations occur over a broad, arc-shaped area, and contain a sequence of interbedded clastics, evaporite and carbonate that dips and thickens in a southwesterly direction. Depositional settings include proximal shelf, shoreface, barrier island, and sabkha environments (Halton, 1981; Barclay and Leckie, 1986; Moslow and Davies, 1992; Willis, 1992). Several *en enchelon* northwest-trending shorelines hosting oil and gas fields are attributed to progradational pulses of sedimentation. Some of these sandbodies are interpreted to have been isolated by episodic erosional events (Campbell et al., 1989). More information can be found in Wittenberg (1992) and Wittenberg and Moslow (1992).

Within a belt parallel to the Halfway shoreline, bar sandstone and coquinoid storm ridge sandstone was also deposited. Bar sandstone consists of fine-grained, well-sorted and subrounded grains of quartz with good intergranular porosity. The coquina facies consists of a mixture of sand and dolomite with abundant moulds of leached fossils.

*Exploration history.* The discovery sequence ($\hat{\beta}$=0.6) and the cumulative in-place volume discovered are shown graphically in Appendix C (Figs. C2.1 and C2.2). The in-place volume has increased from 24 to 89 x $10^6 m^3$ since the GSC's 1987 assessment. The increase is the result of new discoveries and appreciation of existing pools. Pools (in-place volume greater than 1 x $10^6 m^3$) predicted by the GSC's 1987 assessment have been discovered. The cumulative in-place volume graph shows a strong upward increase. The potential and discoveries are summarized in Tables 66 and 67.

*Reservoir parameters.* Reservoirs have pool areas from 35 to 1,230 ha; net pay from 1.4 to 17 m; porosity from 7 to 17%; water saturation from 13 to 48%; and a recovery factor from 0.3 to 25%. The parameters are also shown graphically in Appendix C (Figs. C2.3 to C2.8).

*Halfway–Doig shore zone*

*Play definition.* This play is defined to include isolated oil and gas reservoirs in the Halfway and Doig formations that

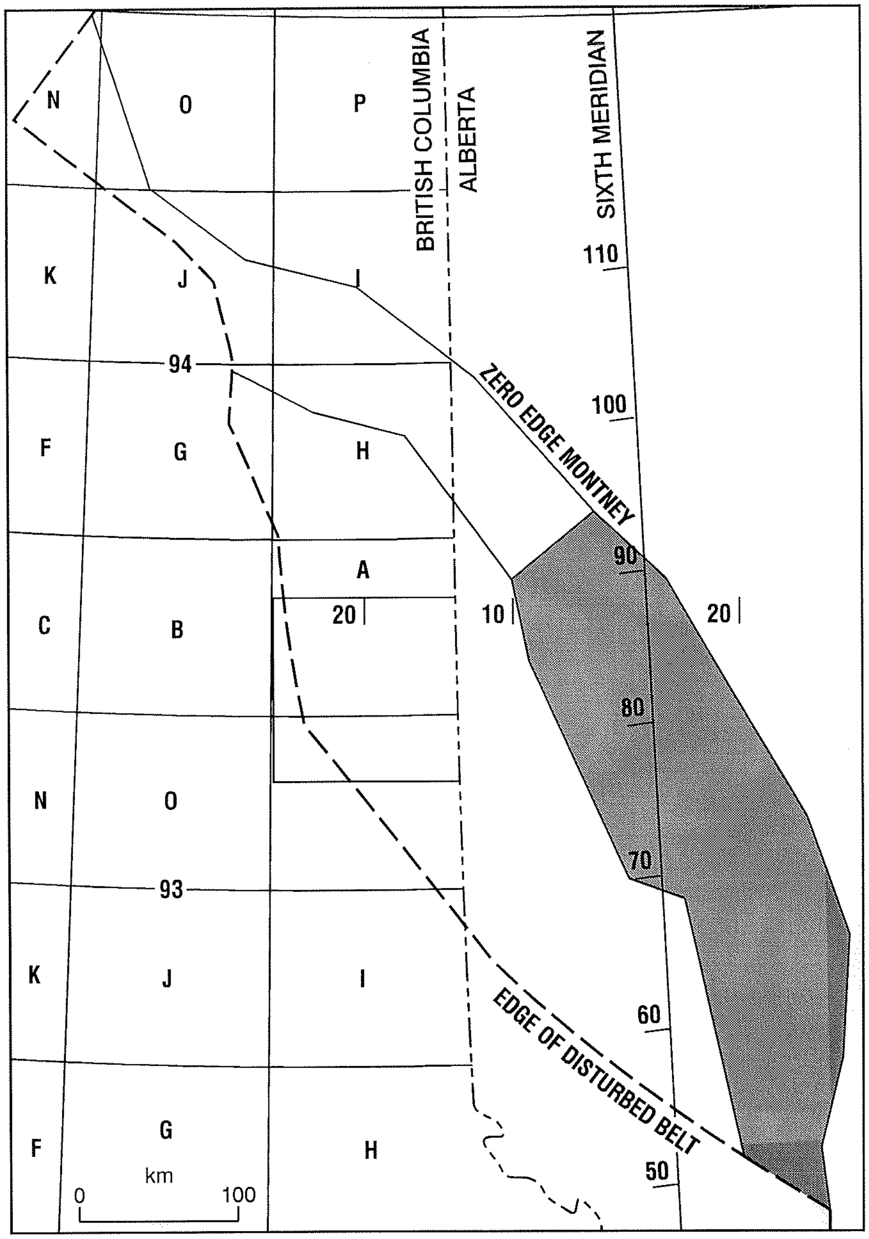


***Figure 44.*** *Map of the Montney subcrop play area (shaded area). The unshaded areas show the Montney play areas for gas-prone plays.*

were deposited in shallow marine to nearshore environments, and overlain by evaporitic rocks of the Charlie Lake Formation. Hydrocarbons are trapped in facies pinchouts. Underlying Doig Formation siltstone and fine-grained sandstone form lateral seals. The play limits are defined by zero edge to the east and north and a change in facies to shelf sandstone to the west. To the south, the play limit is defined by a transition to the more structurally-influenced Halfway–Doig shore zone (Peace River Arch) play (Fig. 46).

*Geology.* Depositional settings include proximal shelf, shoreface, barrier island and sabkha environments. Reservoirs consist of isolated lenses of quartzose and coquinoid sandstone filling erosional lows on the Doig surface (Caplan and Moslow, 1991). The sandstone formed as elongate, southeast-trending bodies, deposited in tidal inlets on an irregular Doig Formation surface. The primary structure of the Milligan Creek oil field was studied by Clark (1961).

*Exploration history.* The discovery sequence ($\hat{\beta}=1.2$) and the cumulative in-place volume discovered are shown graphically in Appendix C (Figs. C3.1 and C3.2). The in-place volume has increased from 44 to 72 x $10^6 m^3$ since the GSC's 1987 assessment. The increase is the result of new discoveries and appreciation of existing pools. The largest pool predicted by the GSC's 1987 assessment has been

**Table 66**

**Pools discovered and predicted for the Halfway–Doig shore zone–Peace River Arch play**

| Pool size class ($10^6 m^3$) | Pools discovered up to 1989 | Pools discovered between 1990 and 1994 | Pools yet to be discovered |
|---|---|---|---|
| < 0.1 | 15 | 4 | 101 |
| 0.1 - 1 | 40 | 7 | 78 |
| 1 - 10 | 16 | 3 | 5 |
| 10 - 100 | 1 | 0 | 0 |
| Total number of pools | 72 | 14 | 184 |
| In-place volume | $82.201 \times 10^6 m^3$ | $6.443 \times 10^6 m^3$ | $2 - 60 \times 10^6 m^3$ |

**Table 67**

**The five largest pools of Table 66 discovered between 1990 and 1994**

| Field, pool | In-place volume ($10^6 m^3$) |
|---|---|
| Woking, Halfway B | 1.756 |
| Bonanza, Doig B | 1.021 |
| Bonanza, Doig C | 1.020 |
| Valhalla, Doig F | 0.787 |
| Valhalla, Halfway J | 0.564 |

**Table 68**

**Pools discovered and predicted for the Halfway–Doig shore zone play**

| Pool size class ($10^6 m^3$) | Pools discovered up to 1989 | Pools discovered between 1990 and 1994 | Pools yet to be discovered |
|---|---|---|---|
| < 0.1 | 9 | 0 | 119 |
| 0.1 - 1 | 34 | 12 | 117 |
| 1 - 10 | 6 | 0 | 1 |
| 10 - 100 | 2 | 0 | 0 |
| Total number of pools | 51 | 12 | 237 |
| In-place volume | $68.933 \times 10^6 m^3$ | $2.761 \times 10^6 m^3$ | $4 - 93 \times 10^6 m^3$ |

**Table 69**

**The five largest pools of Table 68 discovered between 1990 and 1994**

| Field, pool | In-place volume ($10^6 m^3$) |
|---|---|
| Milligan Creek West, Halfway I | 0.579 |
| Milligan Creek West, Halfway H | 0.441 |
| Rigel, Halfway O | 0.329 |
| Wildmint, Halfway I | 0.252 |
| Peejay West, Halfway D | 0.238 |

Overprinting and inversion of earlier structures by subsequent Laramide tectonism combined to form traps. Subtle facies and diagenetic changes are also important in localizing reservoirs in this regionally continuous fine-grained sandstone.

*Exploration history.* The discovery sequence ($\hat{\beta}=0.8$) and the cumulative in-place volume discovered are shown graphically in Appendix C (Figs. C4.1 and C4.2). The in-place volume has increased from 7 to 16 x $10^6 m^3$ since the GSC's 1987 assessment. The increase is the result of new discoveries and appreciation of existing pools. The largest pool predicted by the GSC's 1987 assessment has been

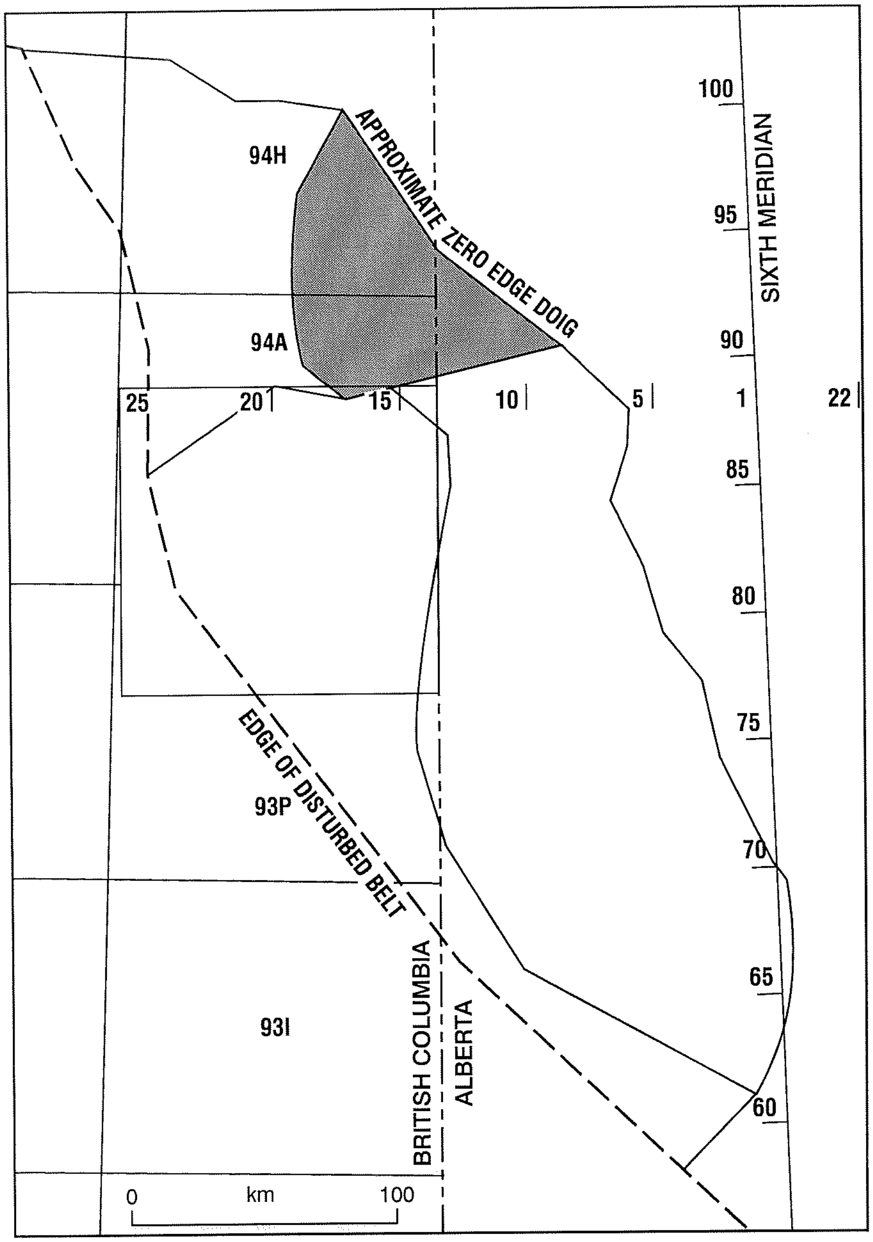


***Figure 46.*** *Map of the Halfway–Doig shore zone play area.*

discovered. The cumulative in-place volume graph shows a strong upward increase. The potential and discoveries are summarized in Tables 70 and 71.

*Reservoir parameters.* Reservoirs have pool areas from 64 to 670 ha; net pay from 0.7 to 12 m; porosity from 6 to 19%; water saturation from 13 to 53%; and a recovery factor from 0.2 to 20%. The parameters are also shown graphically in Appendix C (Figs. C4.3 to C4.8).

*Halfway–Doig shelf*

*Play definition.* This play is defined to encompass Halfway and Doig Formation sandstone reservoirs trapped in combination stratigraphic/structural traps. Gentle Laramide folds, associated with proximity to the western fold belt, overprint subtle facies change and diagenetic traps developed in shelf sandstone of the Halfway and Doig formations. The erosional edge, which forms the northern play boundary, may also be involved in the formation of traps. To the east, the play boundary abuts the primarily stratigraphic, Halfway–Doig shore zone play. The southern limit marks the change in dominance of the Peace River Arch structural influence to a mechanism of gentle folds associated with Laramide compression. The western limit is the Rocky Mountain foreland belt (Fig. 48).

*Geology.* Sandstone reservoirs have variable compositions and occur sporadically throughout the region. Doig

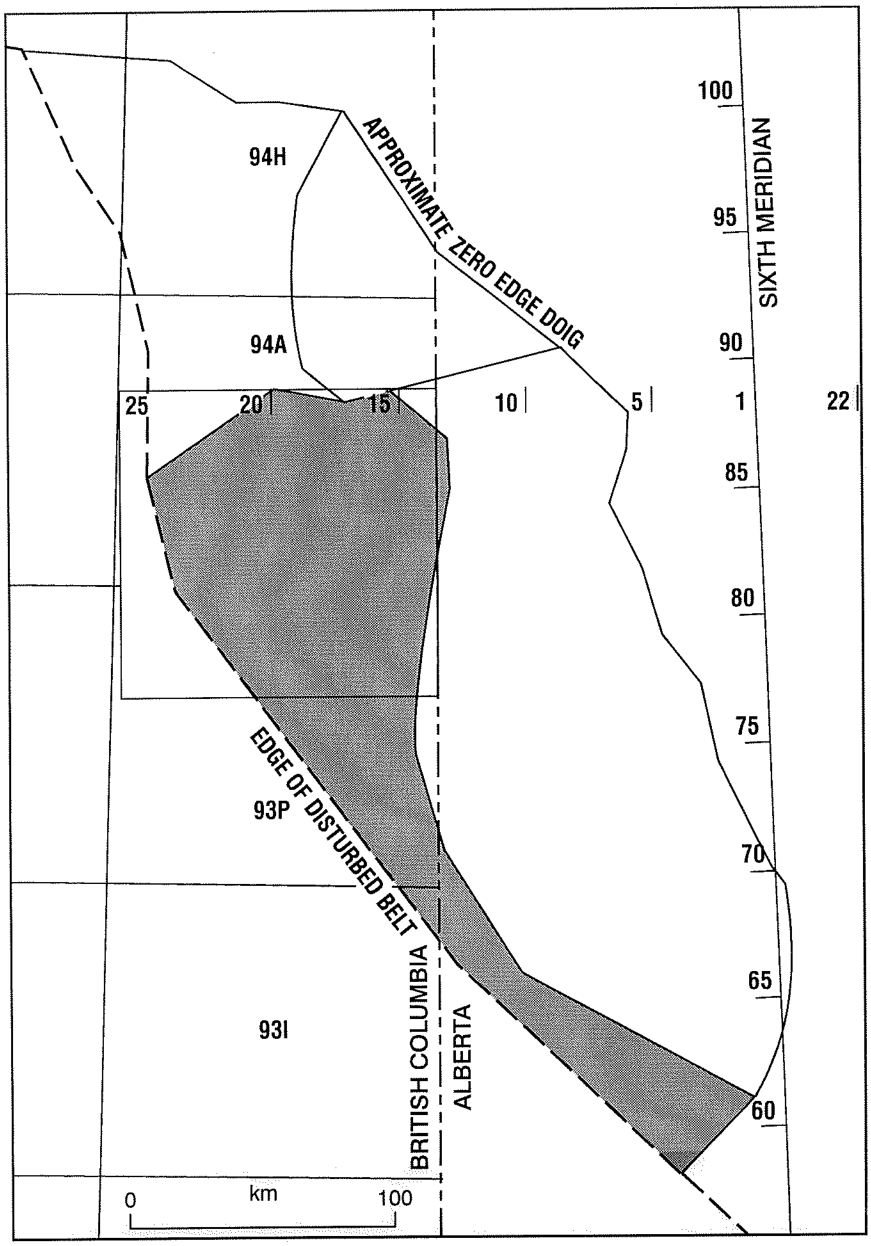


***Figure 47.*** *Map of the Halfway–Doig shelf–Peace River Arch play area.*

Formation sandstone is typically in the upper part of a sequence of interbedded siltstone and shale and represents part of a regressive transition to the Halfway sandstone. Doig Formation sandstone is fine-grained, argillaceous, cemented with carbonate and locally coquinoid (Munroe and Moslow, 1991). Halfway shelf sandstone is fine-grained and poorly sorted, has a high percentage of interstitial clay, and contains less skeletal fragments than sand deposited closer to the eastern shoreface.

*Exploration history*. The discovery sequence ($\hat{\beta}$ =0.8) and the cumulative in-place volume discovered are shown graphically in Appendix C (Figs. C5.1 and C5.2). The cumulative in-place volume graph shows a strong upward increase. This play was not defined in the GSC's 1987 assessment. The potential and discoveries are summarized in Tables 72 and 73.

*Reservoir parameters*. Reservoirs have pool areas from 10 to 250 ha (min-max); net pay from 1 to 21 m (min-max); porosity from 1 to 10% (min-max); water saturation from 1

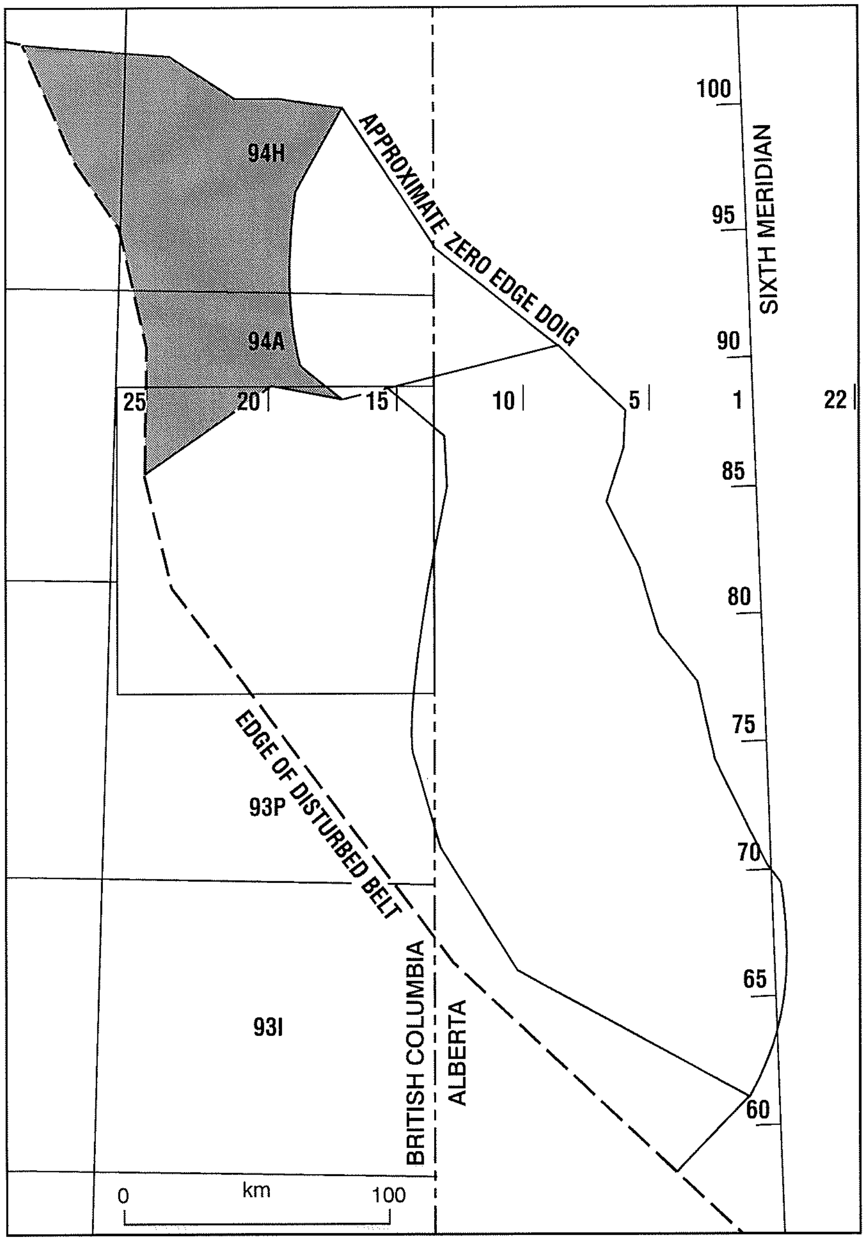


*Figure 48. Map of the Halfway–Doig shelf play area.*

to 20% (min-max); and a recovery factor from 0.10 to 20% (min-max). The parameters are also shown graphically in Appendix C (Figs. C5.3 to C5.8).

*Charlie Lake clastics – Inga*

*Play definition.* This play is defined to include oil and gas pools in Charlie Lake Formation sandstone. Reservoirs occur in stratigraphic traps that have an overprint of structural influence in the form of gentle folds caused by Laramide tectonism. The play is limited to the north and east by the Charlie Lake erosional edge, to the west by the deformed belt, and to the south by a change in structural style to block faulting on the Peace River Arch (Fig. 49).

*Geology.* Reservoirs occur in coastal and shallow marine sandstone deposited in shoreface, sabkha and aeolian environments. Trapping mechanisms include facies pinchouts, diagenetic traps, hydrodynamic traps, and erosional truncation by the post-Triassic unconformity or smaller scale intrasystem unconformities and diastems.

**Table 70**

**Pools discovered and predicted for the Halfway–Doig shelf–Peace River Arch play**

| Pool size class ($10^6m^3$) | Pools discovered up to 1989 | Pools discovered between 1990 and 1994 | Pools yet to be discovered |
|---|---|---|---|
| < 0.01 | 2 | 0 | 149 |
| 0.1 - 0.01 | 6 | 2 | 92 |
| 0.1 - 1 | 8 | 6 | 27 |
| 1 - 10 | 5 | 1 | 2 |
| Total number of pools | 21 | 9 | 270 |
| In-place volume | 12.525 x $10^6m^3$ | 3.236 x $10^6m^3$ | 4 - 20 x $10^6m^3$ |

**Table 71**

**The five largest pools of Table 70 discovered between 1990 and 1994**

| Field, pool | In-place volume ($10^6m^3$) |
|---|---|
| Flatrock West, Halfway G | 1.316 |
| Flatrock, Halfway J | 0.399 |
| Oak, Halfway C | 0.341 |
| Rigel, Halfway F | 0.335 |
| Rigel, Halfway I | 0.266 |

**Table 72**

**Pools discovered and predicted for the Halfway–Doig shelf play**

| Pool size class ($10^6m^3$) | Pools discovered up to 1989 | Pools discovered between 1990 and 1994 | Pools yet to be discovered |
|---|---|---|---|
| < 0.1 | 3 | 0 | 33 |
| 0.1 - 1 | 2 | 2 | 19 |
| 1 - 10 | 1 | 0 | 0 |
| Total number of pools | 6 | 2 | 52 |
| In-place volume | 2.051 x $10^6m^3$ | 1.405 x $10^6m^3$ | 3 - 13 x $10^6m^3$ |

**Table 73**

**The two largest pools of Table 72 discovered between 1990 and 1994**

| Field, pool | In-place volume ($10^6m^3$) |
|---|---|
| Buick Creek, Lower Halfway E | 0.922 |
| Buick Creek, Lower Halfway F | 0.483 |

Laramide structural overprinting in the form of gentle folds provides closure, especially in the western part of the area.

*Exploration history*. The discovery sequence ($\hat{\beta}=1.4$) and the cumulative in-place volume discovered are shown graphically in Appendix C (Figs. C6.1 and C6.2). Due to differing assignments of pools to plays, the number of pools considered in the 1987 assessment was greater than the number in the present study. Only one pool was discovered in 1992. However, the in-place volume has decreased from 21 to 19 x $10^6m^3$ due to the different pool assignments of these two assessments. The cumulative in-place volume graph shows a strong upward increase. The potential and discoveries are summarized in Tables 74 and 75.

*Reservoir parameters*. Reservoirs have pool areas from 10 to 10,000 ha (min-max); net pay from 1 to 2 m (min-max); porosity from 1 to 27% (min-max); water saturation from 1 to 50% (min-max); and a recovery factor from 0.1 to 36% (min-max). The parameters are also shown graphically in Appendix C (Figs. C6.3 to C6.8).

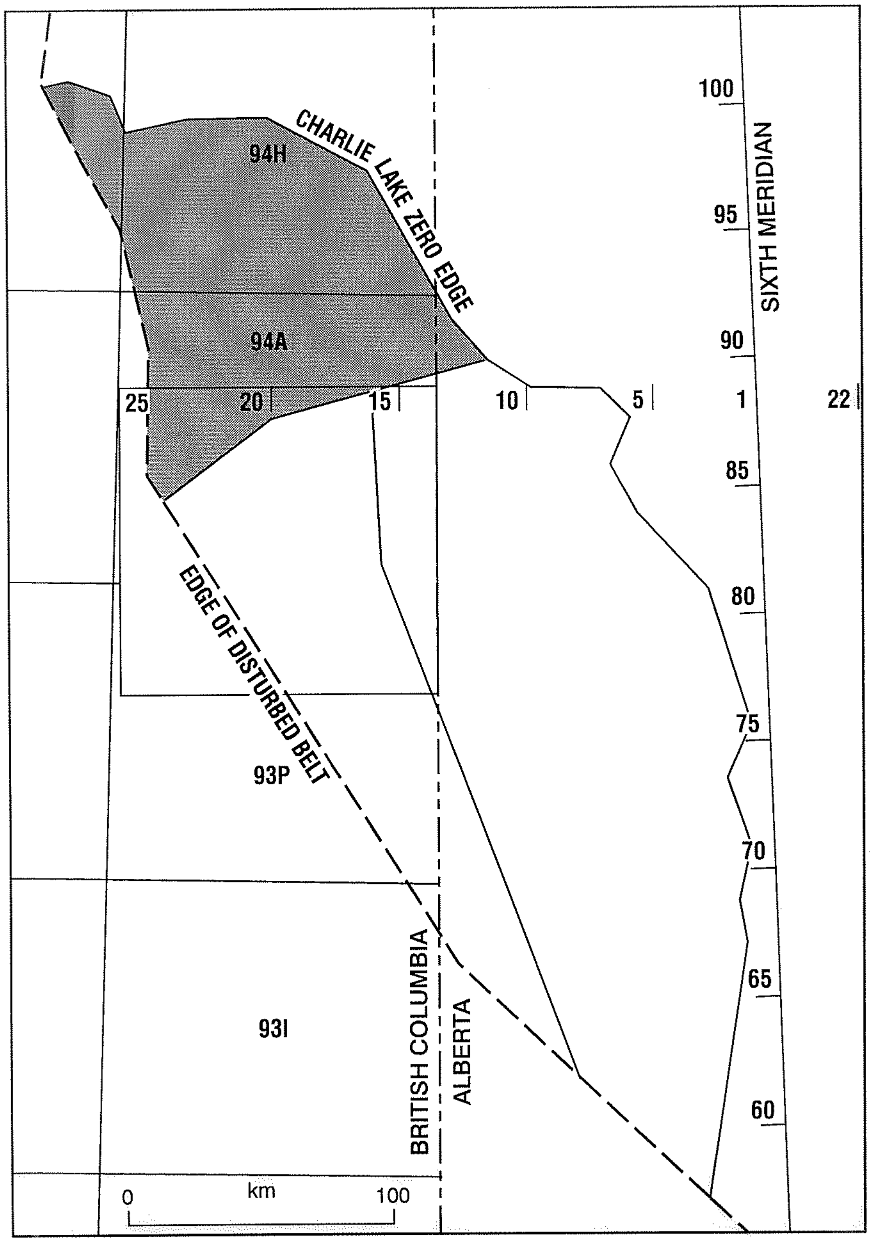


*Figure 49. Map of the Charlie Lake clastics–Inga play area.*

*Charlie Lake clastics — Peace River Arch*

*Play definition.* This play is defined to include all oil and gas pools in Charlie Lake Formation sandstone. Traps are formed in stratigraphic facies pinchouts similar to the Charlie Lake–Inga play to the north, but reservoirs are affected by block faulting associated with the Peace River Arch/Embayment. The eastern play boundary is defined by a lithological change to carbonate. To the west and south, the play is bounded by the Rocky Mountain Foreland structural belt (Fig. 50).

*Geology.* Sandstone reservoirs were deposited in aeolian, shoreface and shoreline environments. Trapping mechanisms include facies pinchouts, diagenetic traps, hydrodynamic traps, erosional truncation by the post-Triassic unconformity or smaller intra-formational unconformities and diastems. Structural influences include drape on Paleozoic Peace River Arch horsts and related fault-cut off traps. Reservoirs are sealed by anhydrite, evaporitic dolomite, siltstone and mudstone.

*Exploration history.* The discovery sequence ($\hat{\beta}=1.2$) and the cumulative in-place volume discovered are shown graphically in Appendix C (Figs. C7.1 to C7.2). The in-place volume has increased from 7 to 16 x $10^6 m^3$ since the GSC's 1987 assessment. The increase is the result of new discoveries. The cumulative in-place volume graph shows a

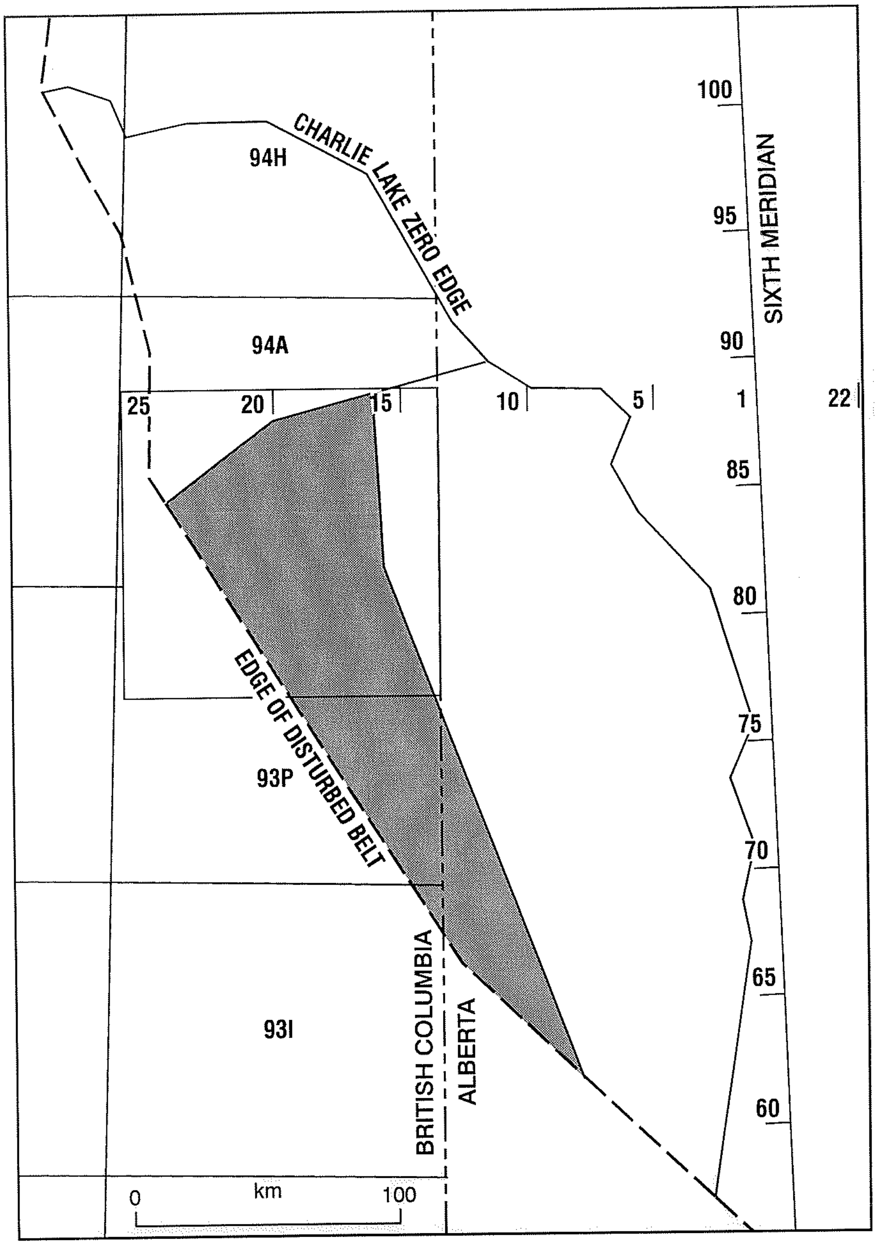


***Figure 50.*** *Map of the Charlie Lake clastics–Peace River Arch play area.*

strong upward increase. This play was under-evaluated by the GSC's 1987 assessment. The potential and discoveries are summarized in Tables 76 and 77.

*Reservoir parameters.* Reservoirs have pool areas from 64 to 480 ha; net pay from 1 to 2.7 m; porosity from 7 to 19%; water saturation from 4 to 37%; and a recovery factor from 1 to 41%. The parameters are also shown graphically in Appendix C (Figs. C7.3 to C7.8).

### *Charlie Lake carbonates*

*Play definition.* This play is defined to include oil and gas pools in algal carbonate of the Charlie Lake Formation, in combination stratigraphic/structural traps and in an area that has been influenced by Peace River Arch /Embayment block faulting. Play limits are defined to the west by a transition to sandstone facies and to the east, north and south by the Charlie Lake Formation erosional edge (Fig. 51). The play boundary between this play and the Charlie Lake clastics play to the west is transitional. The boundary is actually an interbed of sandstone and carbonate.

*Geology.* Reservoirs occur in several carbonate members of the Charlie Lake Formation. Trapping styles are principally stratigraphic, but have an important component of structural influence in the form of drape over older structures, fault traps and porosity enhancement through fractures. Stratigraphic trapping mechanisms include facies pinchouts,

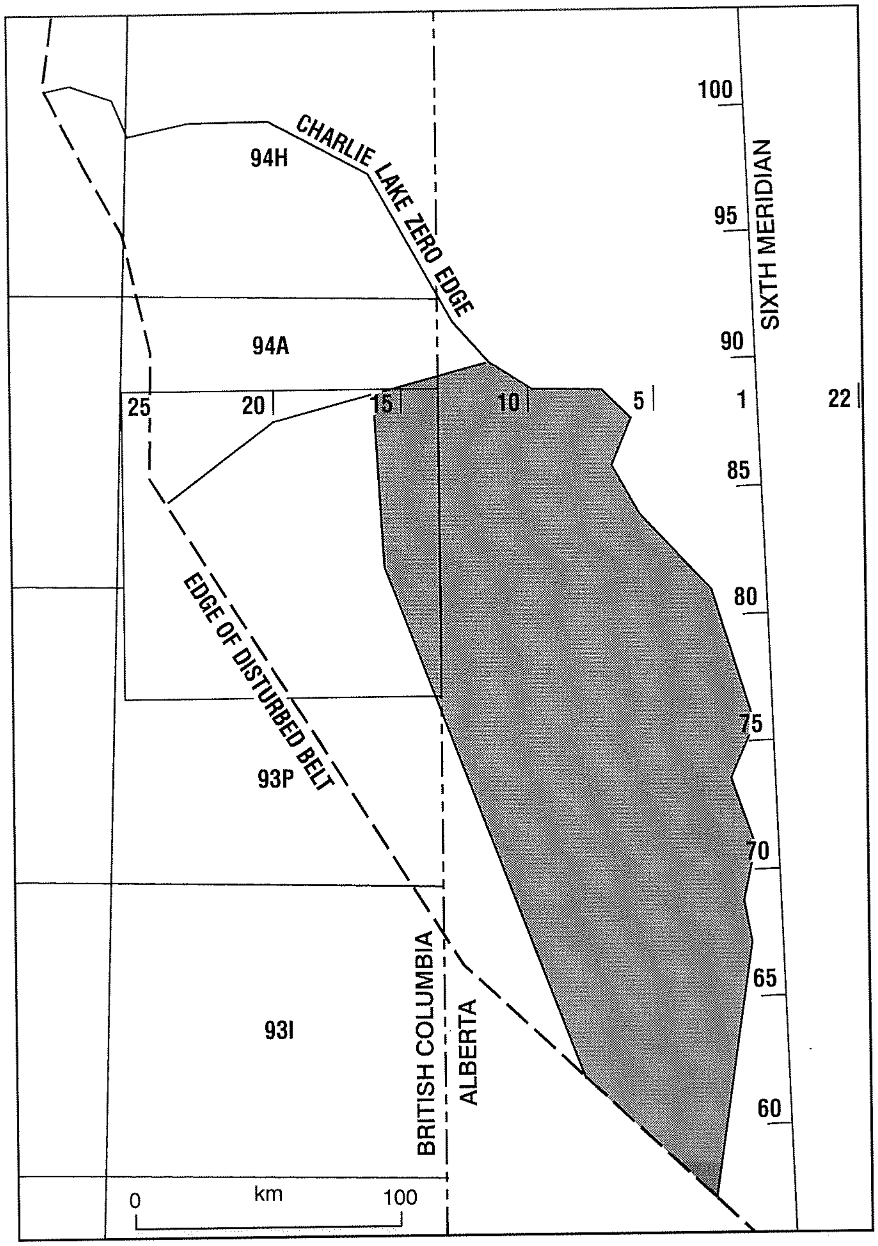


*Figure 51. Map ot the Charlie Lake carbonates (Boundary Lake)–Peace River Arch play area.*

erosional truncation and unconformity related traps. In the Boundary Lake pool, carbonates of the Boundary Member consist of stromatolitic and bioclastic limestone or dolomite deposited in a tidal flat setting (Armitage, 1962; Emond, 1992).

*Exploration history.* The discovery sequence ($\hat{\beta}$=0.8) and the cumulative in-place volume discovered are shown graphically in Appendix C (Figs. C8.1 and C8.2). The in-place volume has increased from 47 to 199 x $10^6 m^3$ since the GSC's 1987 assessment. The increase is the result new discoveries and appreciation of existing pools, especially the Boundary pool. The cumulative in-place volume graph shows a very strong upward increase. This play was under-evaluated by the GSC's 1987 assessment. The potential and discoveries are summarized in Tables 78 and 79.

*Reservoir parameters.* Reservoirs have pool areas from 33 to 1,540 ha; net pay from 0.8 to 6 m; porosity from 10 to 20%; water saturation from 10 to 43%; and a recovery factor from 0.084 to 24%. The parameters are also shown graphically in Appendix C (Figs. C8.3 to C8.8).

Table 74

**Pools discovered and predicted for the Charlie Lake clastics–Inga play**

| Pool size class ($10^6m^3$) | Pools discovered up to 1989 | Pools discovered between 1990 and 1994 | Pools yet to be discovered |
|---|---|---|---|
| < 0.1 | 4 | 0 | 50 |
| 0.1 - 1 | 1 | 1 | 11 |
| 1 - 10 | 0 | 0 | 2 |
| 10 - 100 | 1 | 0 | 0 |
| Total number of pools | 6 | 1 | 63 |
| In-place volume | 18.757 x $10^6m^3$ | 0.124 x $10^6m^3$ | 0.2 - 34 x $10^6m^3$ |

Table 75

**The largest pool of Table 74 discovered between 1990 and 1994**

| Field, pool | In-place volume ($10^6m^3$) |
|---|---|
| Inga, Coplin C | 0.124 |

**Note:** The number of oil pools in the present assessment is less than that in Podruski et al. (1988), because different pool classifications were used.

Table 76

**Pools discovered and predicted for the Charlie Lake clastics–Peace River Arch play**

| Pool size class ($10^6m^3$) | Pools discovered up to 1989 | Pools discovered between 1990 and 1994 | Pools yet to be discovered |
|---|---|---|---|
| < 0.1 | 18 | 6 | 145 |
| 0.1 - 1 | 24 | 8 | 28 |
| 1 - 10 | 2 | 0 | 1 |
| Total number of pools | 44 | 14 | 174 |
| In-place volume | 13.655 x $10^6m^3$ | 2.266 x $10^6m^3$ | 0.3 - 9 x $10^6m^3$ |

Table 77

**The five largest pools of Table 76 discovered between 1990 and 1994**

| Field, pool | In-place volume ($10^6m^3$) |
|---|---|
| Oak, Cecil E | 0.699 |
| Sunset Prairie, Cecil A | 0.398 |
| Flatrock West, Cecil A | 0.191 |
| Oak, Cecil I | 0.165 |
| Saturn, Cecil A | 0.131 |

*Baldonnel subcrop*

*Play definition.* This play is defined to include all oil and gas pools in dominantly stratigraphic facies change traps, with a structural component, in the Baldonnel and Pardonet formations. Play boundaries to the north and east are the Baldonnel erosional edges, to the south, a change in structural influence to drape and fault traps associated with Peace River Arch/embayment, and to the west, structural overprinting by Laramide folding (Fig. 52).

*Geology.* The Baldonnel and Pardonet formations consist of normal to restricted marine sediments which originally accumulated on a gently dipping carbonate shelf. Reservoir rocks consist of dolomitized skeletal calcarenite (Bever and McIlreath, 1984; Bever, 1990).

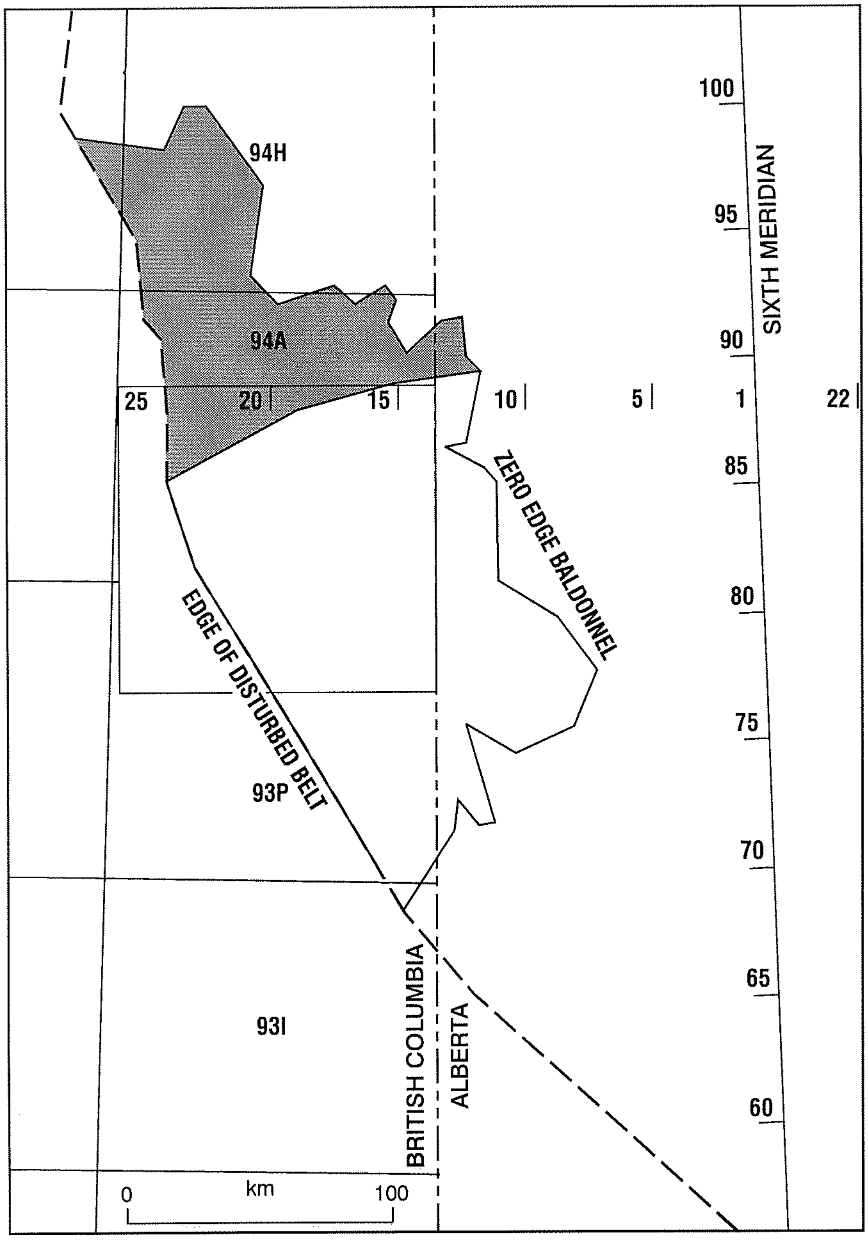


***Figure 52.*** *Map of the Baldonnel subcrop play area.*

Leaching at, or near, the unconformity surface is an important part of the reservoir development mechanism. Erosional remnants of porous units preserved on paleotopographic highs localize the hydrocarbons. Seals are formed by overlying nonpermeable carbonate and Jurassic Nordegg Member shale, or by the in-filling of nonporous units where the sub-Cretaceous unconformity incised deeply into the Baldonnel (Fitzgerald and Peterson, 1967).

In the GSC's 1987 assessment, the Baldonnel oil play was analyzed as a conceptual play and the gas play was considered an immature play. So far, over 30 gas pools and seven oil pools with total reserves of 5.613 x $10^6 m^3$ have been discovered in this play. The potential estimated using the conceptual assessment method ranges from 6 to 18 x $10^6 m^3$.

Table 78

Pools discovered and predicted for the Charlie Lake carbonates play

| Pool size class ($10^6m^3$) | Pools discovered up to 1989 | Pools discovered between 1990 and 1994 | Pools yet to be discovered |
|---|---|---|---|
| < 0.1 | 34 | 2 | 251 |
| 0.1 - 1 | 80 | 15 | 237 |
| 1 - 10 | 16 | 2 | 10 |
| 10 - 100 | 3 | 0 | 0 |
| Total number of pools | 133 | 19 | 498 |
| In-place volume | $186.403 \times 10^6m^3$ | $12.246 \times 10^6m^3$ | $46 - 451 \times 10^6m^3$ |

Table 79

The five largest pools of Table 78 discovered between 1990 and 1994

| Field, pool | In-place volume ($10^6m^3$) |
|---|---|
| Worsley, Charlie Lake H and J | 5.440 |
| Boundary Lake South, Triassic N | 2.352 |
| Valhalla, Boundary M | 0.897 |
| Progress, Boundary B | 0.740 |
| Gold Creek, Charlie Lake E | 0.434 |

## JURASSIC SYSTEM

### Geological framework

Jurassic sediments cover the area between the Peace River and Sweetgrass arches, east of the Foothills and west of the Jurassic erosional edge. Only erosional remnants of what was once an extensive Jurassic cover now provide exploration targets (Fig. 53).

Most Jurassic sediments were deposited in shelf conditions over the craton and in the adjacent miogeocline. Three major depositional cycles comprising sediments of the Fernie Group (Fig. 54) are represented in the sedimentary record below Upper Jurassic foreland sediments.

Each cycle, consisting mainly of clastic sediments, is characterized by a coarsening- and shallowing-upward facies profile. In this region the first cycle consists of two basin-fill events; the first is represented by Sinemurian Nordegg member deposits. In the west, the Nordegg is primarily shale and phosphatic shale and siltstone. In the east, a basal shale passes upward into carbonate and quartz-chert sandstone facies. The second basin-fill episode consists of siltstone, limestone and shale of the Red Deer Member in west central Alberta. The productive J1 channel fill sandstones of the Gilby-Medicine River play might have been deposited during this cycle (Hopkins, 1981).

The second cycle is represented by deposition of the Toarcian Poker Chip (or Paper) Shale overlain by Lower Bajocian Rock Creek member sandstone. The Poker Chip Shale is dark shale with local sandstone or conglomerate lenses. It was deposited on a wide shelf under conditions interpreted as anaerobic (Poulton, 1984, 1993; Springer et al., 1964; Stronach, 1984). The Rock Creek Member consists of black shale with interbeds of calcareous or ferruginous sandstone and sandy limestone and an eastern facies of fine-grained quartzose sandstone and siltstone.

The early transgressive portion of the third cycle consists of phosphatic, pyritic, fossiliferous shale, or pebbly sandstone beds overlain by fossiliferous concretionary limestone beds. The thickest portion of the third cycle is dominated by shale, including anaerobic, restricted-shelf or basin facies of dark, organic rich, silty shale of the Highwood Member (Stronach, 1984). This shale is gradationally overlain by Bathonian Grey Beds shale, locally containing progradational pulses of higher energy clastics.

The Columbian Orogeny profoundly affected sedimentation in the Late Jurassic by alteration of the basin shape and change to western provenance. Foreland basin filling by marine sediments of the eastward-migrating foredeep trough began in the Oxfordian and was succeeded by the Kootenay–Nikanassin continental sedimentation. Additional information can be obtained from Rall (1980).

The oil and gas pools occur in sandstone reservoirs under the following conditions: in stratigraphic traps developed by selective deposition of sandstone on uneven erosional surfaces, by isolation of sandstone bodies by erosion, or by updip depositional or diagentic porosity pinchouts. In some cases, drape of the Jurassic reservoir over Paleozoic erosional remnants creates the hydrocarbon traps. Seals are either Jurassic or Cretaceous shale, siltstone, or impermeable sandstone. Potential source rocks may be Carboniferous, Jurassic, or Cretaceous shale.

The play definitions are based on the framework of Podruski et al. (1988).

### Resource assessment

#### *Jurassic system potential*

The potential of the Jurassic system ranges from 108 to 243 x $10^6 m^3$. The mean (or expected value) of the potential distribution is 167 x $10^6 m^3$. The Rock Creek play contains the greatest potential for oil in the Jurassic system.

The in-place volume has increased from 376 x $10^6 m^3$ to 566 x $10^6 m^3$ since the GSC's 1987 assessment. A total of 22 x $10^6 m^3$ of in-place volume has been discovered between 1990 and 1994. The number of oil pools is displayed in Table 80 and the ten largest oil pools discovered between 1990 and 1994 are listed in Table 81.

#### *Alberta and British Columbia region*

Three established mature plays, Gilby–Medicine River, Rock Creek and Nordegg, and two immature plays, Nikanassin and Swift, are located within this region.

*Gilby–Medicine River*

*Play definition.* This play is defined to include all oil and gas pools that occur in Jurassic and Lower Cretaceous sandstone, filling channels or valleys carved into the Paleozoic surface and sealed by impervious shale of Jurassic age. The play area is a narrow belt in south-central Alberta trending north-northwest along the Jurassic erosional edge as far north as the town of Drayton Valley and as far south as Calgary (Fig. 55).

*Geology.* The Gilby–Medicine River play involves a complex of erosional valleys and headlands with a variety of

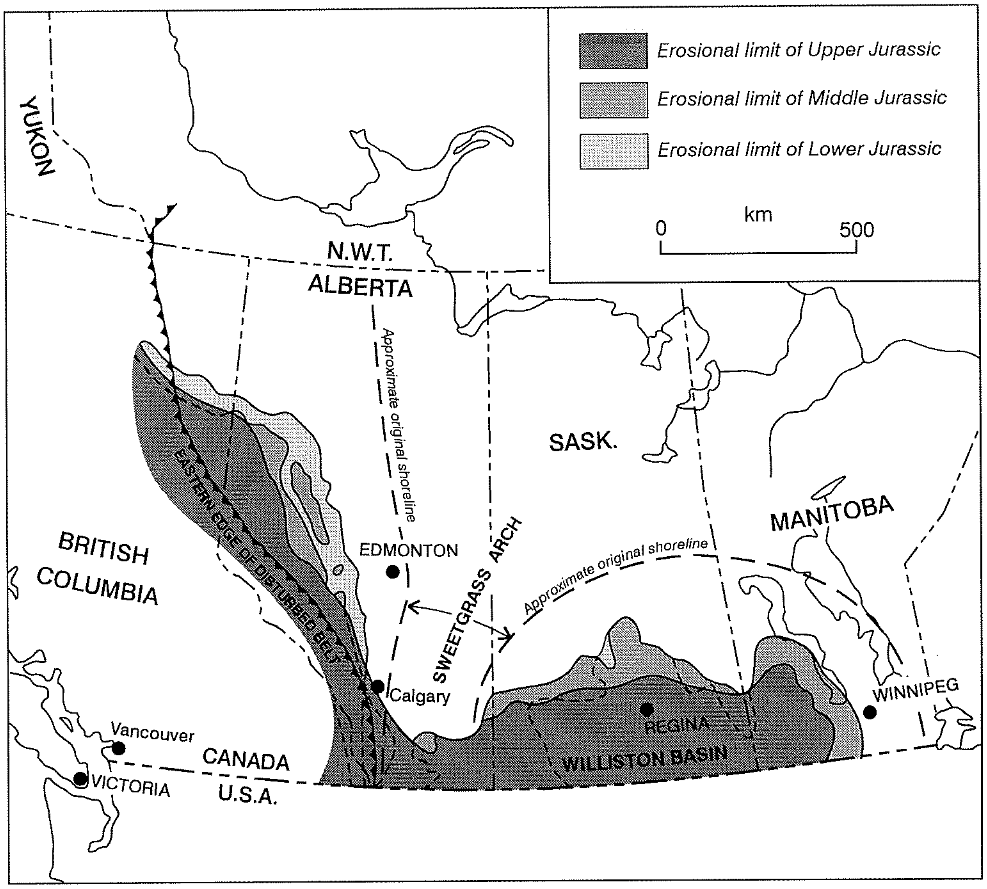


***Figure 53.*** *Distribution of Jurassic rocks, Western Canada Sedimentary Basin (after Springer et al., 1964).*

channel-fill units. Stratigraphically trapped pools produce from valley-fill sands, isolated Jurassic sandstone headland remnants, and sands draped over headland remnants.

A complex drainage pattern existed where post-Paleozoic valleys cut into the Carboniferous surface, with subsequent stages of valley cutting and filling occurring during the Jurassic. Some of these deposits were then sculpted by Cretaceous erosion with the consequence that, without paleontological control, the preserved stratigraphy is difficult to interpret. Depositional environments proposed in the literature range from fluvial, to brackish near-shore, to marine. The structural reversals on the regional dip result from drape over underlying Upper Devonian Leduc–Rimbey reefs, and paleotopography resulting from post-Paleozoic erosion of the Carboniferous. In addition to the light and medium crude oil reserves in the play, two heavy oil pools have been discovered.

*Exploration history.* The discovery sequence ($\hat{\beta}$ =1.6) and the cumulative in-place volume discovered are shown graphically in Appendix D (Figs. D1.1 and D1.2). The in-place volume has increased from 49 to 63 x $10^6 m^3$ since the GSC's 1987 assessment. The increase is the result of new discoveries and appreciation of existing pools. The cumulative in-place volume graph displays a moderate upward increase. The potential and discoveries are summarized in Tables 82 and 83.

*Reservoir parameters.* Reservoirs have pool areas from 17 to 1,450 ha; net pay from 2 to 13 m; porosity from 9 to 22%; water saturation from 19 to 49%; and a recovery factor from 0.04 to 35%. The reservoir parameters are also shown graphically in Appendix D (Figs. D1.3 to D1.8).

*Rock Creek*

*Play definition.* This play is defined to include all oil and gas pools in the Rock Creek Member at updip porosity pinchouts, in erosional remnants, and in channel-fill units. The play area trends northwest in a belt approximately 150 km wide, west of the Jurassic erosional edge, from the international boundary to northeastern British Columbia (Fig. 55).

*Geology.* The Rock Creek was deposited on a sandy shallow marine shelf strongly influenced by storms and tides. Pre-Cretaceous erosion removed much of the eastern deposits and left erosional outliers along the eastern subcrop limit.

## Table 80

### Jurassic oil pools discovered

| Pool size class ($10^6 m^3$) | Pools discovered up to 1989 | Pools discovered between 1990 and 1994 |
|---|---|---|
| < 0.1 | 43 | 27 |
| 0.1 - 1 | 139 | 49 |
| 1 - 10 | 74 | 2 |
| 10 - 100 | 12 | 0 |
| Total number of pools | 268 | 78 |
| Total in-place volume | 544.307 x $10^6 m^3$ | 21.494 x $10^6 m^3$ |

## Table 81

### The ten largest Jurassic pools discovered between 1990 and 1994

| Field, pool | In-place volume ($10^6 m^3$) |
|---|---|
| Gardenhead, Upper Shaunavon | 4.899 |
| Enchant, Ellis L | 2.337 |
| Grand Forks, Sawtooth W | 0.924 |
| Enchant, Ellis V | 0.592 |
| Enchant, Ellis I | 0.571 |
| Grand Forks, Sawtooth P2P | 0.464 |
| Gull Lake, Roseray Sand | 0.464 |
| Grand Forks, Sawtooth C | 0.435 |
| Grand Forks, Sawtooth F2F | 0.415 |
| Enchant, Ellis U | 0.406 |

## Table 82

### Pools discovered and predicted for the Gilby–Medicine River play

| Pool size class ($10^6 m^3$) | Pools discovered up to 1989 | Pools discovered between 1990 and 1994 | Pools yet to be discovered |
|---|---|---|---|
| < 0.1 | 4 | 2 | 103 |
| 0.1 - 1 | 20 | 5 | 30 |
| 1 - 10 | 12 | 0 | 3 |
| 10 - 100 | 1 | 0 | 0 |
| Total number of pools | 37 | 7 | 136 |
| In-place volume | 61.383 x $10^6 m^3$ | 1.232 x $10^6 m^3$ | 1.4 - 47 x $10^6 m^3$ |

## Table 83

### The five largest pools of Table 82 discovered between 1990 and 1994

| Field, pool | In-place volume ($10^6 m^3$) |
|---|---|
| Medicine River, Jurassic Y | 0.290 |
| Medicine River, Jurassic BB | 0.279 |
| Markerville, Jurassic A | 0.211 |
| Gilby, Jurassic Q | 0.171 |
| Medicine River, Jurassic V | 0.154 |

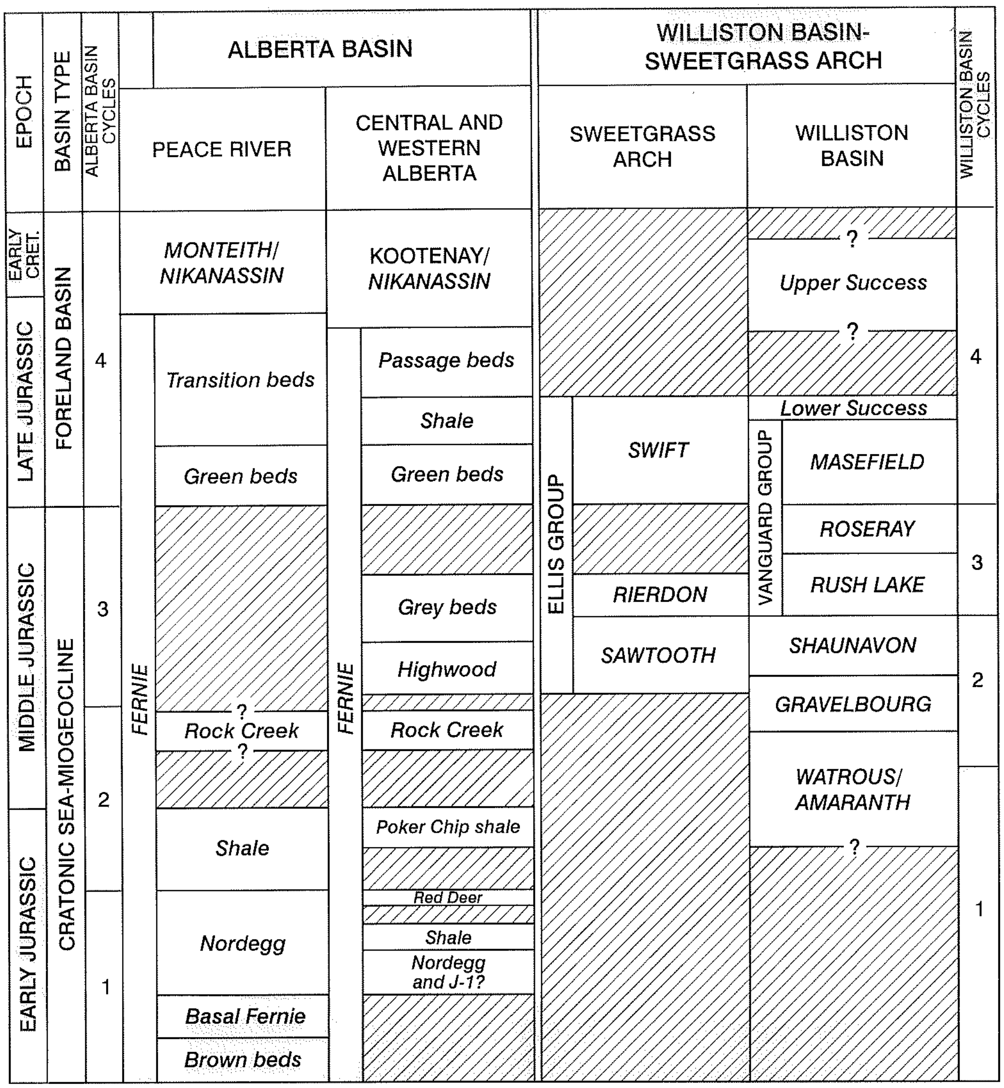


***Figure 54.*** *Table of Jurassic formations, Western Canada Sedimentary Basin.*

The Rock Creek, in west-central Alberta, consists of two coarsening-upward cycles of quartzose and coquinoid sandstone (Marion, 1984). The sandstones are well sorted and fine grained. Diagenetic alterations include quartz overgrowths, calcite cement, and dolomitization of shells in the coquinas. The best reservoirs are present at the top of the cycles. The main trap type appears to be permeability pinchouts of porous sand (possibly shallow bars) into less permeable silt or shale. Other recognized traps include cuesta-like paleohighs beneath the Cretaceous unconformity, truncated sand bars, channel-fill sand, and diagenesis-related porosity pinchouts. Only one heavy oil pool exists in this play.

*Exploration history.* The discovery sequence ($\hat{\beta}=1.0$) and cumulative in-place volume discovered are shown graphically in Appendix D (Figs. D2.1 and D2.2). The in-place volume has increased from 3 to 21 x $10^6m^3$ since the GSC's 1987 assessment. The increase is the result of new discoveries and appreciation of existing pools. The largest yet-to-be discovered pools predicted by the GSC's 1987 assessment have been discovered. The cumulative in-place graph shows a very strong upward increase. The potential and discoveries are summarized in Tables 84 and 85.

*Reservoir parameters.* Reservoirs have pool areas from 64 to 328 ha; net pay from 2 to 13 m; porosity from 8 to 18%; water saturation from 16 to 50%; and a recovery factor from 0.09 to 15%. The parameters are also shown graphically in Appendix D (Figs. D2.3 to D2.8).

*Nordegg*

*Play definition.* This play is defined to include all oil and gas pools that occur in Jurassic and Lower Cretaceous channel-

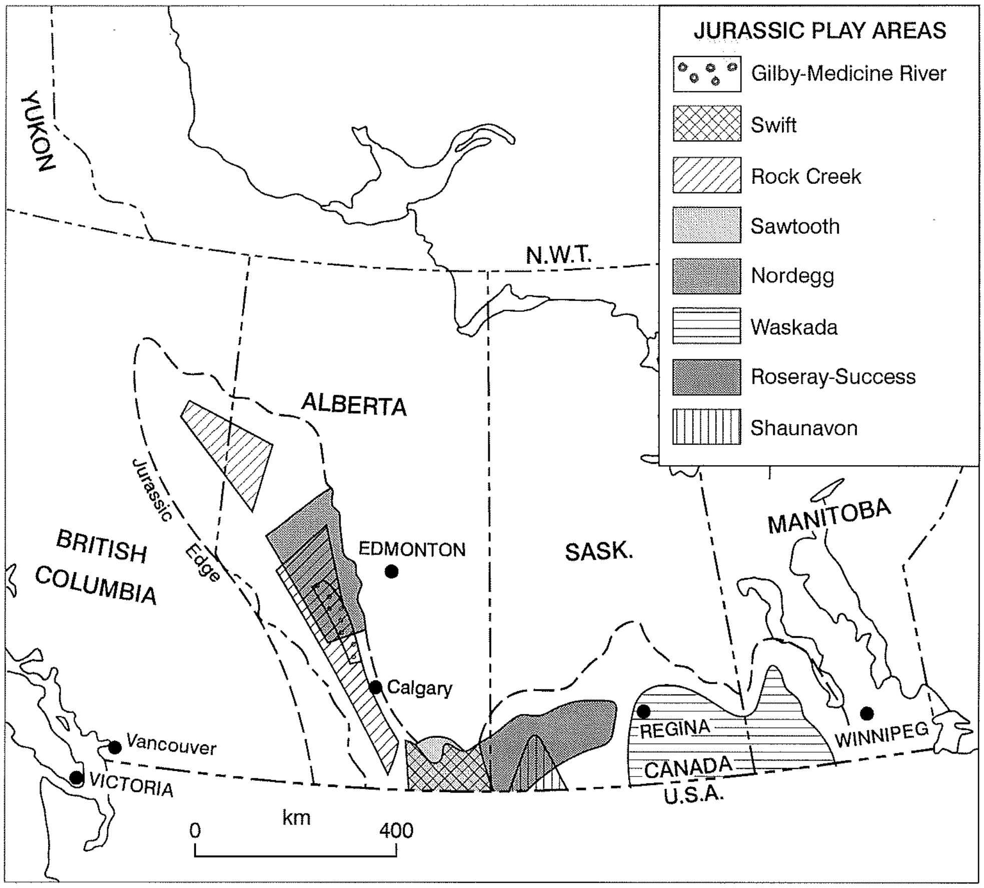


***Figure 55.*** *Jurassic play map.*

and valley-fill sandstone and in Nordegg erosionally isolated shallow marine sandstone. The play limits are the Jurassic erosional edge to the east and south, the Nordegg platform play to the west and the Nordegg shelf/basinal play to the northwest (Fig. 56).

*Geology.* This play involves a complex network of Jurassic and Cretaceous erosional valleys carved into Nordegg shoreline sandstone and underlying Mississippian carbonate. The valleys are filled with Lower Jurassic to Lower Cretaceous sandstones and shales, known as the $J_1$, $J_2$, and $J_3$ units, forming stratigraphic traps which, in some cases, are commingled with underlying Carboniferous pools.

In the Western Canada Jurassic gas assessment, two additional Nordegg plays were identified in the interior plains (Fig. 56). No oil pools have been discovered so far in the Nordegg platform play, and one pool has been found in the Nordegg shelf-basinal play.

*Exploration history.* The discovery sequence ($\hat{\beta}=1.4$) and the cumulative in-place volume discovered are displayed in Appendix D (Figs. D3.1 and D3.2). The in-place volume has increased from 3 to 18 x $10^6 m^3$ since the GSC's 1987 assessment. The increase is the result of the new discoveries. The cumulative in-place volume graph shows a strong upward increase. The potential and discoveries are summarized in Tables 86 and 87.

*Reservoir parameters.* Reservoirs have pool areas from 10 to 1,116 ha (min-max); net pay from 1 to 22 m; porosity from 1 to 23% (min-max); water saturation from 10 to 53% (min-max); and a recovery factor from 0.01 to 10% (min-max). The parameters are also shown graphically in Appendix D (Figs. D3.3 to D3.8).

*Nikanassin*

*Play definition.* This play is defined to include all oil and gas pools in fluvial to marginal marine sandstone of the Nikanassin Formation and its equivalent strata (i.e., Minnes Group). Its play area covers northwest Alberta and northeast British Columbia (Fig. 56).

## Table 84

**Pools discovered and predicted for the Rock Creek play**

| Pool size class ($10^6m^3$) | Pools discovered up to 1985 | Pools discovered between 1986 and 1994 | Pools yet to be discovered |
|---|---|---|---|
| < 0.1 | 7 | 6 | 191 |
| 0.1 - 1 | 22 | 16 | 155 |
| 1 - 10 | 1 | 1 | 1 |
| Total number of pools | 30 | 23 | 347 |
| In-place volume | $13.759 \times 10^6m^3$ | $7.502 \times 10^6m^3$ | $37 - 67 \times 10^6m^3$ |

## Table 85

**The five largest pools of Table 84 discovered between 1986 and 1994**

| Field, pool | In-place volume ($10^6m^3$) |
|---|---|
| Niton, Rock Creek H | 1.827 |
| Pembina, Jurassic R | 0.949 |
| Pembina, Jurassic Q | 0.542 |
| Niton, Rock Creek M | 0.487 |
| Pembina, Jurassic | 0.359 |

## Table 86

**Pools discovered and predicted for the Nordegg play**

| Pool size class ($10^6m^3$) | Pools discovered up to 1984 | Pools discovered between 1985 and 1994 | Pools yet to be discovered |
|---|---|---|---|
| < 0.1 | 1 | 1 | 80 |
| 0.1 - 1 | 4 | 5 | 102 |
| 1 - 10 | 2 | 2 | 3 |
| Total number of pools | 7 | 8 | 185 |
| In-place volume | $9.822 \times 10^6m^3$ | $8.043 \times 10^6m^3$ | $15 - 40 \times 10^6m^3$ |

## Table 87

**The five largest pools of Table 86 discovered between 1985 and 1994**

| Field, pool | In-place volume ($10^6m^3$) |
|---|---|
| Tomahawk, Nordegg B, Banff B and C | 3.383 |
| Leaman, Nordegg C | 1.601 |
| St. Anne, Nordegg A | 0.943 |
| Simonette, Nordegg A | 0.833 |
| Ante Creek, Nordegg A | 0.670 |

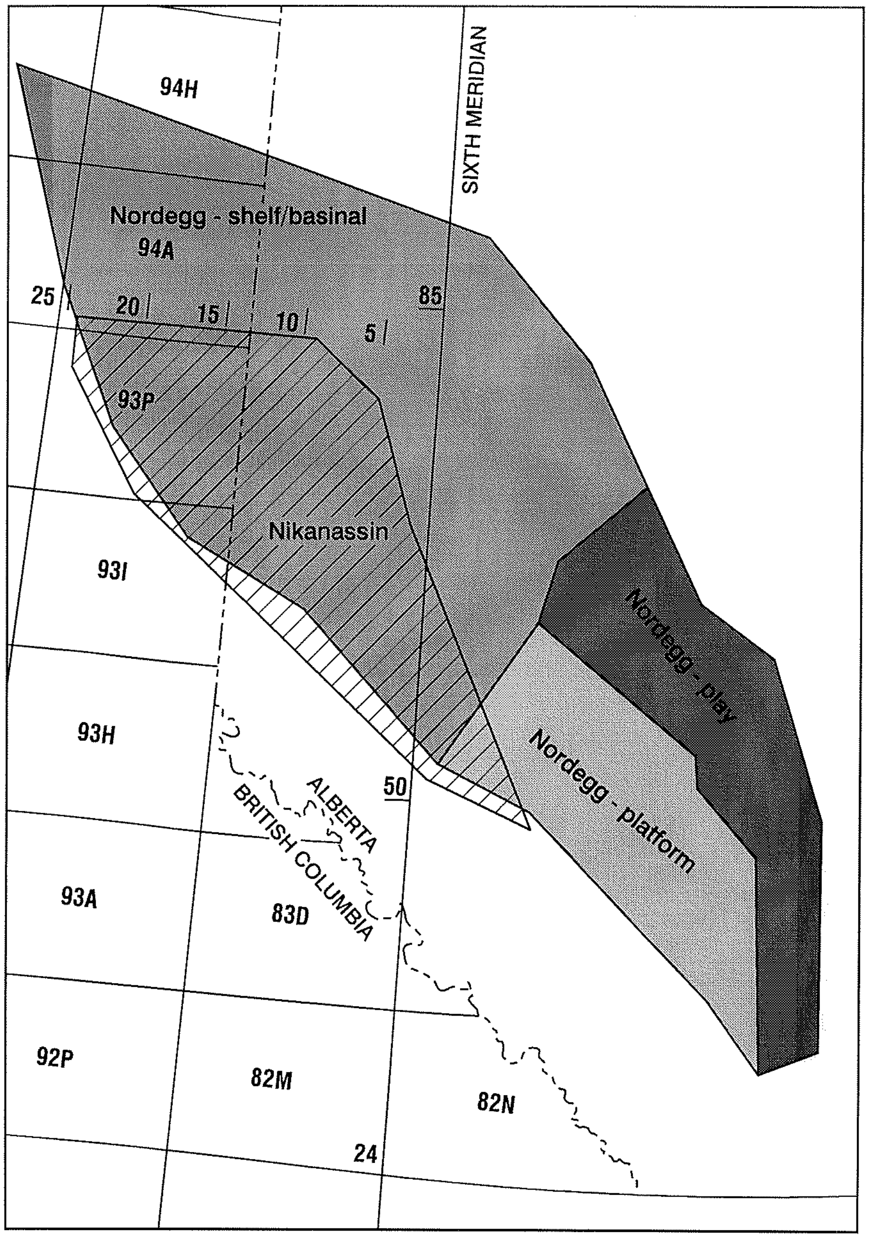


***Figure 56.*** *Nordegg play map.*

*Geology.* The Nikanassin Formation is a thick, gas-prone sequence of sandstone, siltstone and shale with the upper sandstone interpreted as distal braid-plain deposits. It thins to a zero edge to the east and north due to non-deposition and erosion. The sandstone and siltstone are often stacked and are highly compacted, variably cemented and have high clay content creating a low permeability. A total of 59 gas pools have been discovered, but only one oil pool was found with an in-place volume of 0.112 x $10^6m^3$.

This play has an oil potential ranging from 0.2 to 34 x $10^6m^3$

*Swift*

*Play definition.* This play is defined to include all oil and gas pools in marine-shelf sandstone of the Swift Formation of southern Alberta (Fig. 55). The traps occur at or near the pre-Cretaceous erosional surface, in updip porosity pinchouts or in Laramide structural traps.

*Geology.* In southeast Alberta, the Swift Formation consists of basal marine shale that passes upward into marine sandstone, called "Ribbon Sand" (Hayes, 1983; Podruski et al., 1988). This sand is the reservoir unit. It has been dissected by latest Jurassic and earliest Cretaceous valley-cutting processes, particularly near the Swift erosional edge. Swift sands are overlain by Lower Cretaceous sandstone, siltstone and shale.

So far, six gas pools have been discovered, but only one oil pool is designated as a Swift oil pool with an in-place volume of 0.680 x $10^6 m^3$. The play potential ranges from 1 to 42 x $10^6 m^3$.

### *Williston Basin region*

Three established mature plays, Sawtooth, Shaunavon, and Roseray-Success, and one immature play, Waskada, are located within this region.

#### *Sawtooth*

*Play definition.* This play is defined to include all oil and gas pools in the Sawtooth Formation sandstone that occur in stratigraphic facies pinchout and drape structure traps. The play occurs on the Sweetgrass Arch and is limited by depositional edges on the east and west, by the erosional edge to the north, and arbitrarily to the south at the international boundary (Fig. 55).

*Geology.* Stratigraphic pinchouts were formed by localized deposition of sand in depressions on the Carboniferous erosional surface. Traps also occur where sandstone drapes over topographic highs on the Carboniferous surface. Reservoirs consist of fine- to medium-grained quartzose sandstone.

*Exploration history.* The discovery sequence ($\hat{\beta}$=0.8) and cumulative in-place volume discovered are shown graphically in Appendix D (Figs. D4.1 and D4.2). The in-place volume has increased from 5 to 82 x $10^6 m^3$ since the GSC's 1987 assessment. The increase is the result of new discoveries and appreciation of existing pools. The largest undiscovered pool predicted by the GSC's 1987 assessment has been discovered. The in-place cumulative graph shows a strong upward increase. The potential and discoveries are summarized in Tables 88 and 89.

*Reservoir parameters.* Reservoirs have pool areas from 17 to 525 ha; net pay from 1 to 8 m; porosity from 16 to 28%; water saturation from 25 to 55%; and a recovery factor from 0.5 to 45%. Most of the pools contain heavy oil. The parameters are also shown graphically in Appendix D (Figs. D4.3 to D4.8)

#### *Shaunavon*

*Play definition.* This play is defined to include all oil pools in shallow marine and shoreline sandstone of the Upper Shaunavon where they are surrounded by impervious rocks. The play area is restricted to shoreline facies of the formation along the eastern flank of the Jurassic Sweetgrass Arch (Fig. 55). In the GSC's 1987 assessment, each reservoir unit was considered as one pool. In the present assessment, in-place volumes of all reservoir units that belong to one geological pool are added together.

*Geology.* Oil pools are located in shoreline facies near the western edge of the Upper Shaunavon Member. The reservoirs consist of fine-grained dolomitic quartzose sandstone and subordinate coquinoid limestone.

*Exploration history.* The discovery sequence ($\hat{\beta}$=0.8) and cumulative in-place volume discovered are shown graphically in Appendix D (Figs. D5.1 and D5.2). The latest discovery used by the GSC's assessment was dated at 1969. Since then, 10 pools have been discovered. The in-place volume has increased from 148 to 229 x $10^6 m^3$ since the GSC's 1987 assessment. The increase is the result of new discoveries and appreciation of existing pools. The largest undiscovered pools predicted by the GSC's 1987 assessment have been discovered, but pools with a volume of over 1 x $10^6 m^3$ may exist. The cumulative in-place volume graph shows a moderate upward increase. The potential and discoveries are summarized in Tables 90 and 91.

*Reservoir parameters.* Reservoirs have pool areas from 33 to 4,400 ha; net pay from 1 to 8 m; porosity from 12 to 28%; water saturation from 5 to 47%; and a recovery factor from 1.3 to 50%. Most of the oil pools in this play are heavy, but they are treated as light and medium oil. The parameters are also shown graphically in Appendix D (Figs. D5.3 to D5.8).

#### *Roseray–Success*

*Play definition.* This play is defined to include all oil pools in the sandstone of the Roseray and Success formations in stratigraphic facies change and unconformity traps. The play area forms a narrow arcuate belt at the subcrop of the two formations (Fig. 55). In the GSC's 1987 assessment, each reservoir unit was considered as a pool, whereas in the present assessment, the in-place volume of all units belonging to one geological pool were added together.

**Table 88**

**Pools discovered and predicted for the Sawtooth play**

| Pool size class ($10^6m^3$) | Pools discovered up to 1989 | Pools discovered between 1990 and 1994 | Pools yet to be discovered |
|---|---|---|---|
| < 0.1 | 21 | 23 | 106 |
| 0.1 - 1 | 60 | 36 | 30 |
| 1 - 10 | 21 | 1 | 2 |
| Total number of pools | 102 | 60 | 138 |
| In-place volume | 68.744 x $10^6m^3$ | 13.104 x $10^6m^3$ | 1 - 29 x $10^6m^3$ |

**Table 89**

**The five largest pools of Table 88 discovered between 1990 and 1994**

| Field, pool | In-place volume ($10^6m^3$) |
|---|---|
| Enchant, Ellis L | 2.337 |
| Grand Forks, Sawtooth W | 0.924 |
| Enchant, Ellis V | 0.592 |
| Enchant, Ellis I | 0.571 |
| Grand Forks, Sawtooth P2P | 0.464 |

**Table 90**

**Pools discovered and predicted for the Shaunavon play**

| Pool size class ($10^6m^3$) | Pools discovered up to 1983 | Pools discovered between 1984 and 1994 | Pools yet to be discovered |
|---|---|---|---|
| < 0.1 | 0 | 1 | 1 |
| 0.1 - 1 | 5 | 3 | 15 |
| 1 - 10 | 19 | 4 | 5 |
| 10 - 100 | 7 | 0 | 0 |
| Total number of pools | 31 | 8 | 21 |
| In-place volume | 213.641 x $10^6m^3$ | 15.093 x $10^6m^3$ | 3 - 92 x $10^6m^3$ |

**Table 91**

**The five largest pools of Table 90 discovered between 1984 and 1994**

| Field, pool | In-place volume ($10^6m^3$) |
|---|---|
| Gardenhead, Upper Shaunavon | 4.899 |
| Red Jacket, Red Jacket Sand | 4.224 |
| Battle Creek South, Upper Shaunavon | 1.822 |
| Moosomin, Red Jacket | 1.593 |
| Coothill, Red Jacket | 1.167 |

*Geology.* The Roseray–Success play area overlaps and extends north and northeast of the Shaunavon play in southwestern Saskatchewan. Traps include paleo-topographic highs on the eroded Roseray and Success formations or a combination of westerly updip facies change from Roseray sandstone to shale and by tight valley-fill sediments of the Mannville Group to the north and east.

*Exploration history.* The discovery sequence ($\hat{\beta}=1.0$) and the cumulative in-place volume discovered are shown graphically in Appendix D (Figs. D6.1 and D6.2). The in-place volume has increased from 142 to 150 x $10^6m^3$ since the GSC's 1987 assessment. The increase is the result of new discoveries and the appreciation of existing pools. The cumulative in-place volume graph shows a gradual upward increase. The potential and discoveries are summarized in Tables 92 and 93.

*Reservoir parameters.* Reservoirs have pool area 10 to 3,600 ha (min-max); net pay from 1 to 9 m (min-max); porosity from 10 to 29% (min-max); water saturation from 10 to 47% (min-max); and a recovery factor from 1 to 60% (min-max). All pools are heavy oil, but are treated as light and medium oil. The parameters are also shown graphically in Appendix D (Figs. D6.3 to D6.8)

*Waskada*

The Waskada play (Fig. 55), located in the eastern Williston basin, occurs in redbeds of the Amaranth Formation. The reservoir occurs in laminated sandstone and siltstone near the base of the formation. Porosity is both primary intergranular, and secondary intercrystalline in the dolomitic matrix. Most sand in the formation is tight due to anhydrite plugging (Podruski et al., 1988). The Waskada oil is known to have migrated from the underlying Mission Canyon pools (Barchyn, 1982, 1984). This play is not evaluated in this report.

**Table 92**

**Pools discovered and predicted for the Roseray–Success play**

| Pool size class ($10^6 m^3$) | Pools discovered up to 1989 | Pools discovered between 1990 and 1994 | Pools yet to be discovered |
|---|---|---|---|
| < 0.1 | 0 | 0 | 1 |
| 0.1 - 1 | 2 | 1 | 19 |
| 1 - 10 | 12 | 0 | 1 |
| 10 - 100 | 4 | 0 | 0 |
| Total number of pools | 18 | 1 | 21 |
| In-place volume | $149.871 \times 10^6 m^3$ | $0.464 \times 10^6 m^3$ | $2 - 74 \times 10^6 m^3$ |

**Table 93**

**The Roseray–Success pool of Table 92 discovered between 1990 and 1994**

| Field, pool | In-place volume ($10^6 m^3$) |
|---|---|
| Gull Lake, Roseray Sand | 0.464 |

## LOWER CRETACEOUS SYSTEM — MANNVILLE GROUP

### Geological framework

Figure 57 shows the stratigraphic column of the Mannville Group, which was deposited as a foreland clastic wedge to the east of the Cordillera that was uplifted as a result of the Columbian Orogeny. It ranges from zero to more than 700 m thick and rests on the pre-Cretaceous unconformity, which progressively cuts down through strata of Jurassic age in the west to Devonian age in the east. The Mannville Group is approximately equivalent to Assemblage 2 (Aptian to Albian) of the Zuni sequence of Sloss (1963).

The Lower Mannville Formation is characterized by continental deposits, with the lowermost units being the alluvial plain to braided river deposits of the Cadomin Formation. These are overlain by fluvial and lacustrine deposits of the Basal Quartz, Ellerslie, Gething, Cutbank, Sunburst, Dina, and McMurray formations that grade upward into marginal marine deposits. With continued southward transgression of the Boreal Sea, a series of transgressive shorelines was deposited, forming the Bluesky, Wabiskaw, and Cummings formations.

A major change in the depositional style occurred within the Mannville Group at this point from regionally transgressive Lower Mannville Formation to the regionally regressive Upper Mannville Group. The progradational shoreline deposits of the Glauconite and Clearwater formations mark this change. These were followed by further northward progradation represented by the Spirit River Formation, Grand Rapids Formation, and the Upper Mannville Group.

The play definitions of the Mannville were adopted from the work on the assessment of the Mannville gas resource (Warters et al., 1995, 1997). Detailed descriptions about the Mannville Group can be found in Cant (1983, 1989), Cant and Stockmal (1989), Hayes (1982, 1986), Hayes et al. (1994), Wood (1990, 1994), and Wood and Hopkins (1992).

### Resource assessment

#### *Mannville Group potential*

For the light and medium oil (including the Bluesky, Gething, Cadomin, Glauconite, Upper Mannville light and medium, Ostracod, Lower Mannville light and medium, Detrital, and Cantuar plays), the potential predicted ranges from 297 to 602 x $10^6 m^3$. The mean (or expected value) of the potential distribution is 438 x $10^6 m^3$. The Upper Mannville light and medium oil play contains the greatest potential for oil among these plays. The in-place volume of light and medium oil has increased from 378 x $10^6 m^3$ to 821 x $10^6 m^3$ since the 1987 assessment (Podruski et al., 1988). In

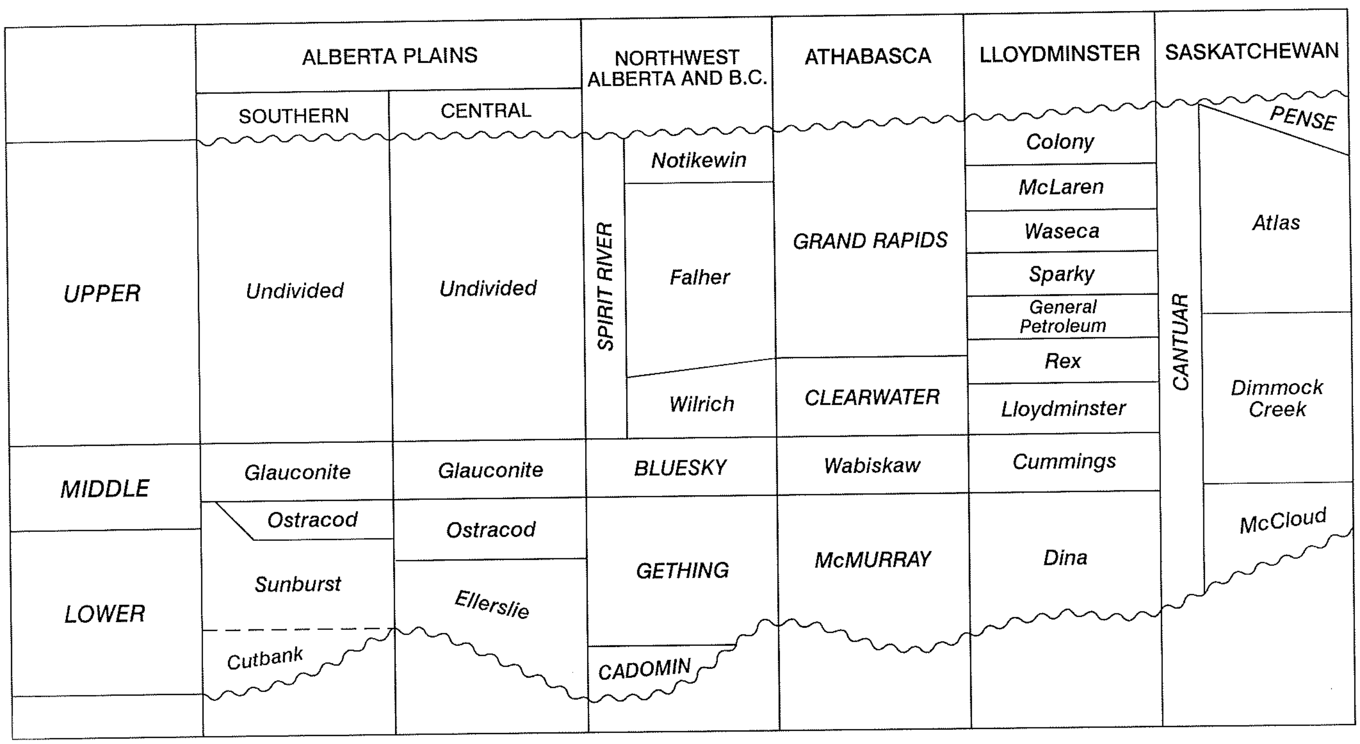


***Figure 57.*** *Stratigraphic column of the Mannville Group.*

addition, a total of 102 x $10^6m^3$ of in-place oil was discovered between 1990 and 1994. The number of pools discovered and the sizes of the ten largest pools discovered between 1990 and 1994 are listed in Tables 94 and 95.

With respect to the heavy oil (including Colony to Lloydminster, Cummings, Dina, Upper Mannville heavy oil, and Lower Mannville heavy oil plays), the potential predicted from these plays ranges from 1,075 to 2,512 x $10^6m^3$. The mean (or expected value) of the potential distribution is 1,796 x $10^6m^3$. In addition, a total of 54 x $10^6m^3$ of in-place oil was discovered between 1990 and 1994. The number of pools discovered and the sizes of the ten largest pools discovered between 1990 and 1994 are listed in Tables 96 and 97. The Colony to Lloydminster play contains the oil greatest potential among the heavy oil plays.

### Northwest Alberta and British Columbia region

Two established mature plays, Bluesky and Gething, and one immature play, the Cadomin, are located within this region.

#### *Bluesky*

*Play definition.* This play includes all oil and gas pools that are contained within the Bluesky Formation in the northwest Alberta and northeast British Columbia play area (Fig. 58). This play was not defined in the GSC's 1987 assessment.

*Geology.* The Bluesky Formation was deposited as a series of regressive pulses during the southward transgression of the Boreal Sea. It can be divided into three main facies: (1) regressive, coarsening-upward, offshore to shallow marine deposits, (2) transgressive conglomerate lags, and (3) incised valley-fill deposits. These divisions also characterize the types of hydrocarbon traps found within the Bluesky Formation in northwest Alberta and British Columbia. The contact between the Bluesky and the underlying coastal plain deposits of the Gething Formation is gradational and picked at the first occurrence of marine sandstone. Marine shale of the Wilrich Member overlie the Bluesky Formation.

*Exploration history.* The discovery sequence ($\hat{\beta}=0.6$) and the cumulative in-place volume discovered are graphically shown in Appendix E (Figs. E1.1 and E1.2). Three oil pools were discovered between 1991 and 1993. The cumulative in-place graph shows a moderate upward increase with a sharp increase in 1989. The potential and discoveries are summarized in Tables 98 and 99.

*Reservoir parameters.* Reservoirs have pool areas from 10 to 1,600 ha (min-max); net pay from 1 to 14 m (min-max); porosity from 10 to 28% (min-max); water saturation from 10 to 50% (min-max); and a recovery factor from 0.1 to 38% (min-max). The parameters are also graphically displayed in Appendix E (Figs. E1.3 to E1.8).

#### *Gething*

*Play definition.* This play includes all oil and gas pools contained within the Gething and Dunlevy formations in northwest Alberta and northeast British Columbia. This play was not evaluated in the GSC's 1987 assessment.

*Geology.* Subsurface correlations and biostratigraphic data from the different units can be interpreted to show that an erosional gap exists between fine-grained Gething sediments and a sandy basal unit, which in places has entirely removed the basal unit and cut into the Cadomin (Warters et al., 1997). Additional unconformities are apparent within the Gething Formation, based on the regional correlations.

*Exploration history.* The discovery sequence ($\hat{\beta}=1.0$) and the cumulative in-place volume discovered are shown in Appendix E (Figs. E2.1 and E2.2). Four oil pools were discovered between 1990 and 1994. The cumulative in-place graph shows a strong upward increase. The potential and discoveries are summarized in Tables 100 and 101.

*Reservoir parameters.* Reservoirs have pool areas from 17 to 320 ha; net pay from 1 to 9 m; porosity from 10 to 23%; water saturation from 17 to 55%; and a recovery factor from 0.15 to 20%. The parameters are also graphically shown in Appendix E (Figs. E2.3 to E2.8).

#### *Cadomin*

*Play definition.* This play includes all oil and gas pools within the Cadomin Formation in the northwest Alberta and northeast British Columbia play area (Fig. 58).

*Geology.* The Cadomin Formation is the basal Mannville conglomerate in northwestern Alberta and northeastern British Columbia. It consists of an eastward-fining wedge of alluvial fan and braided river conglomerate (Varley, 1984) shed from the overthrust belt and onlapping against the Fox Creek Escarpment. In the subsurface, its southern extent is restricted by the thrust front. Because the Cadomin is essentially a sheet of coarse-grained sediment, stratigraphic traps due to lateral facies changes are absent. Two distinct types of petroleum traps occur: (1) conventional structural traps, such as drape over Devonian reefs (e.g., Gold Creek gas field), and stratigraphic traps developed at the updip termination of the Cadomin along the Fox Creek Escarpment (e.g., Kaybob gas field), (2) the so-called Deep Basin trap, in which the Cadomin has undergone permeability reduction by cementation and is saturated by underpressured gas. Only three oil pools have been discovered with a total reserve of 0.256 x $10^6m^3$ of in-place oil.

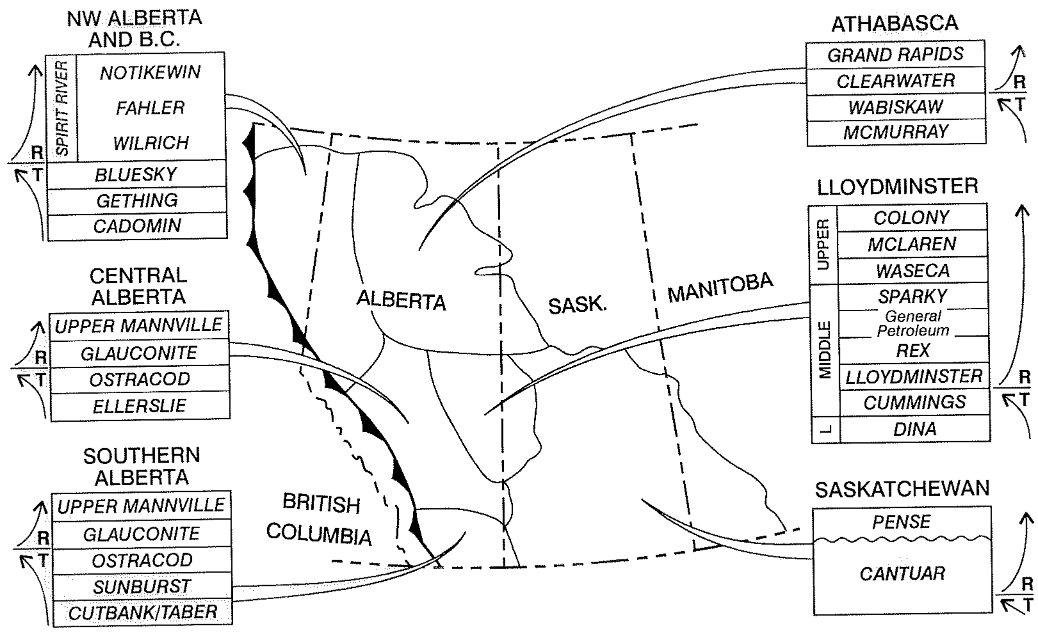


***Figure 58.*** *Play areas of the Mannville Group (after Warters et al., 1995).*

**Table 94**

**Mannville light and medium oil pools discovered**

| Pool size class ($10^6m^3$) | Pools discovered up to 1989 | Pools discovered between 1990 and 1994 |
|---|---|---|
| < 0.1 | 338 | 89 |
| 0.1 - 1 | 813 | 138 |
| 1 - 10 | 138 | 21 |
| 10 - 100 | 6 | 0 |
| Total number of pools | 1295 | 248 |
| In-place volume | 718.821 x $10^6m^3$ | 101.997 x $10^6m^3$ |

**Table 95**

**The ten largest Mannville light and medium oil pools of Table 94 discovered between 1990 and 1994**

| Field, pool | In-place volume ($10^6m^3$) |
|---|---|
| Marengo South, Detrital | 8.125 |
| Provost, Glauconitic A | 7.399 |
| Provost, Ellerslie N | 5.113 |
| Gilby, Upper Mannville J | 4.204 |
| Halkirk, Upper Mannville R | 4.029 |
| Long Coulee, Sunburst K | 3.003 |
| Fenn-Big Valley, Upper Mannville K | 3.000 |
| Countess, Upper Mannville YY | 2.451 |
| Taber, Taber I | 2.208 |
| Long Coulee, Sunburst P | 1.830 |

**Table 96**

**Mannville heavy oil pools discovered**

| Pool size class ($10^6 m^3$) | Pools discovered up to 1989 | Pools discovered between 1990 and 1994 |
|---|---|---|
| < 0.1 | 320 | 97 |
| 0.1 - 1 | 516 | 93 |
| 1 - 10 | 160 | 7 |
| 10 - 100 | 64 | 1 |
| Total number of pools | 1060 | 198 |
| In-place volume | 2,368.410 x $10^6 m^3$ | 54.016 x $10^6 m^3$ |

**Table 97**

**The ten largest Mannville heavy oil pools of Table 96 discovered between 1990 and 1994**

| Field, pool | In-place volume ($10^6 m^3$) |
|---|---|
| Long Lake, Waseca Sand | 11.307 |
| Provost, Lloydminster KK | 2.201 |
| Senlac, Waseca Sand | 2.136 |
| Provost, Dina E5E | 1.733 |
| Provost, Lloydminster UU | 1.623 |
| Provost, Dina W4W | 1.149 |
| Provost, Dina U3U | 1.142 |
| Provost, Upper Mannville M6M | 1.087 |
| Provost, Dina I5I | 0.900 |
| Alderson, Lower Mannville TT | 0.858 |

**Table 98**

**Pools discovered and predicted for the Bluesky play**

| Pool size class ($10^6 m^3$) | Pools discovered up to 1989 | Pools discovered between 1990 and 1994 | Pools yet to be discovered |
|---|---|---|---|
| < 0.1 | 2 | 2 | 105 |
| 0.1 - 1 | 5 | 1 | 80 |
| 1 - 10 | 2 | 0 | 3 |
| Total number of pools | 9 | 3 | 188 |
| In-place volume | 5.113 x $10^6 m^3$ | 1.112 x $10^6 m^3$ | 10 - 20 x $10^6 m^3$ |

**Table 99**

**The three largest pools of Table 98 discovered between 1990 and 1994**

| Field, pool | In-place volume ($10^6 m^3$) |
|---|---|
| Kaybob South, Bluesky D | 0.974 |
| Firebird, Bluesky F | 0.072 |
| Kaybob South, Bluesky L | 0.066 |

**Table 100**

**Pools discovered and predicted for the Gething play**

| Pool size class ($10^6$ $m^3$) | Pools discovered up to 1989 | Pools discovered between 1990 and 1994 | Pools yet to be discovered |
|---|---|---|---|
| < 0.1 | 16 | 1 | 316 |
| 0.1 - 1 | 42 | 3 | 77 |
| 1 - 10 | 4 | 0 | 1 |
| Total number of pools | 62 | 4 | 394 |
| In-place volume | 25.305 x $10^6 m^3$ | 0.691 x $10^6 m^3$ | 11 - 39 x $10^6 m^3$ |

**Table 101**

**The four largest pools of Table 100 discovered between 1990 and 1994**

| Field, pool | In-place volume ($10^6 m^3$) |
|---|---|
| Spirit River, Gething C | 0.289 |
| Rycroft, Gething E | 0.180 |
| Rigel East, Gething A | 0.164 |
| Gold Creek, Gething B | 0.058 |

### *Central and Southern Alberta region*

Within this region, the oil pools are divided into Upper and Lower Mannville units. Oil pools within each member are divided into light and medium, or heavy oil, according to their specific gravity.

*Upper Mannville light and medium, and heavy oil plays*

*Play definition.* These two plays include all oil pools in the Upper Mannville (Fig. 57). Because of the complex stratigraphy of these units, stratigraphic division of the pool database is difficult. These units are consequently grouped into two plays based on oil density, i.e., light and medium oil (density less than 900 kg/$m^3$) and heavy oil ( density greater than or equal to 900 kg/$m^3$).

*Geology.* The Upper Mannville in this area consists of dominantly fine-grained sandstone. The thicker (up to 20 m) fluvial sandstone is nonmarine valley fill in this area, and probably results from the same fluctuations in relative sea level as those that affected Falher shorelines to the north (basinward). The thinner fluvial sandstone (up to about 8 m) may be channels contemporaneous with the adjacent overbank deposits, but this distinction is not certain at present. Reservoirs occur in the fluvial sandstone, trapped by a combination of lateral gradation into shale, and in some cases, structural drape over highs on the unconformity (e.g., Leo Upper Mannville F pool).

*Exploration history (light and medium oil).* The discovery sequence ($\hat{\beta}$=0.8) and the cumulative in-place volume discovered are graphically displayed in Appendix E (Figs. E3.1 and E3.2). The in-place volume has increased from 122 x $10^6 m^3$ (from 177 pools) to 314 x $10^6 m^3$ (from 479 pools) since the GSC's 1987 assessment. The increase is the result of the new discoveries and the appreciation of existing pools. The cumulative in-place graph shows a strong upward increase. The potential and discoveries are summarized in Tables 102 and 103.

*Reservoir parameters (light and medium oil).* Reservoirs have pool areas from 17 to 730 ha; net pay from 1 to 9 m; porosity from 11 to 25%; water saturation from 17 to 50%; and a recovery factor from 0.15 to 35%. The parameters are also graphically shown in Appendix E (Figs. E3.3 to E3.8).

*Exploration history (heavy oil).* The discovery sequence ($\hat{\beta}$=0.8) and the cumulative in-place volume discovered are graphically shown in Appendix E (Figs. E4.1 and E4.2). This play was not defined by the GSC's 1987 assessment. Forty-two oil pools were discovered between 1990 and 1994. The cumulative in-place graph shows a moderate upward increase. The potential and discoveries are summarized in Tables 104 and 105.

*Reservoir parameters (heavy oil).* Reservoirs have pool areas from 17 to 640 ha; net pay from 1 to 11 m; porosity from 14 to 28%; water saturation from 18 to 53%; and a recovery factor from 0.08 to 25%. The parameters are also graphically shown in Appendix E (Figs. E4.3 to E4.8).

*Lower Mannville light and medium, and heavy oil plays*

*Play definition.* These two plays include all light and medium and heavy oil pools in the Lower Mannville Group, which includes the Basal Quartz and Ellerslie members, of the central Alberta play area (Fig. 58).

*Geology.* The isopach map of the transgressive systems tract (Warters et al., 1997) shows that the most critical factor controlling Lower Mannville reservoirs is the topography on the basal unconformity. The valleys in the area are cut on westward-dipping Mississippian to Jurassic sediments, and are filled by a variety of lithofacies. The Basal Quartz is a quartz- and chert-dominated sandstone with some conglomerate, which fills the basal parts of the valleys. Similar to the Cadomin, it is believed to be unconformity-bounded, and possibly much older than the remainder of the unit. The finer grained Ellerslie Member also fills the valleys, but overtops many of the uplands. During Ellerslie deposition, some of the valleys were cut off from a supply of clastics, with the result that marine (Farshori and Hopkins, 1989) and lacustrine sediments filled portions of the valleys. Some cores contain micritic limestones up to 2 m thick within the Ellerslie Member. A series of coarse-grained sandstone bodies within the unit may be the fill of smaller incised valleys. Its top is gradational into the marginal marine to lagoonal sediments of the Ostracod Beds.

*Exploration history (light and medium oil).* The discovery sequence ($\hat{\beta}=0.8$) and the cumulative in-place volume discovered are graphically shown in Appendix E (Figs. E5.1 and E5.2). A total of 92 pools with 31 x $10^6m^3$ in-place volume was discovered between 1990 and 1994. The in-place volume increased from 193 x $10^6m^3$ (from 329 pools) to 274 x $10^6m^3$ (from 678 pools) since the GSC's 1987 assessment. The increase is a result of appreciation in existing pools and the new discoveries. The cumulative in-place graph shows a very strong upward increase. The potential and discoveries are summarized in Tables 106 and 107.

*Reservoir parameters (light and medium oil).* Reservoirs have pool areas from 17 to 315 ha; net pay from 1.3 to 9 m; porosity from 10 to 26%; water saturation from 17 to 52%; and a recovery factor from 0.09 to 25%. The parameters are also graphically shown in Appendix E (Figs. E5.3 to E5.8).

*Exploration history (heavy oil).* The discovery sequence ($\hat{\beta}=0.8$) and the cumulative in-place volume discovered are graphically shown in Appendix E (Figs. E6.1 and E6.2). A total of 32 pools with 5.4 x $10^6m^3$ in-place volume was discovered between 1990 and 1994. The cumulative in-place graph shows a very strong upward increase. The potential and discoveries are summarized in Tables 108 and 109.

**Table 102**

**Pools discovered and predicted for the Upper Mannville light and medium oil play**

| Pool size class ($10^6m^3$) | Pools discovered up to 1989 | Pools discovered between 1990 and 1994 | Pools yet to be discovered |
|---|---|---|---|
| < 0.1 | 86 | 27 | 227 |
| 0.1 - 1 | 245 | 50 | 84 |
| 1 - 10 | 63 | 7 | 10 |
| 10 - 100 | 1 | 0 | 0 |
| Total number of pools | 395 | 84 | 321 |
| In-place volume | 279.833 x $10^6m^3$ | 34.607 x $10^6m^3$ | 26 - 282 x $10^6m^3$ |

**Table 103**

**The five largest pools of Table 102 discovered between 1990 and 1994**

| Field, pool | In-place volume ($10^6m^3$) |
|---|---|
| Alderson, Upper Mannville VVV | 0.840 |
| Jenner, Upper Mannville LL | 0.781 |
| Taber South, Glauconitic E | 0.748 |
| Bow Island, Glauconitic C | 0.727 |
| Cessford, Mannville Z3Z | 0.628 |

**Table 104**

**Pools discovered and predicted for the Upper Mannville heavy oil play**

| Pool size class ($10^6m^3$) | Pools discovered up to 1989 | Pools discovered between 1990 and 1994 | Pools yet to be discovered |
|---|---|---|---|
| < 0.1 | 63 | 17 | 222 |
| 0.1 - 1 | 103 | 25 | 124 |
| 1 - 10 | 31 | 0 | 9 |
| 10 - 100 | 6 | 0 | 0 |
| Total number of pools | 203 | 42 | 355 |
| In-place volume | 267.762 x $10^6m^3$ | 9.133 x $10^6m^3$ | 11 - 212 x $10^6m^3$ |

**Table 105**

**The five largest pools of Table 104 discovered between 1990 and 1994**

| Field, pool | In-place volume ($10^6m^3$) |
|---|---|
| Alderson, Upper Mannville VVV | 0.840 |
| Jenner, Upper Mannville LL | 0.781 |
| Taber South, Glauconitic E | 0.748 |
| Bow Island, Glauconitic C | 0.727 |
| Cessford, Mannville Z3Z | 0.628 |

**Table 106**

**Pools discovered and predicted for the Lower Mannville light and medium oil play**

| Pool size class ($10^6m^3$) | Pools discovered up to 1989 | Pools discovered between 1990 and 1994 | Pools yet to be discovered |
|---|---|---|---|
| < 0.1 | 162 | 39 | 321 |
| 0.1 - 1 | 375 | 46 | 98 |
| 1 - 10 | 47 | 7 | 3 |
| 10 - 100 | 2 | 0 | 0 |
| Total number of pools | 586 | 92 | 422 |
| In-place volume | 243.552 x $10^6m^3$ | 30.833 x $10^6m^3$ | 19 - 144 x $10^6m^3$ |

**Table 107**

**The five largest pools of Table 106 discovered between 1990 and 1994**

| Field, pool | In-place volume ($10^6m^3$) |
|---|---|
| Provost, Ellerslie N | 5.113 |
| Long Coulee, Sunburst K | 3.003 |
| Taber, Taber I | 2.208 |
| Long Coulee, Sunburst P | 1.830 |
| Carmangay, Sunburst A | 1.597 |

**Table 108**

**Pools discovered and predicted for the Lower Mannville heavy oil play**

| Pool size class ($10^6 m^3$) | Pools discovered up to 1989 | Pools discovered between 1990 and 1994 | Pools yet to be discovered |
|---|---|---|---|
| < 0.1 | 72 | 13 | 367 |
| 0.1 - 1 | 98 | 19 | 114 |
| 1 - 10 | 15 | 0 | 1 |
| 10 - 100 | 1 | 0 | 0 |
| Total number of pools | 186 | 32 | 482 |
| In-place volume | $70.514 \times 10^6 m^3$ | $5.439 \times 10^6 m^3$ | $16 - 86 \times 10^6 m^3$ |

**Table 109**

**The five largest pools of Table 108 discovered between 1990 and 1994**

| Field, pool | In-place volume ($10^6 m^3$) |
|---|---|
| Alderson, Lower Mannville TT | 0.858 |
| Taber, Taber F | 0.624 |
| Alderson, Lower Mannville N3N | 0.469 |
| Alderson, Lower Mannville R2R | 0.277 |
| Bantry, Sunburst G | 0.237 |

*Reservoir parameters (heavy oil).* Reservoirs have pool areas from 17 to 174 ha; net pay from 1.3 to 9 m; porosity from 15 to 27%; water saturation from 20 to 50%; and a recovery factor from 0.08 to 20%. The parameters are also graphically shown in Appendix E (Figs. E6.3 to E6.8).

### *Central Alberta region*

Two established plays, Glauconite and Ostracod, are located within this region.

*Glauconite*

*Play definition.* This play includes all oil pools and prospects contained in the Glauconitic sandstone in the central Alberta region (Fig. 58). This play was not defined by the GSC's 1987 assessment.

*Geology.* The Glauconite unit prograded to the northwest, but numerous fluctuations in relative sea level occurred, each generating incision of rivers and deposition of isolated lowstand shoreface sandstone. The incised valleys were commonly backfilled during the subsequent transgressions by estuarine sediments (Wood and Hopkins, 1989; Karvonen and Pemberton, 1989).

*Exploration history.* The discovery sequence ($\hat{\beta}$=0.6) and the cumulative in-place volume discovered are graphically shown in Appendix E (Figs. E7.1 and E7.2). A total of 48 pools with $22.4 \times 10^6 m^3$ in-place volume were discovered. The cumulative in-place graph shows a strong upward increase with a sharp increase in 1990. The potential and discoveries are summarized in Tables 110 and 111.

*Reservoir parameters.* Reservoirs have pool areas from 17 to 480 ha; net pay from 1 to 6.5 m; porosity from 10 to 26%; water saturation from 17 to 47%; and a recovery factor from 0.14 to 25%. The parameters are also graphically shown in Appendix E (Figs. E7.3 to E7.8).

*Ostracod*

*Play definition.* This play includes all oil pools in the Ostracod unit in central Alberta (Fig. 58). Ostracod sandstone is generally recognizable in this area.

*Geology.* The Ostracod Beds is a thin diachronous unit of calcareous mudstone with interbedded limestone, that was deposited in a series of marine bays, brackish-water lagoons, and fresh-water lakes. This unit or facies is found lying behind the shoreface sandstone of the Bluesky Formation (in the north) and the Glauconite unit (in the south). The reservoirs are a series of thin, lowstand, shoreface sandstones that could be correlative to some Glauconite lowstand sandstones or incised valley fills. The trapping mechanisms are dominated by facies changes, with the reservoirs being essentially encased by calcareous mudstone. A few traps involve structural drape over Palaeozoic ridges on the unconformity.

*Exploration history*. The discovery sequence ($\hat{\beta} = 0.3$) and the cumulative in-place volume discovered are graphically shown in Appendix E (Figs. E8.1 and E8.2). The in-place volume has increased from 12 to 23.515 x $10^6 m^3$ since the GSC's 1987 assessment. The increase is a result of the new discoveries. The few largest pools predicted by the GSC's 1987 assessment have been discovered. The cumulative in-place graph shows a very strong upward increase with several jumps in recent years. The potential and discoveries are summarized in Tables 112 and 113.

*Reservoir parameters*. Reservoirs have pool areas from 17 to 1,000 ha; net pay from 1.2 to 11 m; porosity from 8 to 25%; water saturation from 15 to 50%; and a recovery factor from 0.28 to 25%. The parameters are also graphically shown in Appendix E (Figs. E8.3 to E8.8).

### Lloydminster region

Three established plays, Colony to Lloydminster, Cummings and Dina, are located within this region.

#### *Colony to Lloydminster*

*Play definition*. This play includes all oil and gas pools contained in the Lloydminster, Rex, General Petroleum, Sparky, Waseca, McLaren, and Colony members in the Lloydminster play area (Fig. 58). This play was not evaluated in the GSC's 1987 assessment.

*Geology*. Both the facies and trapping mechanisms for this play have been well documented for several fields (Vigras, 1977; Gross, 1980; Putnam, 1982; Zaitlin and Schultz, 1984). The stratigraphic interval consists of at least seven transgressive–regressive shoreline successions, probably deposited as thin wave-dominated delta lobes, which have not been mapped in detail. Each of the regionally extensive shoreface sands is interrupted by a large number of valley fills, cut during falls in relative sea level. In places, the orientation of these valleys is controlled by salt solution effects. The valley fills vary from dominantly mudstone, which may function as seals to reservoirs in the shoreface sandstone, to dominantly sandstone, which functions as reservoirs when surrounded by marine mud or fine-grained, nonmarine to marginal marine, deposits. Other traps occur where sandstone is draped over ridges or highs on the sub-Cretaceous unconformity. A few structures appear to result from drape over older sand-filled channels such as the Sparky Hayter gas field, which occurs in structural closure generated by compactional drape over a Dina channel. Many of the largest gas fields (e.g., Beacon Hill) occur in anticlines related to salt dissolution. Several traps are known to involve more than one mechanism, for example, a local drape structure in which hydrocarbons are trapped against a shale-filled channel.

*Exploration history*. The discovery sequence ($\hat{\beta} =0.8$) and the cumulative in-place volume discovered are graphically displayed in Appendix E (Figs. E9.1 and E9.2). A total of 37 pools with 23.485 x $10^6 m^3$ was discovered between 1990 and 1994. The cumulative in-place graph shows a moderate upward increase. The potential and discoveries are summarized in Tables 114 and 115.

*Reservoir parameters*. Reservoirs have pool areas from 8 to 900 ha; net pay from 1.2 to 7.6 m; porosity from 24 to 35%; water saturation from 10 to 75% (min-max); and a recovery factor from 0.09 to 20%. The parameters are also graphically shown in Appendix E (Figs. E9.3 to E9.8).

#### *Cummings*

*Play definition*. This play includes all oil and gas pools within the Cummings Member in the Lloyminster play area (Fig. 58). This play was not evaluated by the GSC's 1987 assessment.

*Geology*. The Cummings Member is the uppermost portion of the transgressive phase of the Mannville in the Lloydminster area, and corresponds to the Bluesky and Wabiskaw formations in other parts of the basin. The sediments are shoreface sandstone with associated nonmarine, marginal marine, and incised valley deposits. As in equivalent units, the shoreface successions are arranged in a southward backstepping pattern, but in this eastern, low subsidence area, more disconformities are present. As in the Wabiskaw, traps are formed stratigraphically and by salt solution effects.

*Exploration history*. The discovery sequence ($\hat{\beta} =1.0$) and the cumulative in-place volume discovered are graphically shown in Appendix E (Figs. E10.1 and E10.2). A total of 33 oil pools with 3.7 x $10^6 m^3$ was discovered between 1990 and 1994. The cumulative in-place graph shows a moderate upward increase. The potential and discoveries are summarized in Tables 116 and 117.

*Reservoir parameters*. Reservoirs have pool areas from 4 to 400 ha; net pay from 0.7 to 9 m; porosity from 20 to 30%; water saturation from 17 to 50%; and a recovery factor from 0.07 to 30%. The parameters are also graphically shown in Appendix E (Figs. E10.3 to E10.8).

Table 110

Pools discovered and predicted for the Glauconite play

| Pool size class ($10^6m^3$) | Pools discovered up to 1989 | Pools discovered between 1990 and 1994 | Pools yet to be discovered |
|---|---|---|---|
| < 0.1 | 31 | 13 | 213 |
| 0.1 - 1 | 84 | 31 | 206 |
| 1 - 10 | 13 | 4 | 3 |
| 10 - 100 | 1 | 0 | 1 |
| Total number of pools | 129 | 48 | 423 |
| In-place volume | 71.194 x $10^6m^3$ | 22.422 x $10^6m^3$ | 36 - 118 x $10^6m^3$ |

Table 111

The five largest pools of Table 110 discovered between 1990 and 1994

| Field, pool | In-place volume ($10^6m^3$) |
|---|---|
| Provost, Glauconitic A | 7.399 |
| Shouldice, Glauconitic R | 1.477 |
| Cavalier, Glauconitic C | 1.451 |
| Leahurst, Glauconitic B | 1.350 |
| Thorsby, Glauconitic K | 0.942 |

Table 112

Pools discovered and predicted for the Ostracod play

| Pool size class ($10^6m^3$) | Pools discovered up to 1989 | Pools discovered between 1990 and 1994 | Pools yet to be discovered |
|---|---|---|---|
| < 0.1 | 28 | 6 | 94 |
| 0.1 - 1 | 39 | 7 | 77 |
| 1 - 10 | 3 | 2 | 4 |
| Total number of pools | 70 | 15 | 175 |
| In-place volume | 19.393 x $10^6m^3$ | 4.122 x $10^6m^3$ | 14 - 31 x $10^6m^3$ |

Table 113

The five largest pools of Table 112 discovered between 1990 and 1994

| Field, pool | In-place volume ($10^6m^3$) |
|---|---|
| Bigoray, Ostracod H | 1.063 |
| Westpem, Ostracod G | 1.000 |
| Tomahawk, Ostracod F | 0.491 |
| Tomahawk, Ostracod G | 0.456 |
| Tomahawk, Ostracod I | 0.191 |

Table 114

**Pools discovered and predicted for the Colony to Lloydminster play**

| Pool size class ($10^6m^3$) | Pools discovered up to 1989 | Pools discovered between 1990 and 1994 | Pools yet to be discovered |
|---|---|---|---|
| < 0.1 | 135 | 14 | 2432 |
| 0.1 - 1 | 219 | 18 | 1145 |
| 1 - 10 | 89 | 4 | 38 |
| 10 - 100 | 53 | 1 | 2 |
| Total number of pools | 496 | 37 | 3617 |
| In-place volume | 1,846.722 x $10^6m^3$ | 23.485 x $10^6m^3$ | 832 - 2,176 x $10^6m^3$ |

Table 115

**The five largest pools of Table 114 discovered between 1990 and 1994**

| Field, pool | In-place volume ($10^6m^3$) |
|---|---|
| Long Lake, Waseca Sand | 11.307 |
| Provost, Lloydminster KK | 2.201 |
| Senlac, Waseca Sand | 2.136 |
| Provost, Lloydminster UU | 1.623 |
| Provost, Upper Mannville M6M | 1.087 |

Table 116

**Pools discovered and predicted for the Cummings play**

| Pool size class ($10^6m^3$) | Pools discovered up to 1989 | Pools discovered between 1990 and 1994 | Pools yet to be discovered |
|---|---|---|---|
| < 0.1 | 20 | 20 | 484 |
| 0.1 - 1 | 30 | 13 | 71 |
| 1 - 10 | 8 | 0 | 2 |
| 10 - 100 | 2 | 0 | 0 |
| Total number of pools | 60 | 33 | 557 |
| In-place volume | 46.871 x $10^6m^3$ | 3.709 x $10^6m^3$ | 15 - 84 x $10^6m^3$ |

Table 117

**The five largest pools of Table 116 discovered between 1990 and 1994**

| Field, pool | In-place volume ($10^6m^3$) |
|---|---|
| Provost, Cummings A2A | 0.646 |
| Provost, Cummings M and Lloydminster M | 0.311 |
| Provost, Cummings OOO, PPP and Dina E4E | 0.253 |
| Provost, Cummings VVV | 0.231 |
| Provost, Cummings TTT | 0.223 |

*Dina*

*Play definition.* This play includes all oil and gas pools within the Dina Member in the Lloydminster play area (Fig. 58). This play was not evaluated in the GSC's 1987 assessment.

*Geology.* The Dina Member fills large valleys eroded into Palaeozoic rocks in east-central Alberta and west-central Saskatchewan. It is believed to be mainly fluvial (Gross, 1980) but has not been studied in detail. However, it is proximal to the brackish-water McMurray Formation in northeast Alberta, lending support to its probable fluvial origin. Many of the valley fills show complex internal patterns, with sandstones as thick as 90 m laterally adjacent to mudstone-dominated facies. The major fields occur in areas of thick sandstone accumulation. Sandstone distribution is controlled by the sub-Mannville erosion surface. The trapping mechanism is varied; in some cases it is structural drape formed by salt solution, in other cases (e.g., Hayter field), lateral facies changes in the upper part of the valley fill create a permeability barrier to fluid movement.

*Exploration history.* The discovery sequence ($\hat{\beta}=0.8$) and the cumulative in-place volume discovered are graphically shown in Appendix E (Figs. E11.1 and E11.2). A total of 54 oil pools with 12.251 x $10^6 m^3$ was discovered between 1990 and 1994. The cumulative in-place graph shows a moderate to strong upward increase. The potential and discoveries are summarized in Tables 118 and 119.

*Reservoir parameters.* Reservoirs have pool areas from 4 to 366 ha; net pay from 1.8 to 8 m; porosity from 19 to 30%; water saturation from 18 to 51%; and a recovery factor from 0.11 to 40%. The parameters are also graphically shown in Appendix E (Figs. E11.3 to E11.8).

***Southern Alberta region***

Only one established play exists within this region.

*Detrital*

*Play definition.* This play includes all oil and gas pools contained within the Detrital and Deville formations in the Alberta and Saskatchewan play area (Fig. 59). This play was not evaluated by the GSC's 1987 assessment.

*Geology.* The Detrital, or Deville, Formation is an accumulation of weathering products lying directly on Palaeozoic rocks, and separated from the rest of the Mannville Group by an unconformity (Christopher, 1974). It occurs very irregularly throughout much of the basin but it is unclear whether this patchy occurrence is dominantly the result of sub-Mannville erosion or nondeposition. In some places it lies in depressions on the unconformity surface, but in others, it forms the upper part of high standing areas. The unit consists of nonmarine sandstone, mudstone, and some chert-pebble conglomerate, some of which shows evidence of transport (i.e., crossbedding). Accumulation was therefore not entirely in-situ. Pools occur as stratigraphic entrapments against paleotopography on the basal unconformity.

*Exploration history.* The discovery sequence ($\hat{\beta}=1.0$) and the cumulative in-place volume discovered are graphically shown in Appendix E (Figs. E12.1 and E12.2). The largest oil pool with an 8.1 x $10^6 m^3$ in-place volume was discovered in 1991. The cumulative in-place graph shows a moderate upward increase with a sharp increase in 1991. The potential and discoveries are summarized in Tables 120 and 121.

*Reservoir parameters.* Reservoirs have pool areas from 17 to 174 ha; net pay from 1 to 20 m (min-max); porosity from 11 to 31%; water saturation from 15 to 50%; and a recovery factor from 0.04 to 20%. The parameters are also graphically shown in Appendix E (Figs. E12.3 to E12.8).

***Saskatchewan region***

Only the Cantuar established play exists within this region.

*Cantuar*

*Play definition.* This play includes all oil and gas pools in the Cantuar Formation of Saskatchewan. There are nine oil and four gas pools discovered to date in the Cantuar play. In the GSC's 1987 assessment, each unit was considered as one pool, whereas in the present assessment, all units of the same pool were added together as one single pool. Therefore, the numbers of pools for these two assessments vary.

*Geology.* The Cantuar is equivalent to the entire Mannville in Alberta and comprises three members (McLeod, Dimmock Creek, and Atlas). The regional geology of the unit was described by Christopher (1974, 1984), Putnam (1989), and Leckie et al. (1994b). At the base of the Cantuar is a major unconformity that downcuts as much as 74 m into the underlying Jurassic units. The Dimmock Creek and McLeod members are found only at the base of the valley fills. The Atlas Member is deposited within the valleys and overlying the interfluve areas capped by the Jurassic Success S2. Because this was an area of low subsidence rate, sedimentation was generally nonmarine to marginal marine, with numerous incised valleys filled by estuarine deposits and shaly intervals with soil horizons (Leckie et al., 1994b), reflecting base-level changes.

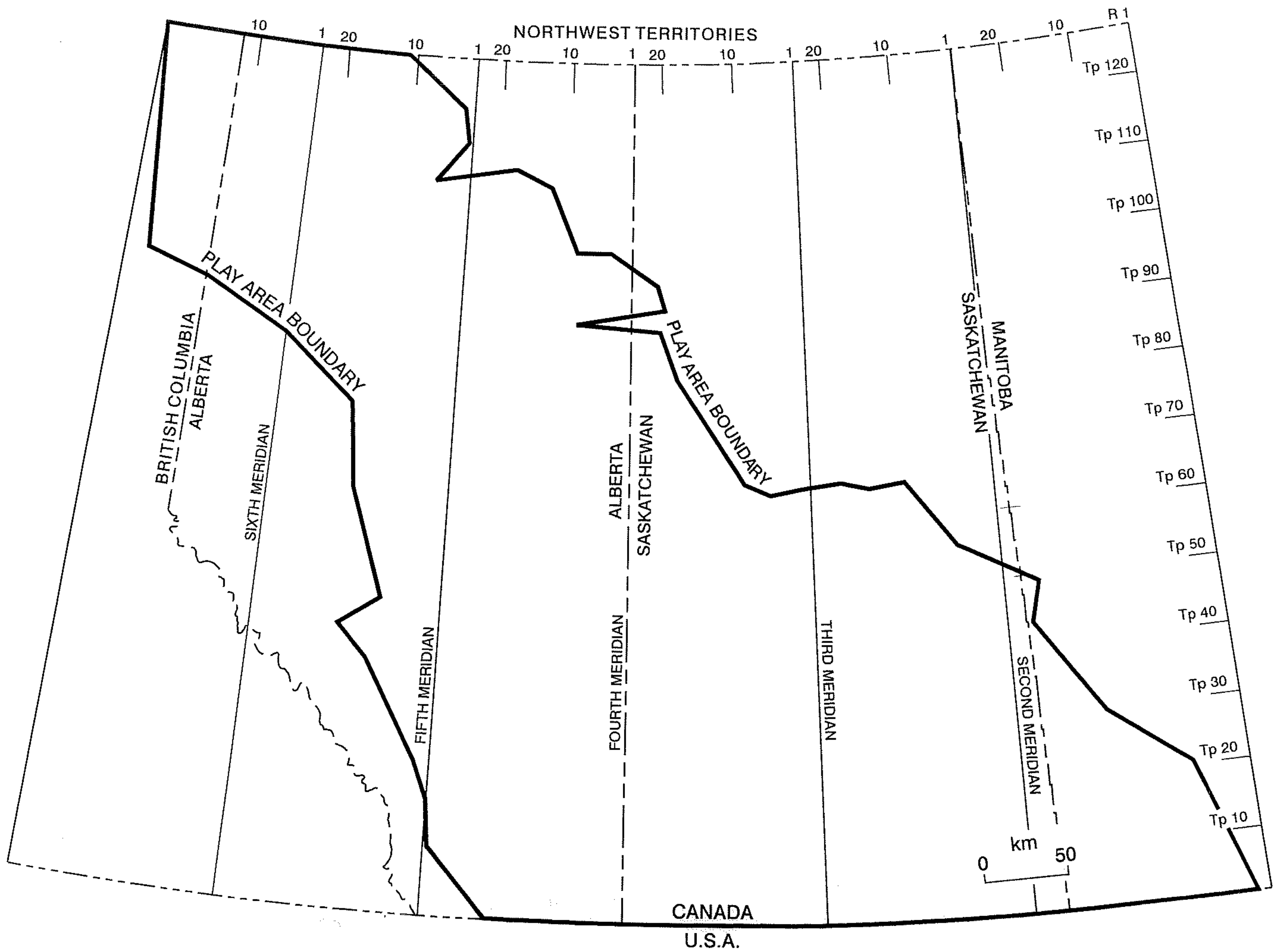


***Figure 59.*** *Play areas in Alberta and Saskatchewan (Detrital).*

*Exploration history.* The discovery sequence ($\hat{\beta}$=1.0) and the cumulative in-place volume discovered are graphically shown in Appendix E (Figs. E13.1 and E13.2). The in-place volume has increased from 51 to 66 x $10^6 m^3$ since the GSC's 1987 assessment. The increase is mainly the result of appreciation in existing pools. The cumulative in-place graph shows a very strong upward increase. The potential and discoveries are summarized in Tables 122 and 123.

*Reservoir parameters.* Reservoirs have pool areas from 10 to 3,200 ha (min-max); net pay from 1 to 7.8 m (min-max); porosity from 10 to 28% (min-max); water saturation from 10 to 60% (min-max); and a recovery factor from 1 to 22% (min-max). The parameters are also graphically shown in Appendix E (Figs. E13.3 to E13.8).

### *Heavy oil assessment comparison*

The heavy oil resource was evaluated by various authors and companies. A comparison of their assessments is given in Table 124.

## Table 118

**Pools discovered and predicted for the Dina play**

| Pool size class ($10^6m^3$) | Pools discovered up to 1989 | Pools discovered between 1990 and 1994 | Pools yet to be discovered |
|---|---|---|---|
| < 0.1 | 30 | 33 | 356 |
| 0.1 - 1 | 66 | 18 | 74 |
| 1 - 10 | 17 | 3 | 1 |
| 10 - 100 | 2 | 0 | 0 |
| Total number of pools | 115 | 54 | 431 |
| In-place volume | 136.542 x $10^6m^3$ | 12.251 x $10^6m^3$ | 17 - 255 x $10^6m^3$ |

## Table 119

**The five largest pools of Table 118 discovered between 1990 and 1994**

| Field, pool | In-place volume ($10^6m^3$) |
|---|---|
| Provost, Dina E5E | 1.733 |
| Provost, Dina W4W | 1.149 |
| Provost, Dina U3U | 1.142 |
| Provost, Dina I5I | 0.900 |
| Provost, Dina I4I | 0.785 |

## Table 120

**Pools discovered and predicted for the Detrital play**

| Pool size class ($10^6m^3$) | Pools discovered up to 1989 | Pools discovered between 1990 and 1994 | Pools yet to be discovered |
|---|---|---|---|
| < 0.1 | 12 | 1 | 414 |
| 0.1 - 1 | 19 | 0 | 149 |
| 1 - 10 | 1 | 1 | 3 |
| Total number of pools | 32 | 2 | 566 |
| In-place volume | 8.091 x $10^6m^3$ | 8.209 x $10^6m^3$ | 45 - 85 x $10^6m^3$ |

## Table 121

**The two largest pools of Table 120 discovered between 1990 and 1994**

| Field, pool | In-place volume ($10^6m^3$) |
|---|---|
| Marengo South, Detrital | 8.125 |
| Capron, Detrital D | 0.083 |

## Table 122

### Pools discovered and predicted for the Cantuar play

| Pool size class ($10^6m^3$) | Pools discovered up to 1984 | Pools discovered between 1985 and 1994 | Pools yet to be discovered |
|---|---|---|---|
| < 1 | 2 | 0 | 23 |
| 1 - 10 | 4 | 1 | 7 |
| 10 - 100 | 2 | 0 | 1 |
| Total number of pools | 8 | 1 | 31 |
| In-place volume | $64.644 \times 10^6m^3$ | $1.440 \times 10^6m^3$ | $3 - 64 \times 10^6m^3$ |

## Table 123

### The Cantuar pool of Table 122 discovered in 1985

| Field, pool | In-place volume ($10^6m^3$) |
|---|---|
| Beverley East, Cantuar Sand | 1.440 |

## Table 124

### Heavy oil assessment comparison

| Study | Discovered ($10^6$ $m^3$) | Potential estimated ($10^6$ $m^3$) |
|---|---|---|
| Energy, Mines and Resources Canada, 1977 | 0.95 | 1.0 probable<br>5.1 ultimate |
| White and Von Osinski, 1977 | N/A | 1.67 ultimate |
| Christopher and Knudsen (UNITAR, 1979) | N/A | 2.38 - 3.18 |
| McCrossan et al.,1979 | N/A | 3.97 probable |
| Gulf (Oilweek, March 1981) | N/A | 3.97 probable<br>9.22 ultimate |
| Petro-Canada | N/A | 2.70 |
| Mitschke, 1982 | 1.1 | 2.30 mean<br>5.56 5th upper percentile |
| Lee (1986) | 1.81 | 2.59<br>(Saskatchewan only) |
| This study (1997) | 2.42 | 1.08 - 2.51<br>(0.9 probability)<br>mean = 1.80<br>(Western Canada Basin) |

## UPPER CRETACEOUS SYSTEM — COLORADO GROUP

### Geological framework

The Colorado Group (Fig. 60) was deposited during a time when eustasy dominated tectonic effects in influencing sedimentation patterns. This assemblage (Albian to Santonian) consists of widespread marine shale with thin shallow marine coarse clastic interbeds. Continental deposits are restricted to the edges of the basin. Initially rising base level accompanying Late Albian transgression removed some Upper Mannville sediments, and reworked them into basal Colorado sandstone. Continued transgression deposited the Joli Fou and Bow Island shales in the south. Equivalent Hasler shales were deposited in the northwestern part of the basin. The Joli Fou is overlain by the first major marine sandstone and conglomerate unit of this succession, the Viking Formation.

A thick sequence of marine deposits overlies the basal sandstone in central and southern Alberta (Base of Fish Scale, Second White Specks). In the northern part of the basin, the equivalent marine shales are interrupted by multi-stage deltaic and shoreline complex deposits of the Dunvegan and Doe Creek formations.

In western Alberta during a Turonian regression, the second major marine sandstone–conglomerate unit, the Cardium Formation, was deposited on Colorado or Kaskapau shale. Following the Cardium deposition, a final transgressive–regressive cycle ended the marine-dominated sedimentation in the Western Canada Sedimentary Basin. This final cycle deposited Upper Colorado-Wapiabi shale, overlain in the south by the First White Specks.

The play definitions are adopted from the work on the gas resource assessment by Reinson et al., (1994).

### Resource assessment

#### *Colorado Group potential*

The potential predicted from the established mature plays ranges from 274 to 903 x $10^6m^3$. The mean (expected value) of the potential distribution is 554 x $10^6m^3$. The Viking transgressive play has the greatest oil potential in the Colorado Group. Immature play potential ranges from 209 to 270 x $10^6m^3$ with an expected value of 240 x $10^6m^3$.

Furthermore, the in-place oil volume has increased from 1,942 x $10^6m^3$ to 2,327 x $10^6m^3$ since the GSC's 1987 assessment. A total of 19 x $10^6m^3$ of in-place volume was discovered between 1990 and 1994. The number of pools discovered and the sizes of the ten largest pools discovered between 1990 and 1994 are shown in Tables 125 and 126.

#### *Plains region*

Seven established mature plays, Cardium, Second White Specks, Doe Creek, Dunvegan, and Viking (transgressive, regressive, and channel), and numerous immature plays are located within this region.

##### *Cardium*

*Play definition.* This play includes all oil and gas pools in the Cardium Formation including shoreline, sheet and scour-fill clastics forming stratigraphic traps. The play area extends from the sandstone depositional edge in the east to the disturbed belt in the west (Fig. 61).

*Geology.* The Cardium Formation consists dominantly of coarsening-upward shoreline and shallow marine sandstone and conglomerate interspersed with marine shale. Progradation occurred to the east, with the continental facies (Moosehound Member) present in the northwest and eastern pinch-out of the sandstone to marine shale. Regional tectonic tilt to the southwest has located the shale updip of the sandstone, providing top and lateral seals.

The complex depositional history of the Cardium has been addressed by many researchers during the last three decades (Swagor et al., 1976; Plint et al., 1986; Krause et al., 1994). General consensus is that several transgressive–regressive sequences occur within the Cardium, though the regional extent of the bounding surfaces and controlling mechanisms are still under investigation. Krause et al. (1994) viewed the complex sequences of the Cardium as a combination of autocyclic and allocyclic processes, with delta avulsion, tectonics, subsidence and eustatic sea level change.

The complex depositional history of the Cardium has resulted in an array of stratigraphic traps. Long, narrow, northwest-trending shelf sandbodies in the lower Cardium contain pools such as Garrington and Crossfield (Krause et al., 1994). In the middle Cardium Formation of southern and central Alberta, stacked coarsening-upward sandstone unconformably overlain by conglomerate occurs as broad sheets or elongate northwest-trending bars. Pembina, a supergiant oil field, occurs in sheet sandstone and conglomerate. Scour-fill sandstone cut into shale or sheet sandstone, forming traps at Ricinus and Cyn-Pem (Barclay and Smith, 1992). To the north, the coastal plain–shoreline sandstone and conglomerate of the Kakwa Member of the upper Cardium are the reservoirs for pools such as Kakwa (Deutsch, 1992) and Wapiti.

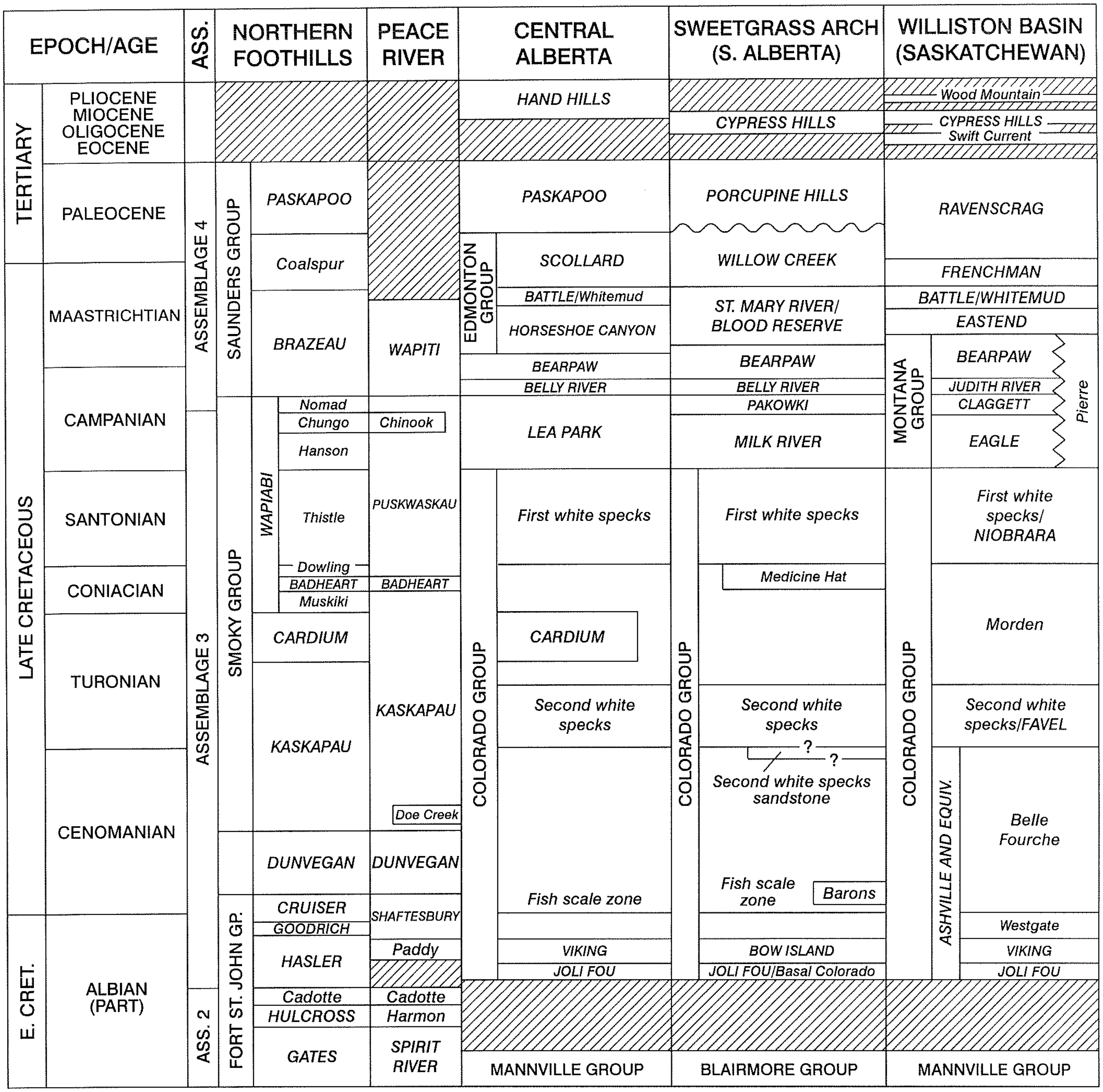


***Figure 60.*** *Table of formations, Late Cretaceous to Tertiary, Western Canada Sedimentary Basin.*

*Exploration history.* The discovery sequence ($\hat{\beta}$ =0.6) and the cumulative in-place volume discovered are graphically shown in Appendix F (Figs. F1.1 and F1.2). The in-place volume has decreased from 1,549 x $10^6 m^3$ (176 pools) to 1,536 x $10^6 m^3$ (210 pools) since the GSC's 1987 assessment. This is because the amount of depreciation from existing pools is greater than the volume of new discoveries. Seven oil pools were discovered between 1990 and 1994. The cumulative in-place graph shows a gradual upward increase. The potential and discoveries are summarized in Tables 127 and 128.

*Reservoir parameters.* There is a significant range in reservoir parameters due to the variation in the pool geometry. For example, the Pembina pool has a pool area of over 200,000 ha. In general, reservoirs have pool areas from 32 to 2,500 ha; net pay from 1 to 7.5 m; porosity from 6 to 16%; water saturation from 10 to 37%; and a recovery factor from 0.18 to 22%. The parameters are also graphically shown in Appendix F (Figs. F1.3 to F1.8).

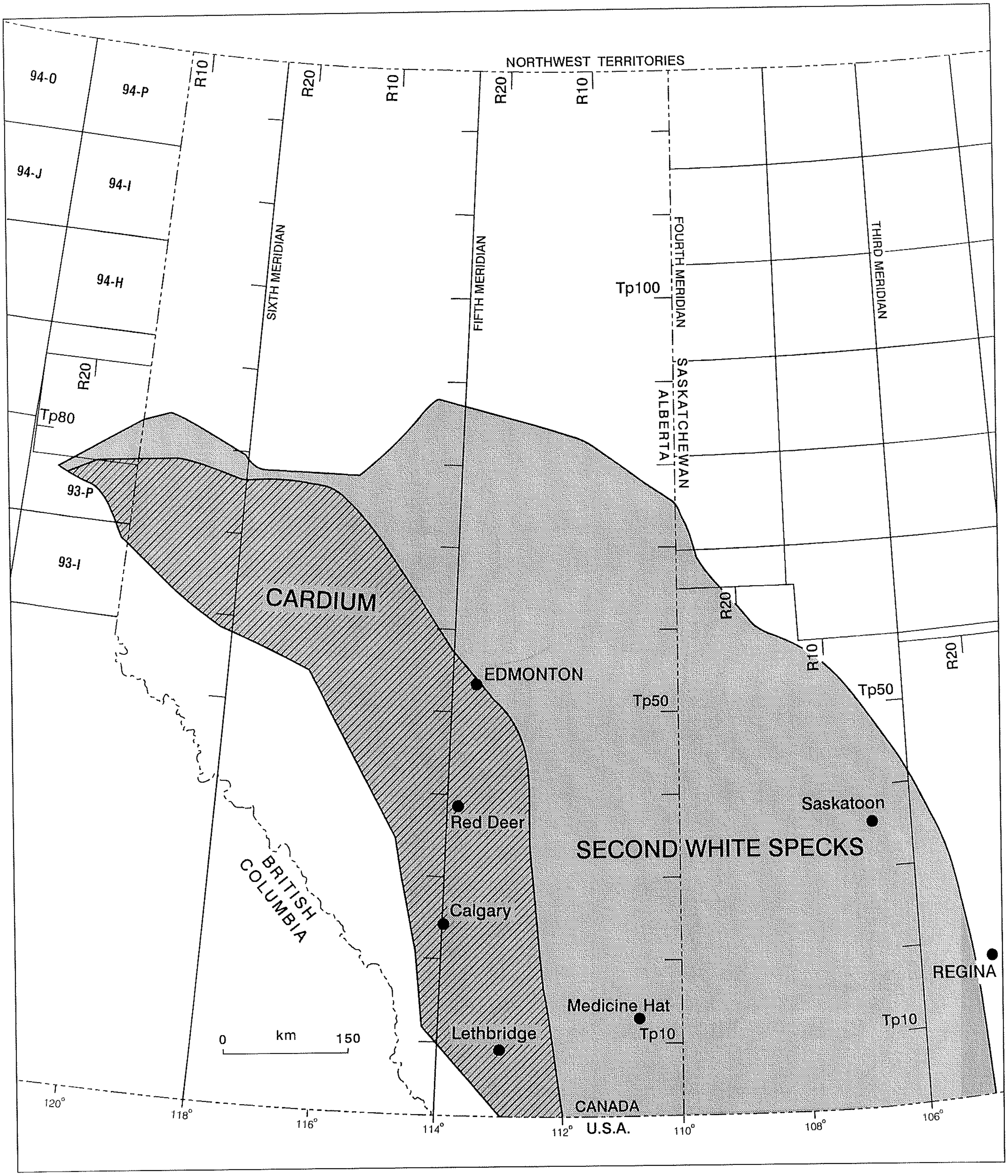


*Figure 61.* *Play maps for the Cardium and Second White Specks.*

**Table 125**

**Colorado Group oil pools discovered**

| Pool size class ($10^6 m^3$) | Pools discovered up to 1989 | Pools discovered between 1990 and 1994 |
|---|---|---|
| < 0.1 | 208 | 13 |
| 0.1 - 1 | 372 | 17 |
| 1 - 10 | 81 | 2 |
| 10 - 100 | 20 | 0 |
| 100 - 1,000 | 1 | 0 |
| > 1,000 | 1 | 0 |
| Total number of pools | 684 | 32 |
| In-place volume | 2,307.915 x $10^6 m^3$ | 19.022 x $10^6 m^3$ |

**Table 126**

**The ten largest Colorado Group pools of Table 125 discovered between 1990 and 1994**

| Field, pool | In-place volume ($10^6$ $m^3$) |
|---|---|
| Gilby, Viking A | 7.041 |
| Valhalla, Doe Creek T and U | 6.009 |
| Valhalla, Doe Creek V | 2.499 |
| Gilby, Second White Specks C | 0.455 |
| Edson, Second White Specks C | 0.315 |
| Spring Coulee, Second White Specks A | 0.250 |
| Cyn-Pem, Cardium W | 0.247 |
| Jumpbush, Bow Island A | 0.219 |
| Fir, Dunvegan A | 0.174 |
| Pembina, Second White Specks C | 0.140 |

**Table 127**

**Pools discovered and predicted for the Cardium play**

| Pool size class ($10^6 m^3$) | Pools discovered up to 1989 | Pools discovered between 1990 and 1994 | Pools yet to be discovered |
|---|---|---|---|
| < 0.1 | 53 | 3 | 114 |
| 0.1 - 1 | 122 | 4 | 76 |
| 1 - 10 | 20 | 0 | 0 |
| 10 - 100 | 6 | 0 | 0 |
| 100 - 1000 | 1 | 0 | 0 |
| 1000 - 10000 | 1 | 0 | 0 |
| Total number of pools | 203 | 7 | 190 |
| In-place volume | 1534.733 x $10^6 m^3$ | 0.754 x $10^6 m^3$ | 21 - 30 x $10^6 m^3$ |

**Table 128**

**The five largest pools of Table 127 discovered between 1990 and 1994**

| Field, pool | In-place volume ($10^6 m^3$) |
|---|---|
| Cyn-Pem, Cardium W | 0.247 |
| Pine Creek, Cardium U | 0.131 |
| Pembina, Cardium Y | 0.129 |
| Pembina, Cardium W | 0.101 |
| Fir, Cardium E | 0.085 |

*Second White Specks*

*Play definition.* This play includes all oil and gas pools in fractured siltstone and shale of the Second White Specks unit. The western boundary of the play is defined by the Foothills and the eastern boundary by the extent of structural-stratigraphic trapping (Fig. 61). The First and Second White Specks were combined as one play in the GSC's 1987 assessment.

*Geology.* During a mid-Cretaceous transgression joining the Gulf of Mexico and the Boreal Sea, the organic-rich Second White Specks shale was deposited. The white specks refer to sand-sized fragments of coccoliths and coccospheres concentrated in the unit by currents (Leckie et al., 1994a). Locally, reservoirs were created from fracturing during Laramide deformation (Podruski et al., 1988). Pine Creek and Willesden Green are two large pools in this play.

*Exploration history.* The discovery sequence ($\hat{\beta}=0.4$) and the cumulative in-place volume discovered are graphically shown in Appendix F (Figs. F2.1 and F2.2). The in-place volume has increased from 7 to 28 x $10^6 m^3$ since the GSC's 1987 assessment. The increase is mainly the result of new discoveries. The few largest oil pools predicted by the GSC's 1987 assessment have been discovered. The cumulative in-place graph shows a very strong upward increase with a sharp increase in 1989. The potential and discoveries are summarized in Tables 129 and 130. It is expected that continued serendipitous discoveries will be made in this play as a result of exploratory drilling for deeper, more predictable plays.

*Reservoir parameters.* Reservoirs have pool areas from 17 to 283 ha; net pay from 2 to 19 m; porosity from 3 to 22%; water saturation from 10 to 50% (min-max); and a recovery factor from 0.20 to 19%. The parameters are also graphically shown in Appendix F (Figs. F2.3 to F2.8).

*Doe Creek*

*Play definition.* This play includes all oil and gas pools in shallow marine sandstone enclosed by marine shale of the Kaskapau Formation, forming stratigraphic traps. Several sandstone members occur in the Kaskapau but oil production is limited to the oldest member, the Doe Creek. The play is confined to northern Alberta and adjacent areas in British Columbia, with the eastern edge defined by the pinchout of the sand and the western edge limited by the gas-charged Deep Basin (Fig. 62). The Doe Creek and Dunvegan plays were combined as a single play in the GSC's 1987 assessment. The combined reserves have increased from 26 to 89 x $10^6 m^3$ since the 1987's assessment. This increase is the result of new discoveries and appreciation of existing pools.

*Geology.* The Doe Creek contains several shallow marine sequences separated from the Dunvegan by laterally extensive marine shale. Overall backstepping during the deposition of the Doe Creek resulted in the sand being shingled in a retrogradational pattern (Wallace-Dudley and Leckie, 1993). Traps are formed mainly by thin northeast-trending bars pinching out into marine shale, which constitute the top, lateral and bottom seals. Valhalla, the largest pool of this play, was discovered in 1982.

*Exploration history.* The discovery sequence ($\hat{\beta}=1.0$) and the cumulative in-place volume discovered are graphically shown in Appendix F (Figs. F3.1 and F3.2). The largest pools predicted by the GSC's 1987 assessment have been discovered. Significant pools were discovered between 1990 and 1994. The cumulative in-place graph shows a very strong upward increase with several sharp increases in recent years. The potential and discoveries are summarized in Tables 131 and 132.

*Reservoir parameters.* Reservoirs have pool areas from 62 to 2,222 ha; net pay from 1 to 4 m; porosity from 14 to 27%; water saturation from 19 to 44%; and a recovery factor from 0.06 to 19%. The parameters are also graphically shown in Appendix F (Figs. F3.3 to F3.8).

*Dunvegan*

*Play definition.* This play includes all oil and gas pools in the fluviodeltaic sandstone of the Dunvegan Formation. The play is located in north-central Alberta and adjacent areas in British Columbia (Fig. 62). Pinchout of the sand defines the eastern edge, and the gas-charged Deep Basin defines the western edge.

*Geology.* Deposition of the Dunvegan occurred in a series of progradational cycles with the source in northeastern British Columbia. The Dunvegan mostly comprises regressive deposits and ranges from 100 to 400 m in thickness. Transgressive units separating the regressive units are generally thin (Bhattacharya and Walker, 1991a). Maximum progradation into the basin was achieved by the middle Dunvegan, which is part of Allomember E as defined by Bhattacharya and Walker (1991a). Subsequent cycles backstepped toward the northwest as the subsidence rate overcame sediment supply. Backstepping continued into the Doe Creek and the shale separating the two reservoir units is highly diachronous (Bhattacharya, 1994).

Reservoir sandstones were deposited in environments ranging from estuarine channel, distributary channel, distributary mouth bar, delta lobes, shoreface/shoreline and fluvial channels (Bhattacharya and Walker, 1991b). Trapping is stratigraphic; marine shale, bay mudstone and intraformational siltstone and tight sandstone form the seals.

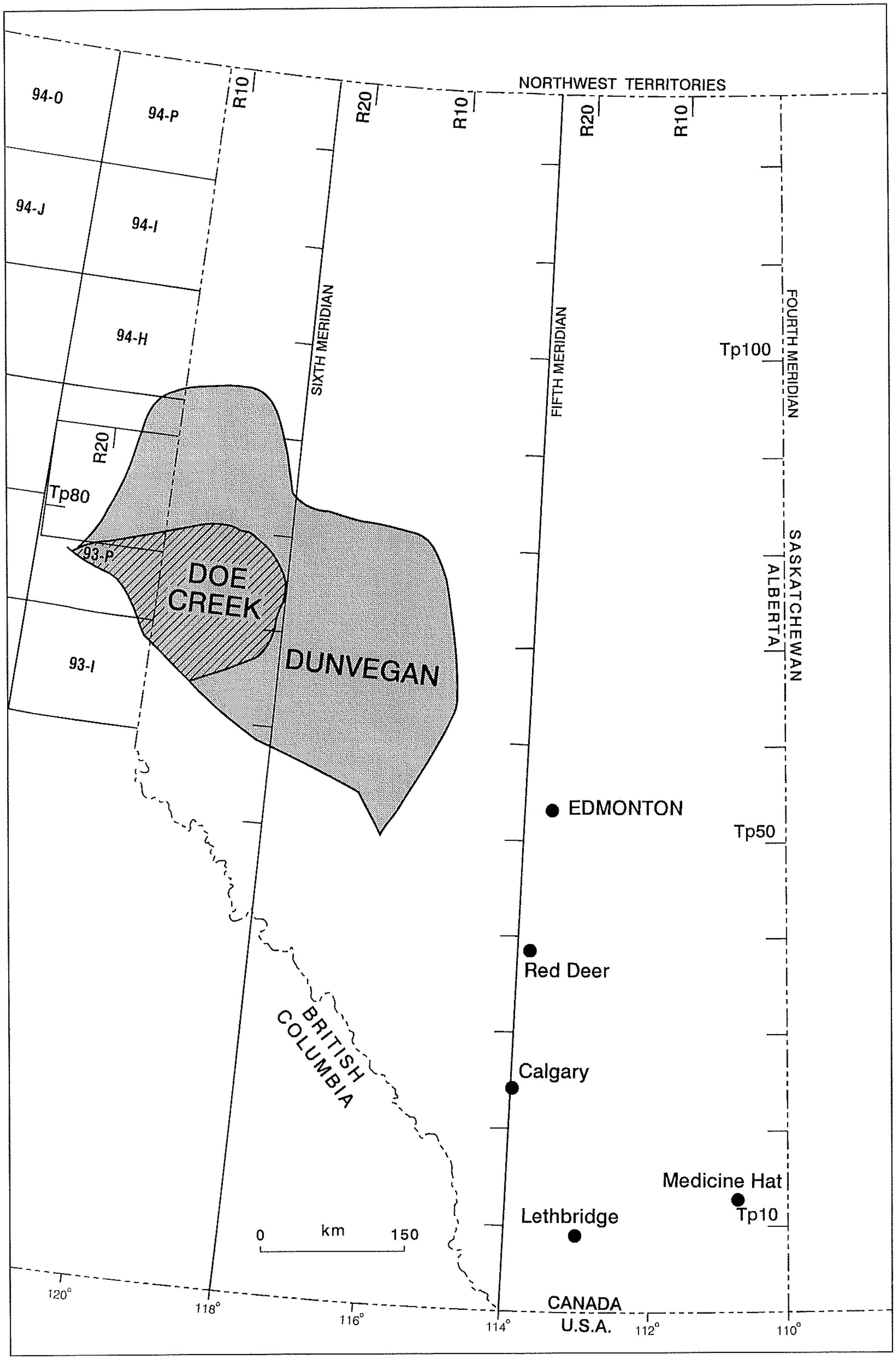


***Figure 62.*** *Play maps for the Doe Creek and Dunvegan.*

## Table 129

**Pools discovered and predicted for the Second White Specks play**

| Pool size class ($10^6m^3$) | Pools discovered up to 1989 | Pools discovered between 1990 and 1994 | Pools yet to be discovered |
|---|---|---|---|
| < 0.1 | 9 | 1 | 83 |
| 0.1 - 1 | 37 | 4 | 155 |
| 1 - 10 | 4 | 0 | 7 |
| Total number of pools | 50 | 5 | 245 |
| In-place volume | $26.583 \times 10^6m^3$ | $1.188 \times 10^6m^3$ | $46 - 79 \times 10^6m^3$ |

## Table 130

**The five largest pools of Table 129 discovered between 1990 and 1994**

| Field, pool | In-place volume ($10^6m^3$) |
|---|---|
| Gilby, Second White Specks C | 0.455 |
| Edson, Second White Specks C | 0.315 |
| Spring Coulee, Second White Specks A | 0.250 |
| Pembina, Second White Specks C | 0.140 |
| Strachan, Second White Specks A | 0.028 |

## Table 131

**Pools discovered and predicted for the Doe Creek play**

| Pool size class ($10^6m^3$) | Pools discovered up to 1989 | Pools discovered between 1990 and 1994 | Pools yet to be discovered |
|---|---|---|---|
| < 0.1 | 3 | 0 | 154 |
| 0.1 - 1 | 11 | 0 | 120 |
| 1 - 10 | 4 | 2 | 4 |
| 10 - 100 | 1 | 0 | 1 |
| Total number of pools | 19 | 2 | 279 |
| In-place volume | $59.049 \times 10^6m^3$ | $8.508 \times 10^6m^3$ | $9 - 151 \times 10^6m^3$ |

## Table 132

**The two largest pools of Table 131 discovered between 1990 and 1994**

| Field, pool | In-place volume ($10^6m^3$) |
|---|---|
| Valhalla, Doe Creek T and U | 6.009 |
| Valhalla, Doe Creek V | 2.499 |

The Simonette and Waskahigan Dunvegan pools produce from estuarine channel sandstone (Bhattacharya, 1989).

*Exploration history.* The discovery sequence ($\hat{\beta}=0.8$) and the cumulative in-place volume discovered are graphically shown in Appendix F (Figs. F4.1 and F4.2).

The second largest pool so far was discovered in 1988. The cumulative in-place graph shows a moderate upward increase with a jump in 1988. The potential and discoveries are summarized in Tables 133 and 134.

*Reservoir parameters.* Reservoirs have pool areas from 17 to 1,200 ha; net pay from 2 to 11 m; porosity from 9 to 18%; water saturation from 25 to 42%; and a recovery factor from 0.07 to 10%. The parameters are also graphically shown in Appendix F (Figs. F4.3 to F4.8).

*Viking plays*

In assessing Viking gas resources, Reinson et al. (1995) divided the Viking into three plays, reflecting the application

**Table 133**

**Pools discovered and predicted for the Dunvegan play**

| Pool size class ($10^6m^3$) | Pools discovered up to 1989 | Pools discovered between 1990 and 1994 | Pools yet to be discovered |
|---|---|---|---|
| < 0.1 | 2 | 0 | 14 |
| 0.1 - 1 | 17 | 2 | 58 |
| 1 - 10 | 6 | 0 | 1 |
| Total number of pools | 25 | 2 | 73 |
| In-place volume | 20.622 x $10^6m^3$ | 0.288 x $10^6m^3$ | 3 - 23 x $10^6m^3$ |

**Table 134**

**The two largest pools of Table 133 discovered between 1990 and 1994**

| Field, pool | In-place volume ($10^6m^3$) |
|---|---|
| Fir, Dunvegan A | 0.174 |
| Waskahigan, Dunvegan E | 0.114 |

of sequence stratigraphy to resource evaluation for this significant hydrocarbon-bearing horizon. This approach was also used in assessing the oil resource, which was subdivided into the regressive, transgressive and channel plays. The three plays occur at different stratigraphic levels. Pools from more than one Viking play are present at some locations.

Separation of the Viking into sequences on a regional scale were demonstrated by Boreen and Walker (1991) and Reinson et al. (1994). Regional cross sections presented by Reinson et al. (1994) show the highstand systems tract of the regressive Viking truncated by a sequence boundary with incised valleys containing channel fill (Viking channel). The upper Viking (Viking transgressive) comprises a transgressive systems tract.

The Viking oil resource was divided into two plays: Viking Alberta and Saskatchewan in the GSC's 1987 assessment. The combined in-place discovered volume for all Viking plays has increased from 360 x $10^6m^3$ to 598 x $10^6m^3$. The increase is the result of new discoveries and appreciation of existing pools.

*Viking transgressive*

*Play definition.* This play includes all oil and gas pools in sandstone and conglomerate deposited in transgressive sequences within the upper portion of the Viking Formation. Most of the play boundaries correspond to the Viking regressive play (Fig. 63). The eastward boundary of the play area is located considerably farther east than that of the regressive play, reflecting the backstepping of reservoir sandstone westward during transgression.

*Geology.* The most common reservoirs in the Viking transgressive play are sandbars such as those of the Gilby field (Reinson et al., 1994). Some pools occur in transgressive sheet sandstone, such as in the large Provost field. The geometry of the pools reflects the shape of the sandbars. Some elongated pools are tens of kilometres long, a few kilometres wide and less than 4 m thick (Reinson et al., 1994). The bars have been interpreted as transgressive bars (Reinson et al., 1994) or tidal sand ridges (Leckie, 1986). Davies and Walker (1993) presented an alternative model for Viking bars in the upper sequence at Caroline and Garrington, suggesting that these bars resulted from lower shoreface deposition during minor forced regressions interspersed within the overall transgression.

Transgressive reworking and a greater abundance of conglomeratic facies results in higher permeability for reservoirs of the transgressive play compared to those of the regressive play.

*Exploration history.* The discovery sequence ($\hat{\beta}=0.6$) and the cumulative in-place volume discovered are graphically shown in Appendix F (Figs. F5.1 and F5.2). The cumulative in-place graph shows a strong upward increase. The potential and discoveries are summarized in Tables 135 and 136.

*Reservoir parameters.* Reservoirs have pool areas from 31 to 3,070 ha; net pay from 0.8 to 6 m; porosity from 6 to 23%; water saturation from 20 to 50%; and a recovery factor from 0.18 to 25%. The parameters are also graphically shown in Appendix F (Figs. F5.3 to F5.8).

*Viking regressive*

*Play definition.* This play includes all oil and gas pools in sandstone of the progradational coarsening-up regressive parasequence in the lower portion of the Viking Formation

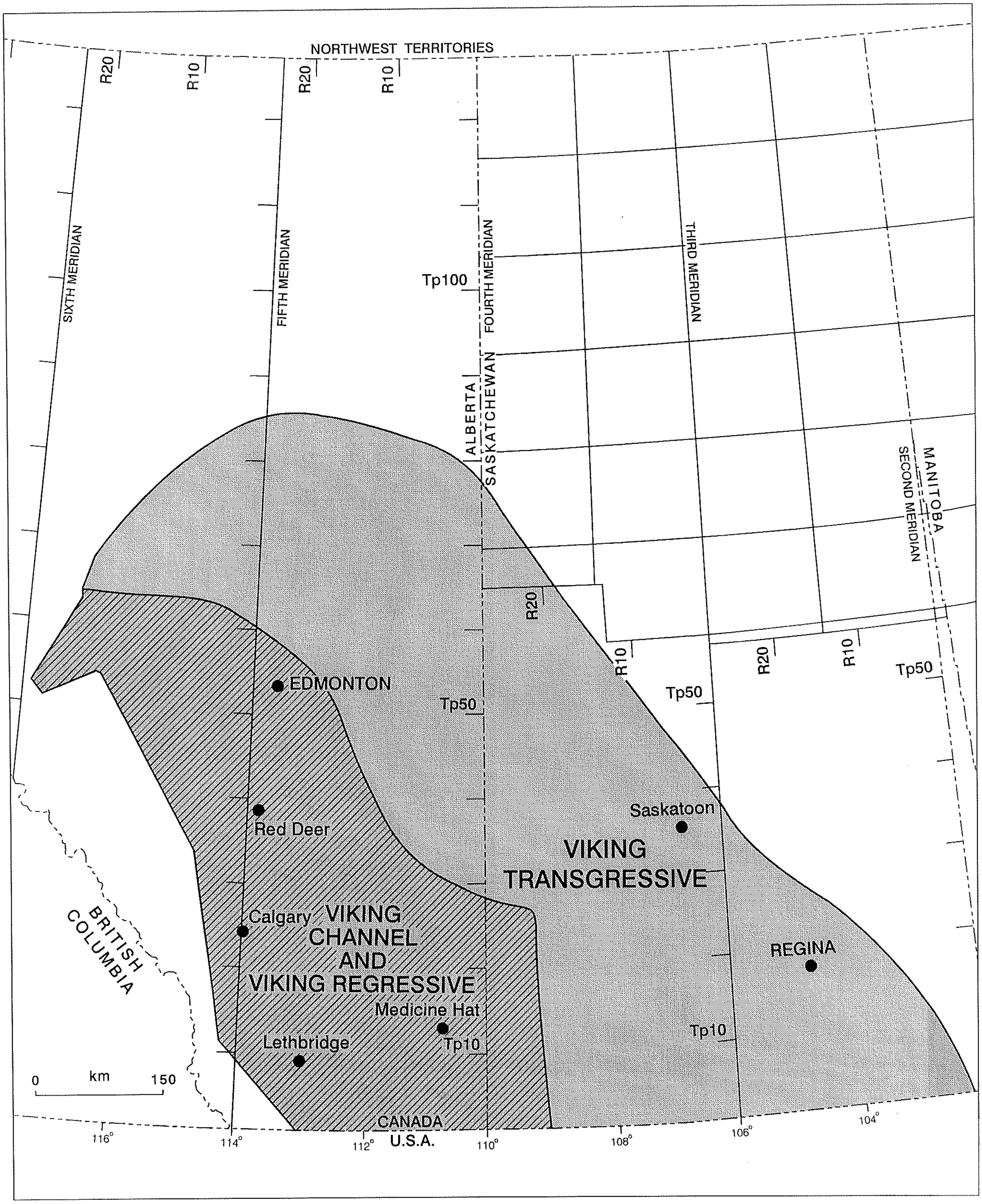


***Figure 63.*** *Play maps for the Viking — transgressive, regressive and channel.*

and equivalent units. Pools are located in central Alberta and Saskatchewan (Viking Formation) and southern Alberta (Bow Island Formation) (Fig. 63). The northwestern boundary is marked by a transition to the gas-charged equivalent, the Paddy Member. Depositional pinch-out of the reservoir sandstones updip forms the eastern boundary. Structural influence from the Laramide Orogeny defines the western edge of the play. The Canadian–American border marks the southern play boundary.

*Geology.* Progradation of the Viking occurred from the Cordillera eastward into the foreland basin occupied by a shallow epicontinental sea joining the Gulf of Mexico and the Boreal Sea. Thickness of the Viking marine shale and marine-influenced sandstone ranges from a few metres at the eastern edge to about 200 m in southwest Alberta.

The most common reservoirs in the Viking regressive play are shoreface bars located in the upper portions of the progradational parasequence. The geometry of the pools reflects the shape of the bars. Some elongated pools are tens of kilometres long, a few kilometres wide and 5 to 10 m thick (Reinson et al., 1994). The dominant northwest trend of the pools coincides with the regional trend of the shoreface and the Cordillera. The Joarcam field is a large pool in the Viking regressive play (Reinson et al., 1994).

*Exploration history.* The discovery sequence ($\hat{\beta}$=0.6) and the cumulative in-place volume discovered are graphically shown in Appendix F (Figs. F6.1 and F6.2). The cumulative in-place graph shows a moderate upward increase. The potential and discoveries are summarized in Tables 137 and 138.

*Reservoir parameters.* Reservoirs have pool areas from 8 to 5,333 ha; net pay from 0.7 to 6 m; porosity from 3 to 22%; water saturation from 16 to 50%; and a recovery factor from 0.24 to 28%. The parameters are also graphically shown in Appendix F (Figs. F6.3 to F6.8).

*Viking channel*

*Play definition.* This play includes all oil and gas pools in valley-fill channel sequences in the Viking Formation. Like the regressive play, the southern and western boundaries for this play are determined by the international border and the influence of the Laramide Orogeny (Fig. 63).

*Geology.* Reservoirs in the channel play consist of fluvial and estuarine conglomerate and sandstone that fill valleys incised into the top of the regressive sequence. Pools are a few kilometres long, a few kilometres wide and over 10 m thick, generally presenting a channel shape in cross section (Reinson et al., 1994). Lithology is highly varied within the valley fill resulting in a higher reservoir heterogeneity than encountered in either the transgressive or the regressive plays. The Crystal field is an example of the pools in the Viking channel play.

*Exploration history.* The discovery sequence ($\hat{\beta}$=0.8) and the cumulative in-place volume discovered are graphically shown in Appendix F (Figs. F7.1 and F7.2). The cumulative in-place graph shows a moderate upward increase. The potential and discoveries are summarized in Tables 139 and 140.

*Reservoir parameters.* Reservoirs have pool areas from 10 to 5,000 ha (min-max); net pay from 1 to 11 m (min-max); porosity from 1 to 18% (min-max); water saturation from 10 to 55% (min-max); and a recovery factor from 1 to 24% (min-max). The parameters are also graphically shown in Appendix F (Figs. F7.3 to F7.8).

**Table 135**

**Pools discovered and predicted for the Viking transgressive play**

| Pool size class ($10^6m^3$) | Pools discovered up to 1989 | Pools discovered between 1990 and 1994 | Pools yet to be discovered |
|---|---|---|---|
| < 0.1 | 104 | 7 | 356 |
| 0.1 - 1 | 107 | 5 | 113 |
| 1 - 10 | 26 | 1 | 20 |
| 10 - 100 | 10 | 0 | 0 |
| 100 - 1000 | 1 | 0 | 0 |
| Total number of pools | 248 | 13 | 489 |
| In-place volume | 512.333 x $10^6m^3$ | 8.032 x $10^6m^3$ | 31 - 626 x $10^6m^3$ |

**Table 136**

**The five largest pools of Table 135 discovered between 1990 and 1994**

| Field, pool | In-place volume ($10^6m^3$) |
|---|---|
| Gilby, Viking A | 7.041 |
| Jumpbush, Bow Island A | 0.219 |
| Garrington, Viking Z | 0.128 |
| Redwater, Lower Viking T | 0.114 |
| Three Hills Creek, Viking B | 0.105 |

## Table 137

**Pools discovered and predicted for the Viking regressive play**

| Pool size class ($10^6m^3$) | Pools discovered up to 1989 | Pools discovered between 1990 and 1994 | Pools yet to be discovered |
|---|---|---|---|
| < 0.1 | 10 | 2 | 213 |
| 0.1 - 1 | 9 | 0 | 61 |
| 1 - 10 | 2 | 0 | 2 |
| 10 - 100 | 1 | 0 | 0 |
| Total number of pools | 22 | 2 | 276 |
| In-place volume | 56.031 x $10^6m^3$ | 0.113 x $10^6m^3$ | 4 - 165 x $10^6m^3$ |

## Table 138

**The two largest pools of Table 137 discovered between 1990 and 1994**

| Field, pool | In-place volume ($10^6m^3$) |
|---|---|
| Cessford, Viking FF | 0.082 |
| Pembina, Viking K | 0.031 |

## Table 139

**Pools discovered and predicted for the Viking channel play**

| Pool size class ($10^6m^3$) | Pools discovered up to 1987 | Pools discovered between 1988 and 1994 | Pools yet to be discovered |
|---|---|---|---|
| < 0.1 | 0 | 1 | 95 |
| 0.1 - 1 | 5 | 0 | 88 |
| 1 - 10 | 2 | 0 | 8 |
| 10 - 100 | 1 | 0 | 0 |
| Total number of pools | 8 | 1 | 191 |
| In-place volume | 21.373 x $10^6m^3$ | 0.315 x $10^6m^3$ | 16 - 71 x $10^6m^3$ |

## Table 140

**The Viking pool of Table 139 discovered between 1988 and 1994**

| Field, pool | In-place volume ($10^6m^3$) |
|---|---|
| Carson Creek, Viking A | 0.315 |

*Immature plays*

The immature plays include Chinook, First White Specks, Base of Fish Scale, and Basal Colorado.

The Chinook play has five discoveries with total reserves of 4.673 x $10^6m^3$. The First White Speckled shale contains calcareous algae. Occasionally, the upward-coarsening sequences from shale to siltstone were locally fractured, thereby creating reservoir porosity and permeability. One oil pool was discovered with reserves of 9.885 x $10^6m^3$. One oil pool with reserves of 0.099 x $10^6m^3$ was discovered in the Base of Fish Scale play. One oil pool was discovered in the Basal Colorado play with total reserves of 11.830 x $10^6m^3$.

The potential for all these immature plays (including the Ricinus Viking play in the Foothills region) ranges from 209 to 270 x $10^6m^3$ with an expected value of 240 x $10^6m^3$.

### *Foothills region*

Two established mature plays, Ricinus Cardium and Ansell Cardium, and one immature play, Ricinus Viking, are located within this region.

#### *Ricinus Cardium*

*Play definition*. This play includes all Cardium oil pools located in the southern Foothills Belt. The play definition and name are adopted from the work on gas assessment (Osadetz et al., in prep.). This play was not defined in the GSC's 1987 assessment (Fig. 64).

*Exploration history*. The discovery sequence ($\hat{\beta}=0.8$) and the cumulative in-place volume discovered are graphically shown in Appendix F (Figs. F8.1 and F8.2). The cumulative in-place graph has a strong upward increase. The potential and discoveries are summarized in Tables 141 and 142.

*Reservoir parameters*. Reservoirs have pool areas from 31 to 700 ha; net pay from 1.5 to 19 m; porosity from 6 to 16%; water saturation from 9 to 31%; and a recovery factor from 0.06 to 19%. The parameters are also graphically shown in Appendix F (Figs. F8.3 to F8.8).

#### *Ansell Cardium*

*Play definition*. This play includes all Cardium oil pools located in the central Foothills Belt. The play definition and name are adopted from Osadetz et al. (in prep.). The play was not defined in the GSC's 1987 assessment (Fig. 65).

*Exploration history*. The discovery sequence ($\hat{\beta}=1.2$) and the cumulative in-place volume discovered are graphically shown in Appendix F (Figs. F9.1 and F9.2). No discovery has been made since 1984. The cumulative in-place graph shows a moderate upward increase. The potential and discoveries are summarized in Table 143.

*Reservoir parameters*. Reservoirs have pool areas from 61 to 2,444 ha; net pay from 0.8 to 3 m; porosity from 6 to 16%; water saturation from 7 to 28%; and a recovery factor from 0.13 to 17%. The parameters are also graphically shown in Appendix F (Figs. F9.3 to F9.8).

#### *Ricinus Viking*

This play has three oil discoveries with a total reserve of 2.013 x $10^6 m^3$ (Fig. 66)

**Table 141**

**Pools discovered and predicted for the Ricinus Cardium play**

| Pool size class ($10^6 m^3$) | Pools discovered up to 1989 | Pools discovered between 1990 and 1994 | Pools yet to be discovered |
|---|---|---|---|
| < 0.1 | 9 | 0 | 47 |
| 0.1 - 1 | 41 | 1 | 48 |
| 1 - 10 | 12 | 0 | 1 |
| 10 - 100 | 1 | 0 | 0 |
| Total number of pools | 63 | 1 | 96 |
| In-place volume | 50.626 x $10^6 m^3$ | 0.139 x $10^6 m^3$ | 2 - 36 x $10^6 m^3$ |

**Table 142**

**The Cardium pool of Table 141 discovered between 1990 and 1994**

| Field, pool | In-place volume ($10^6 m^3$) |
|---|---|
| Brazeau River, Cardium V | 0.139 |

**Table 143**

**Pools discovered and predicted for the Ansell Cardium play**

| Pool size class ($10^6$ $m^3$) | Pools discovered up to 1989 | Pools discovered between 1990 and 1994 | Pools yet to be discovered |
|---|---|---|---|
| < 0.1 | 10 | 0 | 61 |
| 0.1 - 1 | 10 | 0 | 15 |
| 1 - 10 | 4 | 0 | 0 |
| Total number of pools | 24 | 0 | 76 |
| In-place volume | 18.469 x $10^6 m^3$ | 0 | 0.5 - 19 x $10^6 m^3$ |

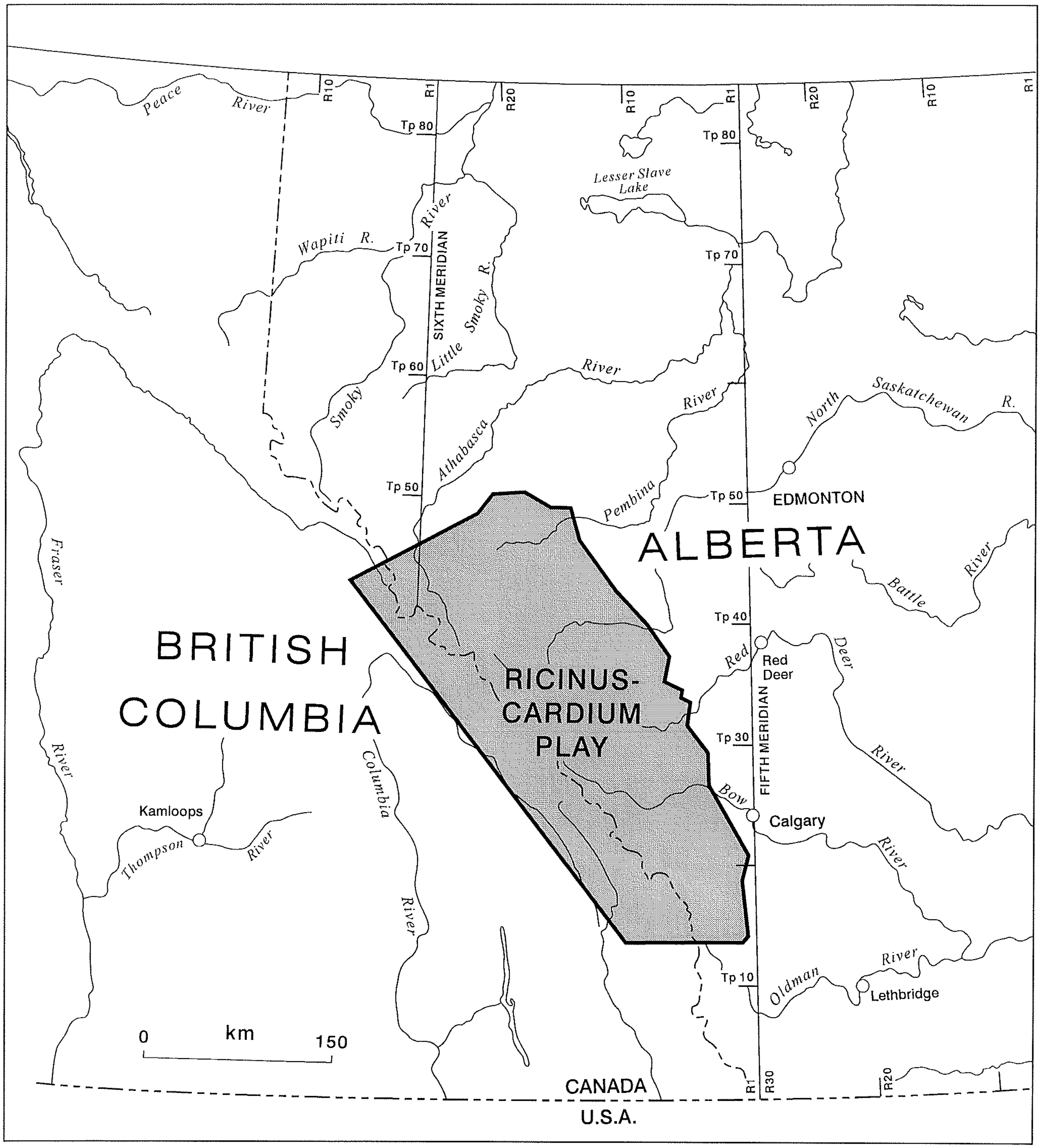


***Figure 64.*** *Play map for the Ricinus Cardium.*


*Figure 65.* Play map for the Ansell Cardium.

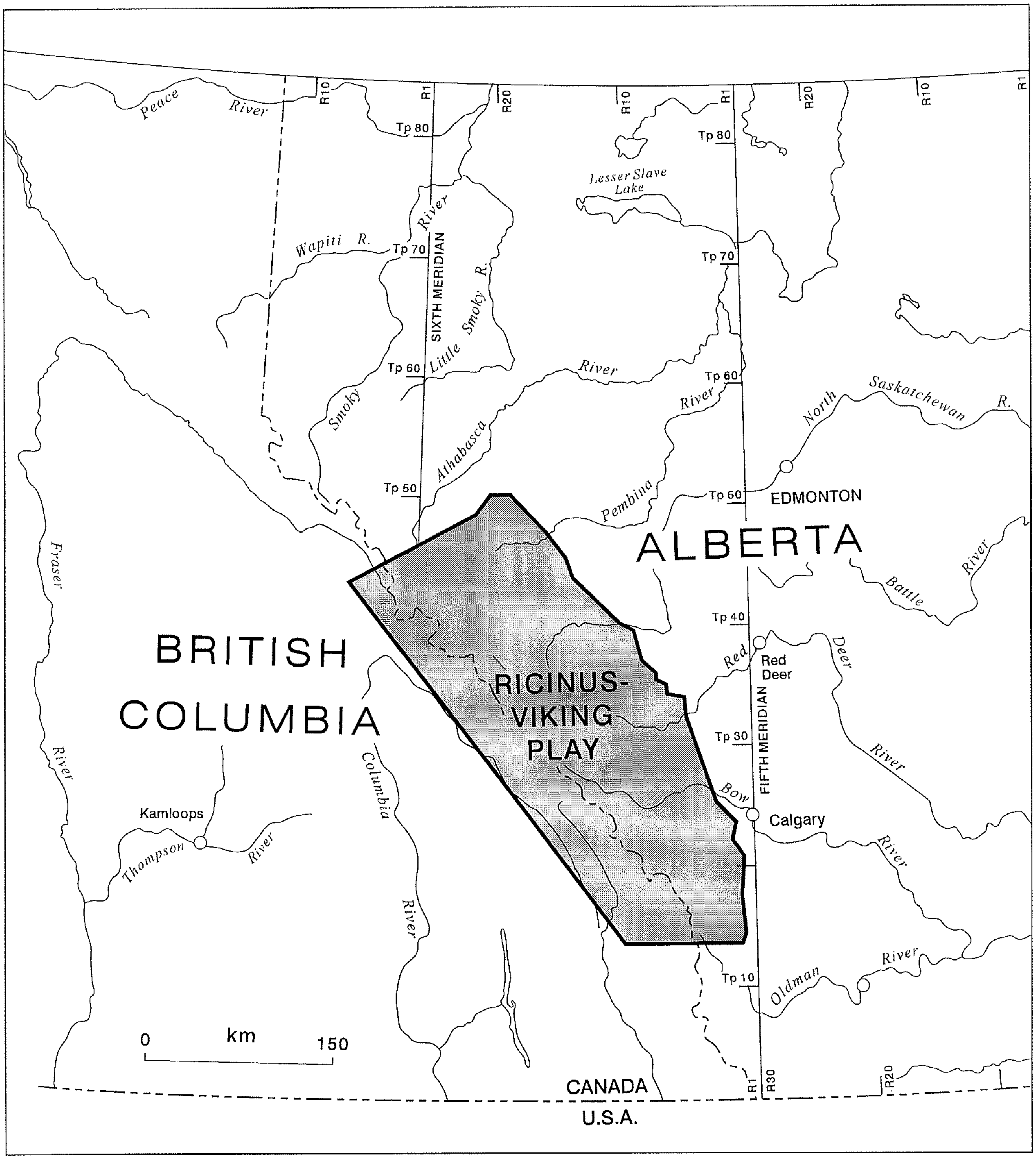


*Figure 66.* Play map for the Ricinus Viking.

## UPPER CRETACEOUS SYSTEM—BELLY RIVER GROUP

### Geological framework

The final assemblage (Campanian to Paleocene) deposited in the Foreland Basin consists of three depositional units (Fig. 67). The initial unit consists of the Claggett, Pakowki, Lea Park, or Nomad shales at the base, followed by Judith River, Belly River or Brazeau coarse clastic rocks that represent eastward-prograding shoreline sequences. Shallow marine shelf sandstones pass upward into fluvio-deltaic and continental sandstones and shales.

Bearpaw shales lie at the base of the second cycle and are overlain by Edmonton sandstones in the eastern parts of the basin. To the north and west, coarse clastic sediments of the Saunders Group are the equivalent units. The upper parts of these strata are entirely continental, and mark the end of marine deposition in the Western Canada Sedimentary Basin. The final unit consists of Paleocene Paskapoo-Porcupine Hills-Ravenscrag coarse clastic alluvial deposits, that have a limited distribution, probably because they were removed by post-Paleocene uplift and erosion.

Post-Colorado strata of the Plains form an enormous prism of clastic sedimentary rock up to 2.5 km thick (up to 4 km in the Foothills), present at surface over much of the western and southern Prairie Provinces. The succession includes at least five distinct sandy clastic wedges separated by marine tongues or unconformities, representing a series of large-scale transgressive-regressive cycles. Each wedge ranges up to 750 m thick, generally thickens to the west or southwest, and thins and passes laterally into marine shale to the east, northeast or southeast.

The post-Colorado succession is an overall coarsening-upward succession (Jerzykiewicz, 1985). At least five major clastic wedges related to orogenic pulses are present, representing infill of the Foreland Basin controlled by variable rates of tectonic subsidence (Jerzykiewicz, 1985; Mack and Jerzykiewicz, 1989). Jerzykiewicz and Labonte (1991) and Leckie and Smith (1993) noted that prevailing drainage in the proximal part of the foreland is perpendicular to the basin axis in overfilled phases and parallel to the basin axis in underfilled phases.

The "Basal Belly River" strata include a series of at least seven stacked, offlapping, regionally mappable, progradational sandstone-dominated cycles, separated by marine flooding surfaces. At any one place, the Basal Belly River is 25 to 75 m thick and consists of one or two cycles (Hamblin and Abrahamson, 1993, 1996; Hamblin, 1993). These seven cycles record overall eastward, but non-continuous, progradation over more than 400 km across Alberta during Foremost time. Each cycle is a composite of several stacked, individual shoreline-related sandstone bodies, and includes both shoreface and channelized facies. Successive cycles offlap and are younger to the east. Here, each cycle is treated as a separate play.

The play definitions are adopted from the work on the gas resource assessment of the Post-Colorado Group (Hamblin and Lee, 1995, 1997).

### Resource assessment

#### *Belly River Group potential*

The potential predicted from the established Belly River Group plays ranges from 87 to 270 x $10^6 m^3$. The mean (or expected value) of the potential distribution is 155 x $10^6 m^3$. The Belly River fluvial play contains the greatest potential for oil in this group. Oil has been discovered in the Belly River Cycles 1, 2 and 3, and Foremost fluvial plays. No oil has yet been discovered in Cycles 4, 5, 6, and 7. The in-place oil volume has increased from 119 x $10^6 m^3$ to 244 x $10^6 m^3$ since the GSC's 1987 assessment. A total of 3.16 x $10^6 m^3$ of in-place oil volume was discovered between 1990 and 1994. The number of pools discovered and the sizes of the ten largest pools discovered between 1990 and 1994 are listed in Tables 144 and 145.

#### *Plains region*

Two established mature plays, Basal Belly River — Cycle 2 and Belly River fluvial, are identified within this region.

*Mature plays: Basal Belly River — Cycle 2*

*Play definition.* This play is defined to include all oil and gas pools in nearshore-shoreline sandstones of the defined progradational Cycle 2 of the Basal Belly River. It includes a large area in west-central Alberta defined on the west, east and south by the 5 m clean sandstone isopach, and on the north by the outcrop belt of the unit (Fig. 68). This play represents the major oil production horizon from the marine Belly River Formation. In the GSC's 1987 assessment, all cycles of the marine Belly River were grouped into one play.

*Geology.* Basal Belly River — Cycle 2 contains clean sandstone up to about 45 m thick, and thins eastward and southeastward as it downlaps and pinches out into the mudstones of the Lea Park in the subsurface, over a distance of about 150 km. It generally comprises a coarsening-upward sequence of mudstone, siltstone, and sandstone and is interpreted as a complex of prograding shallow marine/

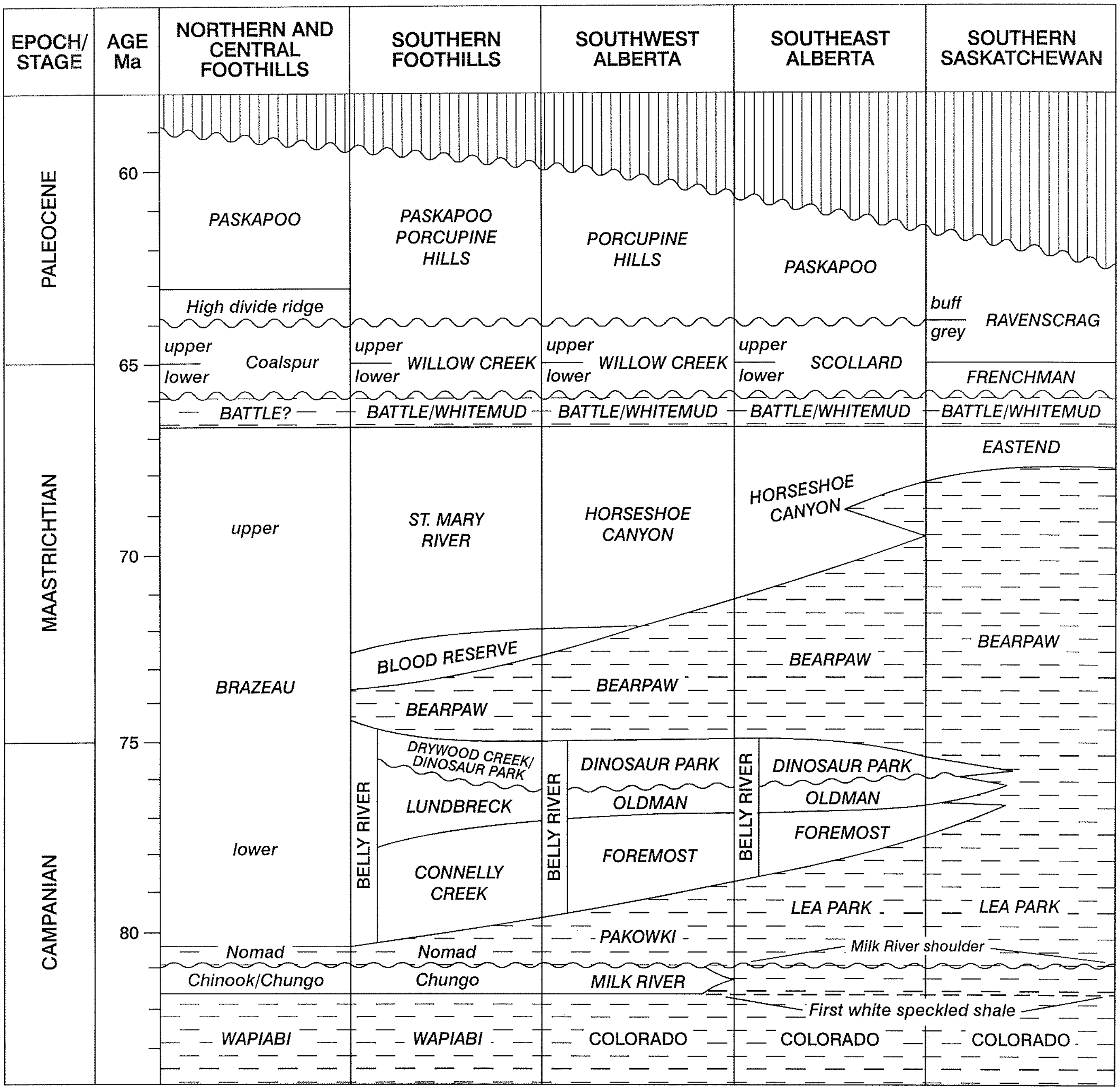


***Figure 67.*** *Table of formations for the Post-Colorado succession, Western Canada Sedimentary Basin.*

shoreface facies. In addition, channel sandstone units occur throughout. Large gas and oil reserves are contained in this cycle. Oil reservoirs in this cycle have been extensively studied by Iwuagwu and Lerbekmo (1981, 1982, 1984), Wasser (1988), Power (1989), and Gardiner et al. (1990), and their potential was assessed by Podruski et al. (1988).

*Exploration history.* The discovery sequence ($\hat{\beta}=0.8$) and the cumulative in-place volume discovered are graphically shown in Appendix G (Figs. G1.1 and G1.2). The in-place volume has increased from 97 to 195 x $10^6 m^3$ since the GSC's 1987 assessment. The increase is the result of the new discoveries and the appreciation of existing pools. The largest two pools predicted by the GSC's 1987 assessment have been discovered. The cumulative in-place graph shows a moderate upward increase. The potential and discoveries are summarized in Tables 146 and 147.

*Reservoir parameters.* Reservoirs have pool areas from 16 to 4,000 ha; net pay from 2 to 10 m; porosity from 11 to 21%; water saturation from 26 to 55%; and a recovery factor from 0.08 to 17%. The parameters are also graphically shown in Appendix G (Figs. G1.3 to G1.8).

**Table 144**

**Belly River oil pools discovered**

| Pool size class ($10^6 m^3$) | Pools discovered up to 1990 | Pools discovered between 1991 and 1994 |
|---|---|---|
| < 0.1 | 19 | 6 |
| 0.1 - 1 | 131 | 13 |
| 1 - 10 | 21 | 0 |
| 10 - 100 | 5 | 0 |
| Total number of pools | 176 | 19 |
| In-place volume | $240.533 \times 10^6 m^3$ | $3.160 \times 10^6 m^3$ |

**Table 145**

**The ten largest Belly River pools of Table 144 discovered between 1990 and 1994**

| Field, pool | In-place volume ($10^6 m^3$) |
|---|---|
| Honeysuckle, Belly River A and B | 0.358 |
| Willesden Green, Belly River DDD | 0.347 |
| Pembina, Belly River X3X | 0.282 |
| Brazeau River, Belly River VV | 0.247 |
| Brazeau River, Belly River UU | 0.226 |
| Brazeau River, Belly River ZZ | 0.212 |
| Hanlan, Belly River A | 0.202 |
| Pembina, Belly River Z3Z | 0.156 |
| Brazeau River, Belly River SS | 0.148 |
| Stewart, Belly River B | 0.141 |

**Table 146**

**Pools discovered and predicted for the Basal Belly River — Cycle 2 play**

| Pool size class ($10^6 m^3$) | Pools discovered up to 1989 | Pools discovered between 1990 and 1994 | Pools yet to be discovered |
|---|---|---|---|
| < 0.1 | 5 | 4 | 36 |
| 0.1 - 1 | 45 | 4 | 69 |
| 1 - 10 | 10 | 0 | 1 |
| 10 - 100 | 5 | 0 | 0 |
| Total number of pools | 65 | 8 | 107 |
| In-place volume | $193.664 \times 10^6 m^3$ | $0.843 \times 10^6 m^3$ | $4 - 179 \times 10^6 m^3$ |

**Table 147**

**The five largest pools of Table 146 discovered between 1990 and 1994**

| Field, pool | In-place volume ($10^6 m^3$) |
|---|---|
| Pembina, Belly River Z3Z | 0.156 |
| Stewart, Belly River B | 0.141 |
| Minnehik-Buck Lake, Belly River L | 0.127 |
| Pembina, Belly River E4E | 0.114 |
| Pembina, Belly River B4B | 0.094 |

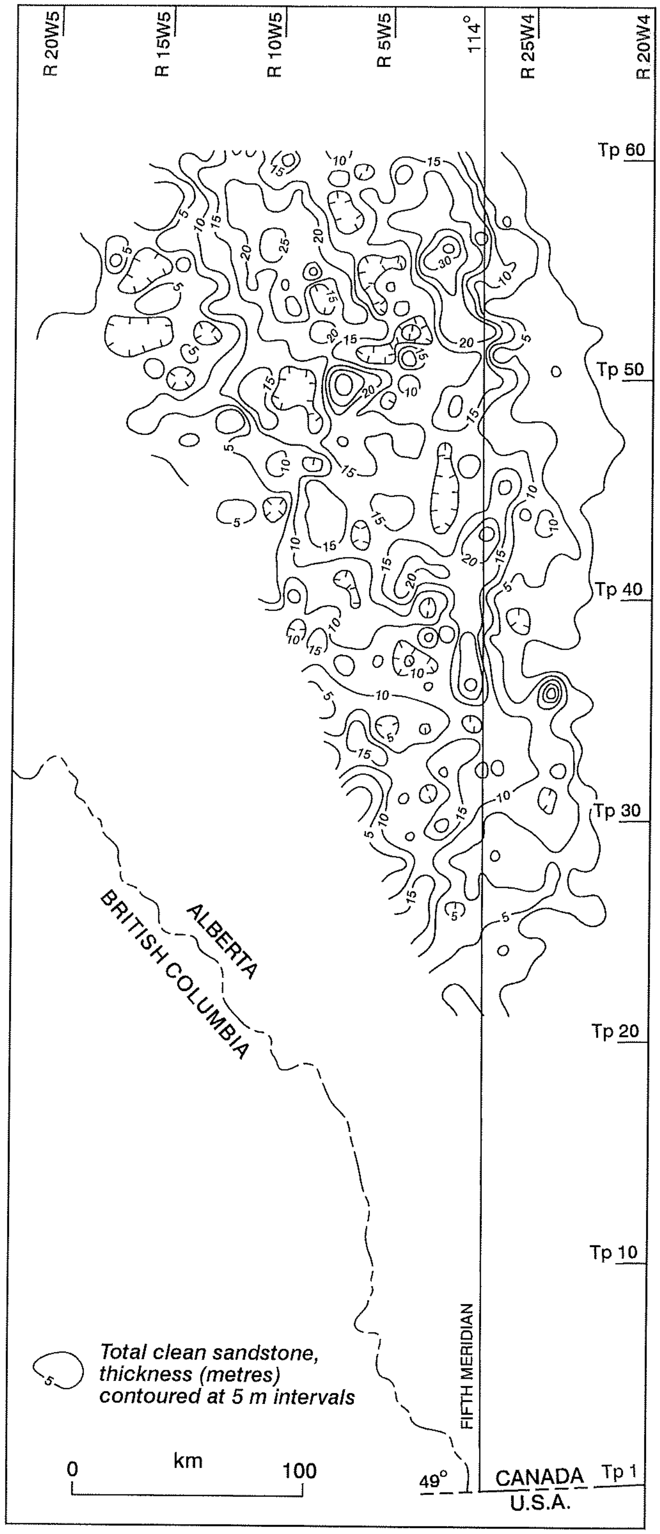


***Figure 68.*** *Play map for the Basal Belly River — Cycle 2.*

*Mature plays: Basal Belly River – fluvial*

*Play definition.* This established mature play is defined to include all oil and gas pools in fluvial channel and overbank sandstones of the Foremost Formation, in the middle part of the Belly River Group. These deposits lie above and westward of the "Basal Belly River" shoreline cycles, and are overlain by the extensively developed sandstones of the Oldman Formation (Comrey unit). The play occurs in a large area of western Alberta, defined on the east and south by the landward margins of the prograding shoreline cycles, on the west by the limit of deformation, and on the north by the outcrop belt of the unit (Fig. 69).

*Geology.* The entire Foremost Formation thins eastward across southern Alberta, from 170 m at Lethbridge to 90 m in southwest Saskatchewan (Williams and Dyer, 1930). The nonmarine strata comprise interbedded grey mudstone, thin coal, and fine-grained sandstone in thin, ripple laminated, overbank units and thicker channel units. The strata are interpreted as lagoon, marsh, and floodplain sediments (Slipper and Hunter, 1931; Ogunyomi and Hills, 1977). In western Alberta, the nonmarine Foremost Formation is characterized by thick, channel-sandstone bodies, encased in mudstone, and thins eastward to zero as the equivalent shoreline units pass into marine shale from the base, over a distance of about 500 km.

The interbedded, nonmarine, fine-grained deposits provide the vertical seal for the pools contained in channel and crevasse splay sandstone bodies, creating many stratigraphic traps.

*Exploration history.* The discovery sequence ($\hat{\beta}=1.0$) and the cumulative in-place volume discovered are graphically shown in Appendix G (Figs. G2.1 and G2.2). The in-place volume has increased from 22 to 39 x $10^6 m^3$ since the GSC's 1987 assessment. The increase is the result of new discoveries and the appreciation of existing pools. The largest pool predicted by the 1987 assessment has been discovered. The cumulative in-place graph shows a strong upward increase. The potential and discoveries are summarized in Tables 148 and 149.

*Reservoir parameters.* Reservoirs have pool areas from 17 to 263 ha; net pay from 2 to 10 m; porosity from 13 to 20%; water saturation from 24 to 60%; and a recovery factor from 0.07 to 10%. The parameters are also graphically shown in Appendix G (Figs. G2.3 to G2.8).

*Immature plays: Basal Belly River – Cycle 1*

*Play definition.* This play is defined to include all oil and gas pools in nearshore–shoreline sandstones of the defined progradational Cycle 1 (lowest and most westerly of seven such cycles) of the Basal Belly River (Fig. 70). It includes a large area in northwestern Alberta defined on the east and south by the 5 m clean sandstone isopach, and on the west by the limit of deformation, and on the north by the outcrop belt of the unit.

*Geology.* The Belly River (Judith River) Group is a dominantly fluvial clastic molassic wedge formed in response to Late Campanian deformation in the Omineca Crystalline Belt (Eisbacher et al., 1974). The wedge thins and the base becomes younger to the east, from over 700 m thick in the Foothills (Jerzykiewicz and Sweet, 1988) to less than 200 m thick in western Saskatchewan, as the underlying and interfingering Pakowki/Lea Park marine shale thickens (Shaw and Harding, 1949). Dowling (1917) recognized the Foremost Formation as the lower two thirds of the Belly River clastic wedge, dominated by thick nonmarine deposits, but including the basal shoreline sandstone facies.

Basal Belly River — Cycle 1 contains clean sandstone up to about 50 m thick. It thins eastward and southeastward as it downlaps and pinches out into the mudstones of the Lea Park in the subsurface, over a distance of about 150 km. It generally comprises a coarsening-upward sequence of mudstone, siltstone, and sandstone, but in many wells the basal contact of the sandstone reservoir is distinct.

So far, only one oil pool with a reserve of 0.130 x $10^6 m^3$ has been discovered within this play area.

*Immature plays: Basal Belly River – Cycle 3*

*Play definition.* This play is defined to include all oil and gas pools in nearshore-shoreline sandstones of the defined progradational Cycle 3 of the Basal Belly River. It includes a large area in central Alberta defined on the west, east and south by the 5 m clean sandstone isopach, and on the north by the outcrop belt of the unit (Fig. 71).

*Geology.* Basal Belly River — Cycle 3 has clean sandstone up to about 35 m thick, and thins eastward and southeastward as it downlaps and pinches out into the mudstones of the Lea Park Formation in the subsurface, over a distance of about 130 km. It generally comprises a coarsening-upward sequence of mudstone, siltstone, and sandstone and is interpreted as a complex of prograding shallow marine/ shoreface facies. In addition, channel sandstone units occur throughout. Significant gas reserves are contained in this cycle, especially in the area with greater than 15 m clean sandstone. Only four oil pools have been discovered, with reserves of about 0.713 x $10^6 m^3$.

## *Foothills region*

### *Belly River — marine*

*Play definition.* This play includes all marine Belly River oil pools located within the Foothills belt. The play definition and name are adopted from the work on gas resource assessment of the disturbed belt (Osadetz et al., in prep.). This play was not evaluated in the GSC's 1987 assessment.

*Exploration history.* The discovery sequence ($\hat{\beta}$=1.2) and the cumulative in-place volume discovered are graphically shown in Appendix G (Figs. G3.1 and G3.2). Two oil pools have been discovered since 1990. The cumulative in-place graph shows a strong upward increase. The potential and discoveries are summarized in Tables 150 and 151.

*Reservoir parameters.* Reservoirs have pool areas from 10 to 1,100 ha (min-max); net pay from 1 to 8 m (min-max); porosity from 1 to 15% (min-max); water saturation from 10 to 46% (min-max); and a recovery factor from 0.1 to 20% (min-max). The parameters are also graphically shown in Appendix G (Figs. G3.3 to G3.8).

### *Belly River — fluvial*

*Play definition.* This play includes all fluvial Belly River oil pools located within the Foothills belt. The play definition and name are adopted from the work on the gas resources of the disturbed belt (Osadetz et al., in prep.). This play was not evaluated in the GSC's 1987 assessment.

*Exploration history.* The discovery sequence ($\hat{\beta}$=1.2) and the cumulative in-place volume discovered are graphically shown in Appendix G (Figs. G4.1 and G4.2). Four pools were discovered in 1990. The cumulative in-place graph shows a strong upward increase. The potential and discoveries are summarized in Tables 152 and 153.

*Reservoir parameters.* Reservoirs have pool areas from 17 to 450 ha; net pay from 1 to 8% (min-max); porosity from 10 to 18% (min-max); water saturation from 10 to 50%; and a recovery factor from 0.2 to 16%. The parameters are also graphically shown in Appendix G (Figs. G4.3 to G4.8).

**Table 148**

**Pools discovered and predicted for the Basal Belly River — fluvial play**

| Pool size class ($10^6 m^3$) | Pools discovered up to 1989 | Pools discovered between 1990 and 1994 | Pools yet to be discovered |
|---|---|---|---|
| < 0.1 | 5 | 1 | 57 |
| 0.1 - 1 | 56 | 3 | 156 |
| 1 - 10 | 2 | 0 | 0 |
| Total number of pools | 63 | 4 | 213 |
| In-place volume | 21.129 x $10^6 m^3$ | 1.076 x $10^6 m^3$ | 31 - 43 x $10^6 m^3$ |

**Table 149**

**The four largest pools of Table 148 discovered between 1990 and 1994**

| Field, pool | In-place volume ($10^6 m^3$) |
|---|---|
| Honeysuckle, Belly River A and B | 0.358 |
| Willesden Green, Belly River DDD | 0.347 |
| Pembina, Belly River X3X | 0.282 |
| Willesden Green, Belly River AAA | 0.089 |

**Table 150**

**Pools discovered and predicted for the Belly River — marine (Foothills) play**

| Pool size class ($10^6m^3$) | Pools discovered up to 1989 | Pools discovered between 1990 and 1994 | Pools yet to be discovered |
|---|---|---|---|
| < 0.1 | 1 | 1 | 66 |
| 0.1 - 1 | 3 | 1 | 24 |
| 1 - 10 | 3 | 0 | 1 |
| Total number of pools | 7 | 2 | 91 |
| In-place volume | $5.802 \times 10^6m^3$ | $0.287 \times 10^6m^3$ | $2.5 - 12 \times 10^6m^3$ |

**Table 151**

**The two largest pools of Table 150 discovered between 1990 and 1994**

| Field, pool | In-place volume ($10^6m^3$) |
|---|---|
| Brazeau River, Belly River ZZ | 0.212 |
| Brazeau River, Belly River TT | 0.075 |

**Table 152**

**Pools discovered and predicted for the Belly River — fluvial (Foothills) play**

| Pool size class ($10^6m^3$) | Pools discovered up to 1989 | Pools discovered between 1990 and 1994 | Pools yet to be discovered |
|---|---|---|---|
| < 0.1 | 7 | 0 | 152 |
| 0.1 - 1 | 24 | 4 | 167 |
| 1 - 10 | 5 | 0 | 1 |
| Total number of pools | 36 | 4 | 320 |
| In-place volume | $17.893 \times 10^6m^3$ | $0.823 \times 10^6m^3$ | $33 - 53 \times 10^6m^3$ |

**Table 153**

**The four largest pools of Table 152 discovered between 1990 and 1994**

| Field, pool | In-place volume ($10^6m^3$) |
|---|---|
| Brazeau River, Belly River VV | 0.247 |
| Brazeau River, Belly River UU | 0.226 |
| Hanlan, Belly River A | 0.202 |
| Brazeau River, Belly River SS | 0.148 |

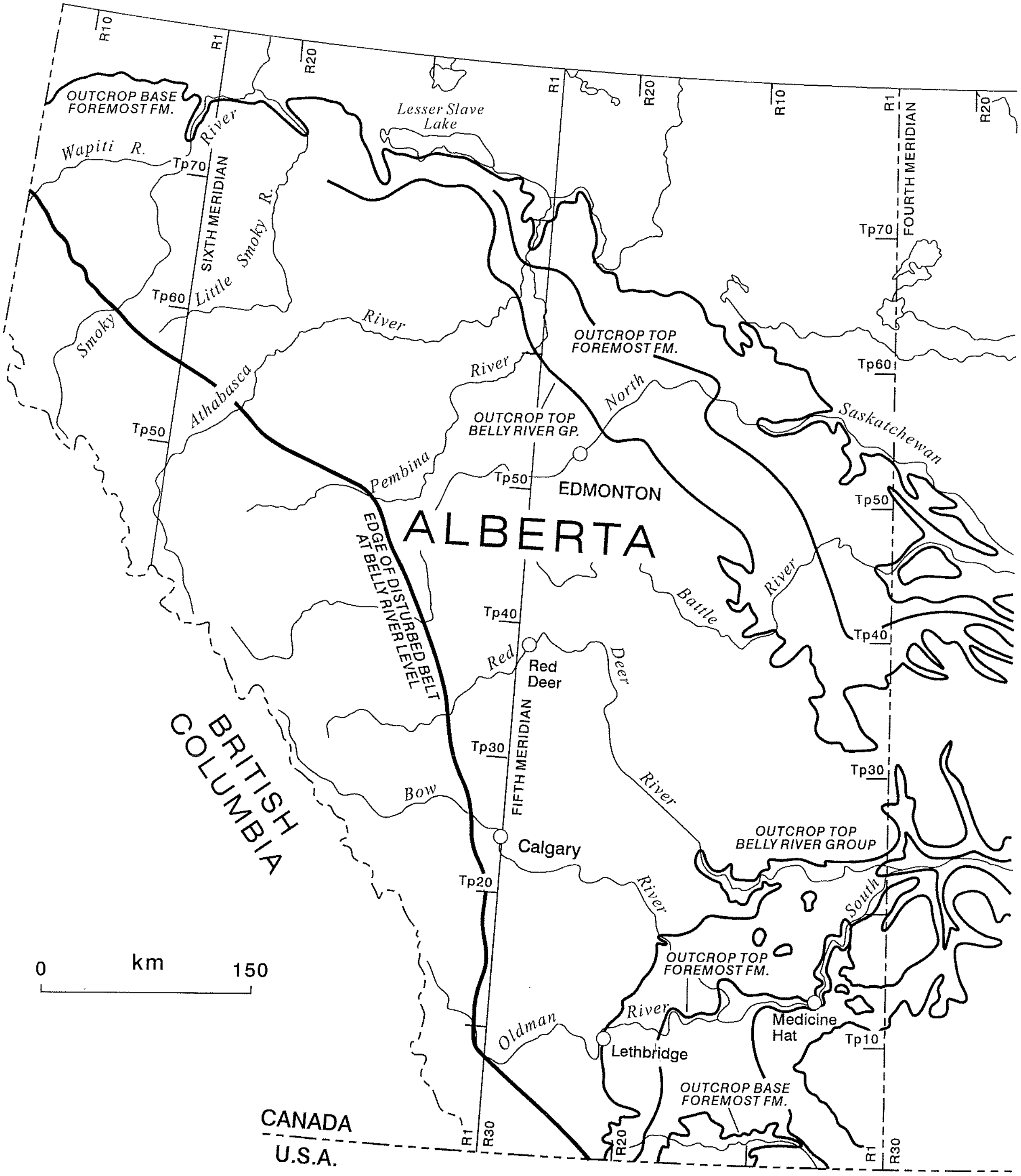


***Figure 69.*** *Play map for the Basal Belly River — fluvial.*

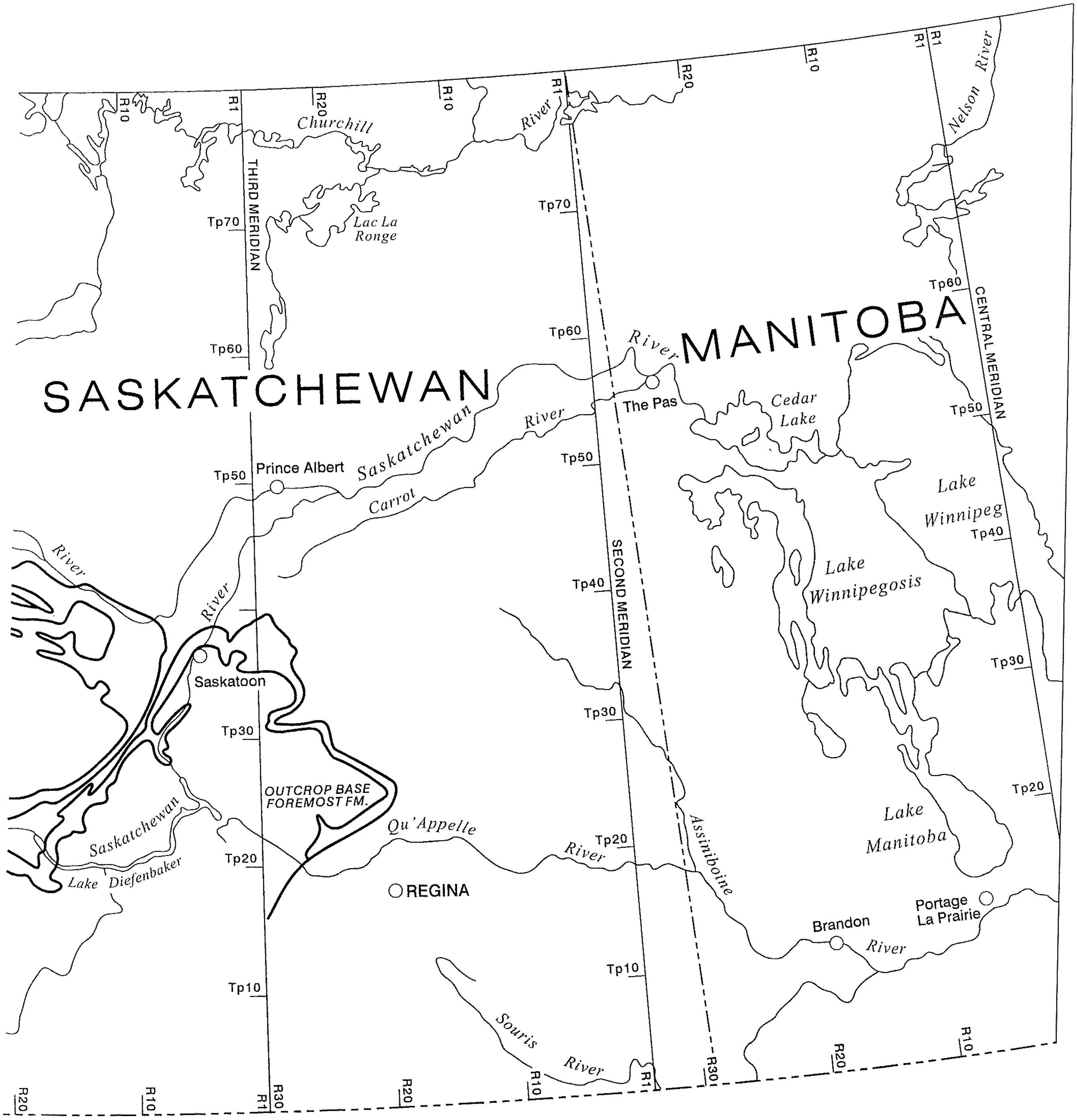


**Figure 69.** *Play map for the Basal Belly River — fluvial (cont'd).*

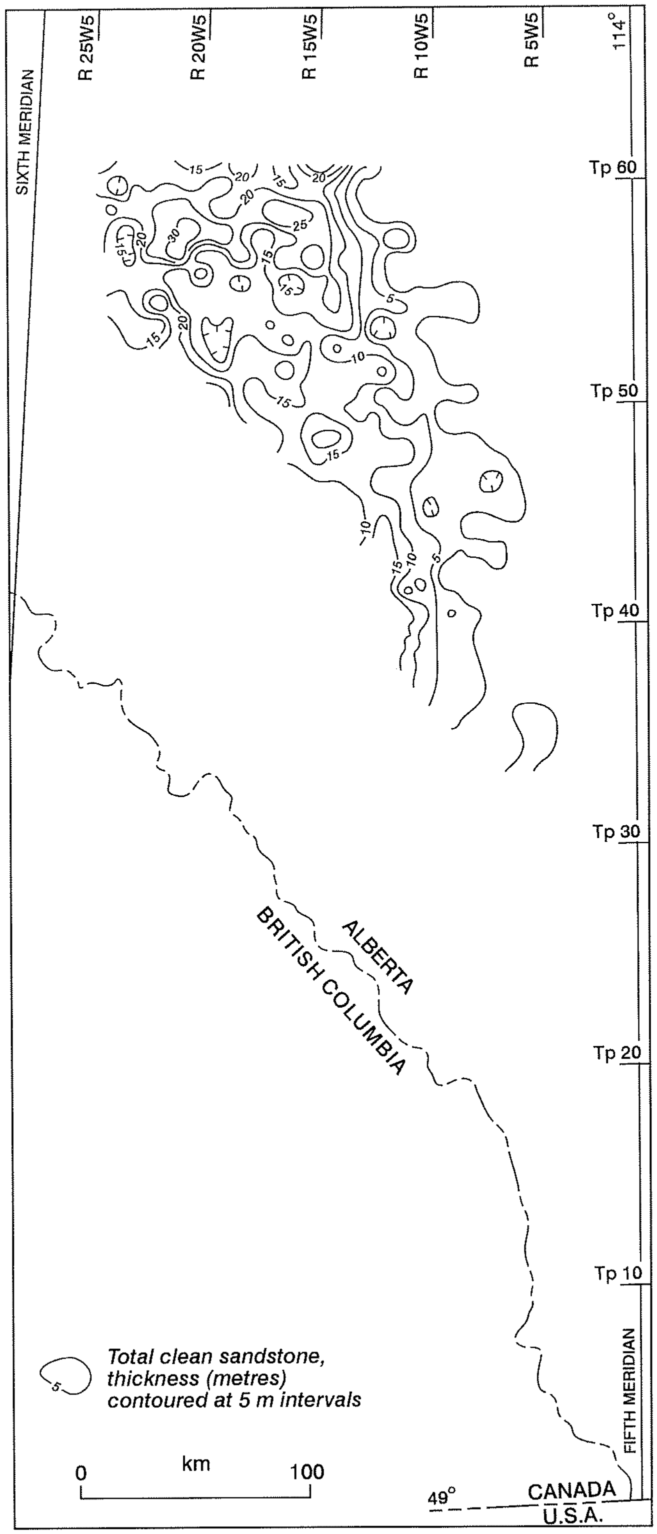


***Figure 70.*** *Play map for the Basal Belly river — Cycle 1.*

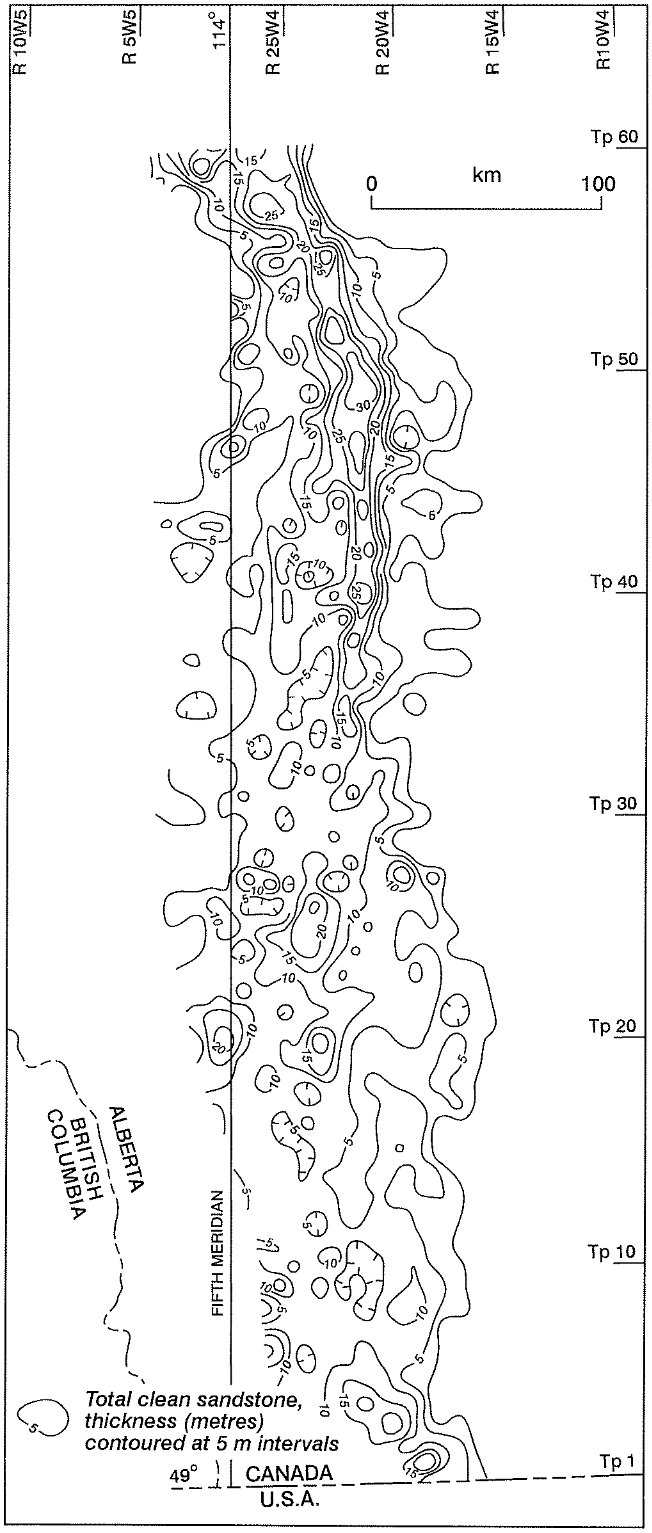


***Figure 71.*** *Play map for the Basal Belly river — Cycle 3.*

## CONCLUDING REMARKS

In Table 154, the oil and gas resources for the Interior Platform geological province within the Western Canada Sedimentary Basin are summarized with respect to geological system (Devonian, Permo-Carboniferous, Triassic, Jurassic and Lower Cretaceous). The Lower Cretaceous system is represented by the Mannville Group. In the Upper Cretaceous system, which includes the Colorado and Belly River groups, the oil and gas resources of both geological provinces (Interior Platform and Cordilleran foreland) are compared. The Mannville, Devonian and Colorado mature plays have the greatest oil potential. The Devonian system shows the greatest oil potential with respect to immature and conceptual plays. Similar distributions with respect to geological systems are also noted for gas resources.

The oil potential is further divided into plays and summarized in Tables 155 to 161 for each geological system. Within each system, the plays are arranged in descending order of expected oil potential. The corresponding gas potential is also given.

**Table 154**

**Oil and gas potential of the Western Canada Basin**

| System or Group | Oil Resources ($10^6m^3$) | | | Gas Resources ($10^6m^3$) | |
|---|---|---|---|---|---|
| | Discovered | Prediction Interval | Expected | Discovered | Expected |
| Devonian mature plays | 3,278 | 631 - 1,627 | 1,066 | 1,568,606 | 564,478 |
| Devonian immature and conceptual plays | 53 | 127 - 3,033 | 1,230 | 17,339 | 1,394,900 |
| Carboniferous and Permian | 1,996 | 478 - 1,577 | 973 | 629,862 | 214,824 |
| Triassic | 469 | 150 - 580 | 345 | 288,400 | 272,124 |
| Jurassic | 566 | 108 - 243 | 167 | 108,123 | 68,225 |
| Mannville - light and medium | 821 | 297 - 602 | 438 | N/A | N/A |
| Mannville - heavy | 2,422 | 1,075 - 2,512 | 1,796 | N/A | N/A |
| Mannville - total* | 3,243 | 1,534 - 2,956 | 2,233 | 1,504,655 | 643,701 |
| Colorado Group (mature plays) | 2,327 | 274 - 903 | 554 | 880,136 | 493,054 |
| Colorado Group (immature plays) | 29 | 209 - 270 | 240 | | |
| Belly River | 244 | 87 - 270 | 155 | 561,441 | 167,670 |
| Total from mature plays | 12,547 | 4,400 - 6,648 | 5,488 | 5,541,252 | 2,424,076 |
| Total from immature and conceptual plays | | N/A | 1,470 | N/A | 3,137,614 |

* Mannville total is not a sum of light and medium, and heavy

## Table 155

### Oil and gas potential of the Devonian system

| Play | Oil Resources ($10^6m^3$) | | | Gas Resources ($10^6m^3$) | |
|---|---|---|---|---|---|
| | Discovered | Prediction Interval | Expected | Discovered | Expected |
| Nisku shelf | 240.687 | 12 - 289 | 118 | 26,499 | 10,352 |
| Middle Devonian clastics | 360.067 | 35 - 648 | 68 | 25,665 | 18,204 |
| Zama and Muskeg | 48.445 | 48 - 87 | 66 | Included in the Rainbow, Shekilie, and Zama sub-basin plays | |
| Leduc—deep basin | 103.617 | 5 - 160 | 62 | 127,776 | 54,449 |
| Keg River–Rainbow sub-basin | 232.972 | 4 - 134 | 52 | 40,704 | 11,436 |
| Slave Point–Peace River Arch | 110.956 | 12 - 99 | 51 | 21,100 | 67,467 |
| Keg River Shekilie sub-basin | 32.502 | 35 - 47 | 41 | 7,084 | 13,858 |
| Keg River Zama sub-basin | 130.149 | 27 - 46 | 37 | 17,544 | 11,132 |
| Arcs structural | 32.810 | 15 - 40 | 26 | 5,844 | Immature play |
| Leduc Bashaw | 92.157 | 2 - 65 | 24 | 66,954 | 8,609 |
| Nisku–Leduc Southern Alberta | 34.593 | 2 - 34 | 16 | N/A | N/A |
| Wabamun–Peace River Arch | 35.084 | 9 - 19 | 14 | 19,281 | 40,870 |
| Beaverhill Lake | 994.503 | 12 - 613 | 13 | 125,835 | 7,758 |
| Keg River–Senex | 56.051 | 4 - 31 | 16 | N/A | N/A |
| Nisku–West Pembina reef | 81.501 | 1 - 24 | 10 | 22,691 | 8,041 |
| Leduc—isolated reef | 621.187 | 2 - 8 | 5 | 297,536 | 46,099 |
| Wabamun—eroded edge | 7.076 | 2 - 9 | 5 | Part of the Upper Devonian subcrop play | |
| Bistcho (Sulphur Point) | 9.749 | 0.2 - 10.5 | 4 | 1,250 | Immature play |
| Leduc–Nisku fringing reef | 3.922 | 0.6 - 4 | 2 | 7,035 | 8,445 |
| Total mature plays | 3,278.138 | 631 - 1,627 | 1066 | 1,568,606 | 564,478 |
| Total immature and conceptual plays | 53 | 127 - 3,033 | 1,230 | 17,339 | 1,394,900 |

## Table 156

## Oil and gas potential of the Carboniferous and Permian systems

| Play | Oil Resources ($10^6 m^3$) | | | Gas Resources ($10^6 m^3$) | |
|---|---|---|---|---|---|
| | Discovered | Prediction Interval | Expected | Discovered | Expected |
| Mississippian subcrop | 447.756 | 103 - 957 | 493 | 499,115 | 52,351 |
| Midale | 677.757 | 15 - 560 | 219 | N/A | N/A |
| Bakken | 178.902 | 5 - 158 | 62 | 3,290 | 12,233 |
| Frobisher - Alida | 452.640 | 4 - 143 | 55 | N/A | N/A |
| Ratcliffe | 54.323 | 27 - 78 | 51 | N/A | N/A |
| Souris Valley - Tilston | 102.395 | 2 - 76 | 28 | N/A | N/A |
| Belloy - Peace River Arch | 57.672 | 1.3 - 53 | 20 | 39,943 | 72,783 |
| Sweetgrass Arch | 16.838 | 14 - 24 | 19 | 6,893 | 6,495 |
| Lodgepole | 56.250 | 1.4 - 47 | 17 | N/A | N/A |
| Debolt | 1.958 | 2 - 4 | 3 | 48,895 | 16,640 |
| Total | 1,995.819 | 478 - 1,577 | 973 | 629,862 | 214,824 |

## Table 157

## Oil and gas potential of the Triassic system

| Play | Oil Resources ($10^6 m^3$) | | | Gas Resources ($10^6 m^3$) | |
|---|---|---|---|---|---|
| | Discovered | Prediction Interval | Expected | Discovered | Expected |
| Charlie Lake carbonates | 198.649 | 46 - 451 | 75 | 20,123 | 9,128 |
| Halfway–Doig—shore zone | 71.694 | 4 - 93 | 40 | 12,731 | 10,839 |
| Halfway–Doig—shore zone–Peace River Arch | 88.644 | 2 - 60 | 24 | 66,600 | 27,905 |
| Montney | 49.967 | 1 - 53 | 19 | 25,876 | 23,258 |
| Halfway–Doig—shelf–Peace River Arch | 15.761 | 4 - 20 | 11 | 39,710 | 88,934 |
| Halfway–Doig—shelf | 3.456 | 3 - 13 | 7 | 25,915 | 23,202 |
| Charlie Lake Clastics–Inga | 18.881 | 0.2 - 34 | 13 | 6,094 | 8,866 |
| Charlie Lake Clastics–Peace River Arch | 15.921 | 0.3 - 9 | 4 | 4,529 | 5,915 |
| Baldonnel Subcrop | 5.6 | 6 - 18 | 12 | 52,614 | 66,610 |
| Total | 468.680 | 150 - 580 | 345 | 288,400 | 272,124 |

## Table 158

## Oil and gas potential of the Jurassic system

| Play | Oil Resources ($10^6 m^3$) | | | Gas Resources ($10^6 m^3$) | |
|---|---|---|---|---|---|
| | Discovered | Prediction Interval | Expected | Discovered | Expected |
| Rock Creek | 21.261 | 37 - 67 | 50 | 39,591 | 25,419 |
| Shaunavon | 228.734 | 3 - 92 | 36 | N/A | N/A |
| Nordegg | 17.865 | 15 - 40 | 26 | 42,018 | 9,205 |
| Roseray–Success | 150.335 | 2 - 74 | 23 | N/A | N/A |
| Gilby–Medicine River | 62.615 | 1.4 - 47 | 19 | N/A | N/A |
| Sawtooth | 81.848 | 1 - 29 | 13 | 5,614 | 7,228 |
| Total | 565.801 | 108 - 243 | 167 | 108,123 | 68,225 |

## Table 159

## Oil and gas potential of the Mannville Group

| Play | Oil Resources ($10^6 m^3$) | | | Gas Resources ($10^6 m^3$) | |
|---|---|---|---|---|---|
| | Discovered | Prediction Interval | Expected | Discovered | Expected |
| Colony to Lloydminster | 1,870.207 | 832 - 2,176 | 1,483 | 212,535 | 87,008 |
| Dina | 148.793 | 17 - 255 | 122 | 11,102 | 13,283 |
| Upper Mannville—light and medium | 314.440 | 26 - 282 | 138 | 354,214 (including Glauconite play) | 121,723 (including Glauconite play) |
| Upper Mannville—heavy | 276.895 | 11 - 212 | 97 | | |
| Lower Mannville—light and medium | 274.385 | 19 - 144 | 77 | 288,263 | 79,404 |
| Glauconite | 93.616 | 36 - 118 | 74 | N/A | N/A |
| Detrital | 16.300 | 45 - 85 | 63 | 11,432 | 33,563 |
| Lower Mannville—heavy | 75.953 | 16 - 86 | 48 | Included in the Lower Mannville light and medium oil play | |
| Cummings | 50.580 | 15 - 84 | 46 | 5,216 | 2,160 |
| Cantuar | 66.084 | 3 - 64 | 27 | 2,434 | Immature |
| Gething | 25.996 | 11 - 39 | 24 | 140,681 | 22,151 |
| Ostracod | 23.515 | 14 - 31 | 22 | 38,084 | 16,677 |
| Bluesky | 6.225 | 10 - 20 | 15 | 105,478 | 48,585 |
| Total | 3243 | 1,534 - 2,956 | 2,233 | 1,504,655 | 643,701 |

## Table 160

## Oil and gas potential of the Colorado Group

| Play | Oil Resources ($10^6m^3$) | | | Gas Resources ($10^6m^3$) | |
|---|---|---|---|---|---|
| | Discovered | Prediction Interval | Expected | Discovered | Expected |
| Viking Transgressive | 520.365 | 31 - 626 | 285 | 343,291 | 126,840 |
| Viking Regressive | 56.144 | 4 - 165 | 65 | 28,033 | 13,217 |
| Doe Creek | 67.557 | 9 - 151 | 67 | 8,349 | 6,578 |
| Viking Channel | 21.688 | 16 - 71 | 39 | 19,500 | 11,235 |
| Second White Specks | 27.771 | 46 - 79 | 61 | 94,421 | 16,298 |
| Cardium | 1,535.487 | 21 - 30 | 25 | 205,861 | 26,724 |
| Dunvegan | 20.910 | 3 - 23 | 12 | 17,935 | 5,687 |
| Ricinus–Cardium | 50.765 | 2 - 36 | 16 | 33,446 | 3,369 |
| Ansell–Cardium | 18.469 | 0.5 - 19 | 7 | 23,189 | 39,179 |
| Total from mature plays | 2,326.937 | 274 - 903 | 554 | 880,136 | 403,054 |
| Total from immature plays | 28.500 | 209 - 270 | 240 | N/A | N/A |

## Table 161

## Oil and gas potential of the Belly River Group

| Play | Oil Resources ($10^6m^3$) | | | Gas Resources ($10^6m^3$) | |
|---|---|---|---|---|---|
| | Discovered | Prediction Interval | Expected | Discovered | Expected |
| Belly River Fluvial | 22.205 | 31 - 43 | 36 | 23,252 | 18,547 |
| Belly River Cycle 2 | 194.500 | 4 - 179 | 69 | 19,997 | 7,404 |
| Belly River Fluvial Foothills | 18.716 | 33 - 53 | 42 | 3,389 | 19,357 |
| Belly River Marine Foothills | 6.089 | 2.5 - 12 | 7 | | |
| Total | 243.693 | 87 - 270 | 155 | 561,441 | 167,670 |

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