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UPPERMOST CRETACEOUS, POST-COLORADO GROUP GAS RESOURCES OF THE WESTERN CANADA SEDIMENTARY BASIN, INTERIOR PLAINS

A.P. Hamblin and P.J. Lee

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GEOLOGICAL PLAY ANALYSIS AND RESOURCE ASSESSMENT

A.P. Hamblin and P.J. Lee

1997

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Cover illustration

Well-developed inclined heterolithic stratification (IHS), comprising thinly interbedded fine sandstone and siltstone in a 10 m set, Oldman Formation, Belly River Group, Bow River near Hays, Alberta. This stratification indicates lateral accretion toward the northeast within a meandering, tidally influenced channel. Sand-rich lateral equivalents present in the subsurface are gas-productive reservoirs, and represent an Upper Cretaceous play with significant gas potential. Inset: Dinosaur remains are common in strata of the Belly River Group, Edmonton Group and Scollard Formation in the southern Alberta Plains. This hadrosaur limb bone was found in a fluvial channel sandstone of the Edmonton Group, Red Deer River valley.

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PREFACE

Appraisals of oil and gas resources in the major sedimentary basins of Canada are undertaken on a continuing basis by Natural Resources Canada. These appraisals provide objective estimates of Canada's oil and gas resources, generate data for forecasting future supply, and serve as a basis for efficient resource management and planning.

Natural gas is playing an increasingly important role in the petroleum industry. This has been demonstrated in the last few years with the building of new production gathering facilities and transportation infrastructure. The creation of new domestic and export markets for western Canadian natural gas is resulting in an increased demand for what has become the fuel of choice for many applications. Thus the systematic estimation of both the amount of undiscovered natural gas and the economic conditions under which it may be extracted and sold continues to be an important priority of Natural Resources Canada.

This study describes the petroleum geology of uppermost Cretaceous–Tertiary exploration plays, and provides an assessment of remaining natural gas potential. The geological analysis and resource assessment were undertaken by the Geological Survey of Canada (Calgary). The estimates of potential, expressed in probabilistic terms, were prepared using statistical techniques developed by the GSC.

This report is one in a series of publications on the natural gas resources of western Canada. The information in these reports will provide a regional synthesis of petroleum geology and will assist in evaluating opportunities for exploration and development in western Canada. The studies also further the understanding of petroleum geology, showing progress in methodologies of resource assessment and economic evaluation.

M.D. Everell
Assistant Deputy Minister
Earth Sciences Sector

PRÉFACE

Le ministère des Ressources naturelles du Canada réalise sur une base continue des évaluations des ressources en pétrole et en gaz des grands bassins sédimentaires du Canada. Ces évaluations fournissent des estimations objectives des ressources en pétrole et en gaz du Canada, produisent des données pour la prévision des approvisionnements futurs et constituent une base pour bien gérer et planifier l'utilisation des ressources.

Le gaz naturel joue un rôle de plus en plus important dans l'industrie pétrolière, comme en témoigne la construction au cours des dernières années de nouvelles installations de collecte de la production, ainsi que de l'infrastructure de transport s'y rattachant. La création de nouveaux marchés intérieurs et d'exportation pour le gaz naturel de l'Ouest du Canada se traduit par une demande accrue d'une substance qui est devenue le combustible de choix pour de nombreuses applications. L'estimation systématique de la quantité de gaz naturel qu'il reste à découvrir et des conditions économiques dans lesquelles celui-ci peut être extrait et vendu continue donc d'être une grande priorité de Ressources naturelles Canada.

La présente étude décrit la géologie pétrolière des zones d'exploration dans la succession sédimentaire du Crétacé sommital et du Tertiaire et fournit une évaluation du potentiel gazier demeurant à être découvert. L'analyse géologique et l'évaluation des ressources ont été entreprises par la Commission géologique du Canada (CGC) à Calgary. Les estimations du potentiel gazier, exprimées en termes probabilistes, ont été préparées au moyen de techniques statistiques mises au point par la CGC.

Le présent rapport fait partie d'une série de publications sur les ressources en gaz naturel de l'Ouest du Canada. L'information contenue dans ces rapports permettra d'établir une synthèse régionale de la géologie pétrolière et nous aidera à évaluer les cibles d'exploration et les possibilités de mise en valeur dans l'Ouest du Canada. Ces études permettent aussi de mieux connaître la géologie pétrolière et témoignent des progrès réalisés dans les méthodes d'évaluation technique et économique des ressources.

M.D. Everell
Sous-ministre adjoint
Secteur des sciences de la Terre

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Abstract

The natural gas resource potential of uppermost Cretaceous–Tertiary, post-Colorado strata in the Western Canada Sedimentary Basin (excluding the Foothills Belt) was evaluated using a combination of geological play analysis and statistical estimation. Post-Colorado strata belong to a foreland basin succession of siliciclastic sediments deposited as the final infill of the Western Canada Sedimentary Basin. The thickest deposits and most prolific oil and gas reservoirs occur in the thick depocentre of southern and west-central Alberta. The post-Colorado succession contains a total discovered in-place volume of 556 280 x 10^6 m^3 (19.8 TCF) raw gas in 12 mature and 2 immature, established plays. In addition, one conceptual play was identified. Exploration plays consist of stratigraphic and stratigraphic-structural combination traps with reservoirs in shoreline, tidal channel, shallow marine, fluvial, and estuarine sandstones. Statistical analysis of the 14 established plays suggests they contain a remaining expected potential of 130 448 x 10^6 m^3 (4.6 TCF). Four of these plays are predicted to contain over half of the remaining gas potential: the Foremost Formation ("Basal Belly River"), Cycle 4 Shoreline play (e.g., Bashaw field, Belly River Pool No. 3), the Foremost Formation, Fluvial play (e.g., Bashaw field, Belly River C pool), the Oldman Formation, Fluvial play (Nevis field, BR C No. 1 pool), and the Dinosaur Park Formation play (e.g., Carbon field, Belly River C pool). The very modest amount of gas estimated to be present in the conceptual and immature plays is consistent with the exploration maturity of the basin, and the idea that established play definitions are sufficiently broad to include variations in trapping mechanism. Over 19 per cent of the total in-place resources remain to be discovered. Post-Colorado strata continue to offer small, but economically attractive exploration targets, particularly for junior operators, as shown by significant recent activity.

Résumé

L'évaluation des ressources potentielles en gaz naturel de la succession du Crétacé sommital-Tertiaire postérieure au Groupe de Colorado du Bassin sédimentaire de l'Ouest du Canada (à l'exclusion du Domaine de l'avant-pays), a été réalisée en combinant une analyse géologique des zones gazéifères à une estimation statistique. Les strates postérieures au Groupe de Colorado font partie d'une succession de roches sédimentaires silicoclastiques d'un bassin d'avant-pays, qui sont les dernières à s'être déposées dans le Bassin sédimentaire de l'Ouest du Canada. Les dépôts les plus épais, de même que les roches réservoirs les plus riches en pétrole et en gaz, se trouvent dans la zone de dépôt maximal de grande épaisseur située dans le sud et le centre ouest de l'Alberta. La succession postérieure au Groupe de Colorado renferme un volume en place de gaz brut jusqu'ici découvert s'élevant au total à 556 280 x 10^6 m^3 (19,8 x 10^{12} pi^3), qui est réparti dans 12 zones prouvées bien explorées et 2 zones prouvées sommairement explorées. En outre, une zone possible ou théorique a également été définie. Les zones d'exploration sont associées à des pièges stratigraphiques ou à des pièges de caractère mixte qui combinent les effets d'éléments structuraux à des pièges stratigraphiques. Les lithologies réservoirs de ces zones se composent de grès déposés dans des milieux littoraux, de passe de marée, de mer peu profonde, fluviaux et estuariens. L'analyse statistique des 14 zones prouvées indique que celles-ci renferment un potentiel prévu non encore découvert de 130 448 x 10^6 m^3 (4,6 x 10^{12} pi^3). Quatre de ces zones contiendraient plus de la moitié du potentiel gazéifère non encore découvert : la Formation de Foremost («Belly River basal»), cycle 4, faciès littoraux (p. ex. champ de Bashaw, gisement de Belly River n° 3), la Formation de Foremost, faciès fluviatiles (p. ex. champ de Bashaw, gisement de Belly River C), la Formation d'Oldman, faciès fluviatiles (champ de Nevis, gisement de Belly River C n° 1) et la Formation de Dinosaur Park (p. ex. champ de Carbon, gisement de Belly River C). Le très faible volume de gaz estimé dans les zones possibles et sommairement explorées témoigne assez bien du stade auquel est rendu l'exploration de ce bassin et du fait que les définitions des zones gazéifères prouvées sont assez larges pour tenir compte de variations dans les mécanismes de piégeage des hydrocarbures. Plus de 19 pour cent des ressources totales en place demeurent à être découvertes. La succession postérieure au Groupe de Colorado renferme encore aujourd'hui des cibles d'exploration de faible étendue mais économiquement attirantes, surtout pour les petits exploitants, comme en témoigne le récent niveau d'activité d'exploration.

Summary

The gas resources contained in uppermost Cretaceous–Tertiary, post-Colorado strata of the Interior Plains portion of the Western Canada Sedimentary Basin are described here in terms of detailed geological play analysis and numerical assessment of undiscovered gas potential.

The natural gas potential of mature, immature, and conceptual plays is estimated using a numerical assessment technique, termed "the discovery process model", which uses the size (volume) and the discovery sequence of individual pools or plays, within a natural population of pools or plays, to predict undiscovered potential. Established plays are defined as those that have discovered pools with established reserves, and are classed as mature or immature depending on the number of pools contained in that play. Mature plays require geological analysis to delineate the type and extent of the pool population for each play, prior to statistical analysis. Geological analysis of immature plays provides subjective comparisons for matching discovered resources in the modelled play population. Discovered in-place volumes for mature and immature plays, total 556 280 x 10^6 m^3 (19.8 TCF), discovered in 1400 pools. Conceptual plays are defined as those plays without discoveries or reserves, but which geological and/or statistical analysis indicate may exist.

Geological analysis by subsurface correlation and mapping, use of Alberta and Saskatchewan government pool data, literature studies, and discussions with government and industry geoscientists enabled the grouping of post-Colorado pools into 12 mature and 2 immature plays, and 1 conceptual play. In each established play, pools form a natural geological population governed by geological controls, such as stratigraphic position, depositional style, structure, or trap geometry. These geological factors control the play boundary and the resulting distribution of pools within that play. Once the play was defined, quantitative analyses based on the exploration discovery history and pool-size distribution were used to assess play potential.

Results from the analysis of mature plays indicate that four mature plays have significant potential for additional amounts of natural gas. These are:

1) Foremost Formation ("Basal Belly River"), Cycle 4 shoreline sandstone reservoirs (e.g., Bashaw field, Belly River No. 3 pool), with an expected potential of 17 733 x 10^6 m^3;
2) Foremost Formation, fluvial sandstone reservoirs (e.g., Bashaw field, Belly River C pool), with an expected potential of 18 547 x 10^6 m^3;
3) Oldman Formation, fluvial sandstone reservoirs, (e.g., Nevis field, BR C No. 1 pool), with an expected potential of 15 691 x 10^6 m^3; and
4) Dinosaur Park Formation, sandstone reservoirs (e.g., Carbon field, Belly River C pool), with an expected potential of 25 283 x 10^6 m^3.

Compared to mature plays, immature and conceptual plays have less potential. This result is consistent with the long history of exploration and the fact that the definitions of mature plays are sufficiently broad to include most play concepts.

The expected potential from all play types (mature, immature, and conceptual) is 130 448 x 10^6 m^3 (4.6 TCF), distributed in about 7000 pools. A more speculative, probable potential volume of 175 858 x 10^6 m^3 (6.2 TCF) provides a more optimistic estimate of the potential gas resource. Three conclusions can be drawn from the numerical estimates:

1. Geological analysis and statistical assessment of gas resources in uppermost Cretaceous, post-Colorado strata of the Interior Plains of the Western Canada Sedimentary Basin suggest that 19 per cent of the total gas resource remains to be discovered (130 448 x 10^6 m^3, or 4.6 TCF). However, removing the very thoroughly explored Milk River/Medicine Hat play from the analysis suggests a much more encouraging 64 per cent of total Belly River/Edmonton gas resource remains to be discovered.

2. Of the undiscovered gas potential, 99 per cent is considered to be present in established mature plays. Only one per cent of the estimated expected volume is predicted to occur in conceptual and immature plays. However, the latter were not exhaustively analysed.

3. The most attractive mature plays with the greatest potential are: i) the Foremost Formation ("Basal Belly River"), Cycle 4 Shoreline play; ii) the Foremost Formation, Fluvial play; iii) the Oldman Formation, Fluvial play; and iv) the Dinosaur Park Formation play. These plays make up about 59 per cent (77 254 x 10^6 m^3, 2.7 TCF) of the total expected (undiscovered) resource.

Sommaire

Les ressources gazières contenues dans la succession du Crétacé sommital-Tertiaire postérieure au Groupe de Colorado, dans la partie des Plaines intérieures du Bassin sédimentaire de l'Ouest du Canada, sont décrites ci-après en termes d'analyse géologique détaillée des zones gazéifères et d'évaluation quantitative du potentiel gazier non découvert.

Le potentiel en gaz naturel des zones bien explorées, sommairement explorées et possibles est évalué au moyen d'une technique d'évaluation quantitative, appelée «modèle de processus de découverte», qui permet de prévoir le potentiel non découvert à partir de la taille (volume) et de la séquence de découverte des différents gisements et zones au sein d'une population naturelle. Les zones prouvées correspondent à des zones qui contiennent des gisements découverts renfermant des réserves prouvées; elles sont subdivisées en zones bien explorées ou sommairement explorées selon le nombre de gisements qu'elles renferment. Avant de procéder à une analyse statistique, il faut soumettre les zones bien explorées à une analyse géologique pour déterminer le type et l'étendue de leur population de gisements. L'analyse géologique des zones sommairement explorées permet d'apparier par comparaisons subjectives les ressources découvertes à celles de la population modélisée de la zone. Au total, le volume de gaz en place découvert dans 1 400 gisements appartenant à des zones bien explorées et sommairement explorées s'élève à 556 280 x 10^6 m^3 (19,8 x 10^{12} pi^3). Les zones possibles (ou théoriques) correspondent aux zones dans lesquelles aucune découverte n'a été effectuée, ou aucune réserve na été établie, mais pour lesquelles l'analyse géologique ou statistique en indique l'existence possible.

L'analyse géologique faisant appel à des corrélations en subsurface et à des levés cartographiques en surface, à l'utilisation des données sur les gisements des gouvernements de l'Alberta et de la Saskatchewan, à des études documentaires et à des échanges avec des géoscientifiques des secteurs public et privé ont permis de classer les gisements identifiés dans la succession postérieure au Groupe de Colorado en 12 zones bien explorées, 2 zones sommairement explorées et une zone possible ou théorique. Dans chaque zone prouvée, les gisements forment une population géologique naturelle qui est régie par des facteurs géologiques comme la position stratigraphique, le faciès sédimentaire des lithologies hôtes, la structure ou la géométrie des pièges. Ces facteurs géologiques déterminent les limites des zones et, par voie de conséquence, la répartition résultante des gisements au sein de celles-ci. Une fois qu'une zone est définie, son potentiel est évalué par une analyse quantitative basée sur l'ordre des découvertes dans le temps et sur la distribution du volume des gisements.

Les résultats de l'analyse des zones bien explorées indiquent que le potentiel d'existence de grandes quantités additionnelles de gaz naturel est élevé dans les quatre zones bien explorées suivantes :

1) Formation de Foremost («Belly River basal»), cycle 4, réservoirs dans des grès littoraux (p. ex. champ de Bashaw, gisement de Belly River n° 3), potentiel prévu de 17 733 x 10^6 m^3;

2) Formation de Foremost, réservoirs dans des grès fluviatiles (p. ex. champ de Bashaw, gisement de Belly River C), potentiel prévu de 18 547 x 10^6 m^3;

3) Formation d'Oldman, réservoirs dans des grès fluviatiles (p. ex. champ de Nevis, gisement de Belly River C n° 1), potentiel prévu de 15 691 x 10^6 m^3; et

4) Formation de Dinosaur Park, réservoirs dans des grès (p. ex. champ de Carbon, gisement de Belly River C), potentiel prévu de 25 283 x 10^6 m^3.

Les potentiels des zones sommairement explorées et possibles sont moins grands que ceux des zones bien explorées, ce qui est un reflet de la longue période sur laquelle des travaux d'exploration ont été effectués et ce qui rend compte du fait que les définitions des zones bien explorées sont assez larges pour englober tous les types de zones.

Le potentiel prévu de l'ensemble des différents types de zones (bien explorées, sommairement explorées et possibles) s'élève à 130 448 x 10^6 m^3 (4,6 x 10^{12} pi^3) et est réparti dans quelque 7 000 gisements. Un volume probable de 175 858 x 10^6 m^3 (6,2 x 10^{12} pi^3), une valeur qui relève d'avantage de la spéculation, apparaît être une estimation plus réaliste du potentiel gazier. Trois conclusions peuvent être tirées des estimations quantitatives :

1. L'analyse géologique et l'évaluation statistique des ressources gazières contenues dans la succession du Crétacé sommital postérieure au Groupe de Colorado, dans la partie des Plaines intérieures du Bassin sédimentaire de l'Ouest du Canada, nous portent à croire que 19 pour cent des ressources gazières totales (130 448 x 10^6 m^3 ou 4,6 x 10^{12} pi^3) n'ont pas encore été découvertes. Toutefois, si on exclut de l'analyse la zone formée des formations de Milk River et de Medicine Hat qui a fait l'objet de travaux d'exploration poussés, il ressort que l'importance des ressources n'ayant pas encore été découvertes est beaucoup plus grande, s'élevant à 64 pour cent des ressources gazières totales pour l'ensemble formé des groupes de Belly River et d'Edmonton.

2. Du potentiel gazier non découvert, 99 pour cent se trouverait dans les zones bien explorées et prouvées. À peine un pour cent du volume prévu d'après les estimations se trouverait dans des zones possibles et sommairement explorées. Ces dernières n'ont toutefois pas été analysées à fond.

3. Les zones bien explorées montrant les plus forts potentiels sont : (i) la zone formée des faciès littoraux du cycle 4 de la Formation de Foremost («Belly River basal»); (ii) la zone formée des faciès fluviatiles de la Formation de Foremost; (iii) la zone formée des faciès fluviatiles de la Formation d'Oldman; et (iv) la zone associée à la Formation de Dinosaur Park. Ces zones constituent au total quelque 59 pour cent (77 254 x 10^6 m^3, 2,7 x 10^{12} pi^3) des ressources prévues (non découvertes).

INTRODUCTION

Scope

Estimates of hydrocarbon resource potential in various parts of Canada have been prepared periodically by the Geological Survey of Canada, using systematic geological basin analysis and statistical resource evaluation methods (e.g., Dixon et al., 1988; Podruski et al., 1988; Wade et al., 1989; Sinclair et al., 1992). The assessment of uppermost Cretaceous strata follows the format and approach of the earlier western Canada oil assessment (Podruski et al., 1988) and the Devonian gas assessment (Reinson et al., 1993b), and is designed to contribute to a complete assessment of all major play groups in the entire Western Canada Sedimentary Basin (WCSB) (see Reinson et al., 1993a).

The initial computer-based statistical evaluation methods were developed within the Geological Survey of Canada by Lee and Wang (1983a, 1983b, 1984, 1985, 1986) and subsequently refined into the present PETRIMES system (Lee and Wang, 1990; Lee and Tzeng, 1993) which is employed in this study for estimating resource potential of established plays.

The gas assessment of western Canada was divided into seven major play groups on the basis of geological criteria, following major stratigraphic units or structural/tectonic provinces. Each group has a distinct set of geological factors which control size, distribution, and type of hydrocarbon play or reservoir. The major play groups are: Devonian, Carboniferous–Permian, Triassic, Jurassic, Mannville, Colorado Group, Upper Cretaceous–Tertiary post-Colorado, and Rocky Mountain Deformed Belt.

About 8.7 per cent of the discovered in-place gas in the Interior Plains of the WCSB is contained in Upper Cretaceous–Tertiary rocks (Fig. 1). Ninety nine per cent of the discovered in-place gas (and about 78 per cent of the remaining expected potential) of the post-Colorado strata are contained in the southern Interior Plains, with the remaining one per cent (and 22 per cent of expected potential) in the Rocky Mountain Foreland Belt of the Cordilleran Orogen (Foothills-Deformed Belt) (Table 1; results from this study and from Osadetz et al., in prep.).

This report documents an assessment of uppermost Cretaceous–Tertiary gas resources in the Interior Plains of the WCSB (Fig. 2). The study area is largely confined to the southern and central Alberta Plains (where much of the post-Colorado succession occurs in the subsurface). It excludes Foothills structural plays (which were evaluated with other Cordilleran structural province plays: see Osadetz et al., in prep.). Preliminary results of this assessment were presented by Hamblin and Lee (1995).

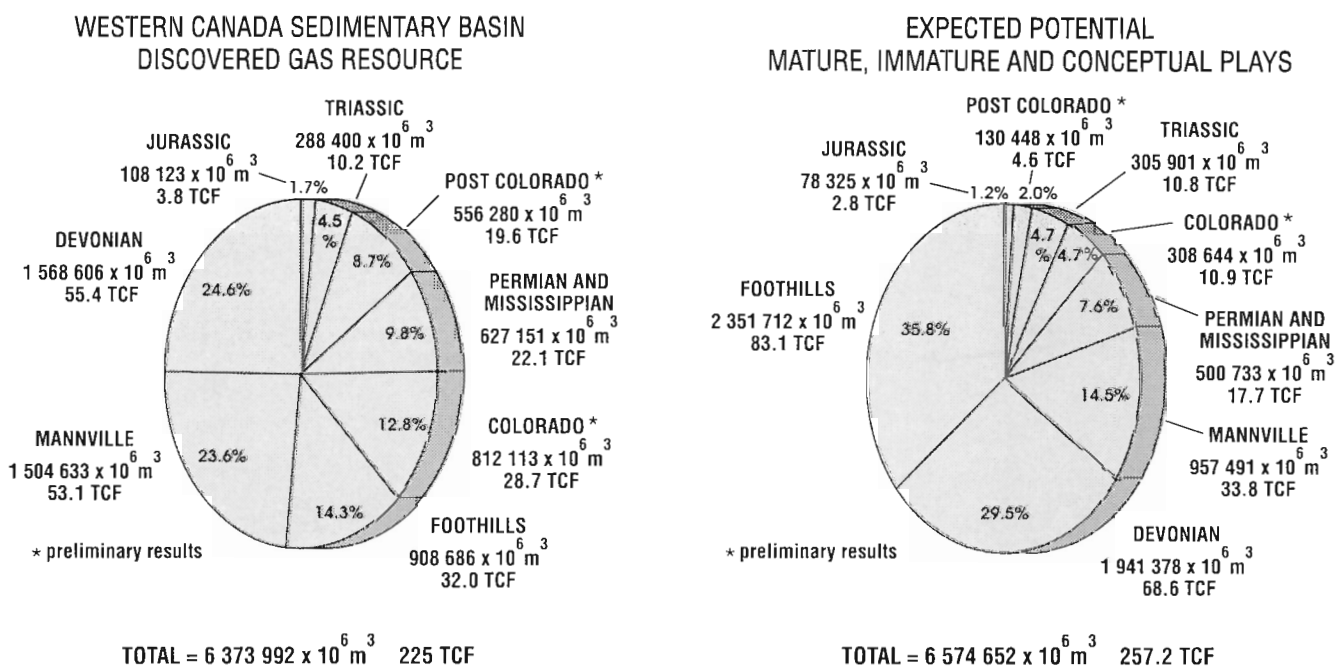


Figure 1. *Gas resources of the Western Canada Sedimentary Basin. (a) Discovered gas resource by stratigraphic horizon. (b) Expected gas potential by stratigraphic horizon. Data from unpublished GSC work.*

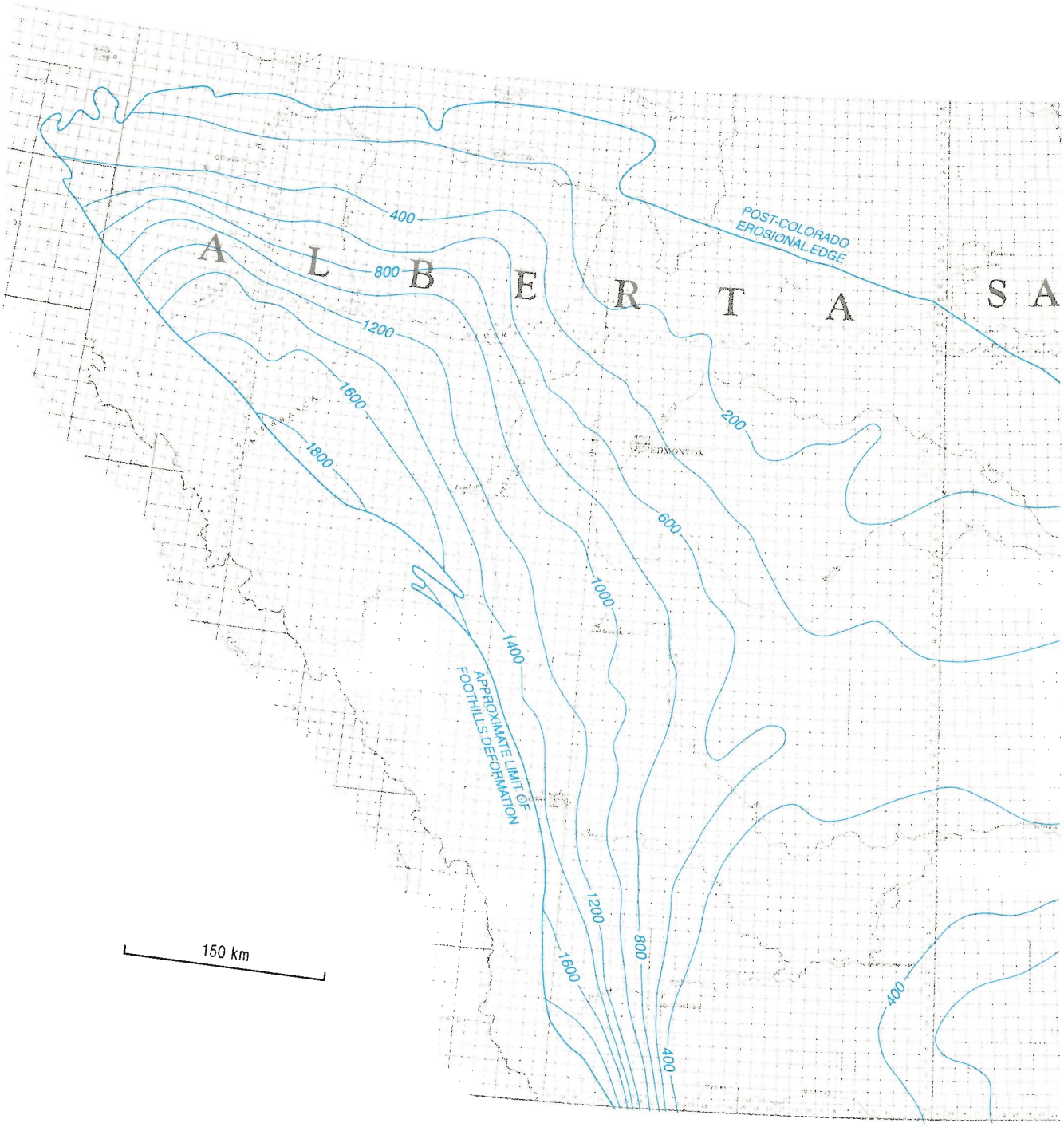


Figure 2. *Distribution and thickness of post-Colorado strata in the Western Canada Sedimentary Basin.*

Figure 2. *(cont'd.)*

Table 1

Discovered and potential in-place gas volumes ($x\ 10^6\ m^3$) for post-Colorado plays in the Interior Plains and Foothills

Area	Discovered in-place volume	Expected potential
WCSB Plains (12 mature, 2 immature plays) (this study)	556 280 x 10^6 m^3 (99%)	130 448 x 10^6 m^3 (78%)
WCSB Foothills (2 mature plays) (Osadetz et al., in press)	5 161 x 10^6 m^3 (1%)	37 222 x 10^6 m^3 (22%)
Total	561 441 x 10^6 m^3 (100%)	167 670 x 10^6 m^3 (100%)

Purpose

The objectives of this study are four-fold: i) to document and describe uppermost Cretaceous–Tertiary, post-Colorado, discovered in-place gas with respect to the plays in which they occur; ii) to outline the geology of the principal gas plays in these strata in a manner that industry can use as a guide for exploration; iii) to estimate the total amount of undiscovered gas that might exist in the post-Colorado strata of western Canada, regardless of its economic exploitability; and iv) to provide the necessary geological and resource potential information to allow industry and government agencies to undertake economic viability studies with respect to exploration, producibility, and ultimate marketability.

Terminology

The terminology and procedures used in this report follow that outlined by Reinson et al. (1993b), and are summarized briefly below.

Natural gas is defined as any gas (at standard pressure and temperature, 101.33 kPa and 15°C) of natural origin, that is composed primarily of hydrocarbon molecules, producible from a borehole (Alberta Energy Resources Conservation Board, 1991). Natural gas may contain non-hydrocarbon components in significant amounts (i.e., H_2S, CO_2, and He). In this study, it was not feasible to separate such components from the total potential. *Raw gas* is unprocessed natural gas, containing methane, inert and acid gases, impurities, and other hydrocarbons, some of which may be recoverable as liquids. *Nonassociated gas* is a natural gas that is not in contact with crude oil in a reservoir. *Associated gas* is natural gas that occurs in crude-oil reservoirs as free gas. Solution gas is natural gas that is dissolved in crude oil under reservoir conditions. This assessment deals only with raw gas.

The terms *resource*, *reserve*, and *potential* as defined by the Geological Survey of Canada (Podruski et al., 1988) are retained in this report. *Resource* is defined as all hydrocarbon accumulations that are known, or inferred to exist, and includes both discovered and undiscovered gas. The term *reserve* refers to 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 as yet undiscovered. The expression *established reserve* is used to describe those reserves which, under given economic conditions and within a specified time frame are *recoverable* with a high degree of confidence from known reservoirs. It should be noted that the term *reserve* has been used elsewhere to refer to *initial marketable gas volume*, so to avoid confusion, *discovered in-place volume* has been used here rather than reserve. The terms *potential* and *undiscovered resource* are synonymous and are used interchangeably.

The term *gas-in-place* refers to the gross volume of gas, at standard conditions found in the ground, regardless of what portion may be recoverable. *Initial in-place volume* refers to the gross volume of raw gas, at standard conditions prior to production.

The terms *play*, *field*, *pool* have the following designated meanings in this report. A *play* consists of a group 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). The term *gas field* is used to designate an area that produces gas from an unspecified stratigraphic interval or intervals. Any number of discrete pools, at varying stratigraphic levels, may exist within a field. A *gas pool* is defined as a discovered accumulation of gas, typically within a single stratigraphic interval, that is hydrodynamically separate from any other gas accumulation.

Plays are grouped into two main categories: *established plays* (those that have discovered pools confirmed by discovery wells with recorded gas-in-place) and *conceptual plays* (those that do not yet have discoveries, but which geological and/or statistical analysis indicates may exist). Established plays are grouped further into *mature* and *immature* plays on the basis of adequacy of the play data for statistical analysis. *Mature* plays are those plays in which the profile of the discovery sequence and the

number of pools is adequate for analysis using a *discovery process model* with the "PETRIMES" assessment procedure. *Immature* plays are those in which the number of pools (and therefore the discovery sequence) is inadequate for application of this model.

Method and content

This study has two essential components: geological analysis and statistical analysis. The geological analysis is the fundamental component and involves characterization of the exploration play. The regional geology and geological play analysis of post-Colorado strata follows the style outlined by Podruski et al. (1988) but also includes more recent regional and local geological work published by Hamblin and Abrahamson (1993) and Hamblin (1993, 1994a, b, c, d) and others.

The statistical analysis uses the assumption that pools (both discovered and undiscovered) form a natural geological population that can be delimited areally within a play. Once the play is defined, a numerical resource assessment is undertaken using pool data from that specific play. The pool and well data used in the assessments are based on data sets of the provincial agencies of Alberta (Alberta Energy Resources Conservation Board, 1991) and Saskatchewan (Saskatchewan Energy and Mines, Reservoir Annual 1991). Since gas pools may be composed of nonassociated, associated, and solution gas, reserves were added together to describe individual pools. As a result, the estimated potential refers only to total raw gas-in-place.

Analysis of the gas potential in post-Colorado strata entailed delineation and systematic evaluation of 14 established plays, 12 mature, and 2 immature, plus a single conceptual play. These are summarized with respect to play definition, geology, exploration history, and estimated resource potential. Each play is designated by geological formation, reservoir or trap type.

RESOURCE ASSESSMENT PROCEDURE

Numerical analysis

Several methods exist for estimating the quantity of hydrocarbons that may be present in a play, region, or basin (White and Gehman, 1979; Masters, 1984; Rice, 1986; Lee, 1993). The initial computer-based statistical evaluation methods were developed by the Geological Survey of Canada (Lee and Wang 1983a, b, 1984, 1985, 1986), and subsequently refined into the present Petroleum Exploration and Resource Evaluation System, "PETRIMES" (Lee and Tzeng, 1989; Lee and Wang, 1990; Lee, 1993), which was employed here to estimate resource potential of exploration plays. This system uses the exploration play definition and compiled pool data, in a discovery process model (Lee and Wang, 1990) to estimate undiscovered pool sizes and total resources.

The underlying assumption of the discovery process model is that discoveries made in the course of an exploration program represent a "biased" sample of the underlying population of pools for that play. The discovery process is biased in the sense that the largest and best prospects in a play tend to be tested first, therefore the largest pools tend to be found early in a play's exploration history. The discovery process model makes use of the two most reliable pool data-sets, pool size and discovery date, to produce estimates of play potential and individual pool sizes. Thus, this model inherently reflects accumulated knowledge and strategy used in the exploration process. The mean volumes of gas in individual discovered and undiscovered pools are then summed to give an estimate (expected value) of the total gas resource in that play.

The assessment procedure has been adequately described in previous reports of this series, in which the various steps in the geological and numerical analysis are listed, using mature plays as examples (Reinson et al., 1993a, b; Bird et al., 1994). The procedure is reviewed very briefly here, using the Foremost Formation ("Basal Belly River"), Cycle 4 Shoreline play as an example.

Geological play definition

The definition of play type and play area are the primary objectives of the geological basin analysis, which precedes the numerical resource evaluation. A properly defined play will possess a single population of pools and thus satisfy the statistical assumptions required for the valid operation of the evaluation models. A mixed population, resulting from an improperly-defined play, will add uncertainty to the resource estimates derived from the statistical evaluation. The areal extent of the play is contained within a *play boundary* or *play polygon*. The play boundary is determined by the geological knowledge of rock distribution and prospective area, and by the distribution of pools within that play. By definition, pools in a specific play form a natural geological population characterized by one or more of the

following: age or stratigraphic position, depositional model, geographical distribution, structural style, trapping mechanism, geometry, and diagenesis. In each case, a play is defined by assembling and comparing the most important characteristics and assigning each pool to the play that best describes it.

Compilation of play data

Once a play is defined and the play boundary has been outlined as a closed polygon, all the wells and pools within that play are retrieved from the PETRIMES well and pool database. The well and pool lists are examined to ensure they are consistent with the play definition and boundary. Pool lists provide the pool sizes and discovery dates for each play, which are used to produce an exploration discovery series, the basic input data required by the discovery process models for estimating undiscovered petroleum resources.

The following list summarizes the procedure for compiling data and defining plays:

1. Conduct a literature search to synthesize information on regional and petroleum geology of the uppermost Cretaceous–Tertiary, post-Colorado strata of western Canada.

2. Carry out extensive, regional surface and subsurface stratigraphic studies to define plays and assign known pools to correct plays, and map the subsurface to define play areas.

3. Assemble and manipulate provincial pool and well data (Alberta Energy Resources Conservation Board, 1991) and PETRIMES to create a pool list for each play that accounts for all pools in the database.

4. Establish a "play polygon" or boundary, defining the area where all pools, including those undiscovered, of a certain play type are most likely to exist. Figure 3 displays the play boundary and pool locations for the Cycle 4 Shoreline play of the Foremost Formation.

Discovery process model

The pools discovered in a specific play represent a sample from the total population of that play. However, the discovered pools are not a random sample, but are the result of a selective process, since explorationists tend to drill the best, and commonly the largest, prospects first. This "biased" nature of the sample population poses a problem for estimation of petroleum resources using standard statistical methods.

Both lognormal and nonparametric discovery process models (Lee and Wang, 1985; 1990) were applied to estimate the pool-size distribution of all plays belonging to the Upper Cretaceous formations.

Three assumptions are inherent in this model:

1) The probability of discovering (sampling) a pool is proportional to its size. To support this assumption, well and pool lists are used to produce an *exploration discovery time-series plot* of the sizes of pools in their order of discovery (Fig. 4), which displays a general declining trend in discovered pool sizes.

2) Sampling occurs without replacement, that is, a pool will not be discovered twice. This second assumption is self-evident.

3) For the lognormal case, the pool sizes of each play are assumed to be lognormally distributed.

The biased nature of the sample obtained from the exploration process contains information not only about the mean and variance of the pool-size population but also about the total number of pools within the play. Therefore, the pool-size distribution and the number of pools can be used to estimate the size of individual pools.

Given the possible truncation of the pool-size data set, estimates of the resources in a play should not be considered as the ultimate resource for that play. The results of an assessment are based on the pool-size data set used: the model only predicts the existence of undiscovered pools based on that data set and does not account for appreciation in reserves of the pools within the data set.

The discovery sequence data (Fig. 4) are entered into the two discovery process models for estimating the number of pools (N) and the pool-size distribution. Figure 5 demonstrates the method for determining the total number of pools, N, by plotting the likelihood values against the N values. The higher the likelihood, the more plausible the N value. In this case, the estimated N is about 600. Utilizing this N value, the pool-size distribution is also estimated (Fig. 6).

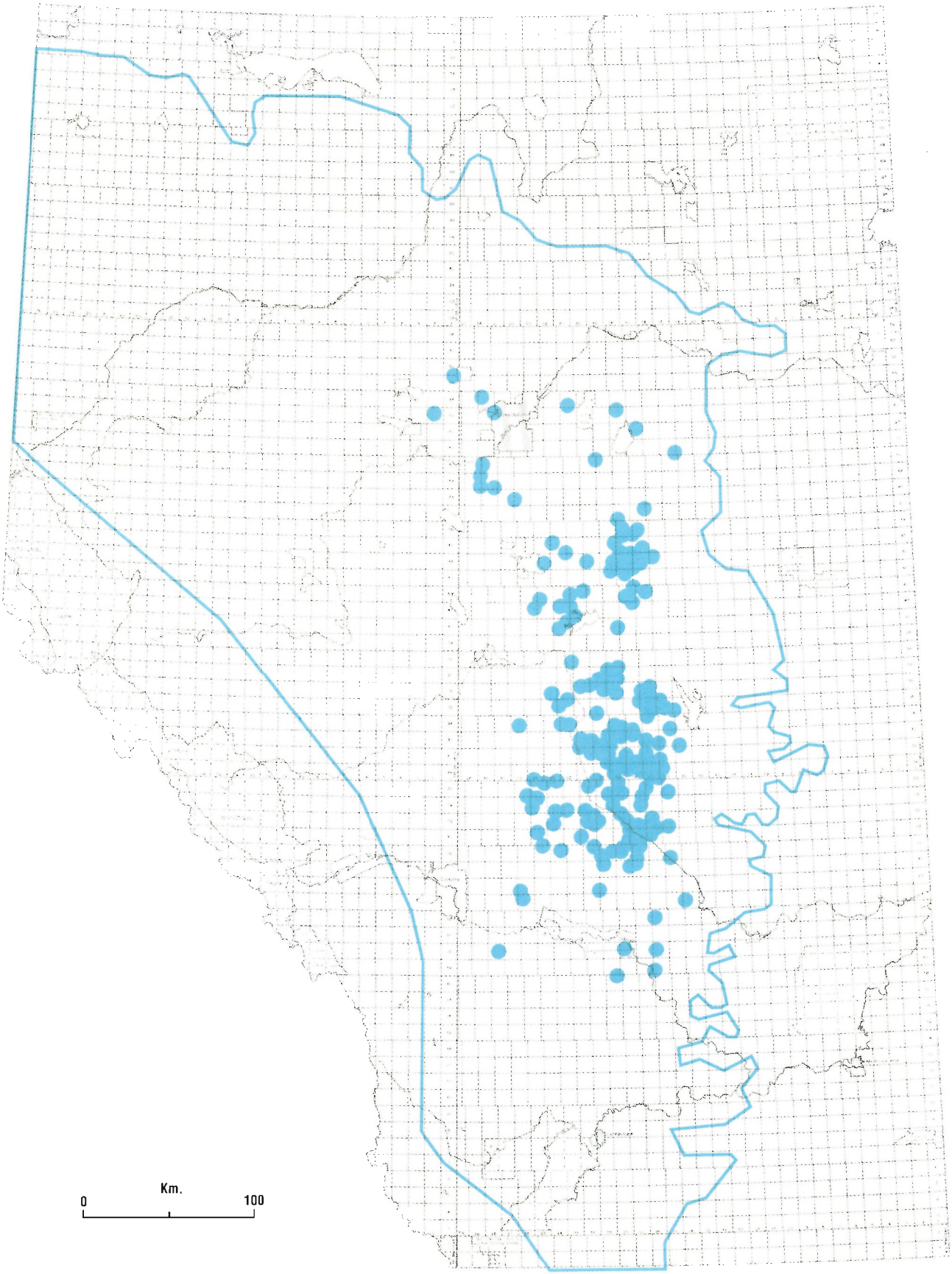


Figure 3. *Map of the areal extent of Cycle 4 of the Foremost Formation ("Basal Belly River") gas play. Dots indicate locations of discovery wells for each pool in the play.*

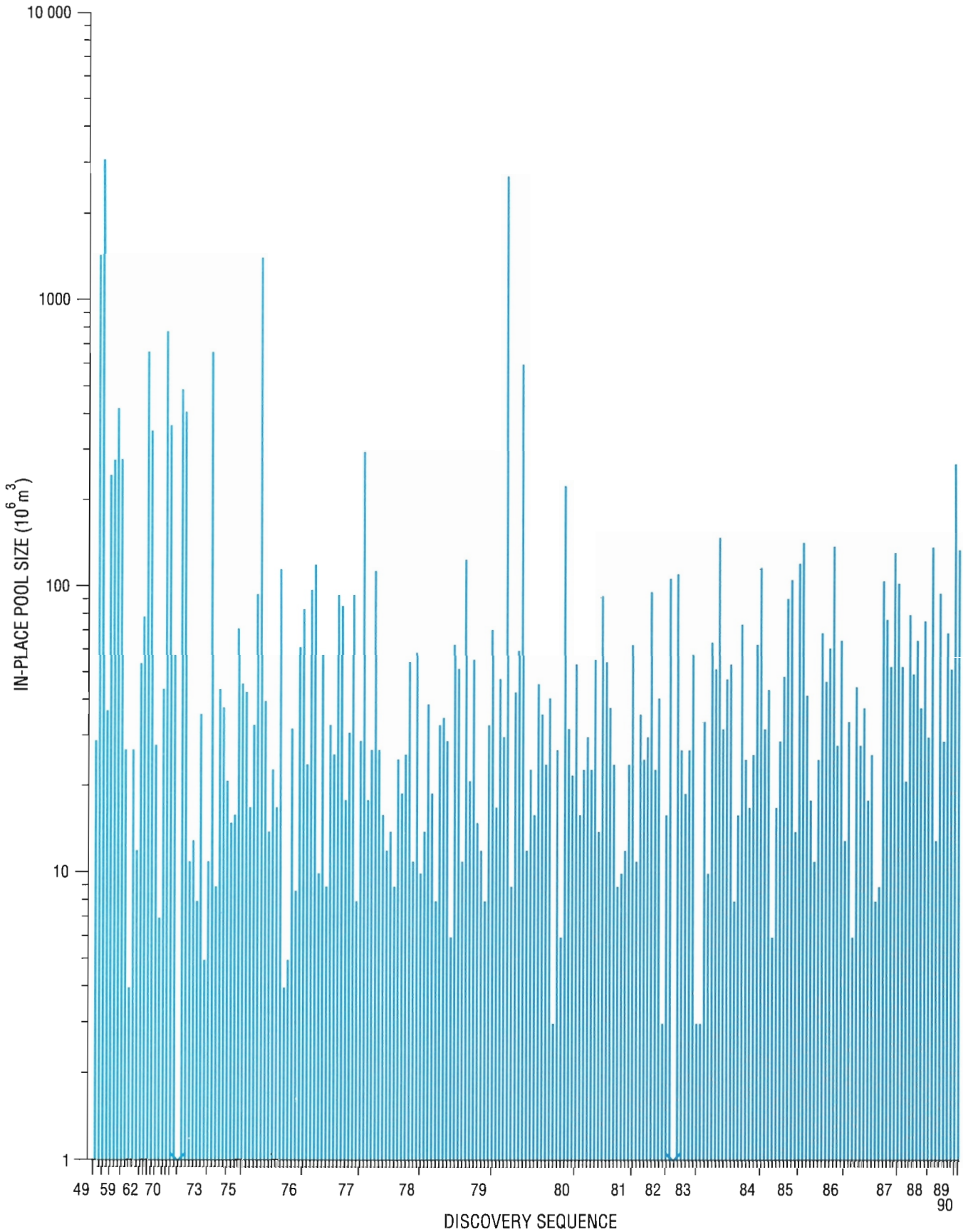


Figure 4. *Discovery sequence of Cycle 4 of the Foremost Formation (''Basal Belly River''). This sequence, which contains information about the total number of pools (discovered and undiscovered), N, and the pool-size distribution, is the data used for the resource assessment.*

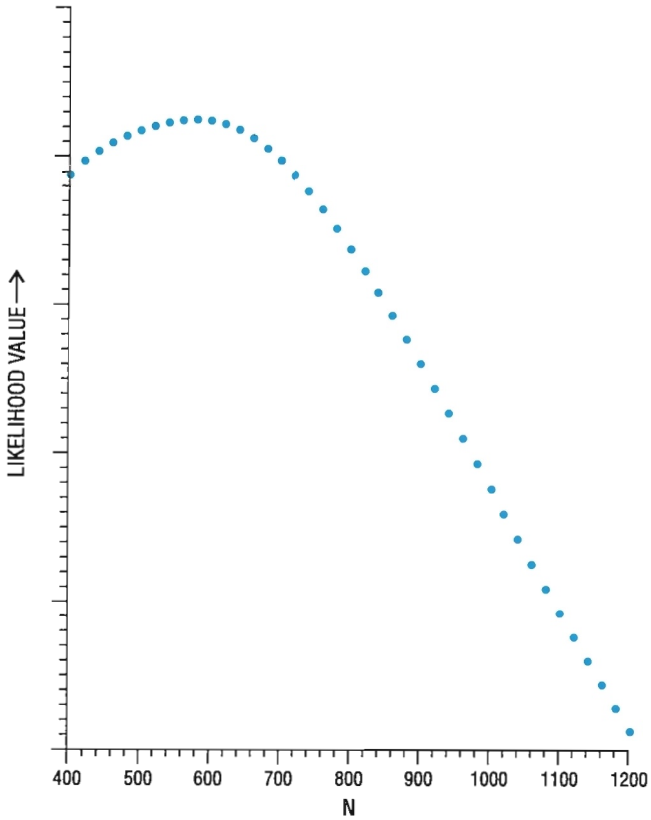


Figure 5. *Diagram illustrating the relation between the likelihood value and the total number of pools, N. The larger the likelihood value, the more plausible the N value. The diagram indicates that the total number of pools in the play is about 600. This likelihood value plot was derived from the discovery process models.*

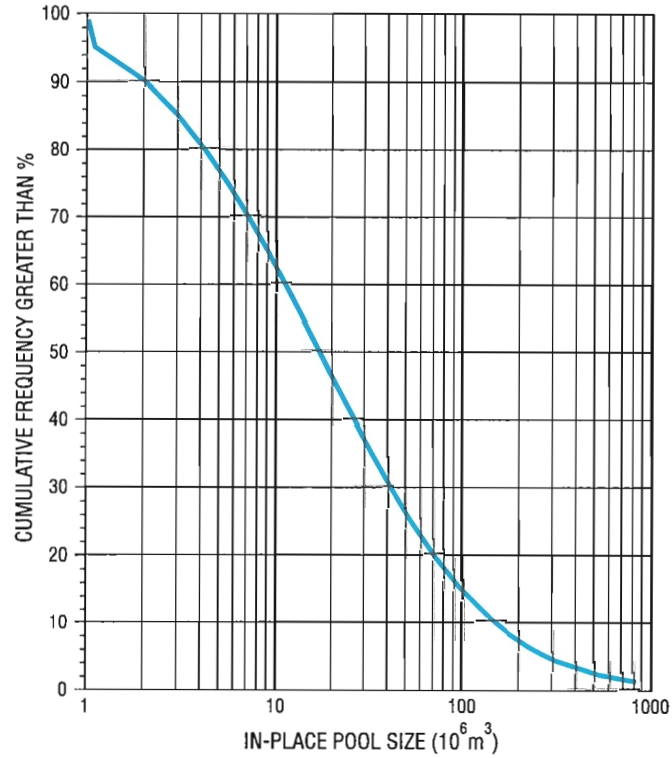


Figure 6. *Pool-size distribution of Cycle 4 of the Foremost Formation ("Basal Belly River"). This distribution was derived from the discovery process models.*

Individual pool-size distribution

The discovery process models generate estimates of the mean, variance, and total number of pools in the underlying pool population or play. The number of pools and the pool-size distribution are used to predict the distribution of the size of individual pools. These predicted pools are represented in graphical form by bars, which indicate the range of possible size of each pool. The graph plots individual pool size against pool rank. A bar with a frequency interval of 5 to 95 indicates there is a 90 per cent chance that the predicted pool will fall somewhere within the size range constrained by the interval.

After the individual pool sizes have been estimated, the discovered pool sizes are matched to this distribution by PETRIMES. The matched (discovered) pools are indicated in graphical form on the plot by dots, and the unmatched (undiscovered) pools by bars. The sizes of the undiscovered pools are then further constrained by the fact that their size ranges cannot exceed, or be less than, any discovered (matched) pools that are ranked greater than the unmatched pool. Figure 7 displays the 50 largest pools in the Foremost Formation ("Basal Belly River"), Cycle 4 Shoreline play, including those pools already discovered and those predicted by the analysis.

Estimate of play resource and potential

The play resource distribution (Fig. 8, curve A) can be estimated from both the total number of pools (N) and the pool-size distribution. Summation of the means of all undiscovered pool sizes yields the mean of the play potential, defined as the *expected potential*. For the Cycle 4 Shoreline play this is 18 000 x 10^6 m^3. The play potential distribution (Fig. 8, curve B) can also be derived from conditions on the discovered resource of a play, defined as the *probable potential*. The probable potential, 28 000 x 10^6 m^3 in this example, has a higher degree of uncertainty than the expected potential.

The expected value of the potential is governed by an estimated range of values for each of the individual pool sizes, and the assigned pool ranks. Both the range

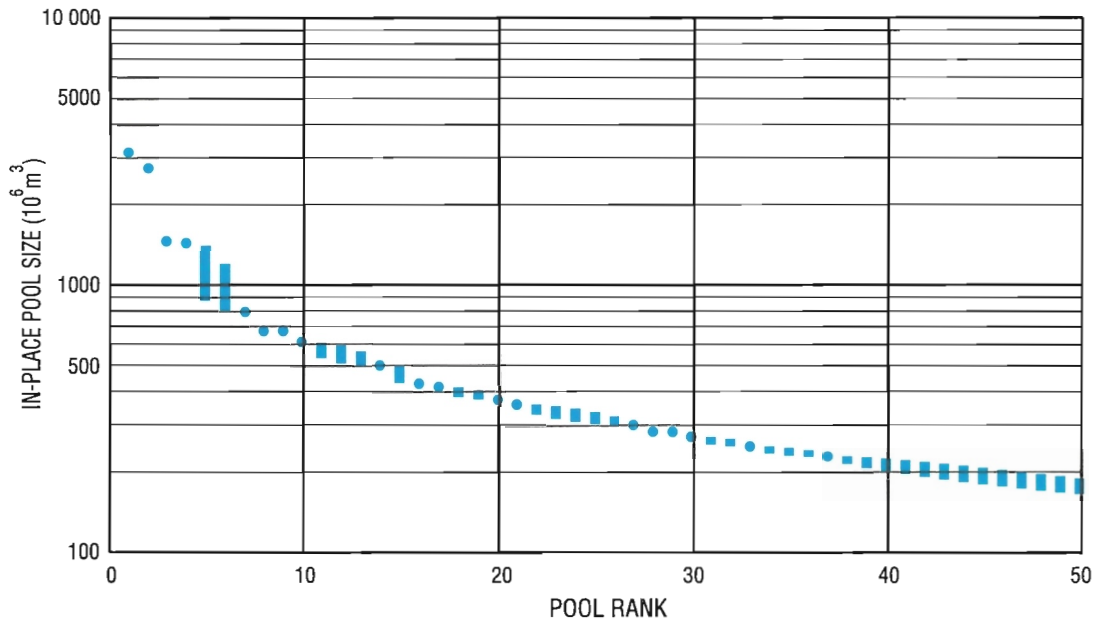


Figure 7. *Pool-size-by-rank plot of Cycle 4 of the Foremost Formation ("Basal Belly River"). The discovered pool sizes are indicated by dots, whereas the estimated pool sizes are indicated by elongated vertical boxes expressed as 5 to 95 per cent prediction interval. Only the largest 50 pools are displayed.*

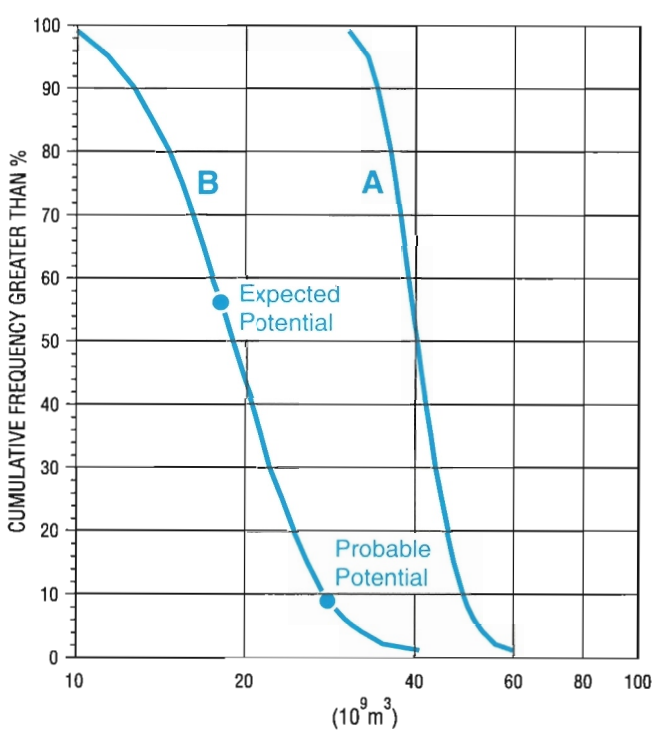


Figure 8. *Probability distributions of the play resource (A) and potential (B).*

of individual pool sizes and the pool ranks are controlled by the quality of the discovered pool database. If the sizes of discovered pools are incorrectly estimated, appreciated or depreciated, or if the rankings are altered, then the expected value of the potential will be altered. Provided that the geology of the play is well understood and documented, the expected value should provide a reliable estimate of the potential of that play. Thus, expected values for the potential are most often adopted for economic analysis.

The cumulative plot of the discovered pool sizes versus the number of exploratory wells drilled through time (Fig. 9) shows an upward-increasing trend. In the more recent years, this trend generally comprises increments of small pool sizes with a higher success ratio. This interpretation is also supported by Figure 4, which shows that the exploration success ratio has been very high in recent years.

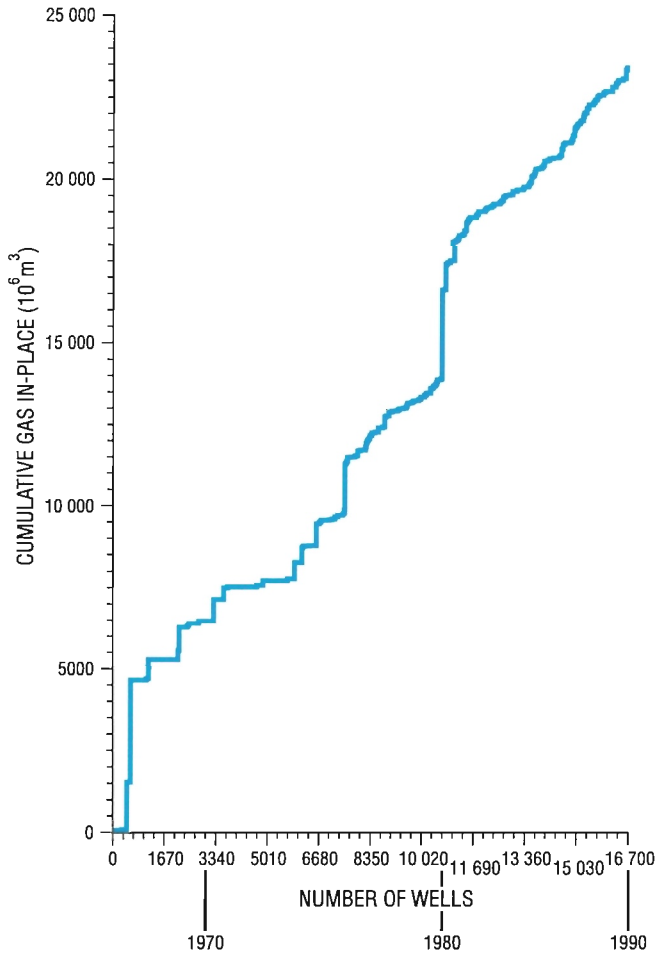


Figure 9. *Cumulative in-place volume plot of Cycle 4 of the Foremost Formation ("Basal Belly River"). The horizontal axis represents drilled exploration wells arranged in time sequence. The vertical axis indicates the cumulative discovered in-place gas volume.*

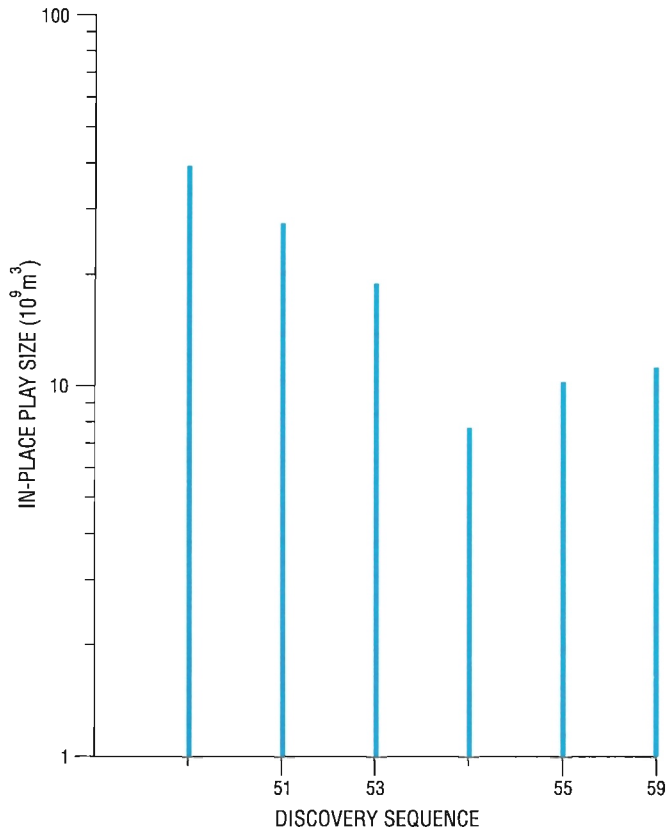


Figure 10. *Discovery sequence plot of the seven shoreline cycles of the lower Foremost Formation ("Basal Belly River") of the Belly River Group. The discovery date of each play (cycle) is assigned by the discovery date of the earliest discovered pool.*

Estimate of resources in immature and conceptual plays

Among the seven shoreline plays within the Foremost Formation, Cycle 1 has a single discovery, and cannot be analysed by the discovery process models as described above. Another method is required to estimate the resource potential of this play.

The seven shoreline plays are considered to belong to a single population of plays, i.e., the lower Foremost Formation. The gas volumes in the discovered pools of Cycles 2 to 7 and their estimated potentials are added together, and plotted according to their discovery dates (Fig. 10). This *play discovery sequence* was used to estimate the play resource of Cycle 1 by the nonparametric discovery process model. The play resource ranges from 1400 to 6100 x 10^6 m^3 (Fig. 11).

The immature Scollard Formation, Basal Sandstone play (with a single discovery), and the conceptual Paskapoo Formation, Basal Sandstone play (with no discoveries) cannot be analysed by current numerical methods or by analogy and, therefore, do not contribute to the numerical estimates presented here.

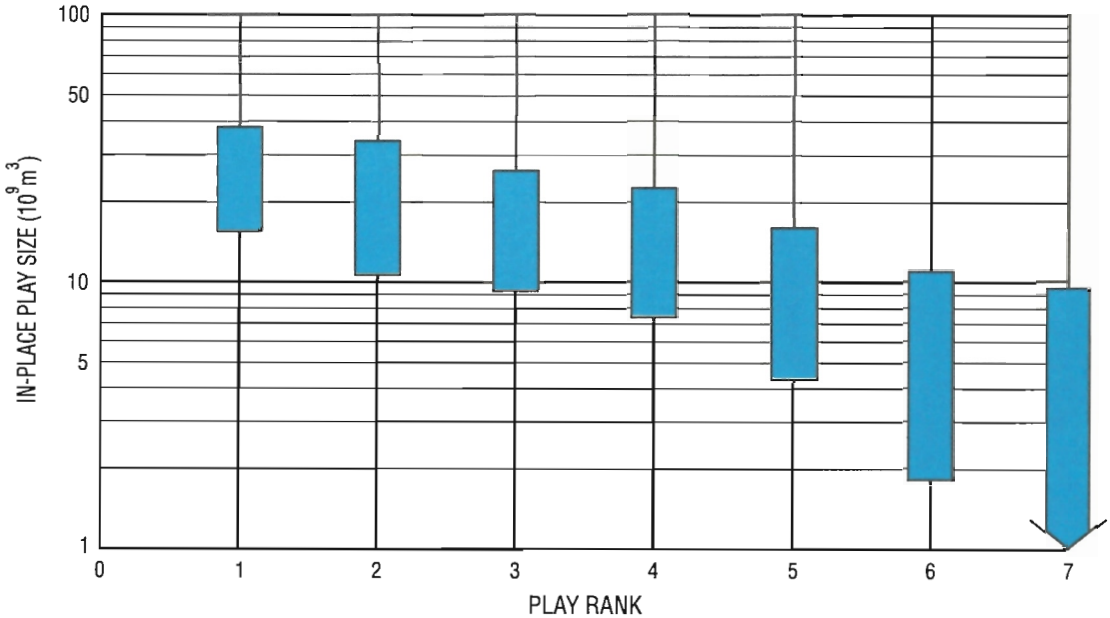


Figure 11. *Pool-size-by-rank plot of the seven shoreline cycles of the lower Foremost Formation ("Basal Belly River") of the Belly River Group. The plot indicates that the play resource of Cycle 1 ranges from 1400 to 6100 x 10^6 m^3 (0.9 probability prediction interval).*

GEOLOGICAL FRAMEWORK

Introduction

Post-Colorado strata of the Interior Plains of western Canada 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 (Fig. 12). In this area, subsurface data are available in tens of thousands of wells. This volume of rock includes about 20 per cent of the preserved Phanerozoic record of the WCSB (about 40 per cent of the total foreland basin succession) and represents a well-preserved foreland basin succession with under- explored resource potential.

The succession includes at least five distinct sandy clastic wedges, deposited over a period of 25 m.y., separated by marine tongues or unconformities, and representing a series of large-scale transgressive-regressive cycles. The wedges range up to 750 m thick, generally thicken to the west or southwest, and thin and pass laterally into marine shale to the east, northeast or southeast. Several had original sediment volumes approximately equal to the entire preserved Mannville Group and are composed predominantly of continental and shoreline deposits.

The oldest four clastic wedges together contain over 1400 gas and oil pools and all five are prime aquifers throughout southern Alberta. Gas resources are concentrated in the Milk River Formation and lower portion of the Belly River Group ("Basal Belly River"), but are also present in the middle and upper Belly River Group, Edmonton Group, and Scollard Formation. Compared to their volumetric and geological importance in the basin, these rocks are under-studied, and may contain more resource potential than commonly realized.

General foreland basin tectonic concepts

The foreland basin succession of the WCSB is up to about 8 km thick, is approximately equivalent to the Zuni Sequence of Sloss (1963), and is a direct result of the evolution of the Canadian Cordillera during Jurassic to Paleocene time (Porter et al., 1982; Price, 1994). Convergence between western North America and allocthonous oceanic composite terranes culminated with oblique collisional accretion of these terranes, which compressed and detached the Paleozoic miogeoclinal wedge, and telescoped and translated these strata as thrust sheets to form the thickened orogenic belt (Porter et al., 1982; Price, 1994).

This thrust-sheet load flexed the crust and induced subsidence of a foredeep, which migrated in front of the advancing thrust stack, while associated uplift and erosion provided the source of detritus deposited in that foredeep (Price, 1994). In addition to these effects, foredeep subsidence created the conditions for source rock maturation, hydrocarbon generation, and updip (eastward) migration and accumulation in traps throughout the strata of the WCSB.

Laramide Orogeny and basin infill

In mid-Cretaceous time a change from orthogonal to oblique northward convergence, as the Kula Plate moved north across the leading edge of advancing North America, caused dextral transcurrent motion to become dominant: western parts of the Cordillera were displaced hundreds of kilometres to the north (Monger, 1989; Price, 1994). From the Late Cretaceous (Turonian/Cenomanian) to Middle Eocene, docking of the oceanic Insular Superterrane (composite of Alexander and Wrangellia terranes) with North America (Monger, 1989; Stockmal et al., 1993; Price, 1994) led to rapidly intensifying tectonic loading, foredeep subsidence (creating accommodation space), and cannibalization of previous deposits, primarily south of 56°N (Stockmal and Beaumont, 1987, Price, 1994). During the Campanian to Paleocene this resulted in the rapid deposition of a series of generally regressive wedges of marine to nonmarine synorogenic molassic clastic sediments up to 2.5 km thick over a period of about 20-25 m.y. (maximum sedimentation rate of about 175m/m.y.; Rosenthal, 1984). This succession is centered in southwestern and west-central Alberta and represents the final compressional stage of foreland evolution (Porter et al., 1982; Price, 1994). An Early to Middle Eocene phase of transtension led to the end of convergence, and subsequent isostatic uplift and erosion of the foreland succession in the plains (Price, 1994).

Regional stratigraphy

According to Embry (1990) and Miall (1991), stratigraphic sequences in foreland basins are clearly controlled by regional tectonism, as evidenced by variation in sediment source, depositional regime, and uplift/subsidence patterns between successive sequences.

The post-Colorado portion of the Zuni Sequence (Sloss, 1963; Porter et al., 1982) in the plains represents an eastward-thinning prism originally 2.5 km, or more, thick, which extended into Manitoba (Dawson et al., 1994). It was later partly eroded as crustal extension began in the Eocene (Monger, 1989; Price, 1994), leaving only erosional remnants over the plains. Probably no major arches were active (although Lorenz, 1982, suggested that uplift of the Sweetgrass/Bow Island Arch was related to Laramide thrusting) and most sediment was supplied through cannibalization of earlier Paleozoic/Mesozoic strata from the emerging Rockies (Rahmani and Lerbekmo, 1975; Porter et al., 1982; Stott, 1984; Jerzykiewicz, 1985; Mack and Jerzykiewicz, 1989; Price, 1994).

Post-Colorado strata form 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 and 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.

A broad, inland seaway existed between the Canadian Shield and the active Cordilleran belt (Stott, 1984) and stretched from the Arctic to the Gulf of Mexico, generally with shorelines trending between northwest and northeast (Rosenthal, 1984). Environments of deposition were generally nonmarine to the west, and sediment-starved marine environments to the east (Leckie and Smith, 1993; Dawson et al., 1994). The deposits consist of a series of stacked transgressive–regressive cycles (Dawson et al., 1994), with less marine influence in the younger cycles. Climatic conditions were warm-temperate to subtropical, and semi-arid to increasingly humid northward (Jerzykiewicz and Sweet, 1988).

The stratigraphic nomenclature of post-Colorado strata of the WCSB, which has had a chequered evolution dominated by inconsistent usage (see Dawson et al., 1994, for review), is illustrated in Fig. 13. The strata are divided into five main clastic wedges, or depositional assemblages. These are:

1) Early Campanian Milk River Formation (and equivalents): shallow-water marine and shoreline, with minor fluvial deposits;

2) Middle to Late Campanian Belly River (Judith River) Group: fluvial, shoreline, estuarine and shallow-water marine deposits;

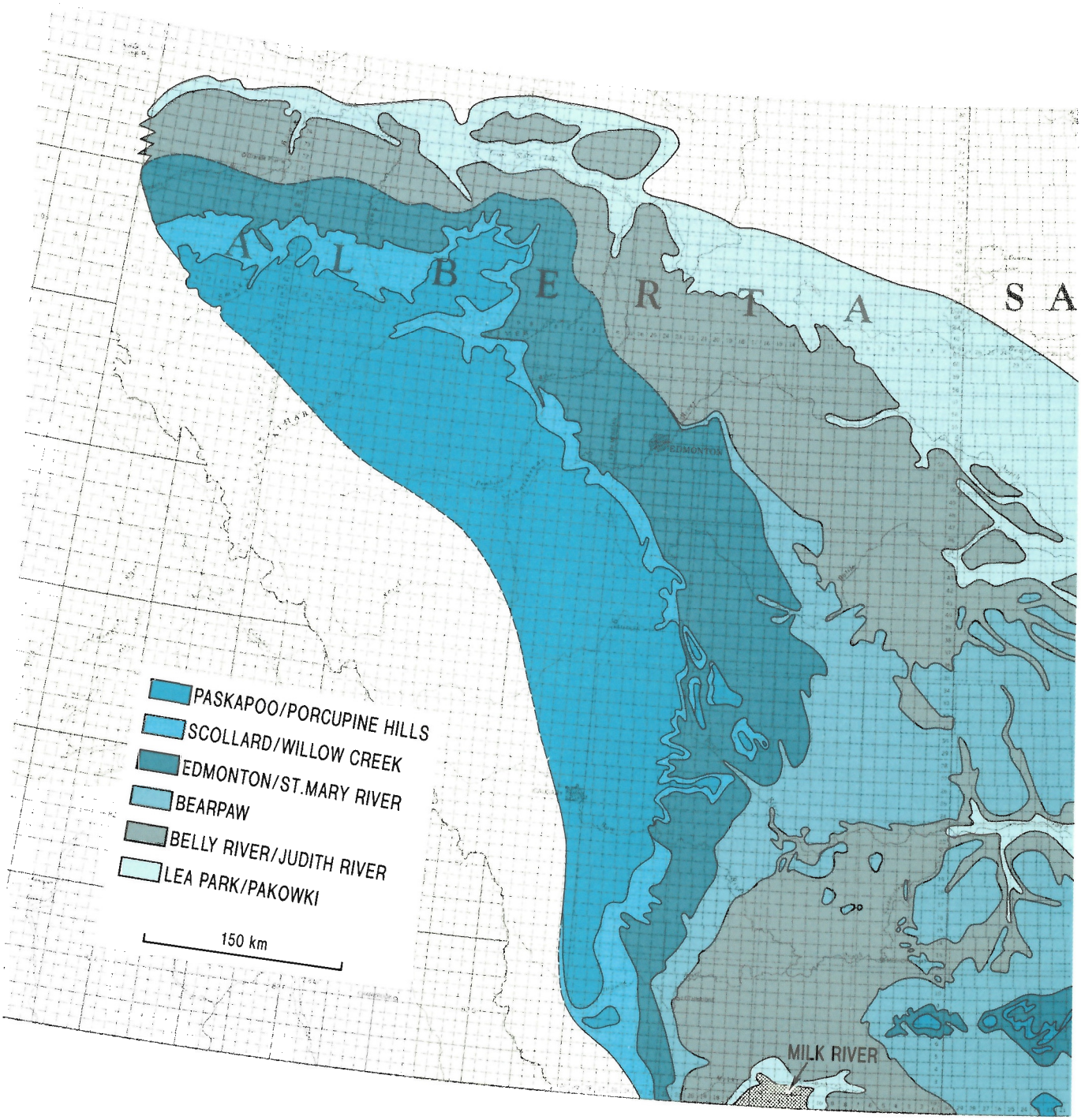


Figure 12. *Distribution of the five nonmarine-shoreline, sandy clastic wedges, and the two related marine mudstone tongues, which are included in the Upper Cretaceous-Tertiary, post-Colorado strata of the Western Canada Sedimentary Basin.*

Figure 12. *(cont'd.)*

3) Middle to Late Maastrichtian Edmonton Group (and equivalents): fluvial, shoreline and shallow-water marine deposits;

4) Late Maastrichtian to Early Paleocene Scollard Formation (and equivalents): fluvial deposits;

5) Early to Late Paleocene Paskapoo Formation (and equivalents): fluvial deposits.

These depositional assemblages are separated by transgressive marine tongues (between lower wedges), or regional unconformities (between upper wedges). Each successive clastic wedge is dominated more by continental facies and less by marine facies. Within the lower assemblages, higher order transgressive–regressive cycles are very important on local scales, and were likely controlled by variations in the interaction of tectonic subsidence and sediment supply.

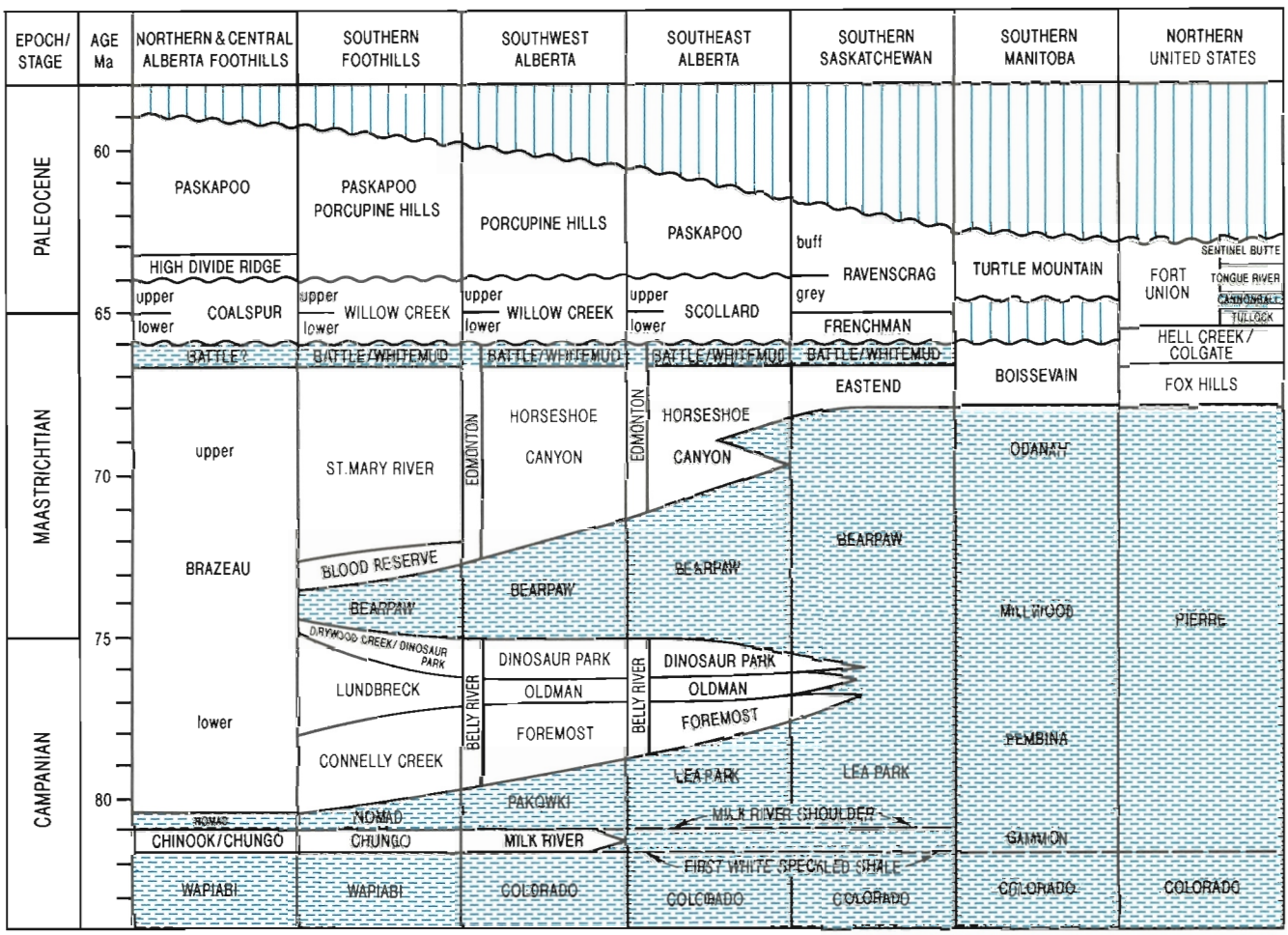


Figure 13. *Stratigraphic correlation chart for post-Colorado strata in the Western Canada Sedimentary Basin and adjacent areas.*

Assemblage 1: Milk River Formation (includes Chungo/Chinook members of the Wapiabi Formation)

Milk River/Chungo/Chinook strata are the initial deposits in the post-Colorado successsion in Alberta. They immediately succeed a deposit formed during maximum transgression, the First White Speckled Shale, at the top of the Colorado Group (Wall and Germundsen, 1963), and represent deposits of the subsequent regression. They herald the beginning of the entire post-Colorado succession and were deposited during the Early Campanian (Stott, 1984; Leckie, 1989). At the time of deposition, the developing Cordillera may have been several hundred kilometres west and southwest of the southern Alberta Plains. There is no evidence of large emergent areas in the Canadian part of the basin.

The Milk River Formation and equivalents, of the extreme southern part of Alberta, are sandy, clastic wedges that rim the western and southwestern margins of the Alberta Basin and represent the more distal portions of depositional lobes (Fig. 14). The various depositional lobes that can be identified may not be strictly time-correlative (Sweet and Braman, 1990) and occupy different geographic positions in the basin. A major, but short-lived transgression, represented by the overlying Nomad/Pakowki/Lea Park marine shale, terminated this progradational cycle.

The Milk River Formation abruptly overlies the First White Speckled Shale at the top of the Colorado Group. The formation is abruptly overlain by marine shales of the Pakowki Member/Lea Park Formation, and this contact is marked over large areas by a thin, chert-pebble bed (Glass, 1990). Paleontological and stratigraphic evidence (Braman and Sweet, 1990) suggest this surface may be a regional disconformity. The formation is divided into three members (Fig. 14), in ascending order: a) the Telegraph Creek Member - interbedded marine mudstone, siltstone and sandstone; b) the Virgelle Member - thick bedded, shoreline-related sandstone; and c) the Deadhorse Coulee Member - interbedded fluvial sandstone, mudstone, and minor coal beds (Meijer Drees and Myhr, 1981). Basinward, to the northeast, these members apparently grade into shallow-water, marine, bioturbated silty mudstone, with thin sandstone interbeds of the Alderson Member (Meijer Drees and Myhr, 1981) (Fig. 14).

The Milk River Formation of southeastern Alberta contains most of the discovered gas reserves in post-Colorado strata in a small number of pools, although there is very little resource remaining to be

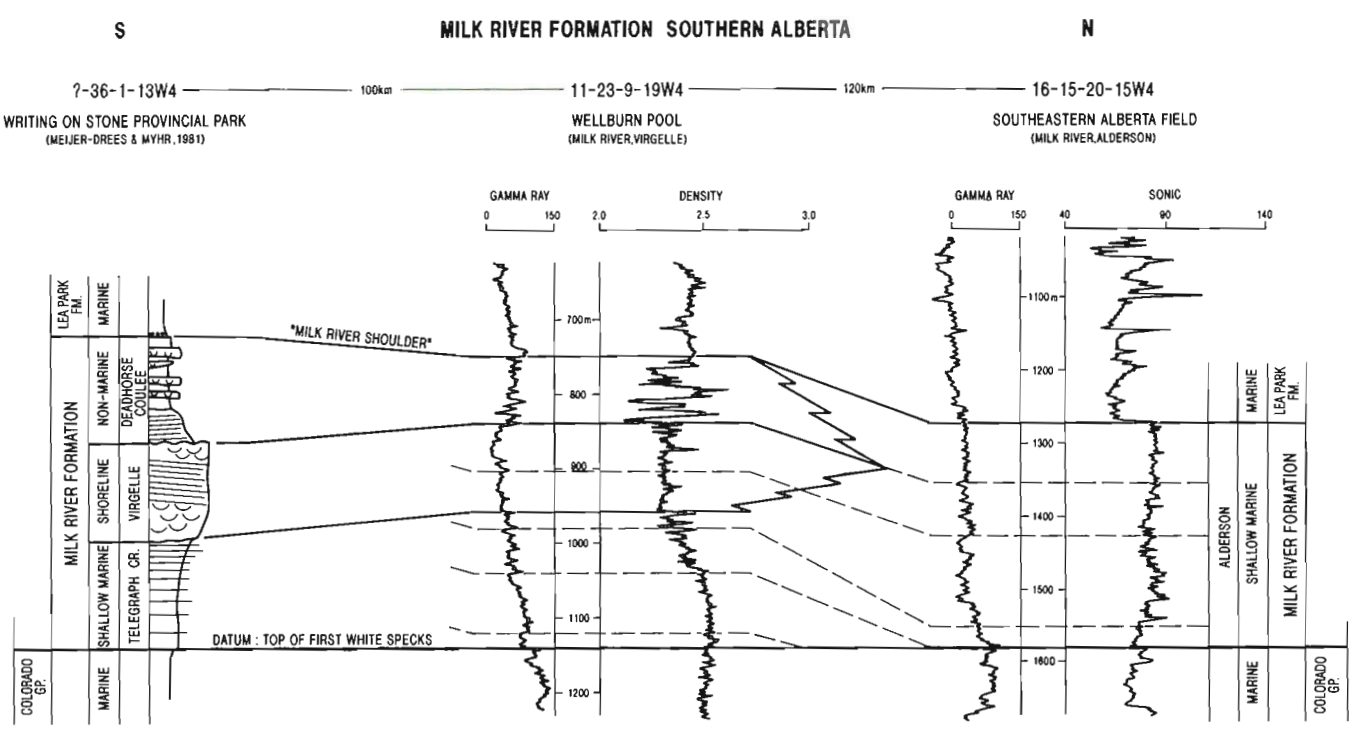


Figure 14. *Stratigraphic cross-section of Milk River Formation in southern Alberta, illustrating the stratigraphy and reservoir facies.*

discovered. Most of the gas is trapped in the fine-grained strata of the Alderson Member.

Stott (1961, 1963, 1967) defined the Chungo Member of the Wapiabi Formation in the southern and central Foothills (Alberta Group) and the northern Foothills (Smoky Group). The Chungo passes eastward across the Foothills into mudstone in the subsurface of the western plains, and apparently occurs as several geographically limited depositional lobes along the length of the Foothills (Stott, 1963). The upper contact is placed at a distinct and regionally persistent (probably disconformable), thin chert-pebble bed (Stott, 1963), sharply overlain by the marine, dark grey mudstone, siltstone, and sandstone of the Nomad Member (Stott, 1963). The Chinook Member of the Wapiabi Formation (Gleddie, 1949) in the northern Foothills extends eastward into the subsurface of the northern plains. The Chinook is underlain by marine mudstone and sharply overlain by marine mudstone of the Nomad Member and therefore is approximately equivalent to the Chungo, as suggested by Stott (1963). It comprises an eastward-thinning, coarsening-upward sequence of mudstone, siltstone, sandstone, and thin capping beds of conglomerate. The conglomerate beds contain gas pools in the northern Foothills (Osadetz et al., in prep.).

Assemblage 2: Belly River (Judith River) Group

As the Laramide Orogeny began, the Campanian Belly River nonmarine/transitional marine clastic wedge prograded eastward (McLean, 1971; Ogunyomi and Hills, 1977; Stott, 1984). Campanian subsidence rates increased markedly, as indicated by increased sedimentation rates up to 120 m/m.y. in the south, decreasing toward the north (Chamberlain et al., 1989). The synchroneity of major lithostratigraphic changes in the central and southern Foothills suggests a regional tectonic control, perhaps with some minor eustatic overprint (Jerzykiewicz and Sweet, 1988).

The Pakowki/Belly River succession represents the Claggett Regressive Cycle of Caldwell (1983), which was synchronous with uplift and deformation east of the Omineca Belt during emplacement of the Insular Superterrane (79-80 Ma) (Leckie, 1989; Dawson et al., 1990; Price, 1994). At the time of deposition, the developing Cordillera was 300-400 km west of the southern Alberta Plains. Cratonic arches were not very active, although there may have been weak pulsatory uplift on the Sweetgrass Arch and minor flexure of the Interior Basin (Caldwell, 1983). There is no evidence of emergent areas in the basin. However, the Bow Island Arch may represent the inflection point between the rapid subsidence area of the Alberta Syncline to the west and the lesser subsidence area of the Williston Basin to the east and where stacked shoreline trends may have been localized.

The dominantly fluvial Belly River clastic wedge is essentially a molassic deposit which thins and becomes younger to the east and northeast as the underlying and interfingering Pakowki/Lea Park marine shale thickens (Shaw and Harding, 1949; Iwuagwu and Lerbekmo, 1984). Jerzykiewicz (1985) suggested that the presence of a clastic wedge, indicating a period of maximum regression between two marine tongues, plus the presence of thick mudstone and coal beds indicates that the rate of tectonic subsidence was not uniform. Most molassic deposition follows longitudinal trends (Eisbacher et al., 1974) and sediment dispersal in the Belly River Group is predominantly from the southwest and northwest into the basin. A high content of volcanic detritus and abundant bentonites in these strata in the central Foothills led Mack and Jerzykiewicz (1989) to conclude that there was a major, combined thrust/volcanic event, or a major thrust event which carried older volcanics into the appropriate drainage area at the beginning of Belly River deposition.

The Belly River (Judith River) Group of the southern plains is underlain and overlain by marine shale and represents a thick clastic wedge of predominantly nonmarine and marginal marine deposits. In ascending order, the Foremost, Oldman, and Dinosaur Park formations are characterized by distinct depositional geometries, tectono-stratigraphic settings and hydrocarbon distribution (Figs. 15, 16).

The Foremost Formation is an eastward-thinning wedge of downlapping, shoreline-related facies tracts, backed by thick aggradational fluvial deposits. Regionally, shoreline tracts of the "Basal Belly River" can be divided into seven stacked, composite, progradational cycles, separated by marine flooding surfaces. Each cycle downlaps and shales-out to the east (Hamblin and Abrahamson, 1993) (Figs. 16, 17). The locus of sandy deposition in each successive cycle is located eastward of, and stratigraphically higher than, the preceding one (Figs. 16, 17, 18a), indicating that the dominance of sediment supply over foreland subsidence allowed eastward, but non-continuous, progradation over more than 400 km into western Saskatchewan during a 3-4 m.y. period (Hamblin and Abrahamson, 1993; Hamblin, 1995). Similar geometric relations are evident within each composite cycle in more localized areas (Power and Walker, in press).

The Oldman Formation thins to the north and northeast and consists of the lower "Comrey sandstone" and the upper "siltstone unit" (Figs. 15, 16). The Comrey sandstone lies on a regionally definable surface and is dominated by southwest-oriented, sandy, incised valley-fills (northeastward paleoflow) composed of stacked, lenticular, low-sinuosity, fining-upward channel units (Hamblin, 1994a) (Figs. 18b, 19). The overlying "siltstone unit" is composed of thinly interbedded mudstone and fine grained sandstone with rooted and pedogenic horizons. Some evidence from the southeast corner of Alberta suggests it is associated with a poorly known transgression from the east (Troke et al., 1992). The Oldman sequence may represent an increase in foreland subsidence, reflected as an increase in accommodation space, slowing of sedimentation rate, and increase in vertical aggradation (Hamblin, 1995).

The Dinosaur Park Formation lies on a regionally definable surface (Figs. 15, 16) and thins to the southeast (Eberth and Hamblin, 1993; Hamblin, 1994c). It is characterized at its base by west-northwest-trending incised valley-fills (east or southeastward paleoflow) composed of thick, multi-storied, high-sinuosity, fining-upward channel-sandstone units (Eberth and Hamblin, 1993) (Figs. 18c, 19). These are overlain by interbedded sandstone and siltstone, followed by the Lethbridge Coal Zone and the marine Bearpaw.

The regionally consistent vertical succession within the Belly River Group is interpreted to represent increasing foreland subsidence in southern Alberta, presaging the Bearpaw marine transgression from the southeast (Hamblin, 1995) (Fig. 18d).

The Belly River (Judith River) Group includes most of the gas pools known in post-Colorado strata, although these represent only 15 per cent of the discovered reserve. However, about 85 per cent of the predicted potential in post-Colorado strata remains to be discovered in rocks of this unit (Hamblin and Lee, 1995).

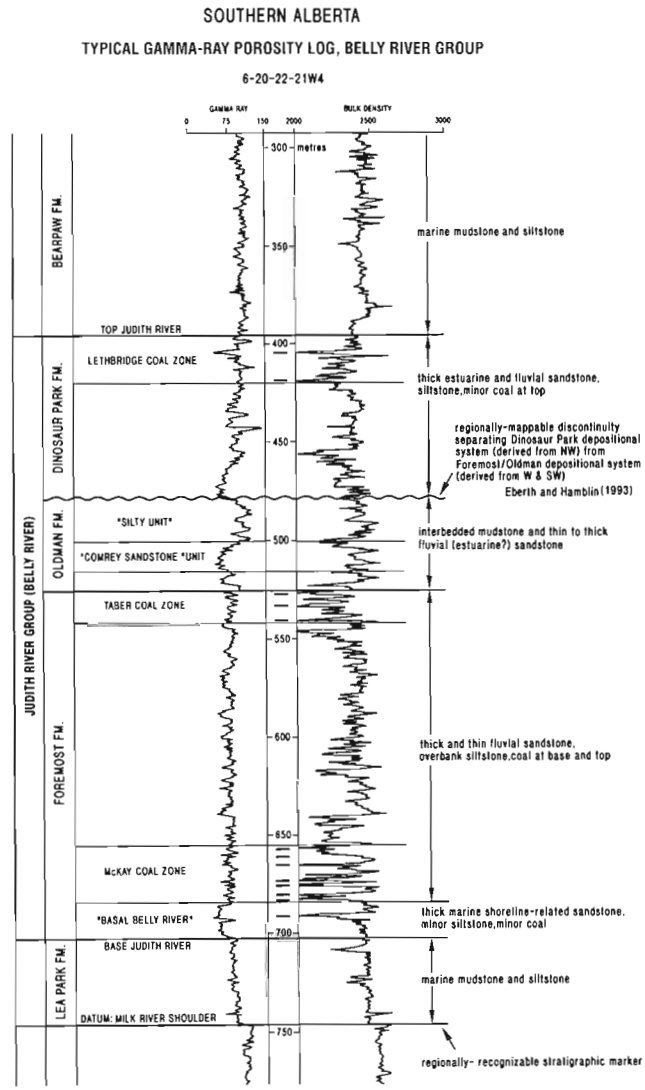


Figure 15. *Internal stratigraphy and typical geophysical log signature of the Belly River Group, subsurface of southern Alberta.*

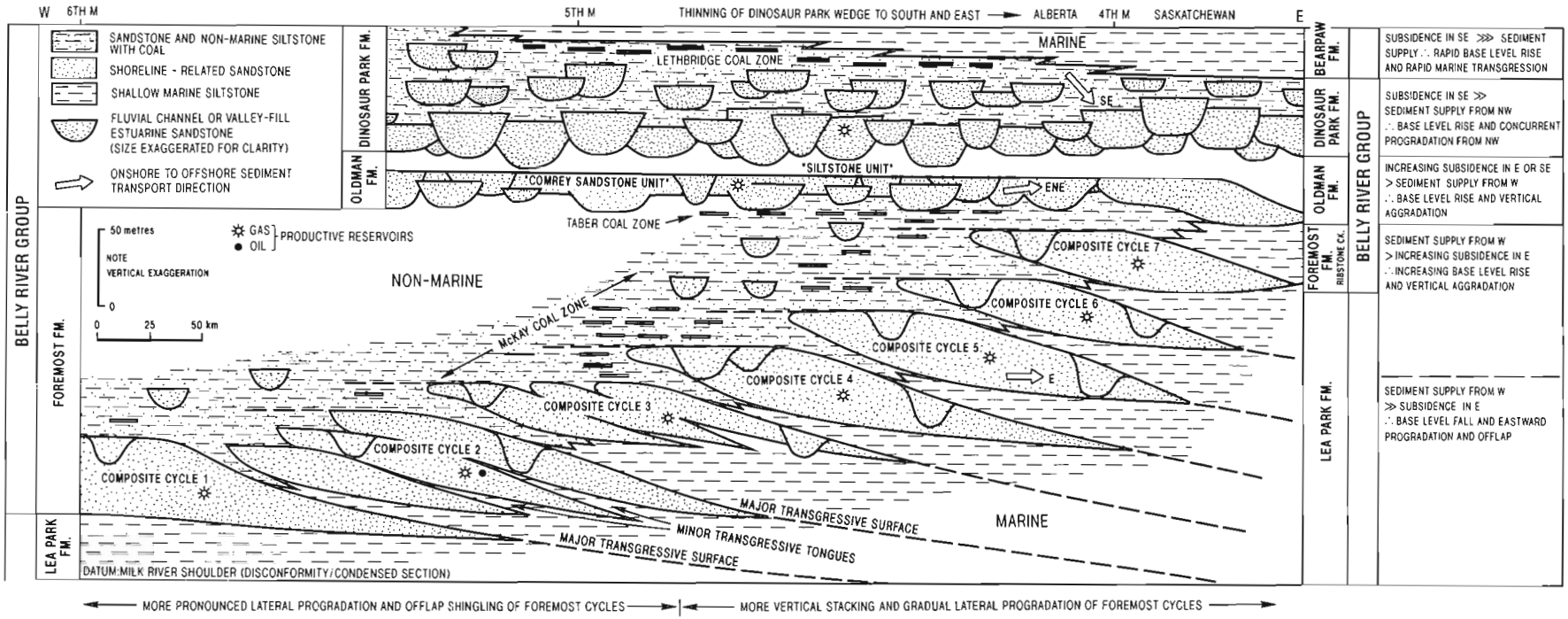


Figure 16. *Schematic west-east cross-section illustrating complex internal architecture and tectono-stratigraphic interpretations of Belly River Group, southern Alberta.*

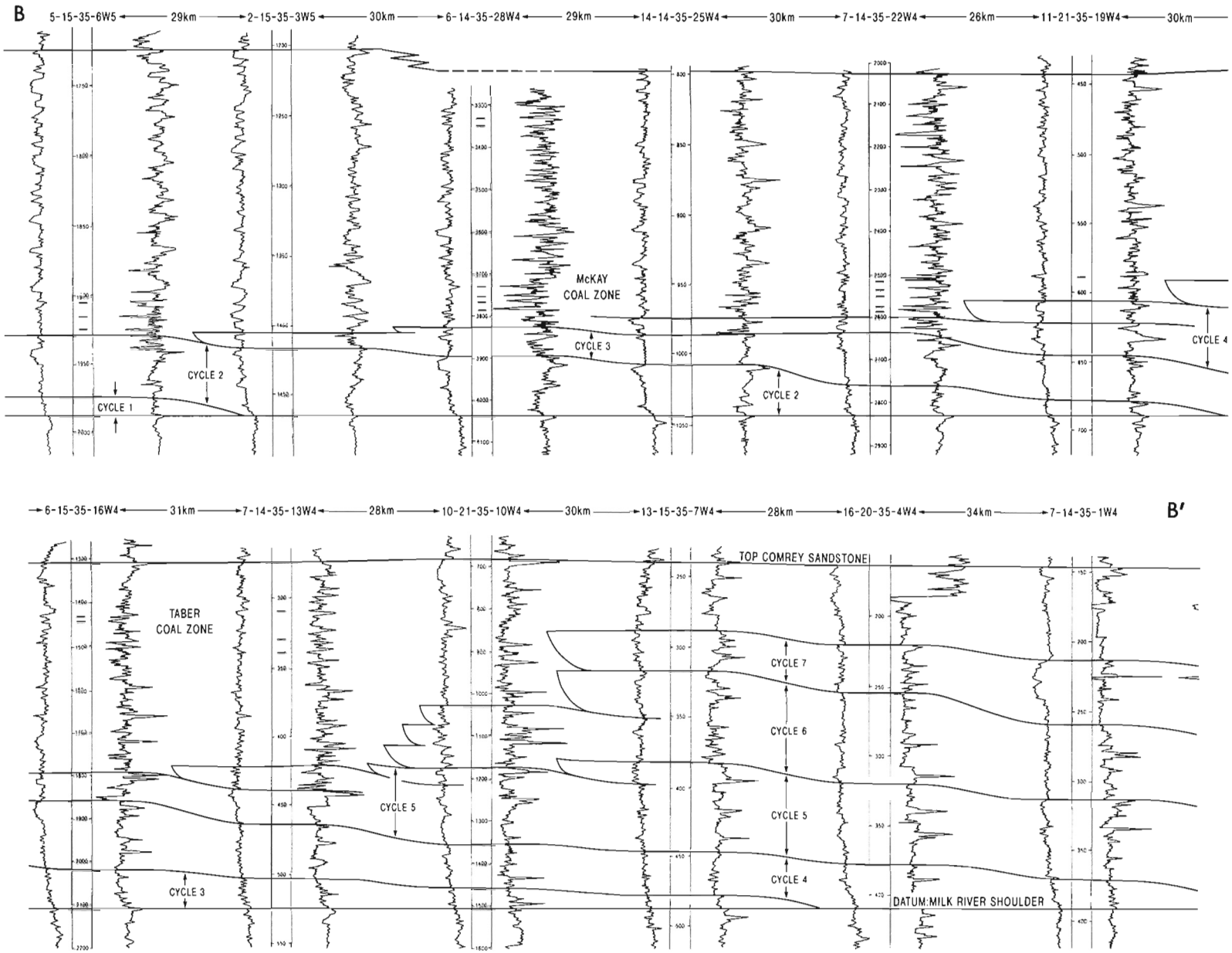


Figure 17. *West-east stratigraphic cross-section of offlapping progradational, shoreline-related, cycles in the Foremost Formation (''Basal Belly River'') southern Alberta.*

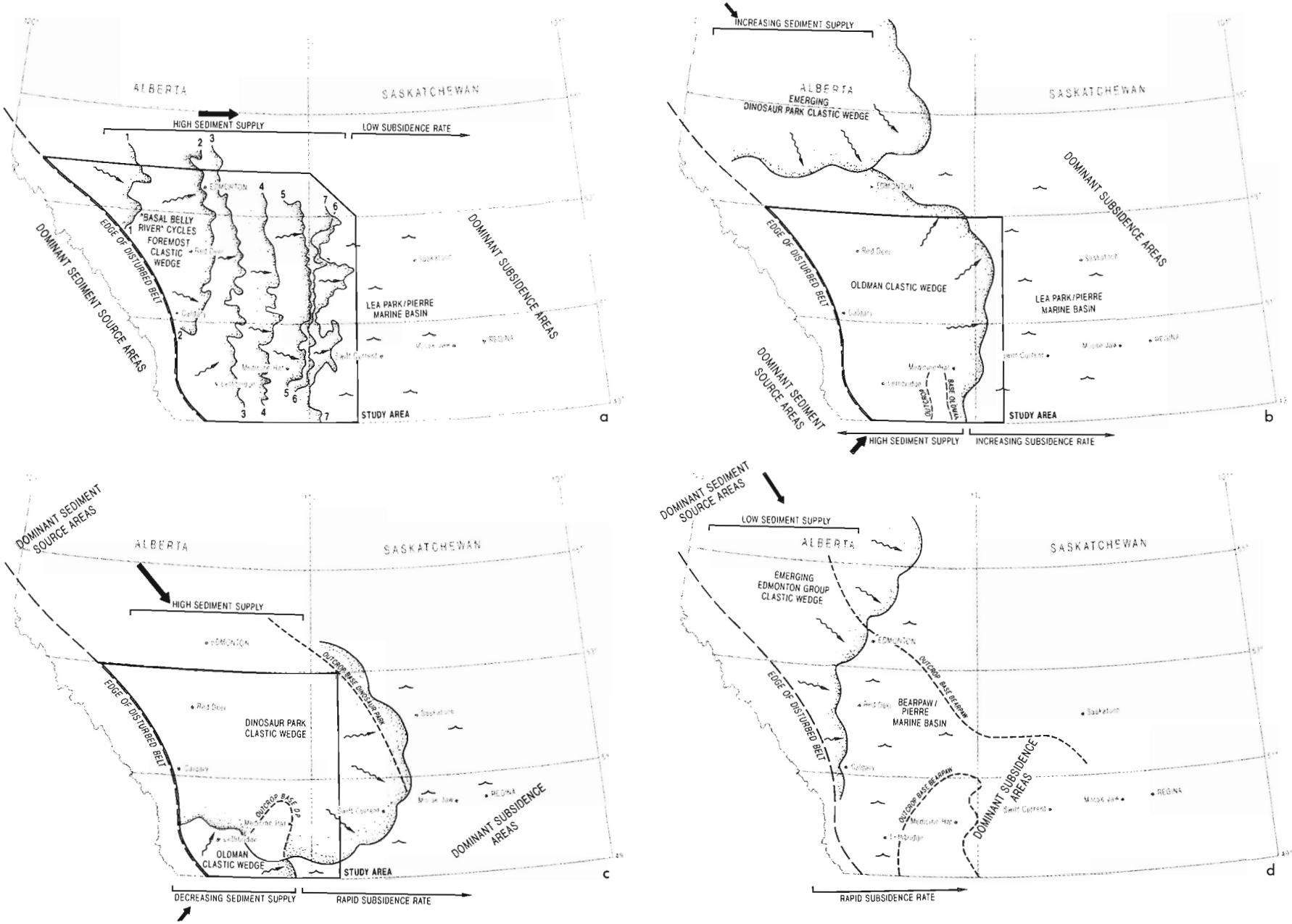


Figure 18. *Evolution of Belly River depositional systems through Campanian time in Western Canada Sedimentary Basin. (a) progradational "Basal Belly River" cycles of the lower Foremost Formation, which prograded eastward across southern Alberta, (b) Oldman depositional system, which prograded from the west or southwest across southern Alberta, (c) Dinosaur Park depositional system, which prograded from the northwest toward the southeast and east into southern Alberta, (d) transgression of Bearpaw shallow-marine deposits in the late Campanian, which overlie and ended deposition of the Belly River clastic wedge.*

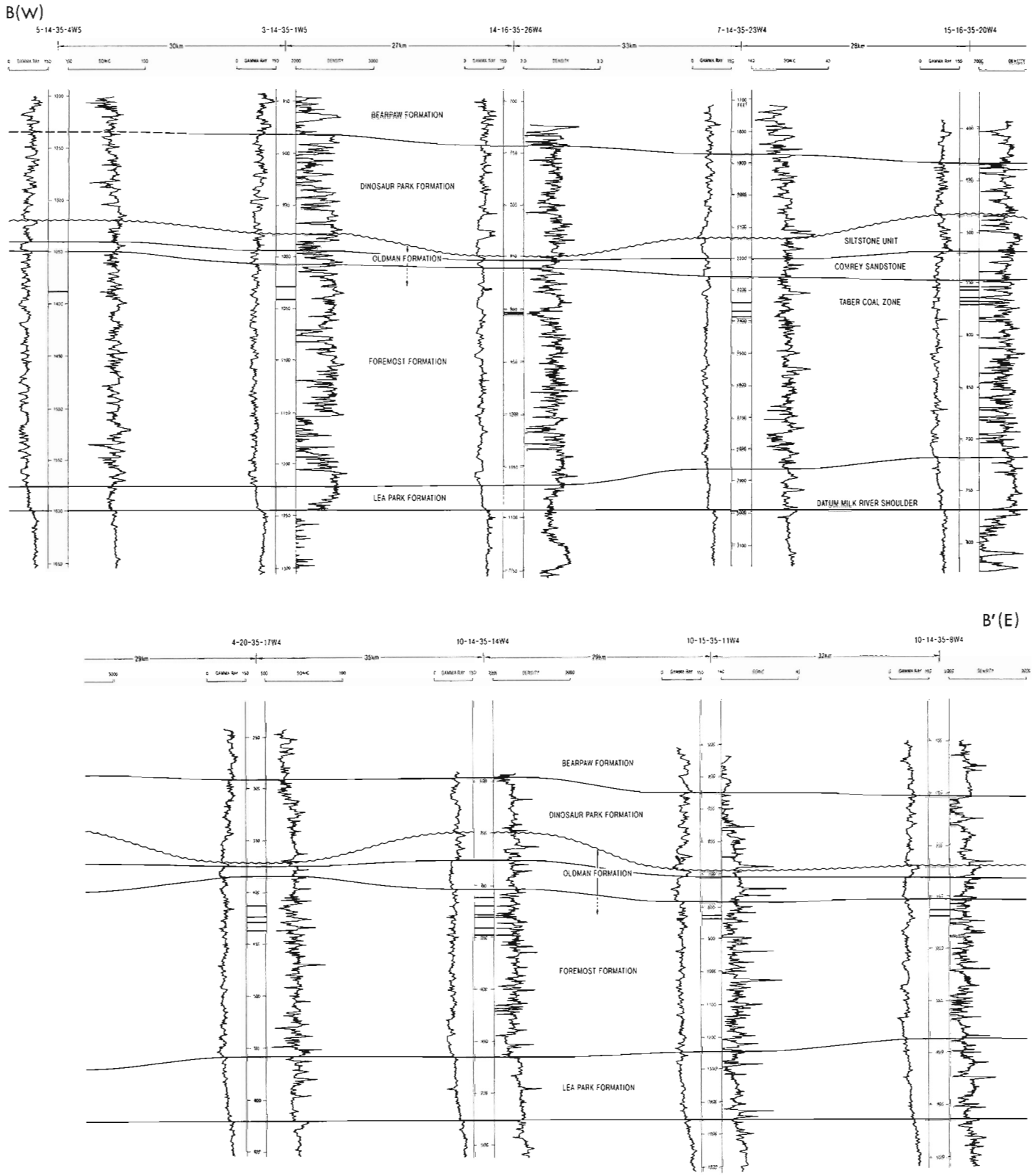


Figure 19. *West-east stratigraphic cross-section illustrating distribution and depositional styles of Oldman and Dinosaur Park formations of the Belly River Group.*

Assemblage 3: Edmonton Group (includes Horseshoe Canyon/St. Mary River/Eastend formations)

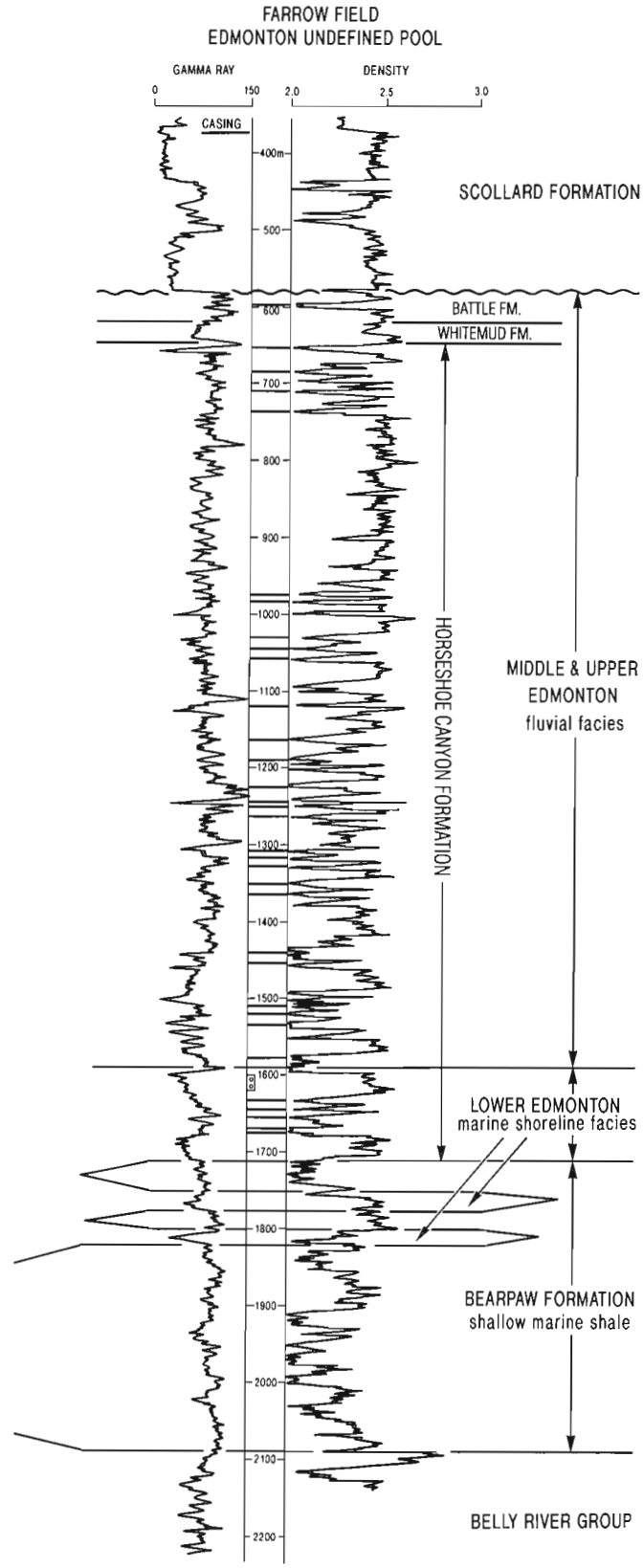
Horseshoe Canyon/St. Mary River/Eastend strata of the plains represent part of a vast, east-thinning wedge of generally nonmarine sediments deposited along the western margin of the subsiding Bearpaw seaway. The seaway may have stretched from the Arctic to the Atlantic to the Gulf of Mexico (Gibson, 1977; Lerand, 1983).

The initial, rapid Bearpaw marine transgression (the last major marine transgression preserved in the stratigraphic record) was related to tectonically-induced subsidence due to movement on major thrust sheets and tectonic loading. It was diachronous in southwest Saskatchewan and extended to the northwest, slightly beyond the Edmonton and Pembina areas, as well as north of Peace River Arch (Shepheard and Hills, 1970; Stelck et al., 1976; McCabe et al., 1989; Nadon, 1988). The Bearpaw Formation shale thins to the west and north, thickens to the east and south, at the expense of the under- and overlying clastic wedges, to become part of the Riding Mountain and Pierre formations (Caldwell, 1968; Shepheard and Hills, 1970; Stelck et al., 1976).

After isostatic relaxation and uplift, the subsequent rapid increase in sediment supply allowed progradation of the nonmarine clastic wedge and concomitant rapid eastward withdrawal of the Bearpaw sea, first from central Alberta, then from southwestern Alberta, and finally from southeastern Alberta and Saskatchewan (Shepheard and Hills, 1970; Rahmani and Schmidt, 1975; McCabe et al., 1986; Nadon, 1988). The resultant complex intertonguing of Maastrichtian Bearpaw Formation marine and Edmonton Group nonmarine strata created a transitional marine/nonmarine diachronous contact, with variable lithologies (Wall et al., 1971; Shepheard, 1978; McCabe et al., 1986).

The Horseshoe Canyon Formation fluvio-deltaic clastic wedge is a succession of complexly interfingering, fresh to brackish water and nonmarine sandstones and siltstones, which thickens rapidly to the west (including all portions of the wedge) (Elliot, 1960; Gibson, 1977). The wedge is characterized by great lateral and vertical variability in facies, general fine grain size, abundant thin coals, and abundant bentonites (Allan and Sanderson, 1945; Havard, 1971). The lower portion has the sedimentary and faunal characteristics of lower delta-plain deposits, with distributary channel, barrier island and backbarrier lagoonal sediments. Deposition was related to an

TYPICAL GAMMA RAY - POROSITY LOG, EDMONTON GROUP
10 - 29 - 19 - 24W4



embayed shoreline in estuarine and barrier island complexes (Rahmani, 1983) (Fig. 20). The shorelines are oriented west-southwest, with open sea to the south at Drumheller, but the overall progradational trend was punctuated by four rapid marine transgressions, recorded within the lower 50 m of transitional stratigraphy (Rahmani, 1983). The upper portion of the clastic wedge has the characteristics of upper delta-plain deposition within a system of large and small braided streams (Gibson, 1977) (Fig. 20). The Horseshoe Canyon/Eastend formations are conformably overlain by fluvial sandstone of the Whitemud Formation, which is in turn overlain conformably by lacustrine shale of the Battle Formation (Irish, 1970). The latter contains several thin tuff beds, the Kneehills Tuff (Allan and Sanderson, 1945; Ritchie, 1960).

Rahmani and Schmidt (1975), and Rahmani and Lerbekmo (1975) postulated sediment transport to the east in short, transverse rivers, which connected to a basinwide, northwest-trending longitudinal drainage system in the plains that flowed from a positive source area in northern/central B.C. (Fig. 18d). Pene-contemporaneous volcanism was prominent. Conversely, Mack and Jerzykiewicz (1989) placed the Edmonton Group in their Petrographic Stage II, with evidence of relative tectonic quiescence, decreasing importance of Rocky Mountain thrust-fault-derived sediment sources, and reincorporation of predominantly Omineca sediment sources. Again, volcanism was clearly prominent.

The Edmonton Group contains a small share of the gas reserves of the post-Colorado strata, present in a small number of pools, and is predicted to include a very modest proportion of the total resource. However, this clastic wedge is not as well understood as the underlying Belly River Group, and further study may elucidate additional possibilities.

Figure 20. *Internal stratigraphy and typical geophysical log signature of the Edmonton Group, subsurface of southern Alberta.*

Assemblage 4: Scollard Formation (includes Coalspur/Willow Creek/Frenchman/Ravenscrag formations)

The Scollard Formation of the plains represents part of an eastward-thinning wedge of generally fluvial strata that extended from the Late Cretaceous/Early Paleocene deformational front in western Alberta to Manitoba (Gibson, 1977; Dawson et al., 1994). Deposition occurred along the western margin of a subsiding, confined marine seaway (possibly connected to the Arctic or the Gulf of Mexico, as indicated by the presence of the equivalent Cannonball Member in Montana, North Dakota and Manitoba Taylor et al., 1964; Rahmani and Lerbekmo, 1975; Gibson, 1977). Thus, much of the preserved sediments were deposited up to 800 km inland from the shoreline (Richardson et al., 1988).

Deposition occurred in an actively subsiding foreland basin, with greater rate of subsidence to the west, as shown by the greater thickness of Scollard and equivalent sediments, greater thickness and number of coals to the west (Richardson et al., 1988). In addition, there was a period of intense volcanism to the south or west, immediately preceding and during deposition (Elliot, 1960; Gibson, 1977; Sweet, 1990). The lower part of the clastic wedge is dominated by coarse grained clastics, minor amounts of coal (Fig. 21), and sedimentary rock fragments that indicate thrusted Paleozoic and Mesozoic rocks supplied the detritus (Mack and Jerzykiewicz, 1989). However, the upper part is dominated by finer grained sediments (Fig. 21), with an increase in metamorphic rock fragments, suggesting that thrust plates may have been partly eroded and some detritus from the Omineca area of central British Columbia was re-incorporated into the dispersal pattern (Mack and Jerzykiewicz, 1989).

The base and top of the Scollard wedge may be disconformable (Dawson, 1990) and there has been considerable discussion of the relations between the over- and underlying units, and their significance. In general, it appears that the base is sharp and marked by the Entrance Conglomerate in the central Foothills and some erosional bevelling to the east (Irish, 1970; Furnival, 1950; Lerbekmo, 1987; Braman, 1990). The upper contact, with the Paskapoo, is marked by the appearance of coarser grained sandstones and some erosional bevelling to the east (Ower, 1960; Elliot, 1960; Allan and Sanderson, 1945). Lerbekmo et al. (1990, 1992) showed that significant erosion occurred beneath the base of the Paskapoo in some areas, equivalent to a hiatus of about 1 to 3 m.y.

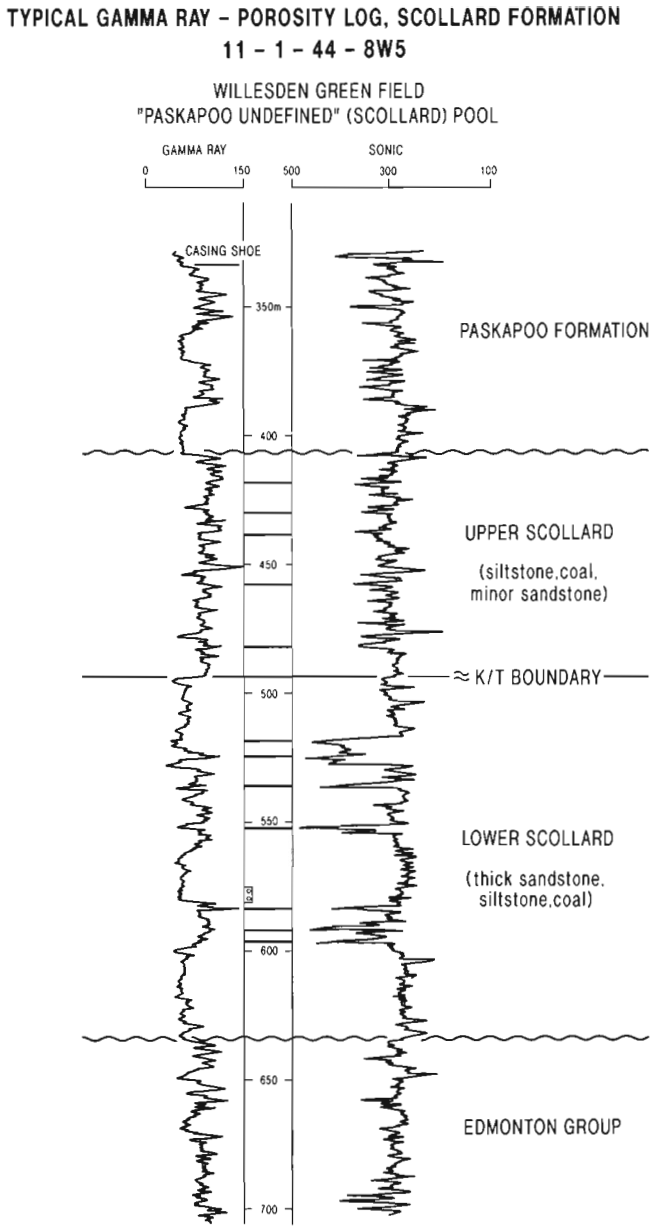


Figure 21. *Internal stratigraphy and typical geophysical log signature of the Scollard Formation, subsurface of southern Alberta.*

Assemblage 5: Paskapoo Formation (includes Porcupine Hills/Ravenscrag formations)

The Paskapoo Formation of the plains and Foothills represents the uppermost eastward-thinning wedge of fluvial sediments that extended from the Paleocene deformational front to Manitoba (Gibson, 1977; Dawson et al., 1994). A small amount of paleocurrent data indicates northeastward dispersal (Jerzykiewicz and Labonte, 1991), whereas mineralogical analysis by Rahmani and Lerbekmo (1975) suggested a regional east- or southeast-flowing fluvial system in western Alberta. The bulk of sedimentary detritus was provided by erosion of Phanerozoic sedimentary rocks in the ancestral Rockies, indicating major tectonic uplift of this source area (Rahmani and Lerbekmo, 1975; Mack and Jerzykiewicz, 1989). Deposition occurred in a subsiding foreland basin with greater rates of subsidence to the west, as shown by the greater thickness of Paskapoo strata to the west. The lower part of the clastic wedge is dominated by coarse grained clastics and sedimentary rock fragments, with minor amounts of metamorphic and volcanic fragments, suggesting that thrusted Paleozoic and Mesozoic rocks supplied the bulk of the detritus (Mack and Jerzykiewicz, 1989). The upper part, where preserved, is dominated by finer grained strata and coal.

The post-Pleistocene erosional remnants, scattered over the southern prairie provinces and northern states, are the only preserved part of a thick, extensive clastic wedge that disconformably overlies the Scollard/ Willow Creek/Frenchman unit. It has an erosional base and its upper limit is the land surface, except on localized plateaux where younger Tertiary gravels are present.

Gibson (1977) and Lerbekmo et al. (1990) stated that the Paskapoo Formation overlies the Scollard Formation with local erosional topography (due to channelization) of up to 25 m, although only a minor time hiatus is represented. Demchuk and Hills (1991) subdivided the Paskapoo into three members in the central Alberta Plains, in ascending order: the Haynes Member, characterized by cliff-forming, medium to coarse grained sandstone; the Lacombe Member, characterized by interbedded mudstone, thin coals, and minor fine grained sandstone (exposed at surface over most of the Paskapoo outcrop area), and the Dalehurst Member, characterized by interbedded fine grained sandstone and mudstone, and at least five thick coal seams (preserved as an erosional remnant in the Hinton area).

Braman (1990) points out that current usage in Saskatchewan has the base of the Ravenscrag at the top of the Frenchman Formation (i.e., the Cretaceous–Tertiary boundary), and therefore includes some upper Scollard-equivalent strata in its lower coaly portion ("grey facies" of Furnival, 1950). Only the upper sandstone-dominated "buff facies" (Furnival, 1950) is equivalent to the middle Paleocene Paskapoo Formation (Sweet, 1990, pers. comm.). The Turtle Mountain Formation of Manitoba and the Tongue River Member of the Fort Union Formation in Montana and Wyoming are approximately equivalent to the Ravenscrag and Paskapoo formations (Williams and Dyer, 1930; Dawson et al., 1994; Sweet, 1990, pers. comm.).

SOURCE ROCKS, RESERVOIR ROCKS, AND TRAP STYLES

The main hydrocarbon source rocks for Upper Cretaceous reservoirs of the WCSB are several condensed sections of marine shale of the Colorado Group: the Second White Speckled Shale, the Fish Scale Zone, and the First White Speckled Shale (Creaney et al., 1994). All are typified by marine Type II organic matter, with TOC up to 12 per cent, HI up to 450, and range from low to high maturity over large portions of the western, deepest part of the foreland basin (Creaney et al., 1994). The greatest subsidence, burial, and thermal hydrocarbon-generating phase was probably associated with the Late Cretaceous–Early Tertiary Laramide Orogeny. Much of the gas in post-Colorado reservoirs in the western part of the basin results from thermal generation from overmature Colorado source rocks. However, large volumes of post-Colorado, shallow dry-gas of eastern Alberta, including that in Milk River/Medicine Hat reservoirs, is derived from early biogenic (bacterial) decay of organic matter in the immediately underlying First White Speckled Shale (Creaney et al., 1994). In addition, unknown amounts of methane may be derived from adjacent, commonly occurring coal seams: typically bituminous/sub-bituminous coal with high-reactive macerals (especially vitrinite) and low sulphur contents (Smith et al., 1994).

Belly River Group reservoirs are predominantly gas-bearing, except for the "Basal Belly River" of west-central Alberta, at Pembina (Twps 47-48, Rges 2-7W5) and Peco (Twps 47-48, Rges 14-17W5). However, the latter are the only well-studied reservoirs, hence most data come from those examples. In the Foothills, the regional hydrodynamic flow is to the southwest, therefore all effective porosity can be hydrocarbon-saturated, as in the Deep Basin, although because of shallow depth the hydrocarbon is likely to be oil (Putnam and Moore, 1987; Putnam, 1993). At Peco, the pools are structurally controlled and identifiable on seismic, positioned on the hanging wall of a thrust fault, and in an anticline over an underlying thrust (Gardiner et al., 1990). Here, "Basal Belly River" conglomerate-dominated channel deposits stack vertically in discrete east or northeast trending fairways (Putnam, 1993). Up to 14 m of continuous, porous conglomerate/sandstone (porosity 4 to 12 per cent; average 8 per cent) is concentrated and most continuous along the channel axes over areas up to 3 km long by 1 km wide (Gardiner et al., 1990). Production is best from the lower, coarser grained portion of the channel fills, where primary porosity is present.

In the plains, where regional structural dip is 6m/km to the west (or even less in eastern Alberta), most hydrocarbons are stratigraphically trapped (Hartling and Wasser, 1989). Shouldice (1979) summarized the play types in the plains as follows: (1) updip pinchout of basal shoreline or channel sandstone into marine shale (common west of the 5th M.) which generally produce more than their estimated reserves, e.g., Pembina, Herronton, Ferrybank, Rowley; (2) subtle structural drape of nearly horizontal, widespread, shoreline sandstones which intertongue with marine shale in southern Alberta and Saskatchewan, over the crest of the Sweetgrass Arch or underlying Paleozoic structures, e.g., Atlee–Buffalo, and (3) small, laterally discontinuous, fluvial channel sandstones (most common in the middle and upper Judith River Formation) which may concentrate into trends of one or two pools.

Most porosity in the post-Colorado strata of the plains is secondary, due to quartz, calcite, and feldspar dissolution (Iwuagwu and Lerbekmo, 1982) and tends to increase as reservoirs become shallower to the east (Shouldice, 1979). Porosity in the shoreface-related sandstone typical of the lower Foremost Formation ("Basal Belly River") ranges from 10 to 24 per cent and averages about 18 per cent, with 8 md of permeability (Shouldice, 1979; Hartling and Wasser, 1989). In the shoreface facies, permeability generally increases upward with grain size in the Milk River and Belly River units (Wasser, 1995; Meyer and Krause, 1995). In shoreline-related channel sandstones, porosity averages 18 per cent, with 45 md of permeability (Hartling and Wasser, 1989). Permeability is greater because of the coarser grain size (Wasser, 1995). Crevasse-splay sandstones generally have a muddy matrix and little porosity (Iwuagwu and Lerbekmo, 1984). Abundant clay-rich horizons and

discrete horizons of calcite-cemented rock create abundant vertical and lateral permeability barriers (Storey, 1979; Hartling and Wasser, 1989).

Belly River reservoirs are commonly damaged during drilling and production primarily because of their generally under-pressured condition and clay content (Putnam, 1993). Drilling for deeper targets with overbalanced and/or freshwater mud affects most of these reservoirs since they are commonly not considered as primary or even secondary targets (Shouldice, 1979; Putnam, 1993). Clays represent up to 20 per cent of the rock, with 10 per cent kaolinite booklets, up to 5 per cent chlorite rosettes, and the remainder illite, montmorillonite and smectite (Storey, 1979). Under high-pressure drilling, kaolinite can migrate to block pore throats, and illite/montmorillonite/smectite can swell to block pore throats (Iwuagwu and Lerbekmo, 1984). In addition, acid treatment during production can cause precipitation of iron oxide gel from chlorite, which also can block pore throats (Iwuagwu and Lerbekmo, 1982, 1984). These problems may be avoided by drilling with air or a balanced, oil-based mud, and only treating the reservoir with a frac. The micro-porosity and irreducible water associated with clays also can make reservoir evaluation more difficult, by causing over-estimation of porosity and water saturation (Shouldice, 1979; Iwuagwu and Lerbekmo, 1981; Wasser, 1995).

ESTABLISHED PLAYS: GEOLOGICAL DEFINITION AND RESOURCE ASSESSMENT

The combination of updip pinchout, internal facies variation and subtle, but regional structural drape over underlying features provide numerous opportunities for the entrapment of gas, either locally sourced, or migrating from deeper in the basin. A total of 14 established plays (12 mature and 2 immature) were defined within the upper Colorado Group, Belly River Group, Edmonton Group, and Scollard Formation (Table 14). All plays are primarily stratigraphic but have varying amounts of subtle structural overprinting due to the overall structural orientation of the basin, or to the underlying presence of the Sweetgrass Arch. Plays are named using their Group or Formation name, and depositional style. Each play type is presented in stratigraphic sequence and described in terms of play definition, geology, exploration history, and play potential. To avoid repetition, the regional geological setting is not repeated for multiple plays that belong to a play group.

Upper Colorado Group composite play

Medicine Hat and Milk River formations

Play definition

This established composite play is defined to include all gas pools and prospects in: a) thin Medicine Hat Sandstone, present beneath the First White Speckled Shale and within the uppermost Colorado Group, b) nearshore-shoreline sandstones of the Virgelle Member, c) fluvial sandstones of the Deadhorse Coulee Member, and d) offshore marine siltstones and thin interbedded sandstones of the Alderson Member. The latter three units are members of the Milk River Formation, which overlies the First White Speckled Shale at the top of the Colorado Group, and are present only in the extreme southern portion of Alberta and southwestern Saskatchewan, over the crest of the Sweetgrass Arch. The Medicine Hat Sandstone is included in this play only because much of the production is co-mingled with that of the Milk River Formation throughout the play area. The play area is confined on its northern and northeastern sides by reservoir pinchout, on the west by the limit of Foothills deformation, and on the south by the International Boundary or by updip presence of a diagenetic/hydrodynamic boundary (Fig. 22). Gas pools contained in the partly correlative Chinook sandstone of northwestern Alberta are included in the assessment of the Foothills deformed belt (see Osadetz et al., in prep.).

Geology

Medicine Hat Sandstone: The Medicine Hat Sandstone (Santonian age; Glass, 1990) of southeastern Alberta lies about 30 m below the top of the Colorado Group (Russell and Landes, 1940), and underlies the Milk River Formation at shallow depths in the area comprising Twps 1-25, Rges 1W4-25W4, on the eastern, western and northern flanks of the Sweetgrass Arch (Glass, 1990). It is included with the post-Colorado plays and the Milk River Formation only because much of the production is co-mingled with that of the Milk River in this area. The Medicine Hat Sandstone is up to 14 m thick, thinning to the north and east. It has a gradational base and a sharp upper contact marked by a thin, calcareous, concretionary bed and a thin bentonite (Glass, 1990). The unit is a thickening- and coarsening-upward sequence of thinly interbedded grey, burrowed, fine-grained sandstone and mudstone. Granule,

Figure 22. *Map of the Milk River Formation (and equivalents) play area. Discovery wells of gas pools, and the vast, southeastern Alberta, Milk River-Medicine Hat field are plotted. Isopachs of clean sandstone also shown.*

pebble, and coquina layers are common in the upper few metres. It can be interpreted as a shallow-water marine sandstone derived from the south in Montana, pinching out into marine shale in southern Alberta.

The coarsest grained upper part of the unit forms the reservoir. The 30 m of First White Speckled Shale overlying it is the vertical seal, and equivalent marine shales to the east, north, and west provide the lateral seals. The source of the gas is unknown, but it probably was derived by decomposition of organic matter by anaerobic bacteria in the First White Speckled Shale.

Milk River Formation: The Milk River Formation (early to middle Campanian age; Braman and Sweet, 1990) of southern Alberta is approximately equivalent to the Chungo Member of the southern and central Foothills, and the Chinook Member of the northern Foothills, both of the Wapiabi Formation (Stott, 1963). These sandy, clastic wedges rim the western and southwestern margins of the Alberta Basin, representing more distal portions of depositional lobes. The formation is divided into four members (Meijer Drees and Mhyr, 1981), which are, in ascending order: a) lower Telegraph Creek Member: interbedded marine mudstone and sandstone with no reservoir potential, and discussed no further, b) Virgelle Member: thick bedded, shoreline-related sandstone, c) Deadhorse Coulee Member: nonmarine sandstone, mudstone and coal, and d) the basinward-equivalent Alderson Member: bioturbated marine siltstone with thin sandstone interbeds. The Milk River Formation is both a major aquifer and a major gas reservoir in southern Alberta (Meyboom, 1960).

The Virgelle Member is up to 30 m thick and thins to zero northeastward, into the subsurface, over a distance of about 100 km. In outcrop, the lower portion consists of up to 18 m of fine to medium grained sandstone, interpreted as lower and upper shoreface deposits of a storm- and wave-dominated prograding shoreline (McCrory and Walker, 1986). The upper portion consists of 5-8 m of erosionally based, medium grained sandstone, interpreted as channelized, tidally influenced deposits (McCrory and Walker, 1986; Cheel and Leckie, 1990). The shoreline was oriented northwest, with channels trending perpendicular, and the offshore basin to the northeast (Cheel and Leckie, 1990). Permeability ranges from 15 to 520 md, averaging 374 md (Meyboom, 1960).

The Deadhorse Coulee Member is up to 52 m thick and thins to zero northeastward, into the subsurface, over a distance of about 75 km. In outcrop it consists of interbedded fine grained, lenticular sandstone, carbonaceous sandy mudstone, and minor coal (Meijer Drees and Mhyr, 1981). It is interpreted as a floodplain deposit, consisting of fluvial channel and overbank sediment (McCrory and Walker, 1986; Cheel and Leckie, 1990). Paleocurrent data from the fluvial channels indicate flow to the northeast (Cheel and Leckie, 1990).

The Alderson Member is present basinward of the Milk River shoreline complex, and ranges from 70 to 90 m thick. Thinning of the unit to the northeast occurs over a distance of about 100 km before it passes basinward into laminated mudstone of the Lea Park Formation in central Alberta and western Saskatchewan (Williams and Burke, 1964; Meijer Drees and Mhyr, 1981). The Alderson Member comprises a vaguely coarsening-upward succession of stacked, distal parasequences of bioturbated, silty mudstone, with thin interbeds of porous and permeable siltstone to very fine grained sandstone (Meijer Drees and Mhyr, 1981). These deposits are the main productive unit of the gigantic southeastern Alberta (Milk River) gas field. Porosity in the siltstone is 17 per cent and permeability is 1 md, whereas in the thin, discontinuous, very fine grained sandstone beds porosity ranges from 17 to 26 per cent and permeability from 3 to 259 md (Meijer Drees and Mhyr, 1981). The excellent reservoir quality of these fine grained strata may be due to extensive fracturing. Gas reservoirs are presumably in the thin sandstone beds, trapped by water impairment from outcrop recharge into the updip porous sandstones (i.e., a hydrodynamic trap; Masters, 1982). Gas is present at very shallow depths (300–400 m), is at very low pressure, but includes enormous reserves (Masters, 1982).

The overlying marine shale of the Pakowki Formation is the vertical seal for the pools and, updip to the south, water recharge at the outcrop may create a hydrodynamic trap (Masters, 1982). Shallow burial depth has limited compaction, thus preserving reservoir quality (Hankel et al., 1989), although reservoir pressure and permeability are low. The gas is non-associated and probably largely biogenic. The source of the hydrocarbons may be the underlying First White Speckled Shale of the Colorado Group, produced by the biogenic decomposition of organic matter by anaerobic bacteria (Rice and Schurr, 1978; Creaney et al., 1994).

Exploration history

The initial discovery well was drilled in 1884 in the Medicine Hat Field, No. 1 (Main Street) 5-31-12-5W4, with gas produced from the Medicine Hat Sandstone (Fig. 23). Much of the play area has been extensively drilled over the decades and only minor potential remains. The largest discovered pool (Milk River Pool No. 1) has an initial in-place gas volume of 238 060 x 10^6 m^3. The mean pool depth is 438 m, mean net pay is 2.2 m, and mean porosity is 18.8 per cent. There have been 25 pools discovered in this play, and the discovered in-place gas volume is 455 493 x 10^6 m^3 (Table 2) with a mean gas-in-place pool size of 18 220 x 10^6 m^3.

Play potential

Estimates of the expected potential for this play indicate an in-place gas volume of 4862 x 10^6 m^3, representing only about 1 per cent of the total play resource (Table 2). This estimate assumes a total pool population of 600, with the largest undiscovered pool containing 200 x 10^6 m^3 of initial gas-in-place (Fig. 24). Although this play is ranked first in order of discovered gas volume (by far), it is only ranked eleventh in expected potential and thirteenth in probable potential, due to its long and thorough drilling history (Tables 15, 16, 17). The potential gas resources in this play will likely be found through infill drilling in very small pools.

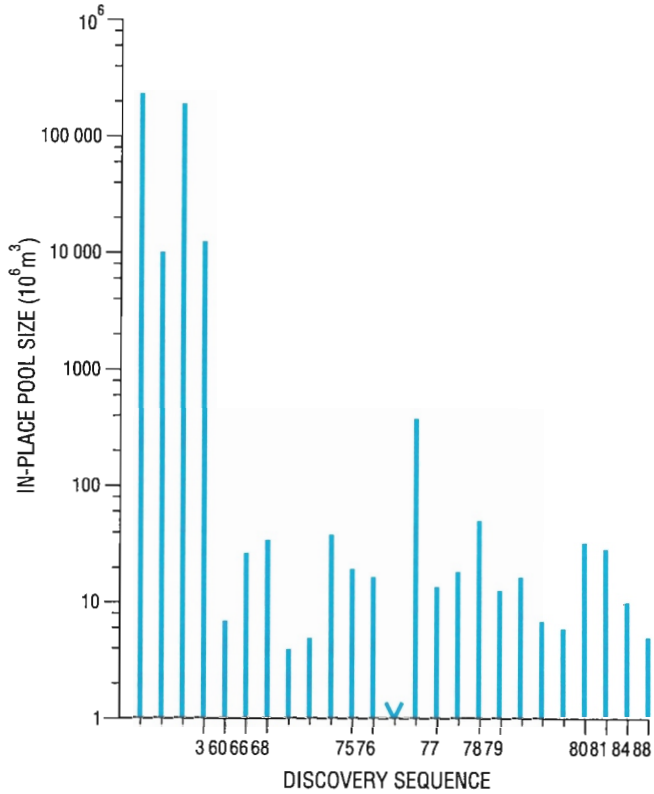


Figure 23. *Discovery sequence plot for Medicine Hat and Milk River formations play.*

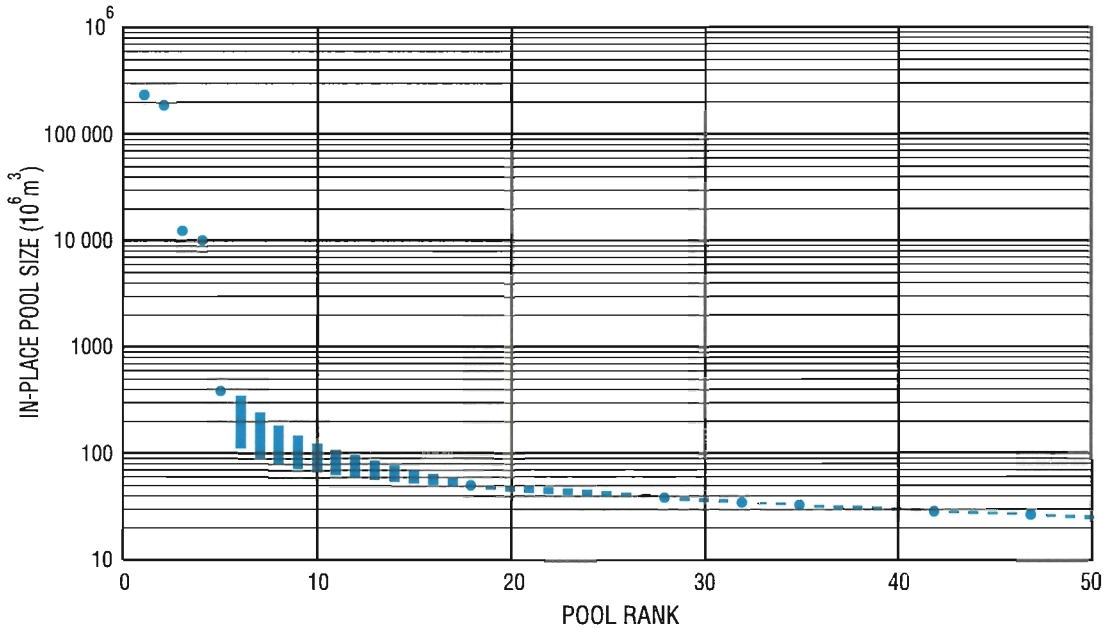


Figure 24. *Pool-size-by-rank plot for the Medicine Hat and Milk River formations play, showing the top 50 pools (discovered and undiscovered).*

Table 2

Top 20 discovered pools and play resource summary, Medicine Hat and Milk River formations

Pool rank	Field/Pool Name	Pool type	Discovered in-place volume (x 10^6 m^3)	Discovery date
1	Milk River Pool No. 1	NA	238 060	03/04/01
2	Medicine Hat Pool No. 1	NA	193 700	03/94/01
3	Medicine Hat Pool No. 3	NA	12 694	03/04/01
4	Medicine Hat Pool No. 4	NA	10 293	03/04/01
5	Medicine Hat, MR	NA	387	77/07/25
18	Retlaw, MR	NA	51	78/09/15
28	Retlaw, MR	NA	39	75/07/94
32	Pendant d'Oreille, MH B	NA	35	68/03/04
35	Armada, Milk River A	NA	33	80/12/28
42	Turin, MR	NA	29	81/04/27
47	Enchant, MR	NA	27	66/04/04
68	Retlaw, Milk River C	NA	20	75/10/02
73	Blackfoot, MH SD	NA	19	78/01/04
82	Medicine Hat, MR	NA	17	76/12/10
83	Comrey, MH SD	NA	17	80/02/28
103	Princess, Colorado A	NA	14	77/08/27
111	Cypress, MR	NA	13	79/09/22
144	Enchant, MR	NA	10	84/01/25
194	Black Butte, Medicine Hat A	NA	7	60/04/17
195	Pendant, d'Oreille, MH SD	NA	7	80/03/09
Initial in-place volume (discovered) (10^6 m^3)			455 493	
Initial in-place volume (potential) (10^6 m^3)			4 862	
Per cent play resources undiscovered			1	
Total pools discovered			25	
Total pool population			600	

NA, nonassociated gas

Belly River Group plays

Foremost Formation ("Basal Belly River"), Cycle 1 Shoreline

Play definition

This established, but immature play is defined to include all gas-bearing pools and prospects in nearshore and shoreline sandstones of the defined progradational Cycle 1 (lowest and most westerly of seven such cycles) of the "Basal Belly River" (Fig. 25). It occurs in a large area of northwestern Alberta; defined on the east and south by the 5 m isopach of clean sandstone, on the west by the limit of deformation, and on the north by the outcrop belt of the unit (Fig. 26).

Geology

The Belly River (Judith River) Group is a dominantly fluvial, clastic wedge that formed in response to Late Campanian deformation in the Omineca Crystalline Belt (Eisbacher, 1974). It is middle Late Campanian in age and deposition spanned approximately 5 m.y. (Braman and Sweet, 1990). 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 (Glass, 1990), 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.

The "Basal Belly River" strata include at least seven stacked, offlapping, regionally mappable, progradational, sandstone-dominated cycles, separated by marine flooding surfaces (Hamblin and Abrahamson, 1993; Hamblin, 1993). At any one place the "Basal Belly River" is 25 to 75 m thick and consists of one or two cycles. These seven cycles record overall eastward, but noncontinuous progradation over more than 400 km across Alberta during Foremost deposition (3–4 m.y.). 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. Each cycle is treated as a separate play, but detailed descriptions are not repeated for each.

"Basal Belly River" Cycle 1, present in Twps 40-70, Rges 8W5, to the edge of the disturbed belt in the west, 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 sandstone reservoir facies is sharp-based. The pinchout of the clean sandstone follows an arcuate trace from Twp 40, Rge 10W5, to Twp 70, Rge 8W5. Minor gas reserves are contained in this cycle.

For all "Basal Belly River" cycles, the intervening, thin, transgressive marine shale tongues and the overlying, nonmarine fine grained deposits provide the vertical seal for the pools, and updip, to the east, the pinchout of clean sandstone may create a stratigraphic trap. The source of hydrocarbons may be the marine shales of the underlying Colorado Group (requiring long-distance migration), or the adjacent, nonmarine, coal-bearing strata (local source).

Exploration history

There has been only one gas pool discovered in this immature play, at a depth of 820 m in the Wapiti 9-28-67-11W6 well. The total discovered gas-in-place is 116 x 10^6 m^3, covering an area of 250 ha, with a net pay of 9 m and porosity of 12 per cent. Several oil pools are present in Cycle 1, at the Pine Creek and Minehead fields.

Play potential

Cycle 1 is an immature play, but is directly analogous to the mature plays of Cycles 2 to 7. Therefore, a different method of assessment was followed in the analysis of this play, as described previously, in the Resource Assessment Procedure section. Estimates of the expected potential for this play indicate an in-place gas volume of 3605 x 10^6 m^3, representing approximately 97 per cent of the total play resource (Table 16). This estimate is based on a comparison with the other six "Basal Belly River" cycles, as previously discussed (Fig. 11). The potential gas resources in this play will likely be found in very small pools in northwestern Alberta.

Figure 25. *Five metre isopach of ''clean'' sandstone at marineward edge of each ''Basal Belly River'' cycle, successively offset to the east through time, which approximates play boundaries for each play.*

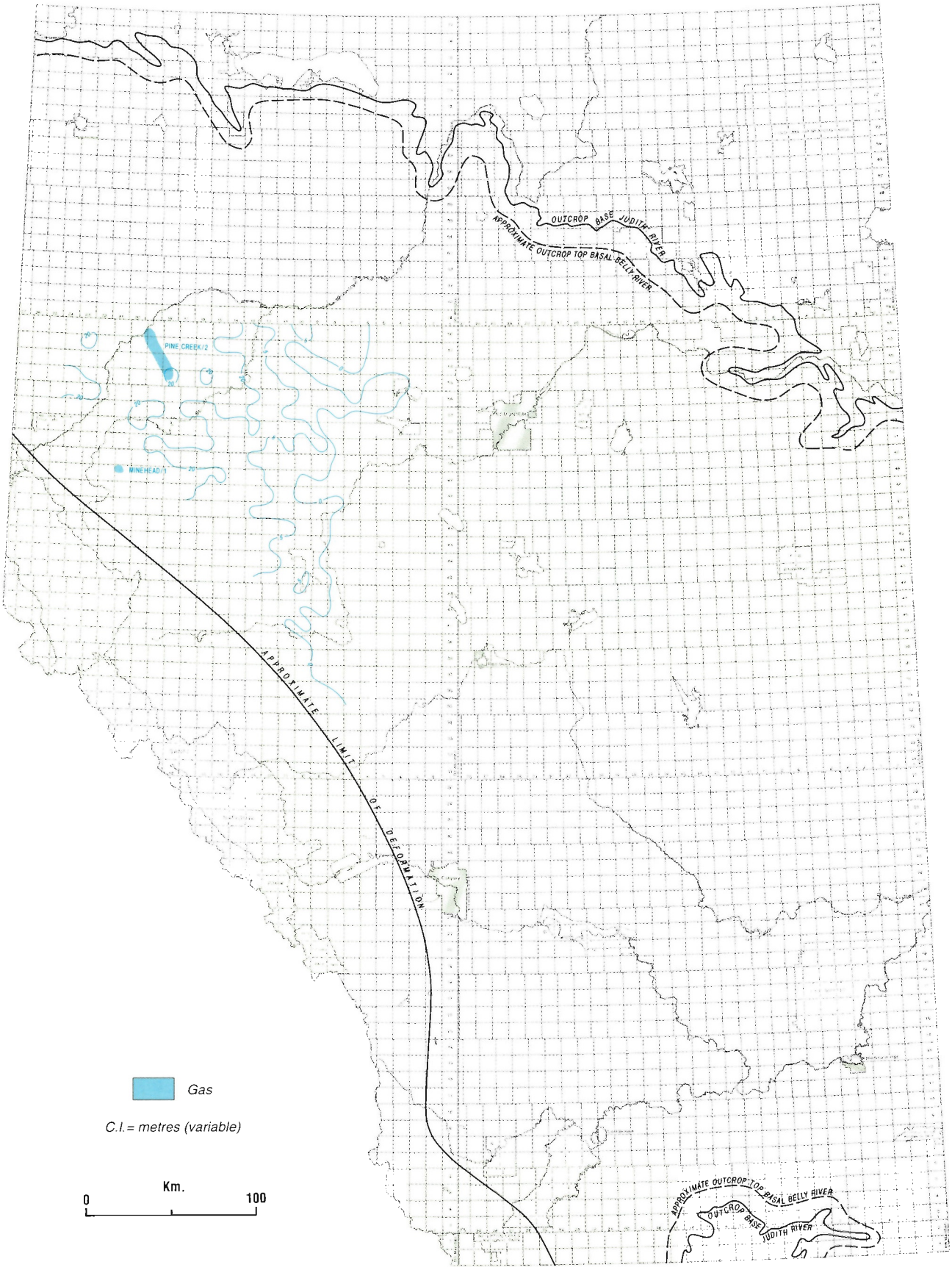


Figure 26. *Play area for Foremost Formation, Cycle 1 Shoreline play.*

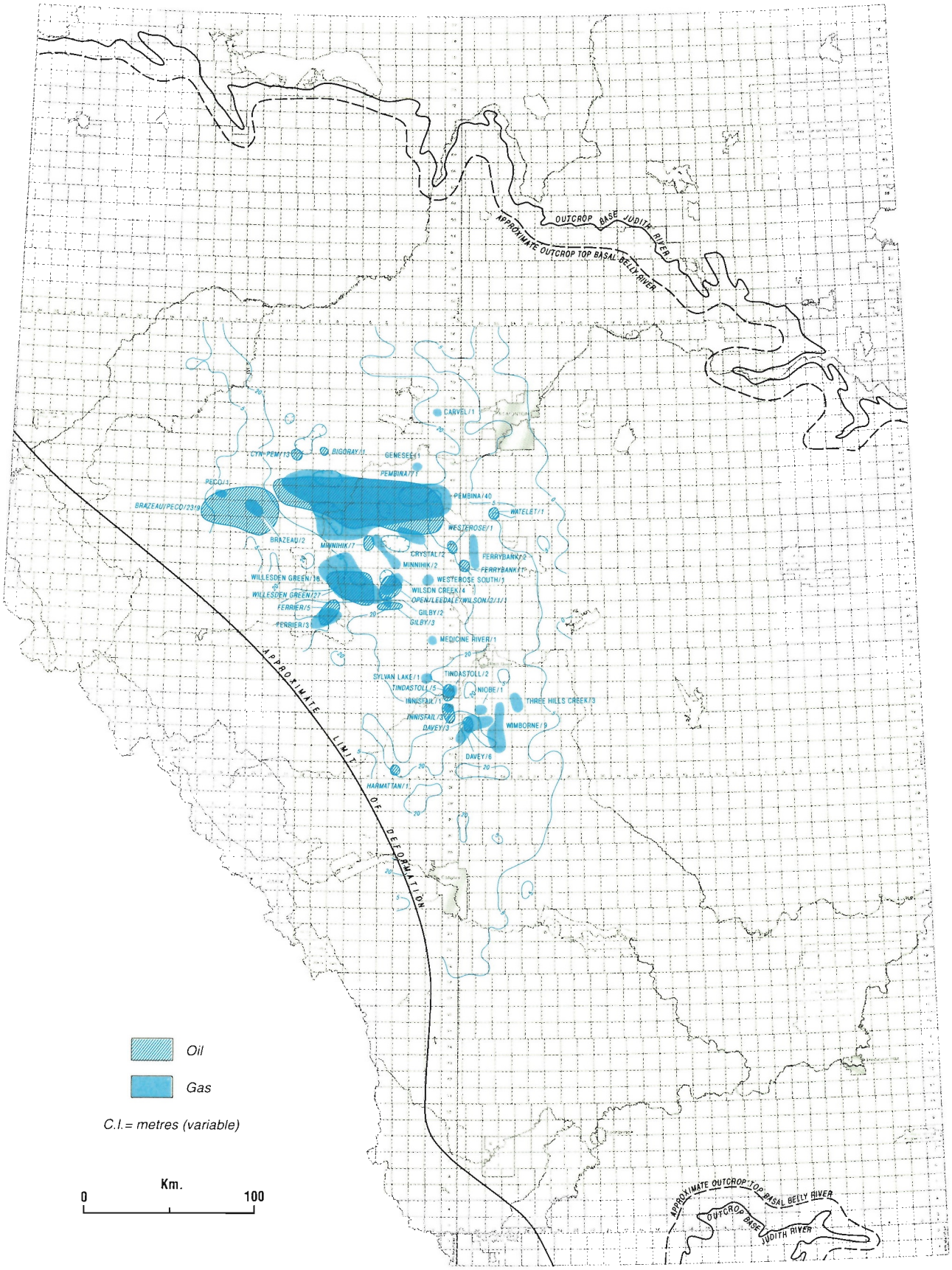


Figure 27. *Play area for Foremost Formation, Cycle 2 Shoreline play, showing gas and oil fields/pools and isopach values of the cycle thickness.*

Foremost Formation ("Basal Belly River"), Cycle 2 Shoreline

Play definition

This established, mature play is defined to include all gas-bearing pools and prospects in nearshore and shoreline sandstones of Cycle 2 of the "Basal Belly River". It occurs in a large area in west-central Alberta and its limit on the west, east and south is defined by the 5 m isopach of clean sandstone, and on the north by the outcrop belt of the unit (Fig. 27).

Geology

"Basal Belly River" Cycle 2, present in Twps 20-70, Rges 22W4-15W5, has 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 Formation 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, nearshore to shoreface facies. In addition, channelized sandstone units occur throughout. The pinchout of clean sandstone follows an arcuate trace from Twp 20, Rge 20W4 to Twp 65, Rge 1W5. 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), Wasser (1988), Wasser and Hartling (1989), Power (1989), and Gardiner et al. (1990), and their potential was assessed by Podruski et al. (1988).

Exploration history

The initial discovery well was drilled in 1951 (Fig. 28). Discovered gas pools are concentrated in west-central Alberta, in the Pembina, Minnehik, Brazeau, and Peco fields. The largest discovered pool (Ferrybank, Belly River C) has a discovered in-place gas volume of 2558 x 10^6 m^3. The mean pool area is 594 ha, mean net pay is 4.2 m, mean porosity is 17.4 per cent, and mean pool depth is 1167 m. There have been 104 pools discovered in this play and the total discovered in-place gas volume is 19 997 x 10^6 m^3 (Table 3), with a mean pool size of 193 x 10^6 m^3 of in-place gas. In addition, about 40 oil pools are known from this cycle.

Play potential

Estimates of the expected potential for this play indicate an in-place gas volume of 7404 x 10^6 m^3, representing approximately 27 per cent of the total play resource (Table 3). This estimate assumes a total pool population of 280, with an in-place volume for the largest undiscovered pool of 1606 x 10^6 m^3 (Fig. 29). This play is ranked sixth in expected potential and fifth in probable potential, but is ranked first in largest undiscovered pool-size (Tables 16, 17, 19) only because PETRIMES predicts that the second largest pool remains to be discovered. The potential gas resources in this play will likely be found in medium- to small-sized pools located in west-central Alberta.

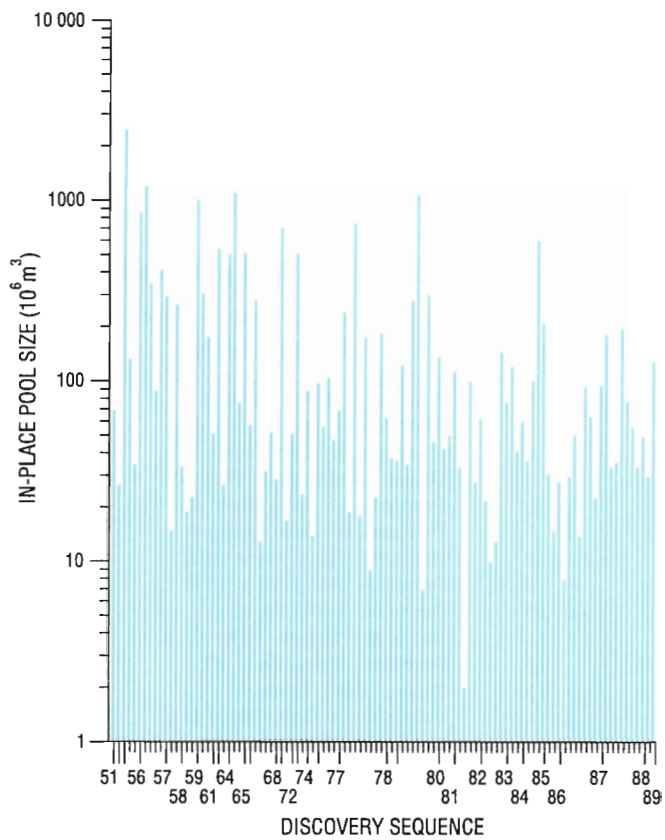


Figure 28. *Discovery sequence plot for Foremost Formation, Cycle 2 Shoreline play.*

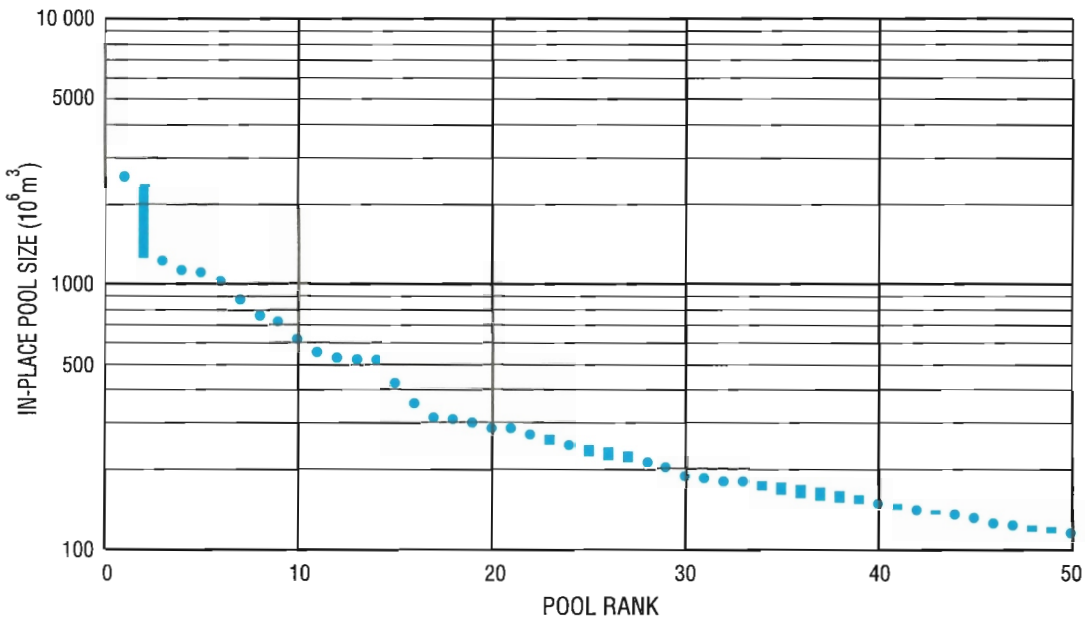


Figure 29. *Pool-size-by-rank plot for Foremost Formation, Cycle 2 Shoreline play, showing the top 50 pools (discovered and undiscovered).*

Table 3

Top 20 discovered pools and play resource summary, Foremost Formation, Cycle 2 Shoreline play

Pool rank	Field/Pool Name	Pool type	Discovered in-place volume (x 10^6 m^3)	Discovery date
1	Ferrybank, Belly River C	AG, SG	2 558	55/03/26
3	Pembina, K Belly River B	SG	1 225	57/02/01
4	Pembina, K Belly River X	AG, SG	1 128	65/01/19
5	Wilson Creek Belly River A	AG, SG	1 108	80/07/29
6	Pembina, K Belly River C	SG	1 026	59/10/11
7	Pembina, K Belly River A	NA	879	56/11/16
8	Pembina, Belly River A2A	AG, SG	766	78/06/06
9	Pembina, Belly River FFF	SG	720	70/01/15
10	Pembina, Belly River I	SG	620	85/08/24
11	Willesden Green, Belly R. J	AG, SG	555	63/02/18
12	Pembina, Belly River ZZ	NA	528	65/06/21
13	Davey, Belly River A	NA	520	73/12/28
14	Pembina, K Belly River U	SG	517	64/03/29
15	Pembina, Belly River SS	NA	422	57/07/03
16	Pembina, Belly River AA	AG, SG	354	57/06/04
17	Wimborne, Belly River A	NA	313	61/08/30
18	Minnehik-Buck Lk., Belly R. C	AG, SG	309	80/10/01
19	Pembina, Belly River T2T	NA	300	57/08/17
20	Westerose South, Belly R. A	NA	286	80/05/07
21	Willesden Green, Belly R. H	SG	286	68/03/20
Initial in-place volume (discovered) (10^6 m^3)			19 997	
Initial in-place volume (potential) (10^6 m^3)			7 404	
Per cent play resources undiscovered			27	
Total pools discovered			104	
Total pool population			280	

AG, associated gas; SG, sour gas; NA, nonassociated gas

Foremost Formation ("Basal Belly River"), Cycle 3 Shoreline

Play definition

This play is defined to include all gas-bearing pools and prospects in nearshore and shoreline sandstones of Cycle 3 of the "Basal Belly River". It occurs in a large area of central Alberta; limited on the west, east and south by the 5 m isopach of clean sandstone, and on the north by the outcrop belt of the unit (Fig. 30).

Geology

"Basal Belly River" Cycle 3, present in Twps 5-65, Rges 15W4-8W5, has up to about 35 m of clean sandstone, 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, nearshore and shoreface facies. In

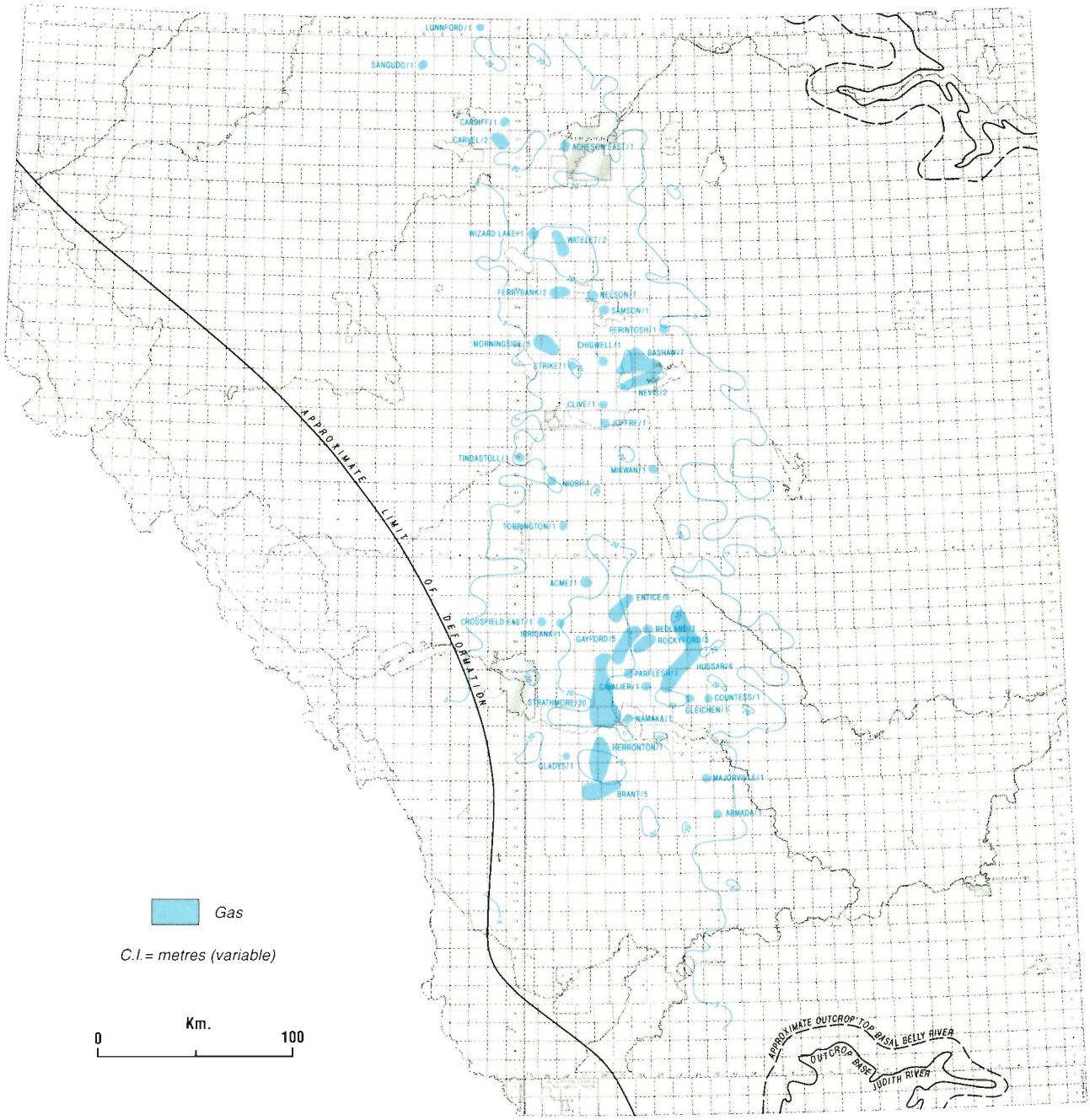


Figure 30. *Play area for Foremost Formation, Cycle 3 Shoreline play, showing location of gas fields/pools and isopach values of cycle thickness.*

addition, channelized sandstone units occur throughout. The pinchout of clean sandstone follows an arcuate trace from Twp 5, Rge 18W4 to Twp 65, Rge 1W5. Significant gas reserves are contained in this cycle, especially in the area with greater than 15 m of clean sandstone.

Exploration history

The initial discovery well was drilled in the Samson Field in 1953 (Fig. 31; Table 4). Discovered gas pools are concentrated in the Strathmore, Hussar, and Herronton fields in the south, and in the Bashaw, Morningside, and Ferrybank fields in the north. The largest discovered pool (Herronton, Belly River A) has an initial in-place gas volume of 1383 x 10^6 m^3. The mean pool area is 565 ha, mean net pay is 4.1 m, mean porosity is 22.4 per cent, and mean pool depth is 813 m. There have been 96 pools discovered in this play and the total discovered in-place volume is 12 295 x 10^6 m^3 (Table 4), with a mean pool size of 128 x 10^6 m^3 of in-place gas.

Play potential

Estimates of the expected potential for this play indicate an initial in-place volume of 6615 x 10^6 m^3, representing approximately 35 per cent of the total play resources (Table 4). This estimate assumes a total pool population of 360, with an in-place volume for the largest undiscovered pool of 295 x 10^6 m^3 (Fig. 32). The potential gas resources in this play will likely be found in small pools situated in central Alberta.

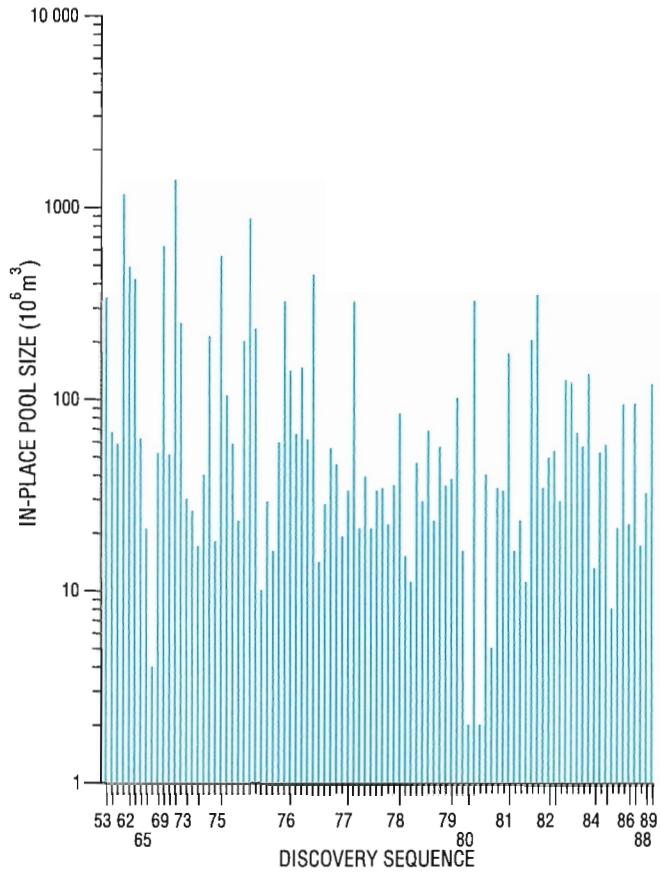


Figure 31. *Discovery sequence plot for Foremost Formation, Cycle 3 Shoreline play.*

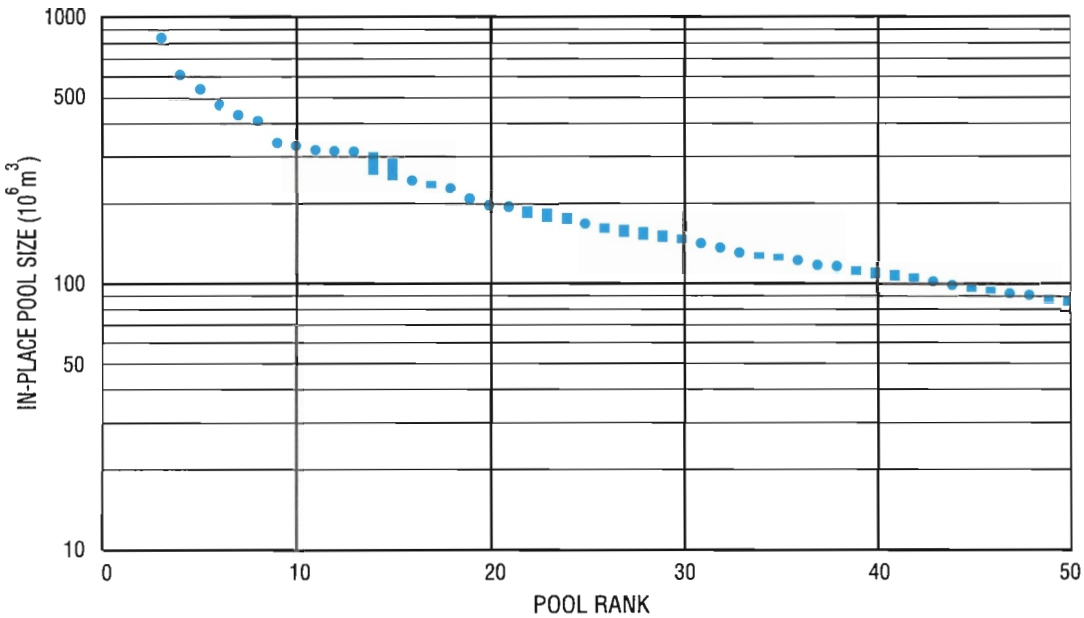


Figure 32. *Pool-size-by-rank plot for Foremost Formation, Cycle 3 Shoreline play, showing the top 50 pools (discovered and undiscovered).*

Table 4

Top 20 discovered pools and play resource summary, Foremost Formation, Cycle 3 Shoreline play

Pool rank	Field/Pool Name	Pool type	Discovered in-place volume (x 10^6 m^3)	Discovery date
1	Herronton, Belly River A	NA	1 383	72/12/13
2	Strathmore, Belly River A	NA	1 163	62/07/08
3	Strathmore, Belly River E	NA	865	76/04/23
4	Entice, Belly River K	NA	624	69/10/04
5	Strathmore, Belly River J	NA	555	75/10/16
6	Strathmore, Belly River B	NA	487	62/08/01
7	Gaylord, Belly River A	NA	442	77/04/14
8	Strathmore, Belly River H	NA	421	63/10/31
9	Brant, Belly River D	NA	347	82/03/14
10	Samson, Belly River A	NA	337	53/05/24
11	Clive, Belly River A	NA	324	81/01/13
12	Strathmore, Belly River N	NA	322	76/01/12
13	Strathmore, Belly River I	NA	320	78/01/12
16	Herronton, Belly River B	NA	249	73/06/08
18	Strathmore, Belly River K	NA	233	76/06/10
19	Strathmore, Belly River F	NA	213	75/09/12
20	Herronton, Belly River O	NA	202	82/02/17
21	Strathmore, Belly River M	NA	200	76/03/16
25	Ferrybank, Belly River	NA	172	81/12/29
31	Carvel, BSL Belly River	NA	145	77/03/03
Initial in-place volume (discovered) (10^6 m^3)			12 295	
Initial in-place volume (potential) (10^6 m^3)			6 615	
Per cent play resources undiscovered			35	
Total pools discovered			96	
Total pool population			360	

NA, nonassociated gas

Foremost Formation ("Basal Belly River"), Cycle 4 Shoreline

Play definition

This play is defined to include all gas-bearing pools and prospects in nearshore and shoreline sandstones of Cycle 4 of the "Basal Belly River". It occurs over a large area of central Alberta; limited on the west, east and south by the 5 m isopach of clean sandstone, and on the north by the outcrop belt of the unit (Fig. 33).

Geology

"Basal Belly River" Cycle 4 is present in Twps 5-65, Rges 5W4-5W5, immediately west of the crest of the Sweetgrass Arch. It has up to 50 m of clean sandstone 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 170 km. It generally comprises a coarsening-upward sequence of mudstone, siltstone, and sandstone and is interpreted as a complex of prograding nearshore and shoreface facies. In addition, channelized sandstone units occur throughout. The updip pinchout of clean sandstone follows an arcuate trace from Twp 5, Rge 10W4 to Twp 55, Rge 10W4. This pinchout approximately coincides with the structural culmination of the Sweetgrass Arch complex in southeastern Alberta. Large gas reserves are contained in this cycle, especially in the area with greater than 15 m of clean sandstone.

Exploration history

The initial discovery well was drilled in 1949 (Fig. 34). The numerous gas pools discovered are widespread, but concentrated in the Wayne–Rosedale, Drumheller, Fenn, Bashaw, and Holmberg fields. The largest discovered pool (Bashaw, Belly River Pool No. 3) has an initial in-place volume of 3115 x 10^6 m^3. The mean pool area is 673 ha, mean net pay is 3.4 m, mean porosity is 15.2 per cent, and mean pool depth is 584 m. There have been 229 pools discovered in this play and the total in-place reserve volume is 21 513 x 10^6 m^3 (Table 5), with a mean pool size of 103 x 10^6 m^3 in-place gas.

Play potential

Estimates of the expected potential for this play indicate an initial in-place volume of 17 733 x 10^6 m^3, representing approximately 45 per cent of the total play resources (Table 5). This estimate assumes a total pool population of 600, with an in-place volume for the largest undiscovered pool of 1128 x 10^6 m^3 (Fig. 35). This play is ranked third in discovered gas volume, third in expected potential, first in probable potential, and second in largest undiscovered pool size, suggesting a very positive outlook (Tables 15, 16, 17, 19). The potential gas resources in this play will likely be found in medium- to small-sized pools, situated in east-central Alberta, just to the west of the subtle structural culmination of the Sweetgrass Arch.

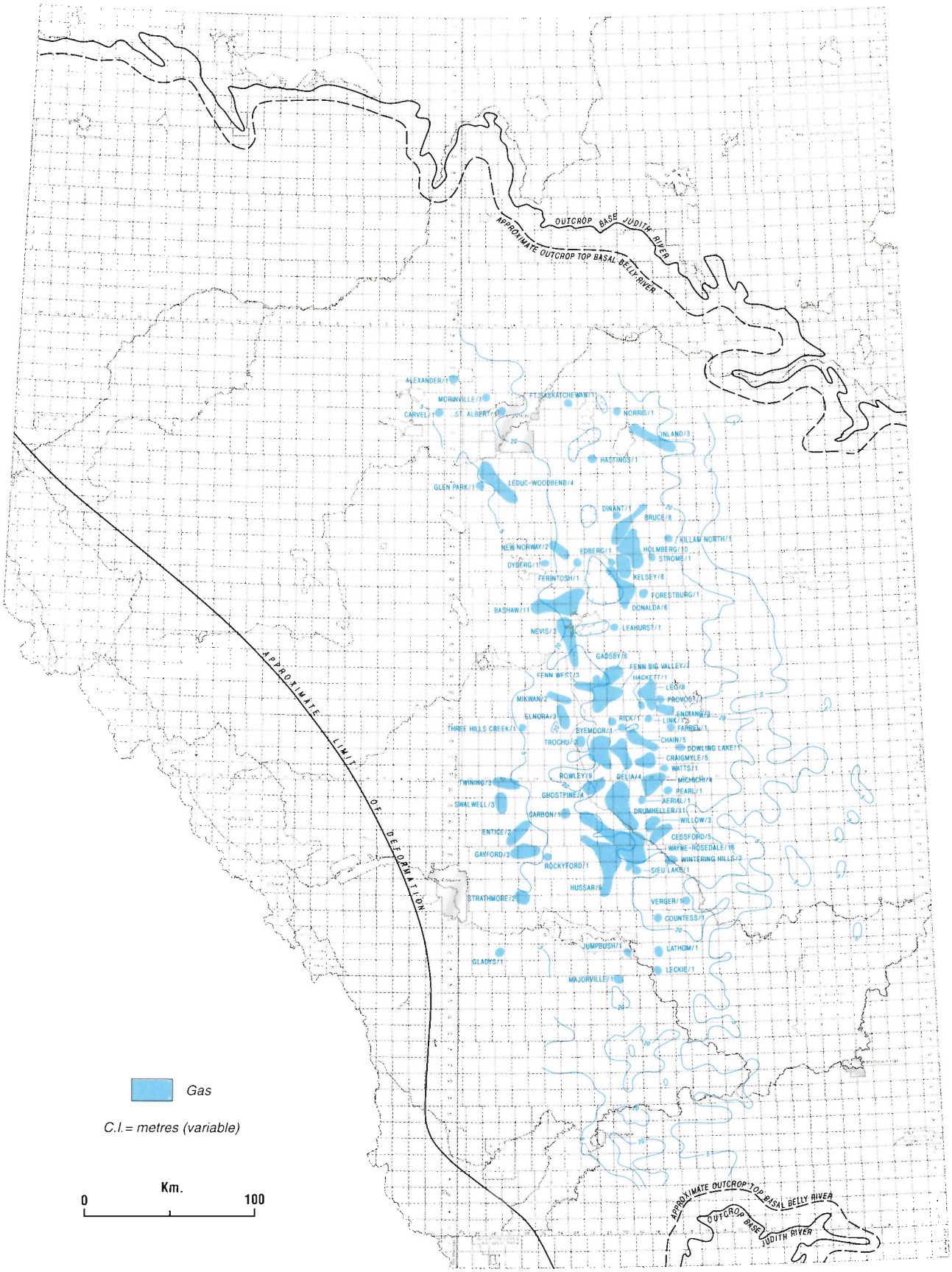


Figure 33. *Play area for Foremost Formation, Cycle 4 Shoreline play, showing locations of gas fields/pools and isopach values of cycle thickness.*

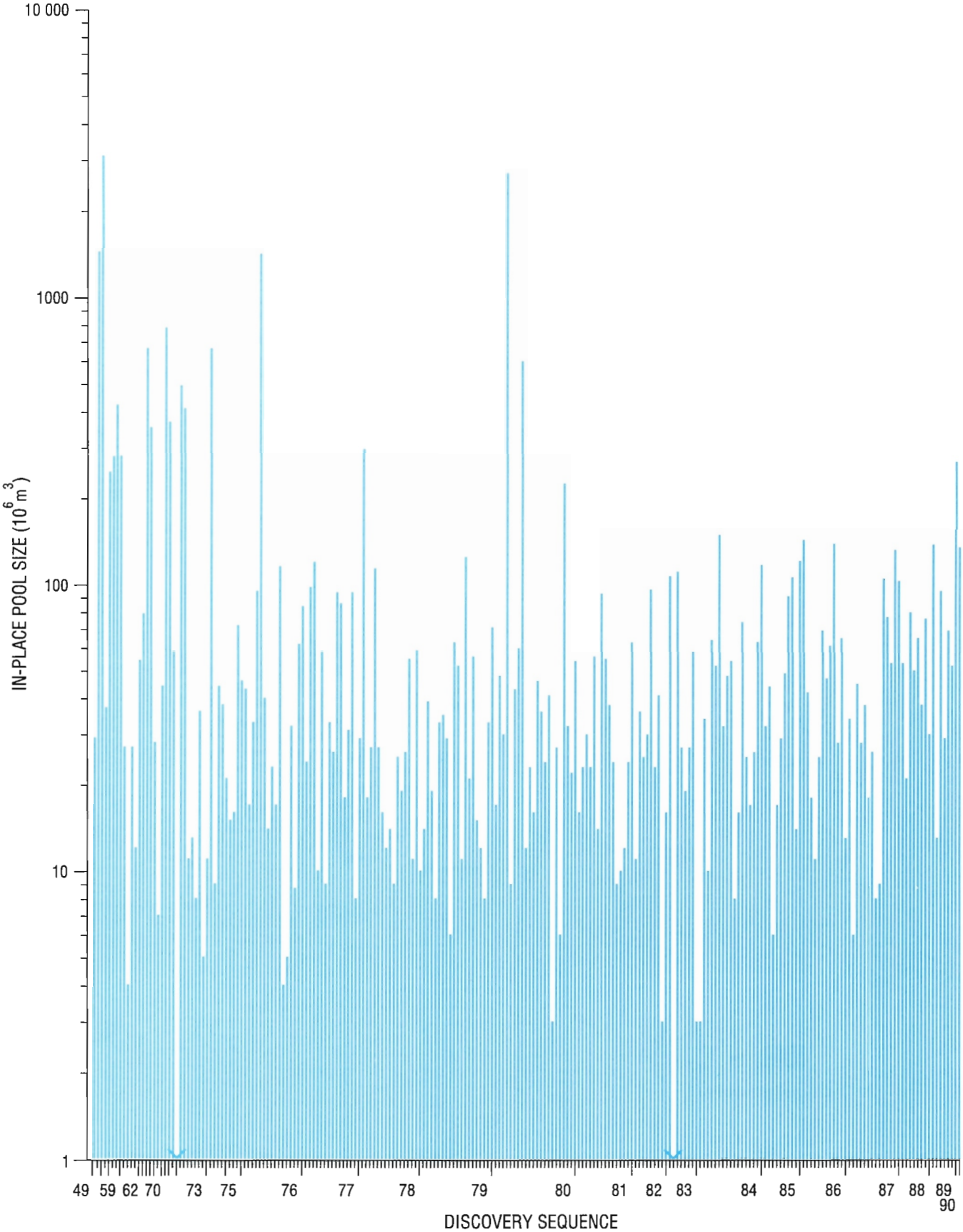


Figure 34. *Discovery sequence plot for Foremost Formation, Cycle 4 Shoreline play.*

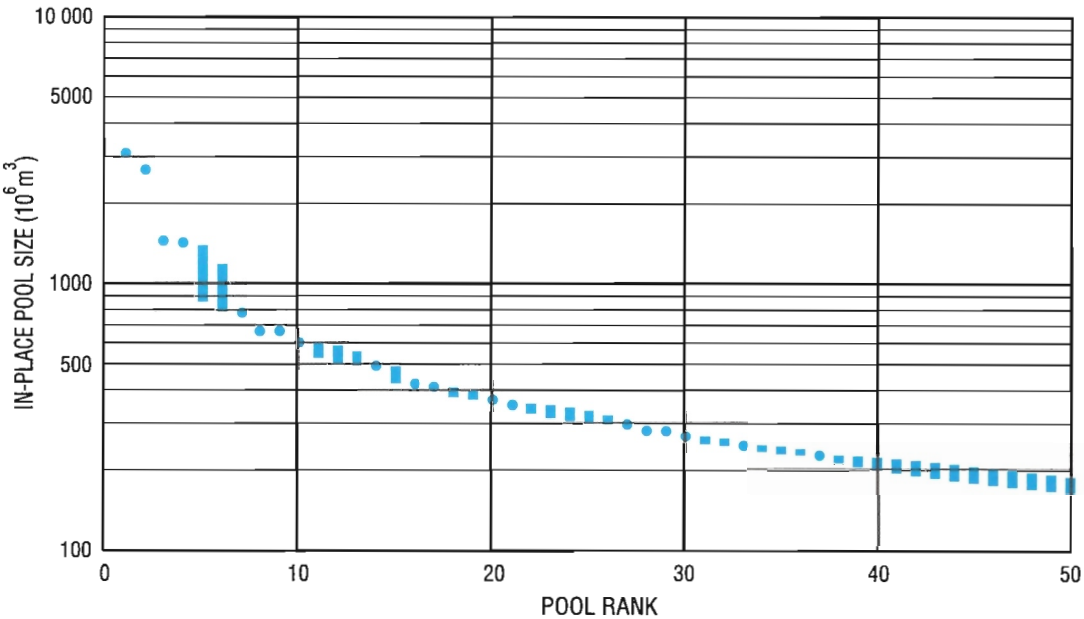


Figure 35. *Pool-size-by-rank plot for Foremost Formation, Cycle 4 Shoreline play, showing the top 50 pools (discovered and undiscovered).*

Table 5

Top 20 discovered pools and play resource summary, Foremost Formation, Cycle 4 Shoreline play

Pool rank	Field/Pool Name	Pool type	Discovered in-place volume (x 10^6 m^3)	Discovery date
1	Belly River Pool No. 3	NA	3 115	51/08/02
2	Belly River Pool No. 1	NA	2 713	80/03/15
3	Craigmyle, Belly River A	NA	1 448	51/02/04
4	Delia, Belly River A	NA	1 424	76/05/17
7	Belly River Pool No. 2	NA	786	70/12/10
8	Kelsey, Belly River B	NA	667	74/05/31
9	Rowley, Belly River A	NA	667	64/11/14
10	Michichi, Belly River F	NA	603	80/08/01
14	Leo, Belly River A	NA	494	73/01/10
16	Hussar, Belly River A	NA	424	59/12/23
17	Inland, Belly River F	NA	412	73/07/21
20	Holmberg, Belly River A	NA	370	71/06/22
21	Wayne-Rosedale, Belly River S	NA	354	65/12/21
27	Link, Belly River H	NA	297	78/01/10
28	Husar, Belly River D	NA	281	59/12/23
29	Wayne-Rosedale, Belly River O	NA	280	59/11/17
30	Rowley, Belly River I	NA	268	89/11/29
33	Glen Park, Belly River	NA	247	54/08/10
37	Bashaw, Belly River A	NA	226	80/11/30
59	Gadsby, Belly River B	NA	149	84/03/06
Initial in-place volume (discovered) (10^6 m^3)			21 513	
Initial in-place volume (potential) (10^6 m^3)			17 733	
Per cent play resources undiscovered			45	
Total pools discovered			229	
Total pool population			600	

NA, nonassociated gas

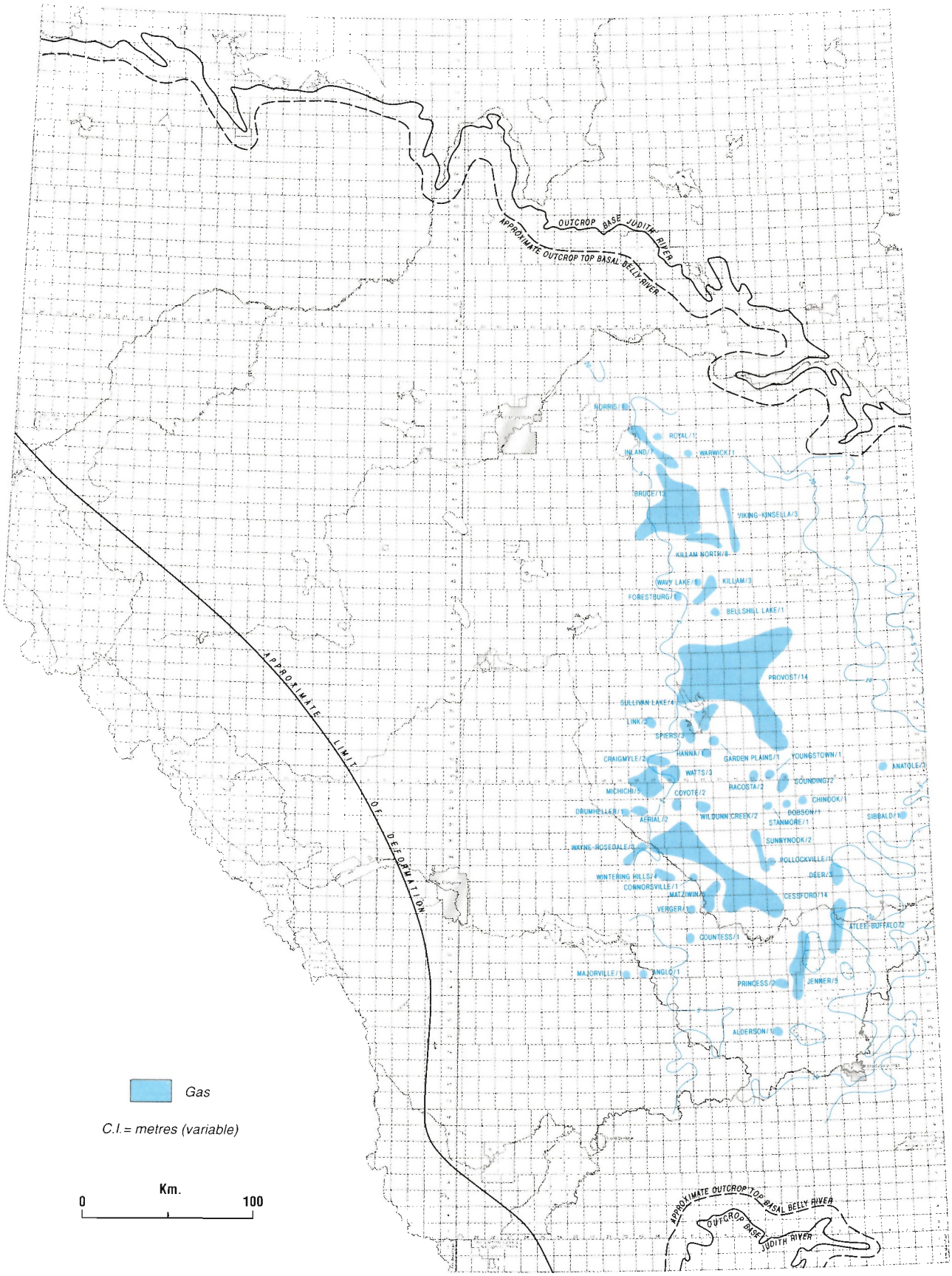


Figure 36. *Play area for Foremost Formation, Cycle 5 Shoreline play, showing locations of gas fields/pools and isopach values of cycle thickness.*

Foremost Formation ("Basal Belly River"), Cycle 5 Shoreline

Play definition

This established, mature play is defined to include all gas-bearing pools and prospects in nearshore and shoreline sandstones of Cycle 5 of the "Basal Belly River". It occurs in a large area of east-central Alberta, over the crest of the Sweetgrass Arch. The play area is limited on the west and east by the 5 m isopach of clean sandstone, and on the north and south by the outcrop belt of the unit (Fig. 36).

Geology

"Basal Belly River" Cycle 5 is present in Twps 5-55, Rges 28W3-20W4, over the crest of the Sweetgrass Arch, where the strata are nearly flat-lying. It has up to 55 m of clean sandstone and thins eastward as it downlaps and pinches out into the mudstones of the Lea Park Formation in the subsurface, over a distance of about 160 km. It generally comprises a coarsening-upward sequence of mudstone, siltstone, and sandstone and is interpreted as a complex of prograding nearshore and shoreface facies. In addition, channelized sandstone units occur throughout. The updip pinchout of clean sandstone follows an arcuate trace from Twp 5, Rge 5W4 to Twp 50, Rge 1W4. Gas reserves are contained in this cycle, especially in the area with greater than 20 m of clean sandstone.

Exploration history

The initial discovery well was drilled in 1959 (Fig. 37). Discovered gas pools are concentrated in the Cessford, Provost, and Bruce fields in eastern Alberta. The largest discovered pool (Sullivan Lake, Belly River A) has an initial in-place volume of 627 x 10^6 m^3. The mean pool area is 330 ha, mean net pay is 3.1 m, mean porosity is 28.3 per cent, and mean pool depth is 359 m. There have been 141 pools discovered in this play and the total discovered in-place volume is 6147 x 10^6 m^3 (Table 6), with a mean pool size of 44 x 10^6 m^3 of in-place gas.

Play potential

Estimates of the expected potential for this play indicate an in-place volume of 5088 x 10^6 m^3, representing approximately 45 per cent of the total play resources (Table 6). This estimate assumes a total pool population of 320, with an in-place volume for the largest undiscovered pool of 365 x 10^6 m^3 (Fig. 38). The potential gas resources in this play will likely be found in medium- to small-sized pools situated in east-central Alberta.

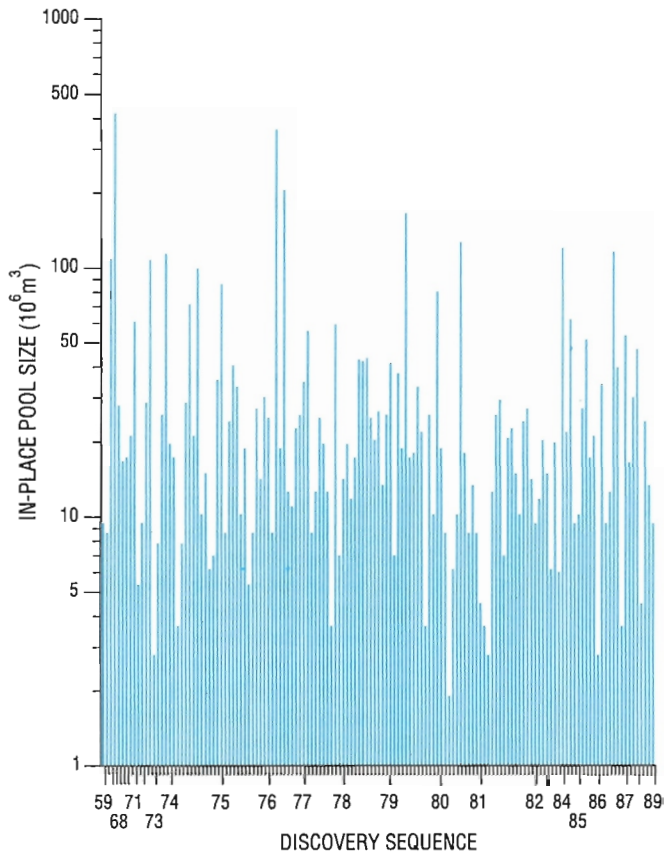


Figure 37. *Discovery sequence plot for Foremost Formation, Cycle 5 Shoreline play.*

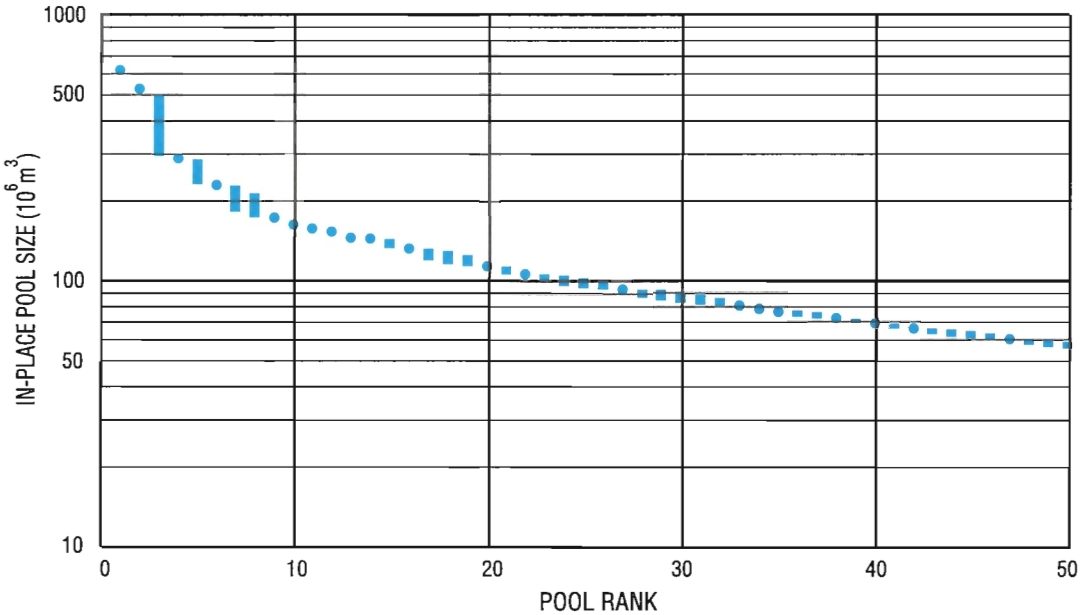


Figure 38. *Pool-size-by-rank plot for Foremost Formation, Cycle 5 Shoreline play, showing the top 50 pools (discovered and undiscovered).*

Table 6

Top 20 discovered pools and play resource summary, Foremost Formation, Cycle 5 Shoreline play

Pool rank	Field/Pool Name	Pool type	Discovered in-place volume (x 10^6 m^3)	Discovery date
1	Sullivan Lake, Belly River A	NA	627	67/08/01
2	Wayne-Rosedale, Belly River K	NA	534	77/04/30
4	Inland, Belly River G	NA	293	77/07/26
6	Wayne-Rosedale, Belly River Q	NA	233	80/06/30
9	Michichi, Belly River B	NA	176	81/04/14
10	Craigmyle, Belly River I	NA	166	84/09/04
11	Drumheller, Belly River J	NA	160	87/04/21
12	Sounding, Belly River B	NA	156	74/09/16
13	Wintering Hills, Belly River B	NA	148	63/05/15
14	Deer, Belly River	NA	147	73/05/12
16	Verger, Belly River B	NA	135	75/10/04
20	Majorville, Belly River A	NA	116	75/12/07
22	Cessford, Belly River T	NA	108	80/11/22
27	Dobson, Belly River A	NA	95	75/09/02
33	Spiers, Belly River C	NA	82	85/03/01
34	Sounding, Belly River A	NA	80	71/11/19
35	Spiers, Belly River B	NA	78	78/10/31
38	Matziwin, Belly River C	NA	73	78/03/08
40	Deer, BSL, Belly River C	NA	70	87/12/09
42	Aerial, Belly River A	NA	67	86/05/28
Initial in-place volume (discovered) (10^6 m^3)			6 147	
Initial in-place volume (potential) (10^6 m^3)			5 088	
Per cent play resources undiscovered			45	
Total pools discovered			141	
Total pool population			320	

NA, nonassociated gas

Foremost Formation ("Basal Belly River"), Cycle 6 Shoreline

Play definition

This established, mature play is defined to include all gas-bearing pools and prospects in nearshore and shoreline sandstones of Cycle 6 of the "Basal Belly River". It occurs in a large area of eastern Alberta, over the crest and along the east flank of the Sweetgrass Arch. The play area is limited on the west and east by the 5 m isopach of clean sandstone, and on the north and south by the outcrop belt of the unit (Fig. 39).

Geology

"Basal Belly River" Cycle 6 is present in Twps 5-50, Rges 25W3-15W4, over the crest of the Sweetgrass Arch, where the strata are nearly flat-lying. It has up to 60 m of clean sandstone and thins eastward as it

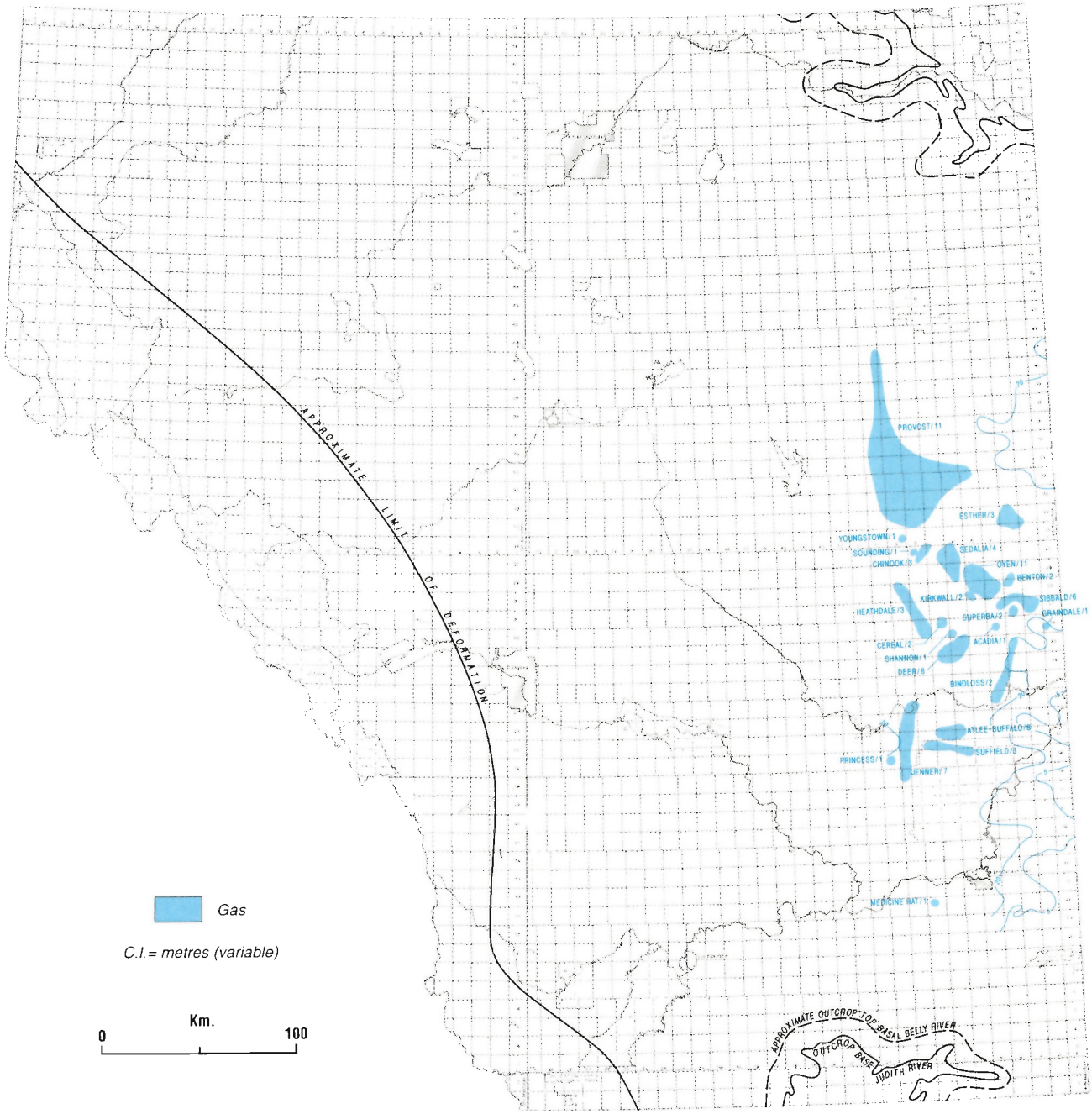


Figure 39. *Play area for Foremost Formation, Cycle 6 Shoreline play, showing locations of gas fields/pools and isopach values of cycle thickness.*

downlaps and pinches out into the mudstones of the Lea Park Formation 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 nearshore and shoreface facies. In addition, channelized sandstone units occur throughout. The updip pinchout of clean sandstone line follows an arcuate trace from Twp 5, Rge 1W4 to Twp 50, Rge 25W3. Gas reserves are contained in this cycle, especially in the area with greater than 20 m of clean sandstone.

Exploration history

The initial discovery well was drilled in Atlee-Buffalo Field in 1955 (Fig. 40; Table 7). Discovered gas pools are concentrated in the Suffield, Atlee–Buffalo, and Provost fields of southeastern Alberta. The largest discovered pool (Sedalia, Belly River D) has an initial in-place volume of 552 x 10^6 m^3. The mean pool area is 451 ha, mean net pay is 2.5 m, mean porosity is 29.8 per cent, and mean pool depth is 266 m. There have been 90 pools discovered in this play and the total discovered in-place volume is 4281 x 10^6 m^3 (Table 7), with a mean pool size of 48 x 106 m^3 of in-place gas.

Play potential

Estimates of the expected potential for this play indicate an in-place gas volume of 3406 x 10^6 m^3, representing approximately 44 per cent of the total play resources (Table 7). This estimate assumes a total pool population of 380, with an in-place volume for the largest undiscovered pool of 189 x 10^6 m^3 (Fig. 41). The potential gas resources in this play will likely be found in small pools situated in eastern Alberta, near the Saskatchewan border.

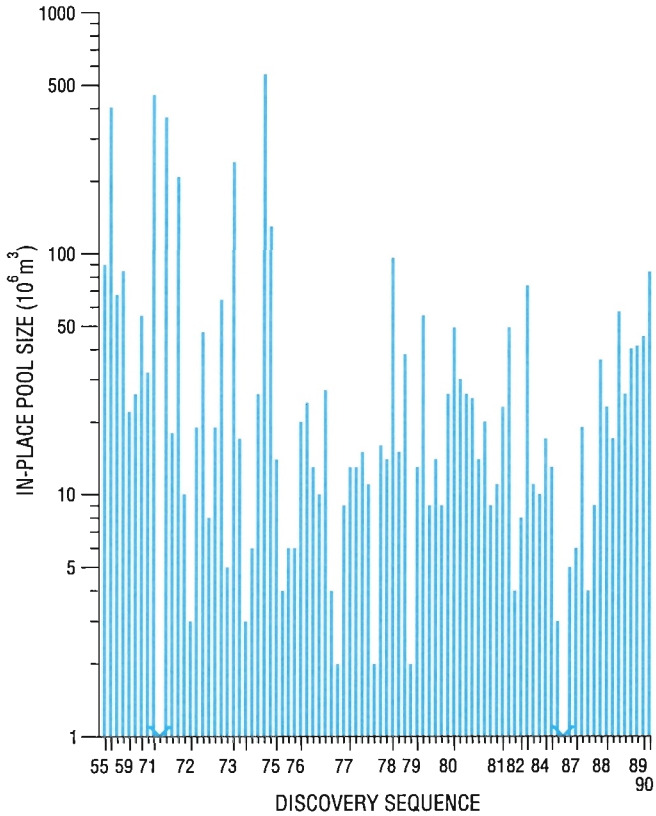


Figure 40. *Discovery sequence plot for Foremost Formation, Cycle 6 Shoreline play.*

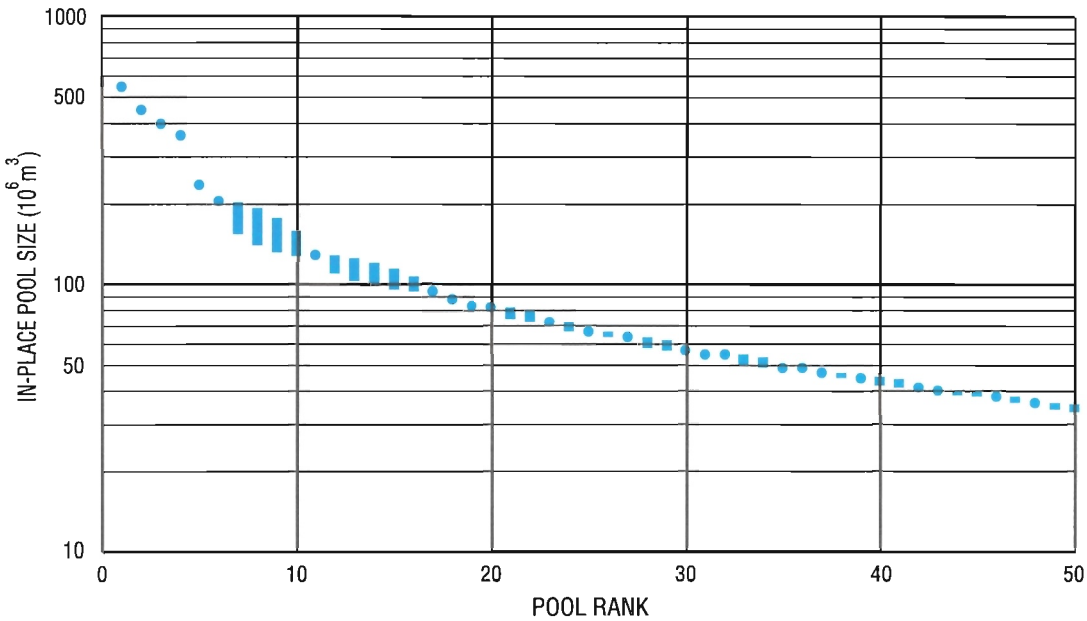


Figure 41. *Pool-size-by-rank plot for Foremost Formation, Cycle 6 Shoreline play, showing the top 50 pools (discovered and undiscovered).*

Table 7

Top 20 discovered pools and play resource summary, Foremost Formation, Cycle 6 Shoreline play

Pool rank	Field/Pool Name	Pool type	Discovered in-place volume (x 10^6 m^3)	Discovery date
1	Sedalia, Belly River D	NA	552	75/08/10
2	Provost, Belly River B	NA	454	71/11/16
3	Esther, Belly River A	NA	404	56/10/16
4	Chinook, Belly River A	NA	367	72/09/08
5	Sedalia, Belly River B	NA	239	73/12/09
6	Oyen, Belly River B	NA	208	72/10/19
11	Sedalia, Belly River E	NA	130	75/08/10
17	Provost, Belly River K	NA	95	78/06/28
18	Atlee-Buffalo, Belly River G	NA	89	55/01/05
19	Jenner, Belly River D	NA	84	59/10/29
20	Oyen, Belly River D	NA	83	90/06/28
23	Sedalia, Belly River	NA	73	83/12/22
25	Heathdalem, Belly River	NA	67	59/03/03
27	Atlee-Buffalo, Foremost A	NA	64	73/09/16
30	Atlee-Buffalo, Foremost	NA	57	89/05/31
31	Provost, Belly River M	NA	55	67/05/31
32	Atlee-Buffalo, Foremost B	NA	55	80/08/12
35	Heathdale, Belly River	NA	49	82/10/15
36	Sibbald, Belly River	NA	49	80/12/14
37	Cereal, BSL, Belly River	NA	47	73/06/29
Initial in-place volume (discovered) (10^6 m^3)			4 281	
Initial in-place volume (potential) (10^6 m^3)			3 406	
Per cent play resources undiscovered			44	
Total pools discovered			90	
Total pool population			380	

NA, nonassociated gas

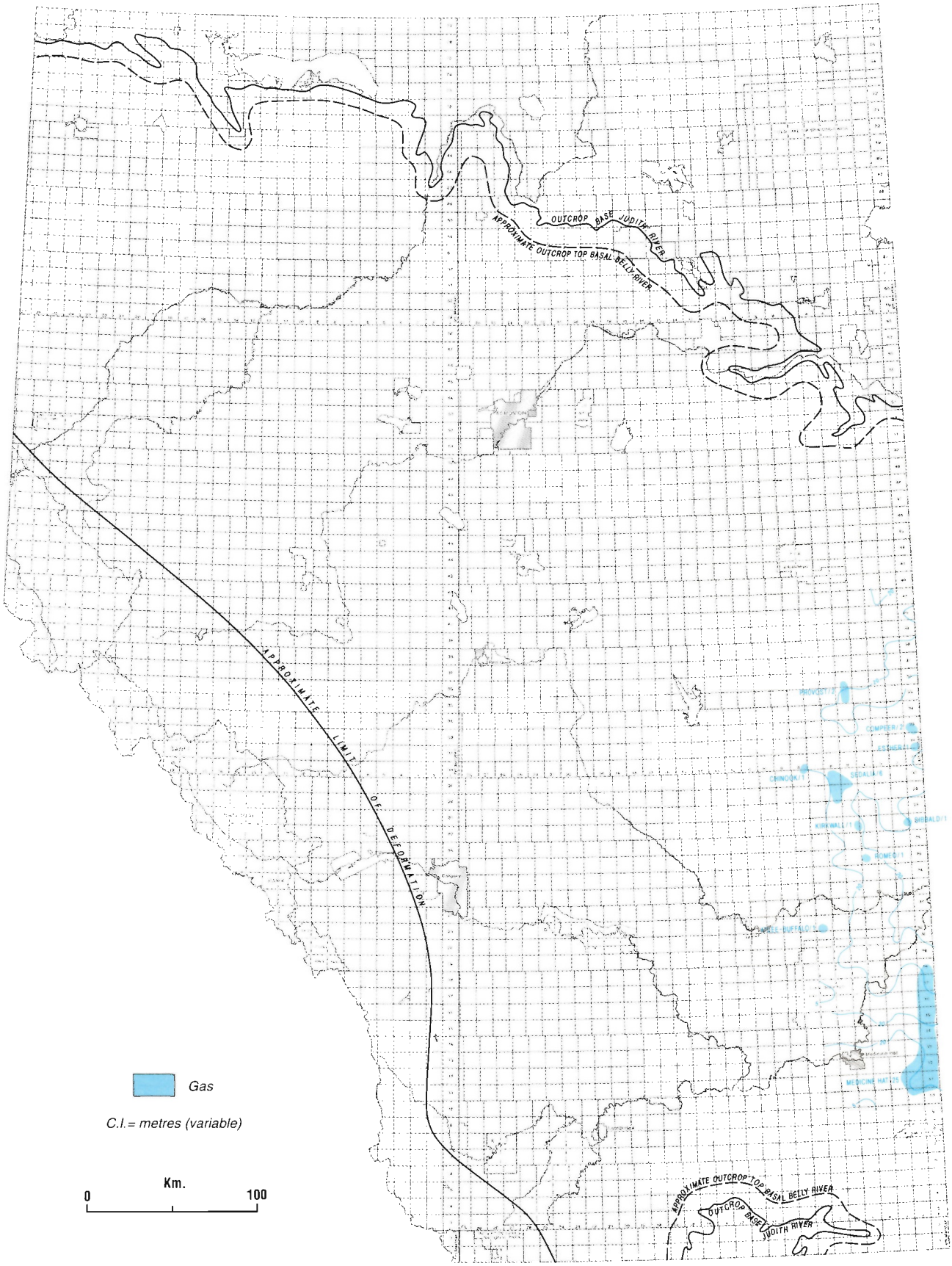


Figure 42. *Play area for Foremost Formation, Cycle 7 Shoreline play, showing locations of gas fields/pools and isopach values of cycle thickness.*

Foremost Formation ("Basal Belly River"), Cycle 7 Shoreline

Play definition

This established, mature play is defined to include all gas-bearing pools and prospects in nearshore and shoreline sandstones of Cycle 7 of the "Basal Belly River". It includes a large area in eastern Alberta and part of western Saskatchewan, over the crest and along the east flank of the Sweetgrass Arch. The play area is limited on the west and east by the 5 m isopach of clean sandstone, and on the north and south by the outcrop belt of the unit (Fig. 42).

Geology

"Basal Belly River" Cycle 7 is present in Twps 5-45, Rges 25W3-10W4 in eastern Alberta and western Saskatchewan, over the crest and on the east flank of the Sweetgrass Arch, where the strata are nearly flat-lying. It has up to 35 m of clean sandstone and thins eastward as it downlaps and pinches out into the mudstones of the Lea Park Formation in the subsurface, over a distance of about 100 km. It generally comprises a coarsening-upward sequence of mudstone, siltstone, and sandstone and is interpreted as a complex of prograding nearshore and shoreface facies. In addition, channelized sandstone units occur throughout. The pinchout of clean sandstone follows an arcuate trace from Twp 5, Rge 27W3 to Twp 45, Rge 25W3. Gas reserves are contained in this cycle in the area with greater than 20 m of clean sandstone.

Exploration history

The initial discovery well was drilled in Whiteside Field in 1962 (Fig. 43; Table 8). Discovered gas pools are concentrated in the Medicine Hat field, with some in the Sedalia and western Saskatchewan areas. The largest discovered pool (Sedalia, Belly River A) has an initial in-place volume of 1464 x 10^6 m^3. The mean pool area is 577 ha, mean net pay is 3.0 m, mean porosity is 30.3 per cent, and mean pool depth is 202 m. There have been 46 pools discovered in this play and the total discovered in-place volume is 3552 x 10^6 m^3 (Table 8), with a mean pool size of 77 x 10^6 m^3 of in-place gas.

Play potential

Estimates of the expected potential for this play indicate an in-place volume of 6666 x 10^6 m^3, representing approximately 65 per cent of the total play resources (Table 8). This estimate assumes a total pool population of 280, with an in-place volume for the largest undiscovered pool of 789 x 10^6 m^3 (Fig. 44). The potential gas resources in this play will likely be found in medium- to small-sized pools situated in a belt straddling the southern Alberta-Saskatchewan border.

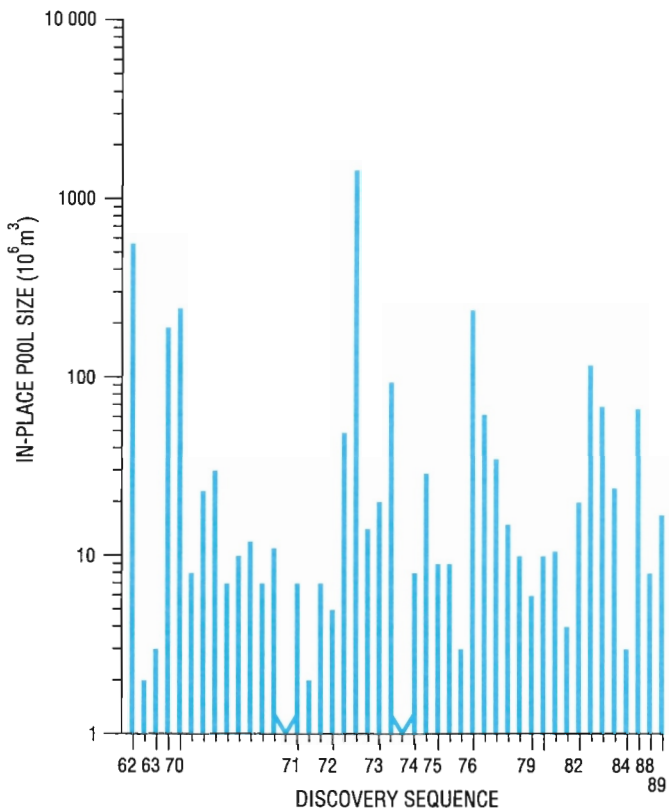


Figure 43. *Discovery sequence plot for Foremost Formation, Cycle 7 Shoreline play.*

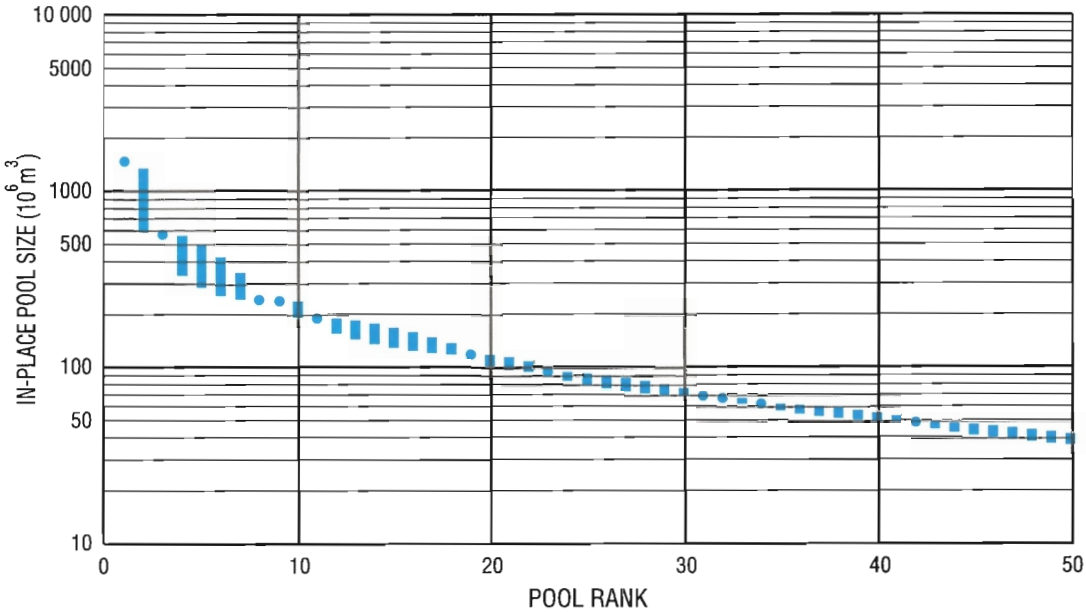


Figure 44. *Pool-size-by-rank plot for Foremost Formation, Cycle 7 Shoreline play, showing the top 50 pools (discovered and undiscovered).*

Table 8

Top 20 discovered pools and play resource summary, Foremost Formation, Cycle 7 Shoreline play

Pool rank	Field/Pool Name	Pool type	Discovered in-place volume (x 10^6 m^3)	Discovery date
1	Sedalia, Belly River A	NA	1 464	73/07/23
3	Whiteside, Ribstone Crk Sand	NA	564	62/00/00
8	Medicine Hat, Belly River C	NA	244	70/10/20
9	Sedalia, Belly River L	NA	240	76/10/15
11	Medicine Hat, Belly River A	NA	190	66/10/29
19	Whiteside West, Ribstone Crk Sand	NA	118	84/00/00
23	Medicine Hat, Belly River FF	NA	94	74/09/25
31	Esther, BSL, Belly River	NA	69	84/03/01
32	Atlee-Buffalo, Belly River D	NA	67	85/07/31
34	Provost, Belly River N	NA	62	79/01/28
42	Medicine Hat, Belly River GG	NA	49	73/06/24
54	Provost, Belly River	NA	35	79/03/08
60	Medicine Hat, Belly River N	NA	30	71/10/19
62	Chinook, Belly River	NA	29	75/10/25
70	Medicine Hat, Belly River JJ	NA	24	84/11/02
72	Medicine Hat, Belly River R BB	NA	23	71/10/15
78	Sedalia, Belly River J	NA	20	73/12/09
79	Sedalia, Belly River K	NA	20	82/11/24
87	Compeer, BSL, Belly River	NA	17	89/08/10
94	Medicine Hat, Belly River CC	NA	15	79/02/28
Initial in-place volume (discovered) (10^6 m^3)			3 552	
Initial in-place volume (potential) (10^6 m^3)			6 666	
Per cent play resources undiscovered			65	
Total pools discovered			46	
Total pool population			280	

NA, nonassociated gas

Foremost Formation ("Basal Belly River") Fluvial

Play definition

This established, mature play is defined to include all gas-bearing pools and prospects 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. 45).

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 coals, 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). The nonmarine portion of the Foremost Formation is present over a very large area, in Twps 5 to 65, Rges 10W4 to 27W5 in western Alberta. It 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. Large gas reserves are contained in this composite unit, in a large number of small pools.

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. The source of the hydrocarbons is probably the adjacent and interbedded coal.

Exploration history

The initial discovery well was drilled in 1945 (Fig. 46). A very large number of gas pools have been discovered in this play and they are concentrated in the Hussar, Entice, Rowley, Fenn, Huxley, Willisden Green, and Pembina areas. The largest discovered pool (Bashaw, Belly River C) has an initial in-place volume of 1589 x 10^6 m^3. The mean pool area is 310 ha, mean net pay is 3.6 m, mean porosity is 23.7 per cent, and mean pool depth is 695 m. There have been 452 pools discovered in this play and the total discovered in-place volume is 23 252 x 10^6 m^3 (Table 9), with a mean pool size of 51 x 10^6 m^3 of in-place gas.

Play potential

Estimates of the expected potential for this play indicate an in-place volume of 18 547 x 10^6 m^3, representing approximately 44 per cent of the total play resources (Table 9). This estimate assumes a total pool population of 1280, with an in-place volume for the largest undiscovered pool of 882 x 10^6 m^3 (Fig. 47). This play is ranked second in discovered resources, second in expected potential, third in probable potential, and third in largest undiscovered pool size, suggesting an encouraging resource distribution (Tables 15, 16, 17, 19). The potential gas resources in this play will likely be found in medium- to small-sized pools, situated in central and southern Alberta.

Figure 45. *Play area for Foremost Formation, Fluvial play.*

Figure 45. *(cont'd.)*

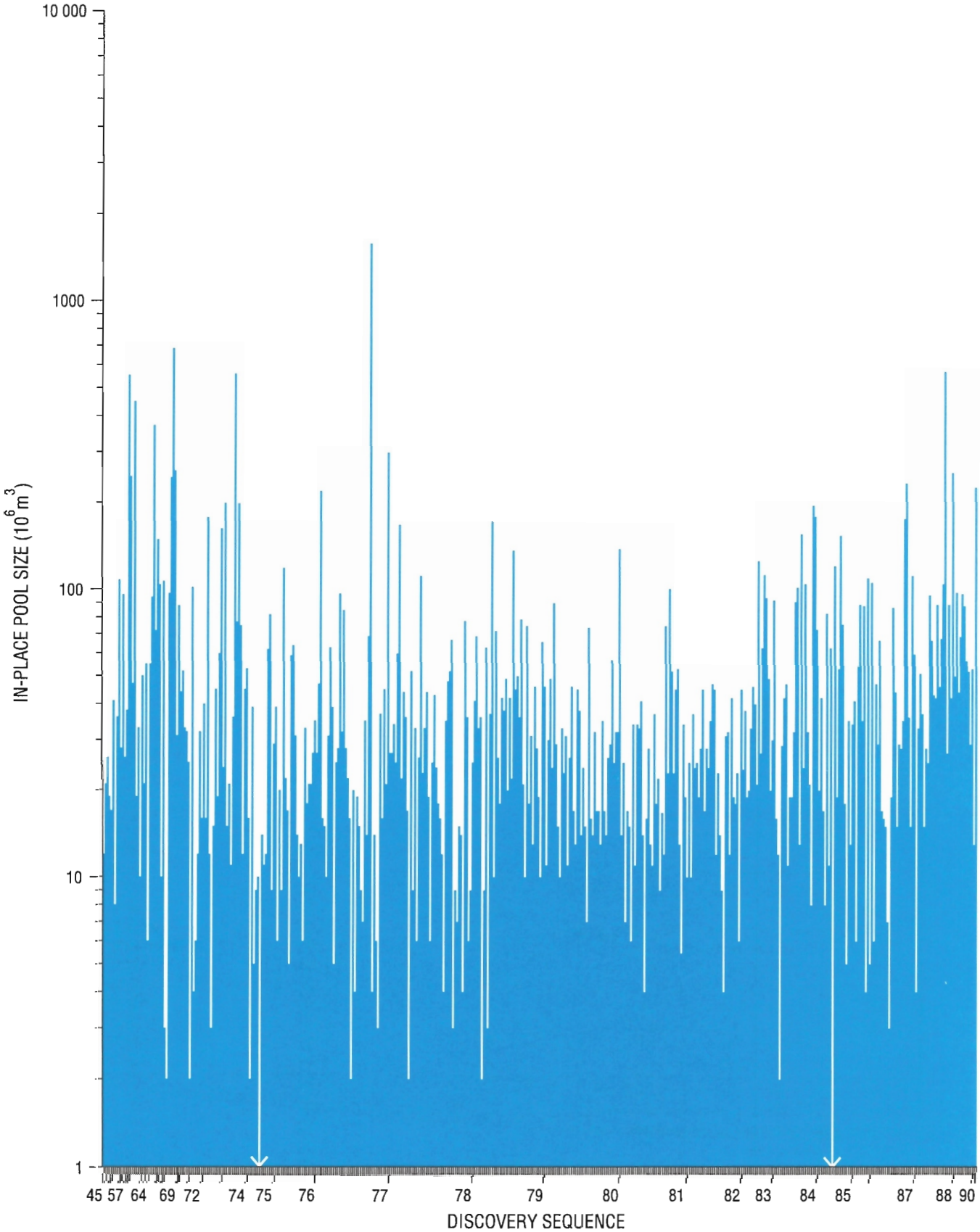


Figure 46. *Discovery sequence plot for Foremost Formation, Fluvial play.*

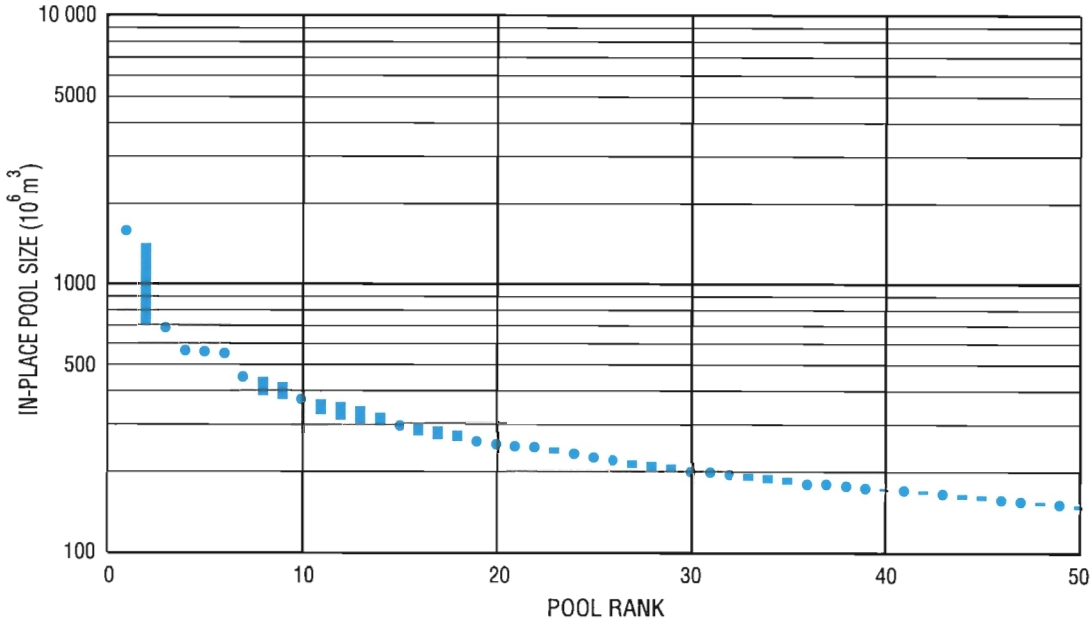


Figure 47. *Pool-size-by-rank plot for Foremost Formation, Fluvial play, showing the top 50 pools (discovered and undiscovered).*

Table 9

Top 20 discovered pools and play resource summary, Foremost Formation, Fluvial play

Pool rank	Field/Pool Name	Pool type	Discovered in-place volume (x 10^6 m^3)	Discovery date
1	Bashaw, Belly River C	NA	1 589	77/06/12
3	Entice, Belly River B	NA	687	69/10/04
4	Seiu Lake, Belly River B	NA	567	88/09/22
5	Entice, Belly River P	NA	562	74/09/12
6	Wayne-Rosedale, Belly River A	NA	554	60/07/07
7	Willesden Green, Belly River A	SG	450	61/05/29
10	Willesden Green, Belly River G	NA	372	65/02/05
15	Shaunicy, Belly River	NA	299	77/11/16
19	Mikwan, Belly River A	NA	259	69/12/13
20	Three Hills Creek, Belly River D	NA	253	88/10/20
21	Willesden Green, Belly River E	NA	247	61/02/01
22	Gayford, Belly River A	NA	245	69/09/11
24	Willesden Green, BSL, Belly River	NA	232	87/10/20
25	Chain, Belly River D	NA	225	90/06/20
26	Highvale, Belly River A	NA	220	77/01/31
30	Sedalia, Belly River H	NA	200	74/02/16
31	Entice, Belly River F	NA	199	74/09/18
32	Ewing Lake, Belly River B	NA	195	84/10/02
36	Hastings, Belly River A	NA	178	73/07/13
37	Gadsby, Belly River	NA	178	84/10/17
Initial in-place volume (discovered) (10^6 m^3)			23 252	
Initial in-place volume (potential) (10^6 m^3)			18 547	
Per cent play resources undiscovered			44	
Total pools discovered			452	
Total pool population			1 280	

NA, nonassociated gas; SG, sour gas

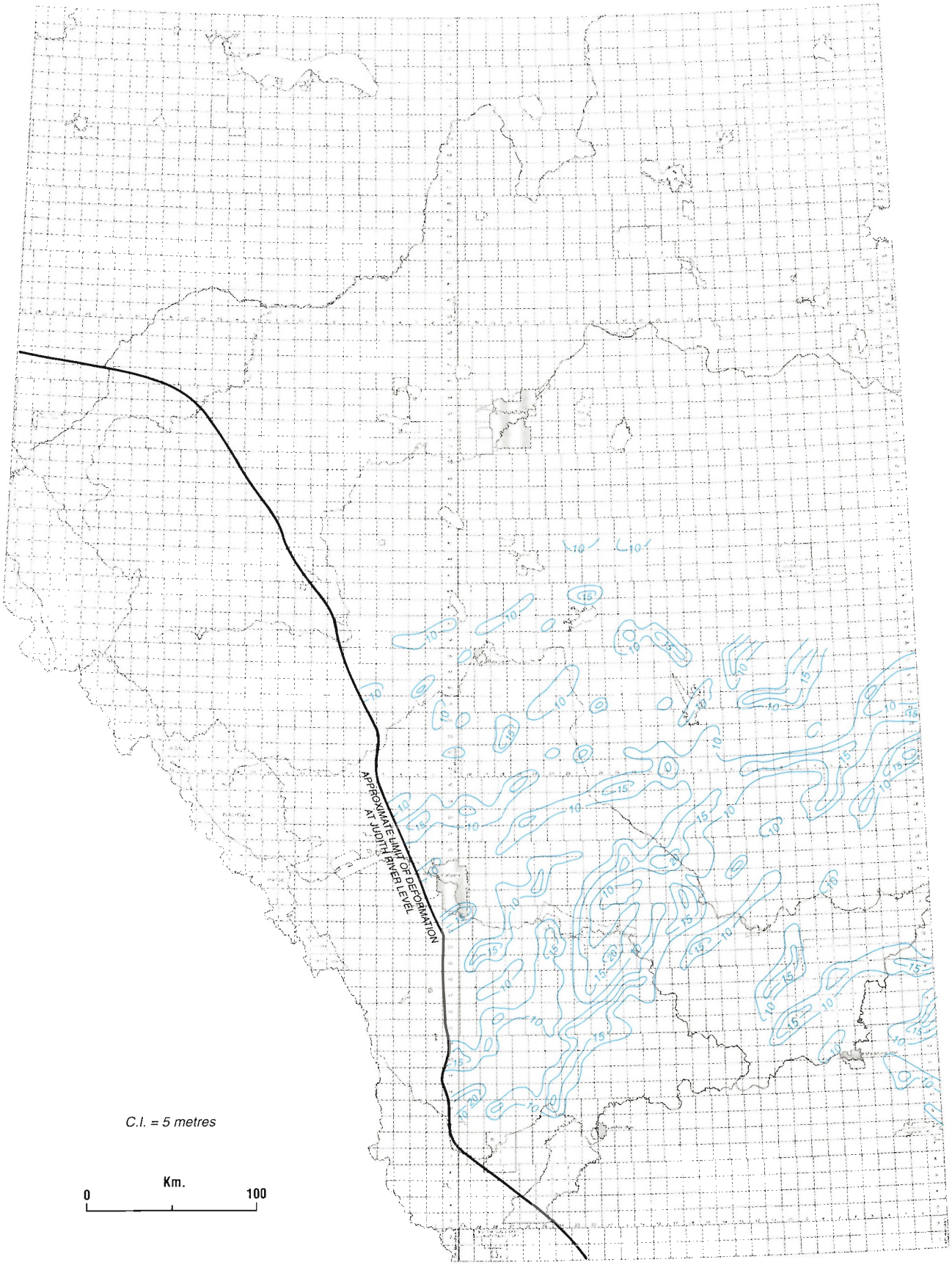


Figure 48. *Play area for Oldman Formation, Fluvial play.*

Oldman Formation (Comrey Member), Fluvial

Play definition

This established, mature play is defined to include all gas-bearing pools and prospects in the extensive sandstones of the Comrey Member in the lower part of the Oldman Formation (Belly River Group). These deposits lie above the fluvial and shoreline-related facies of the Foremost Formation, immediately above the Taber Coal Zone, and are overlain by a distinct fine grained unit that persists throughout central Alberta. The play occurs in a large area of central and western Alberta, defined on the east by pinchout, on the west by the limit of deformation, and on the north and south by the outcrop belt of the unit (Fig. 48). This stratigraphic unit, and play, traditionally have not been recognized as a specific target by explorationists.

Geology

Dowling (1917) recognized, and Russell and Landes (1940) named the Oldman Formation, which overlies the Foremost strata in southern Alberta. The "Comrey Member" (Russell and Landes, 1940) sandstone lies in the lower portion of the Oldman and is exposed in outcrops along the Milk River, in Twps 1 and 2, Rges 5-7W4 (Glass, 1990). In outcrop, the Comrey consists of crossbedded, fine to medium grained sandstone, with minor conglomerate and caliche zones, arranged in multi-storied, scour-based bodies interpreted as low-sinuosity channels (Troke et al., 1992). Paleocurrent data suggest fluvial flow to the northeast. Comrey deposition was followed by a marine incursion (Troke et al., 1992). The Comrey Member is present in Twps 5-55, Rges 1W4-10W5, across southern Alberta (Hamblin, 1994a, b). It has up to 25 m of clean sandstone. Significant gas reserves are contained in this unit in a large number of small pools.

The overlying fine grained unit provides the vertical seal for the pools contained in Comrey sandstone bodies, creating many stratigraphic traps. The source of hydrocarbons may be the adjacent and interbedded coals.

Exploration history

The initial discovery well was drilled in 1969 (Fig. 49). Discovered gas pools are concentrated in the Wayne-Rosedale, Twining, Provost, and Bashaw fields. The largest discovered pool (Nevis, BR C No. 1) has an initial in-place volume of 1846 x 10^6 m^3. The mean pool area is 556 ha, mean net pay is 3.2 m, mean porosity is 25.9 per cent, and mean pool depth is 526 m. There have been 43 pools discovered in this play and the total discovered in-place volume is 3179 x 10^6 m^3 (Table 10), with a mean pool size of 74 x 10^6 m^3 of in-place gas.

Play potential

Estimates of the expected potential for this play indicate an in-place volume of 15 691 x 10^6 m^3, representing approximately 83 per cent of the total play resource (Table 10). This estimate assumes a total pool population of 1000, with an in-place volume for the largest undiscovered pool of 323 x 10^6 m^3 (Fig. 50). Although this play is ranked tenth in discovered resource, it is ranked fourth in expected potential and fourth in probable potential (Tables 15, 16, 17). The potential gas resources in this play will likely be found in small pools situated throughout central and southern Alberta.

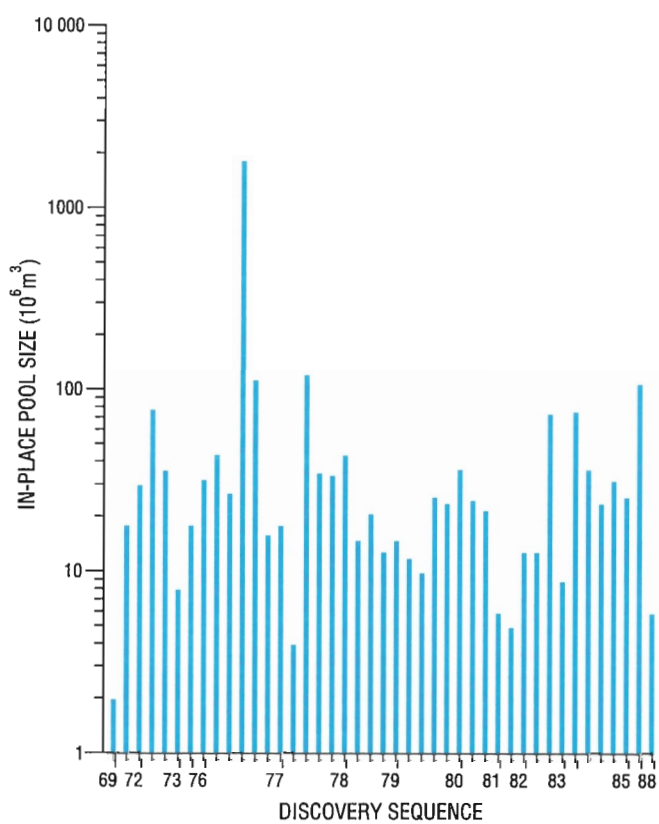


Figure 49. *Discovery sequence plot for Oldman Formation, Fluvial play.*

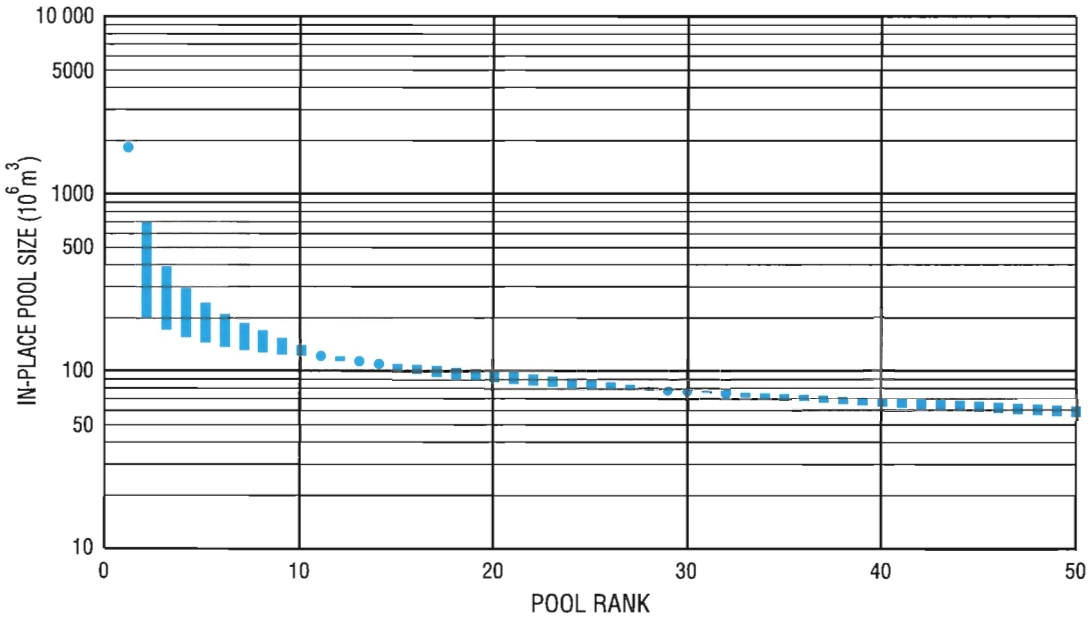


Figure 50. *Pool-size-by-rank plot for Oldman Formation, Fluvial play, showing the top 50 pools (discovered and undiscovered).*

Table 10

Top 20 discovered pools and play resource summary, Oldman Formation, Fluvial play

Pool rank	Field/Pool Name	Pool type	Discovered in-place volume (x 10^6 m^3)	Discovery date
1	Nevis, Belly River C No. 1 Pool	NA	1 846	77/06/12
11	Twining, Belly River F	NA	122	78/08/05
13	Highvale, Belly River	NA	114	77/06/17
14	Highvale, Belly River	NA	110	87/05/31
29	Minnehik-Buck Lk, BSL, Belly River	NA	78	73/03/02
30	Bruce, Belly River M	NA	77	84/05/25
32	Homeglen-Rimbey, Belly River	NA	75	83/06/22
82	Sangudo, Belly River	NA	44	77/03/08
83	Wayne-Rosedale, Belly River H	NA	44	78/11/25
108	Bashaw, Belly River	NA	37	80/11/28
109	Bruce Belly River	NA	37	85/02/01
113	Provost, Belly River D	NA	36	73/07/17
118	Wayne-Rosedale, Belly River J	NA	35	78/10/21
123	Hussar, Belly River K	NA	34	71/10/27
133	Gartley, Belly River	NA	32	85/03/05
134	Watelet, Belly River	NA	32	76/12/30
147	Provost, Belly River H	NA	30	72/08/10
170	Hussar, U Belly River	NA	27	77/05/14
177	Morinville, Belly River	NA	26	85/07/26
178	Watelet, Belly River	NA	26	80/11/22
Initial in-place volume (discovered) (10^6 m^3)			3 179	
Initial in-place volume (potential) (10^6 m^3)			15 691	
Per cent play resources undiscovered			83	
Total pools discovered			43	
Total pool population			1 000	

NA, nonassociated gas

Dinosaur Park Formation, Estuarine Valley-fill

Play definition

This established, mature play is defined to include all gas-bearing pools and prospects of the thick, lower sandstones of the Dinosaur Park Formation at the top of the Belly River Group. These strata lie above the Oldman Formation (Comrey Member fluvial facies and a distinct fine-grained unit that persist throughout central Alberta), and a regionally mappable discontinuity surface (Eberth and Hamblin, 1993; Hamblin, 1994c, d). The Dinosaur Park Formation is capped by the Lethbridge Coal Zone, in turn overlain by the transgressive marine shales of the Bearpaw Formation. The play occurs in a large area of west-central and southwestern Alberta, defined on the north and east by surface outcrop, on the west by the limit of deformation, and on the south by pinchout of the unit (Fig. 51). This stratigraphic unit and play, traditionally have not been recognized as a specific target by explorationists.

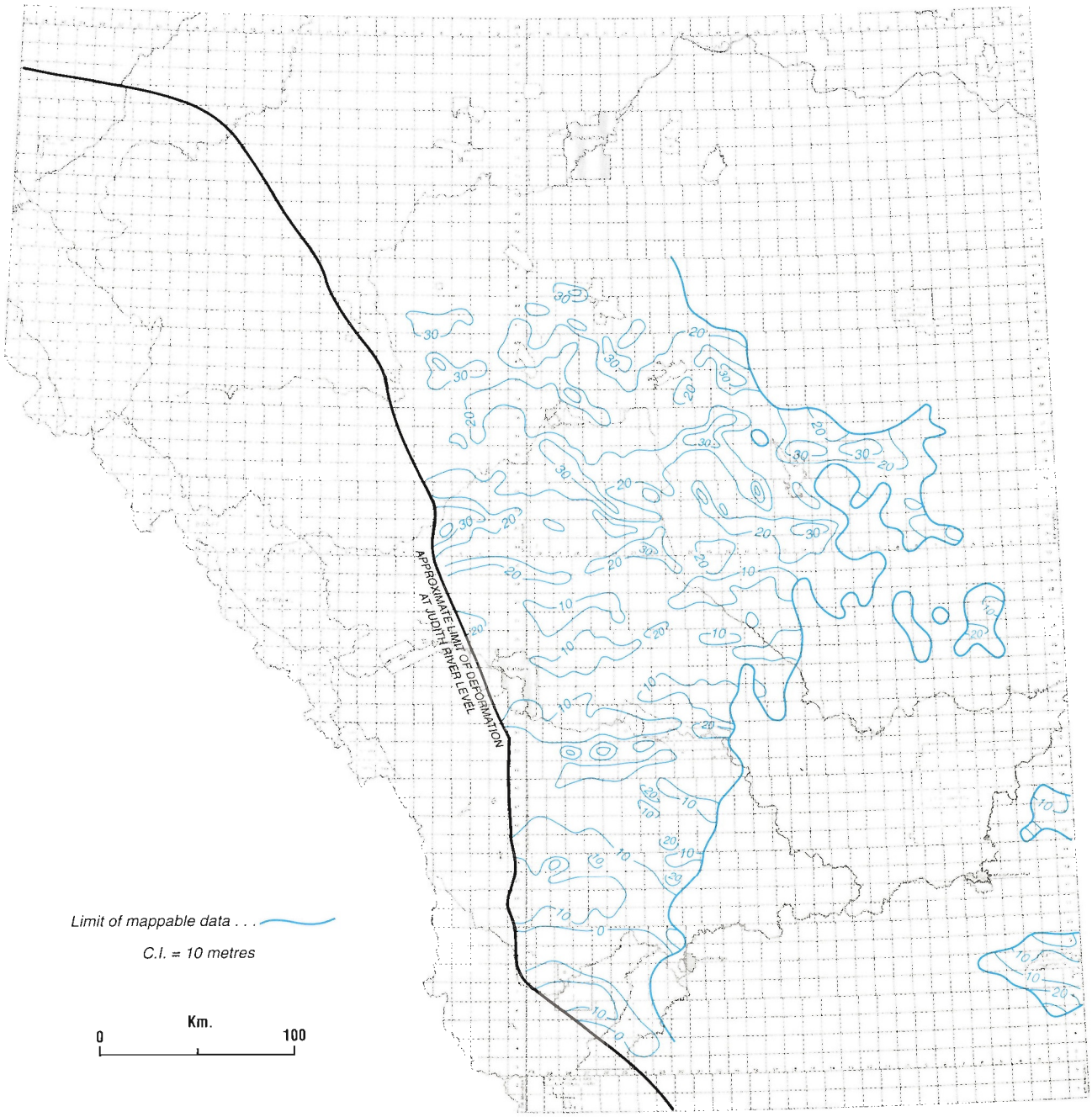


Figure 51. *Play area for Dinosaur Park Formation, Valley-fill play, showing isopachs of clean sandstone.*

Geology

Eberth and Hamblin (1993) redefined the Oldman Formation and established the Dinosaur Park Formation as the upper unit in the clastic wedge. The Dinosaur Park Formation is extensively exposed in Dinosaur Provincial Park, and along the Red Deer and South Saskatchewan rivers in eastern Alberta (Twps 12-23, Rges 1-15W4). The base of the formation is marked by a regional discontinuity, with localized erosion, and it is characterized by thick, multi-storied channel-fill of medium to coarse grained sandstone enclosed in interchannel siltstone (Eberth and Hamblin, 1993). These channel deposits are oriented toward the east or southeast, and are interpreted to have been deposited under the influence of tides (Eberth, 1990).

The Dinosaur Park Formation is present over a very large area in Twps 10-60, Rges 1W4-27W5, throughout southern Alberta. It has up to 40 m of clean sandstone and thins southward to zero in Twp 10. Moderate gas reserves are contained in this unit in a number of small pools. The interbedded fine grained deposits and the overlying thick, Bearpaw shale provide the vertical seal for the pools contained in channel sandstones, creating many stratigraphic traps. The source of hydrocarbons may be the adjacent Bearpaw shales, or the under- and overlying coals.

Exploration history

The initial discovery well was drilled in 1961 (Fig. 52). A large number of discovered gas pools are concentrated in the Herronton, Swalwell, Huxley, and Bashaw fields of south-central Alberta. The largest discovered pool (Carbon, Belly River C) has an initial in-place volume of 274 x 10^6 m^3. The mean pool area is 278 ha, mean net pay is 3.4 m, mean porosity is 25.2 per cent, and mean pool depth is 503 m. There have been 137 pools discovered in this play and the total discovered in-place volume is 4686 x 10^6 m^3 (Table 11), with a mean pool size of 34 x 10^6 m^3 of in-place gas.

Play potential

Estimates of the expected potential for this play indicate an in-place volume of 25 283 x 10^6 m^3, representing approximately 84 per cent of the total play resource (Table 11). This estimate assumes a total pool population of 2000, with an in-place volume for the largest undiscovered pool of 197 x 10^6 m^3 (Fig. 53). Although this play is ranked seventh in order of discovered gas volume, it is ranked first in order of expected potential gas volume and second in probable potential (Tables 15, 16, 17). The potential gas resources in this play will likely be found in small pools throughout central Alberta.

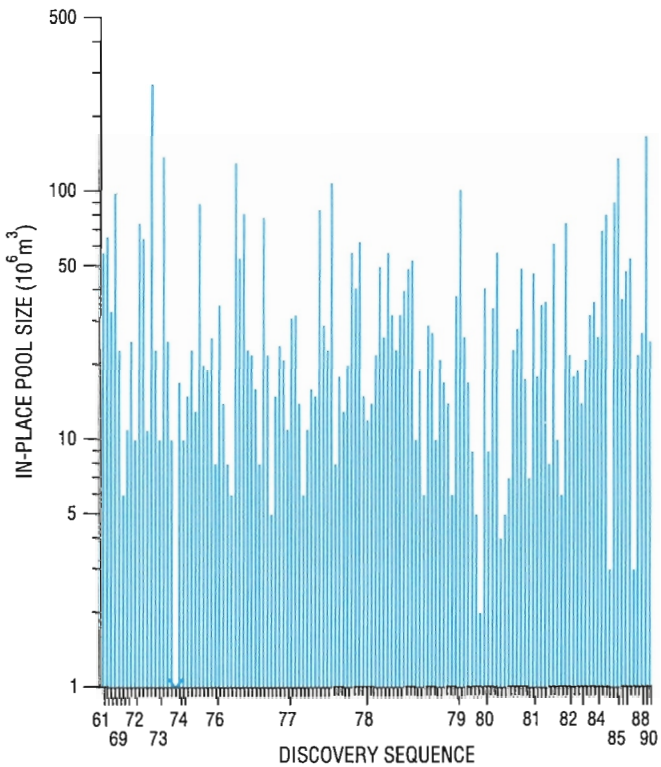


Figure 52. *Discovery sequence plot for Dinosaur Park Formation, Valley-fill play.*

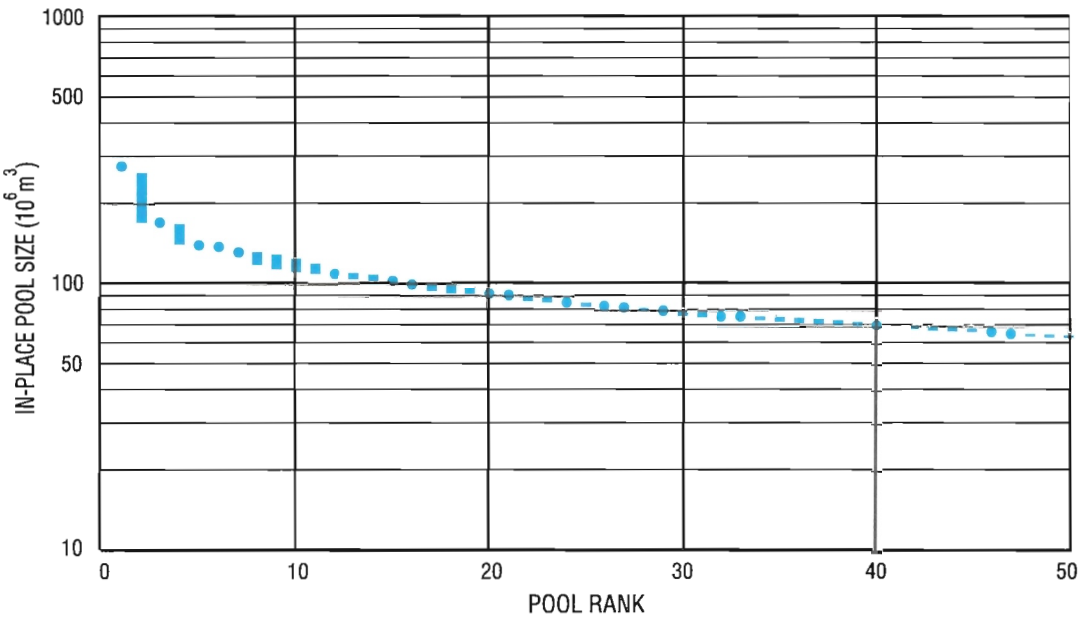


Figure 53. *Pool-size-by-rank plot for Dinosaur Park Formation, Valley-fill play, showing the top 50 pools (discovered and undiscovered).*

Table 11

Top 20 discovered pools and play resource summary, Dinosaur Park Formation, Valley-fill play

Pool rank	Field/Pool Name	Pool type	Discovered in-place volume (x 10^6 m^3)	Discovery date
1	Carbon, Belly River C	NA	274	73/07/29
3	Provost, Belly River X	NA	168	89/11/23
5	Barrhead, Belly River	NA	139	74/03/20
6	Watelet, Belly River	NA	137	85/10/20
7	Leduc-Woodbend, Belly River	NA	131	77/03/17
12	Carvel, Belly River	NA	109	78/08/02
15	Farrow, Belly River B	NA	102	80/01/24
16	Provost, Belly River A	NA	99	68/09/20
20	Pembina, Belly River	NA	91	85/09/29
21	Swalwell, Belly River A	NA	90	76/07/05
24	Huxley, Belly River D	NA	85	78/06/09
26	Three Hills Creek, Belly River	NA	82	77/06/22
27	Whitecourt, Belly River J	NA	81	85/02/06
29	Delia, Belly River	NA	79	77/10/23
32	Dorenlee, Belly River	NA	75	82/11/28
33	Herronton, Belly River C	NA	75	73/05/20
40	Pembina, Belly River	NA	70	85/01/16
46	Ardenode, Belly River	NA	66	64/10/12
47	Herronton, Belly River K	NA	65	73/05/20
51	Hussar, Belly River M	NA	63	78/12/01
Initial in-place volume (discovered) (10^6 m^3)			4 686	
Initial in-place volume (potential) (10^6 m^3)			25 283	
Per cent play resources undiscovered			84	
Total pools discovered			137	
Total pool population			2 000	

NA, nonassociated gas

Edmonton Group plays

Edmonton Group, shoreline

Play definition

This established, mature play is defined to include all gas-bearing pools and prospects in nearshore and shoreline sandstones of the lower Edmonton Group (lower Horseshoe Canyon Formation). It occurs in a large area of west-central and northwestern Alberta. The play area is defined on the west and southwest by the limit of deformation, and on the east and north by the outcrop belt of the unit (Fig. 54).

Geology

The Edmonton Group/St. Mary River Formation/ Eastend Formation, fluvio-deltaic clastic wedge (mid to late Maastrichtian age) is a sequence of complexly interfingering, fresh to brackish and nonmarine strata that thicken rapidly to the west (Gibson, 1977; Elliot, 1960). It is underlain and interfingers with the Bearpaw marine shale, and is disconformably overlain by the Scollard clastic wedge. The entire clastic wedge thins eastward from about 500 m in the southern Foothills (Williams and Dyer, 1930; Glass, 1990) to 250 m along the Red Deer River (Allan and Sanderson, 1945; Ower, 1960), to about 36 m thick in the Cypress Hills

Figure 54. *Play area for Edmonton Group, Shoreline play. Dots indicate locations of discovery wells for each pool in the play.*

(Furnival, 1950). The lower portion (lower Horseshoe Canyon/Blood Reserve/Eastend) includes a series of sandy tongues that extend basinward into the Bearpaw shale. The strata are lower delta-plain, estuarine, and shoreline complexes related to an embayed shoreline oriented west-southwest, with an open sea to the south (Gibson, 1977; Rahmani, 1983).

In southwestern Alberta, the Blood Reserve Formation consists of uniform, fine- to medium-grained sandstone in a coarsening-upward sequence interpreted as tidally influenced shoreline deposits, which include tidal channel and shoreline sandstone facies that prograded eastward into the southern portion of the Bearpaw sea (Young and Reinson, 1975; Nadon, 1988). In central Alberta, the Bearpaw–Horseshoe Canyon transition includes several tongues that have coarsening-upward, deltaic or barrier island sandstone units oriented northeast, and tidal channel sandstones oriented northwest (Shepheard and Hills, 1970; Rahmani, 1983). In Cypress Hills, the Eastend Formation (Horseshoe Canyon-equivalent) is the shoreline transition from the underlying Bearpaw Formation. It comprises fine- to medium-grained, coarsening-upward sandstone, with minor siltstone and coaly interbeds toward the top (Russell and Landes, 1940; Furnival, 1950).

Shoreline deposits of the lower Horseshoe Canyon Formation are present in the subsurface from about Twps 5 to 55, Rge 15W4 to the disturbed belt in the west. Minor gas reserves are contained in a small number of small pools. The overlying nonmarine, fine grained deposits and the thin marine shale tongues that separate the shoreline-related sandstone tongues are the vertical seal for the pools, and updip to the east or southeast, the pinchout of clean sandstone also may create stratigraphic traps. The source of hydrocarbons may be the underlying Bearpaw marine shales, or the adjacent nonmarine, coal-bearing strata.

Exploration history

The initial discovery well was drilled in Sylvan Lake Field in 1960 (Fig. 55; Table 12). Discovered gas pools are concentrated in the Leo, Bashaw, and Pembina fields. The largest discovered pool (Bashaw, Edmonton pool No. 1) has an initial in-place volume of 862 x 10^6 m^3. The mean pool area is 1146 ha, mean net pay is 3.3 m, mean porosity is 23.8 per cent, and mean pool depth is 446 m. There have been 18 pools discovered in this play and the total discovered in-place volume is 1237 x 10^6 m^3 (Table 12), with a mean pool size of 72 x 10^6 m^3 in-place gas.

Play potential

Estimates of the expected potential for this play indicate an in-place volume of 9714 x 10^6 m^3, representing approximately 89 per cent of the total play resource (Table 12). This estimate assumes a total pool population of 580, with an in-place volume for the largest undiscovered pool of 324 x 10^6 m^3 (Fig. 56). The potential gas resources in this play will likely be found in small pools located in west-central Alberta.

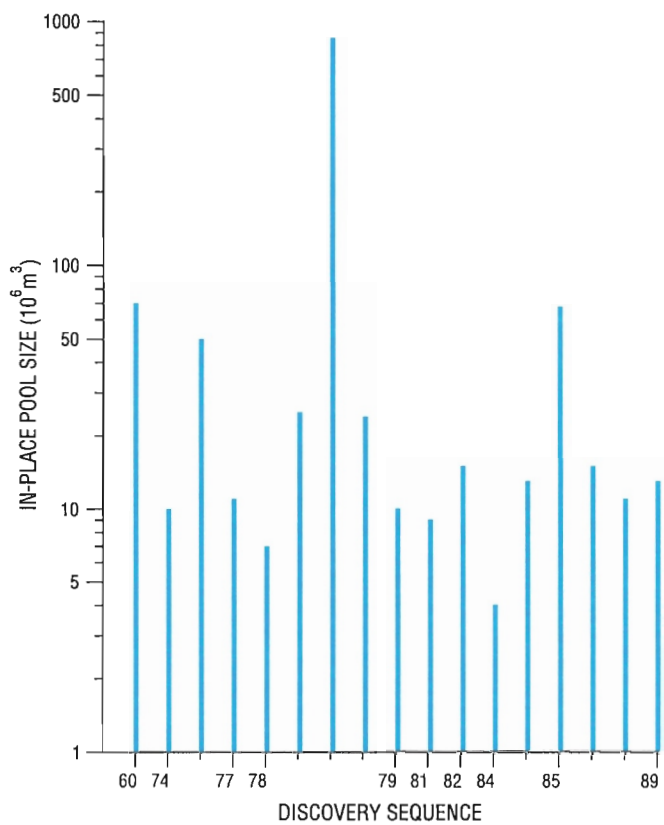


Figure 55. *Discovery sequence plot for Edmonton Group, Shoreline play.*

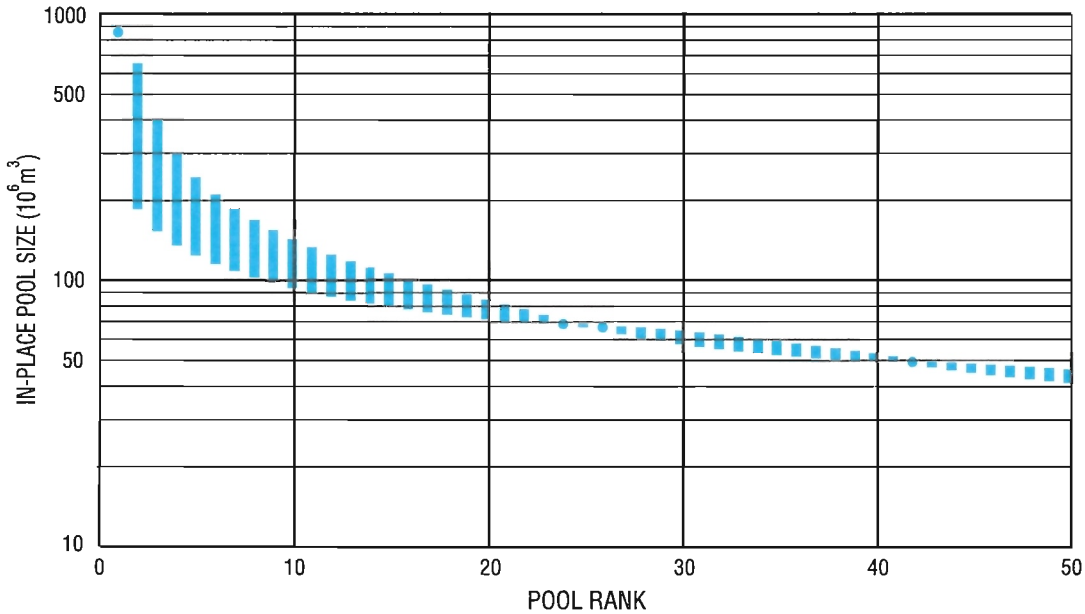


Figure 56. *Pool-size-by-rank plot for Edmonton Group, Shoreline play, showing the top 50 pools (discovered and undiscovered).*

Table 12

Discovered pools and play resource summary, Edmonton Group, Shoreline play

Pool rank	Field/Pool Name	Pool type	Discovered in-place volume (x 10^6 m^3)	Discovery date
1	Edmonton Pool No. 1	NA	862	79/10/26
24	Sylvan Lake, Edmonton	NA	70	60/12/01
26	Link, Edmonton B	NA	68	85/11/29
42	Pembina, Edmonton	NA	50	77/08/26
109	Pembina, Edmonton	NA	25	79/03/01
114	McLeon, Edmonton	NA	24	79/12/02
185	Michichi, Edmonton	NA	15	89/06/01
186	Pembina, Edmonton	NA	15	82/11/15
210	Fenn West, Edmonton	NA	13	89/10/06
211	Link, Edmonton A	NA	13	85/09/13
241	Michichi, Edmonton	NA	11	77/12/11
242	Michichi, Edmonton	NA	11	89/07/31
259	Farrow, Edmonton	NA	10	74/08/05
260	Leo, Edmonton	NA	10	79/12/07
280	Cessford, Edmonton A	NA	9	81/01/02
327	Coral, Edmonton	NA	7	78/03/05
426	Farrell, Edmonton	NA	4	84/08/25
Initial in-place volume (discovered) (10^6 m^3)			1 237	
Initial in-place volume (potential) (10^6 m^3)			9 714	
Per cent play resources undiscovered			89	
Total pools discovered			18	
Total pool population			580	

NA, nonassociated gas

Edmonton Group, fluvial

Play definition

This established, mature play is defined to include all gas-bearing pools and prospects in fluvial channel sandstones of the middle and upper Horseshoe Canyon Formation of the Edmonton Group. It occurs in a large area of west-central Alberta. The play area is defined on the west and southwest by the limit of deformation, and on the east and north by the outcrop belt of the unit (Fig. 57).

Geology

Most of the Horseshoe Canyon Formation of central Alberta, and the St. Mary River Formation in southwestern Alberta, were deposited in an upper delta-plain environment, behind the shoreline complexes of the lower portion of the Edmonton clastic wedge (Gibson, 1977). Strata consist of thick, fluvial-channel sandstones interbedded with overbank mudstone and coal.

Figure 57. *Play area for Edmonton Group, Fluvial play. Dots indicate locations of discovery wells for each pool in the play.*

The St. Mary River Formation of southwestern Alberta includes fine to medium grained, fining-upward, fluvial channel sandstones up to 4.5 m thick and thin, fine to medium grained sandstones, and overbank, rooted siltstone, limestone, and caliche beds (Nadon, 1988). In west-central Alberta the middle and upper Horseshoe Canyon is dominated by interbedded mudstone, thick channel sandstones, and abundant coal seams (Ower, 1960). In the upper portion, the thin Drumheller Marine Tongue and overlying distinct green mudstone units (Allan and Sanderson, 1945; Gibson, 1977) have little potential reservoir rock, but are overlain by thick, channel sandstones and coals of the uppermost Horseshoe Canyon (Nurkowski and Rahmani, 1984). Throughout much of southern Alberta these deposits are blanketed by the argillaceous sandstone of the Whitemud Formation and the bentonitic mudstone of the Battle Formation (Irish, 1970).

Fluvial deposits of the middle and upper Horseshoe Canyon Formation are present in the subsurface, beneath all of western Alberta, from about Twps 10-60, Rge 23W4 to the disturbed belt in the west. Minor gas reserves are contained within a few small pools. The overlying and interbedded nonmarine, fine grained deposits within the Horseshoe Canyon and Battle formations are the vertical seal for the pools in fluvial channels, creating stratigraphic traps. The source of hydrocarbons may be the underlying marine shales of the Bearpaw Formation, or the interbedded nonmarine, coal-bearing strata.

Exploration history

The initial discovery well was drilled in the Bigoray Field in 1958 (Fig. 58; Table 13). Discovered gas pools are scattered throughout central Alberta. The largest discovered pool (Pembina) has an initial in-place volume of 128 x 10^6 m^3. The mean pool area is 203 ha, mean net pay is 5.5 m, mean porosity is 24.8 per cent, and mean pool depth is 525 m. There have been 17 pools discovered in this play and the total discovered in-place volume is 532 x 10^6 m^3 (Table 13), with a mean pool size of 31 x 10^6 m^3 in-place gas.

Play potential

Estimates of the expected potential for this play indicate an in-place volume of 5834 x 10^6 m^3, representing approximately 92 per cent of the total play resource (Table 13). This estimate assumes a total pool population of 600, with an in-place volume for the largest undiscovered pool of 335 x 10^6 m^3 (Fig. 59). The potential gas resources in this play will likely be found in small pools situated in the plains of west-central Alberta.

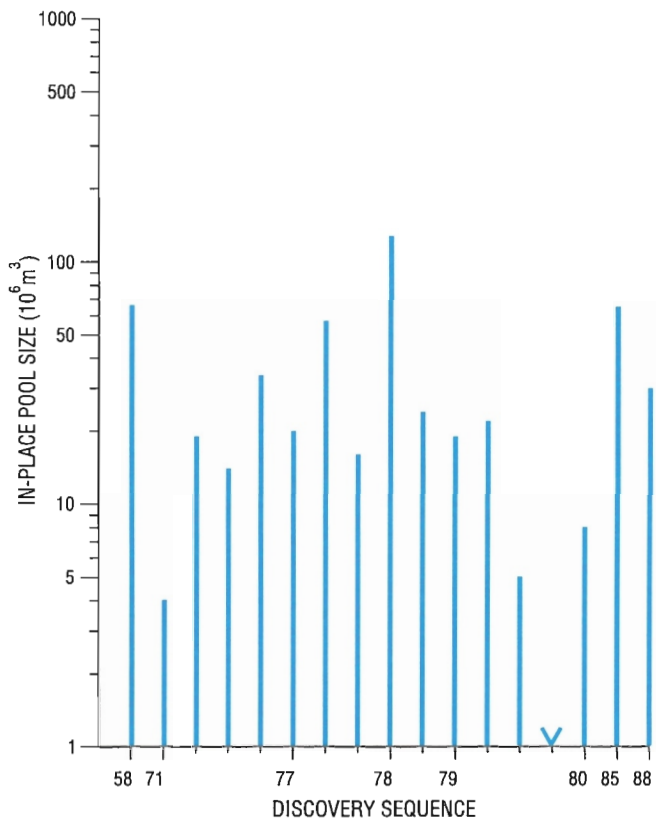


Figure 58. *Discovery sequence plot for Edmonton Group, Fluvial play.*

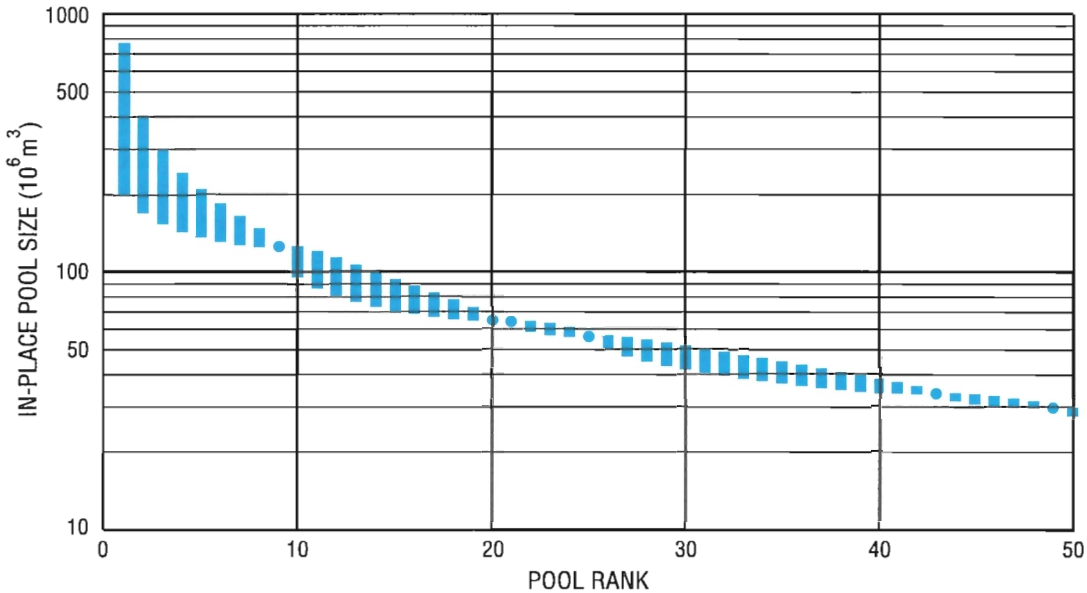


Figure 59. *Pool-size-by-rank plot for Edmonton Group, Fluvial play, showing the top 50 pools (discovered and undiscovered).*

Table 13

Discovered pools and play resource summary, Edmonton Group, Fluvial play

Pool rank	Field/Pool Name	Pool type	Discovered in-place volume (x 10^6 m^3)	Discovery date
9	Pembina, Edmonton	NA	128	78/11/08
20	Bigoray, Paskapoo	NA	66	58/11/13
21	Ferrier, Edmonton	NA	65	85/10/13
25	Minnehik-Buck Lake, Edmonton	NA	57	78/01/22
43	Davey, Edmonton	NA	34	77/08/03
49	Pembina, Edmonton	NA	30	88/02/20
60	Ferrybank, Edmonton	NA	24	79/11/01
65	Chickadee, Edmonton	NA	22	80/04/23
71	Leaman, Edmonton	NA	20	77/08/27
73	Minnehik-Buck Lake, Edmonton	NA	19	79/12/28
74	Morkill, Edmonton	NA	19	77/01/01
86	Bigoray, Edmonton	NA	16	78/03/02
96	Ferrybank, Edmonton	NA	14	77/07/03
146	Pembina, Edmonton	NA	8	80/10/02
197	Morningside, Edmonton	NA	5	80/08/13
224	Bigoray, Paskapoo A	NA	4	71/05/28
397	Chickadee, Edmonton A	NA	1	80/10/02
Initial in-place volume (discovered) (10^6 m^3)			532	
Initial in-place volume (potential) (10^6 m^3)			5 834	
Per cent play resources undiscovered			92	
Total pools discovered			17	
Total pool population			600	

NA, nonassociated gas

Scollard Formation play

Scollard Formation, Basal Sandstone

Play definition

This established, but immature play is defined to include all gas-bearing pools and prospects in fluvial channel sandstones of the lower part of the Scollard Formation. It occurs in a large area of western Alberta, along the axis of the Alberta Syncline. The play area is defined on the west and southwest by the limit of deformation, and on the east, north, and south by the outcrop belt of the unit (Fig. 60). The play is very immature, and is essentially conceptual.

Geology

The Scollard/Coalspur/Willow Creek formations of the plains (Maastrichtian–Paleocene age) are part of a thick, eastward-thinning wedge of fluvial strata that originally extended from the Late Cretaceous/Early Paleocene deformational front in western Alberta to Manitoba, along the western margin of a seaway (Taylor et al., 1964). The base and top of the wedge are probably disconformable (Dawson, 1990; Glass, 1990; Lerbekmo et al., 1990) with erosional bevelling of underlying units to the east. The lower part of the wedge, beneath the Cretaceous–Tertiary boundary, is dominated by sandy deposits, whereas the upper part, above the boundary, is dominated by interbedded

Figure 60. *Play area for Scollard Formation, Basal sandstone play. Dot indicates location of discovery well for single pool in the play.*

mudstone and coal, and includes the Cannonball marine shale in Manitoba (Sweet, 1990).

In the southern Foothills, the Willow Creek Formation (up to 1000 m thick) is predominantly interbedded mudstone and thick, coarse grained sandstone, with minor conglomerate (Russell and Landes, 1940; Douglas, 1950). In the central Foothills, the lower Coalspur Formation (about 250 m thick) includes basal Entrance Conglomerate and thick, sharp-based, fine to coarse grained, fluvial channel sandstones (Jerzykiewicz and McLean, 1980), whereas the upper Coalspur Formation (about 200 m thick) is dominated by floodplain mudstone and thin coals (Jerzykiewicz, 1985).

In west-central Alberta, the Scollard Formation thins rapidly from 400 m in the west to less than 100 m thick at the outcrop belt along the Red Deer River (Member E of the Edmonton Formation of Ower, 1960; Richardson et al., 1988). The lower half, beneath the Cretaceous–Tertiary boundary, is dominated by thick, multi-storied, erosively based, fluvial channel sandstones up to 8.5 m thick, with minor mudstone (Gibson, 1977; Jerzykiewicz and Sweet, 1988). Sandstones are fine to coarse grained, well sorted, and trough crossbedded (Gibson, 1977). According to Sternberg (1947) they have excellent aquifer (reservoir) quality. The upper half is dominated by floodplain bentonitic mudstone and coal (Jerzykiewicz and Sweet, 1988). A minor amount of paleocurrent data from the sandy lower part indicates paleoflow to the northeast (Jerzykiewicz and Labonte, 1991).

The Scollard Formation is present in the subsurface of west-central Alberta, in the area of Twps 10-60, Rge 25W4 to the disturbed belt in the west. The overlying and interbedded nonmarine, fine-grained deposits are the vertical seal for pools in fluvial channel stratigraphic traps. The source of hydrocarbons may be the coals of the underlying Horseshoe Canyon Formation, or the overlying nonmarine, coal-bearing strata of the upper Scollard.

Exploration history

The only discovery to date was drilled in the 11-1-44-8W5 well (Fig. 60), at Willisden Green, and has an initial in-place volume of 29 x 10^6 m^3, with a net pay of 5 m. The total discovered volume is 29 x 10^6 m^3 of in-place gas.

Play potential

Estimates of the potential for this very immature play are not possible because of the limited data available at this time.

Results

The volume of discovered gas and expected potential gas for the 12 mature plays and one immature play (no current analysis for Scollard play) are listed in Table 14. The total volume for the 14 established plays is 556 280 x 10^6 m^3 (19.8 TCF) of discovered, initial in-place gas with an additional 130 448 x 10^6 m^3 (4.6 TCF) of expected potential. The total probable potential for the established plays is 175 858 x 10^6 m^3 (6.2 TCF), which is a more speculative value based on conditional probability of the total discovered resource.

Table 14

Discovered and potential in-place gas volumes (x 10^6 m^3) for mature, post-Colorado plays

Play	Discovered	Expected potential	Probable potential	Discovered Pools/ Expected pools
Scollard Formation				
Basal Sandstone*	29	not analysed		1/?
Edmonton Group				
Fluvial	532	5 834	5 834	17/600
Shoreline	1 237	9 714	10 070	18/580
Belly River Group				
Dinosaur Park	4 686	25 283	26 502	137/2000
Oldman Fluvial	3 179	15 691	15 691	43/1000
Foremost Fluvial	23 252	18 547	22 812	452/1280
Foremost Shoreline				
Cycle 1*	116	3 605	7 390	1/?
Cycle 2	19 997	7 404	15 267	104/280
Cycle 3	12 295	6 615	14 180	46/360
Cycle 4	21 513	17 733	27 484	229/600
Cycle 5	6 147	5 088	7 114	141/320
Cycle 6	4 281	3 406	6 109	90/380
Cycle 7	3 552	6 666	11 543	46/280
Total (7 cycles)	67 901	50 517	89 087	707/22204
Medicine Hat/Milk River	455 493	4 862	4 862	25/600
Total	556 280 (19.8 TCF)	130 448 (4.6 TCF)	175 858 (6.2 TCF)	1400/82804

*immature plays

CONCEPTUAL PLAY: GEOLOGICAL PLAY DEFINITION

Paskapoo Formation play

Paskapoo Formation, Basal Sandstone

Play definition

This conceptual play is defined to include all potential gas-bearing pools and prospects in fluvial channel sandstones of the lower Paskapoo Formation. It occurs in a large area of western Alberta, along the axis of the Alberta Syncline. The play area is defined on the west and southwest by the limit of deformation, and on the east, north, and south by the outcrop belt of the unit (Fig. 61). The upper part of the formation is exposed throughout western Alberta.

Geology

The Paskapoo/Porcupine Hills formations of the plains (Paleocene age) are part of a thick and widely distributed, eastward thinning wedge of fluvial strata that originally extended from the Late Cretaceous/ Early Paleocene deformational front in western Alberta to Manitoba, along the western margin of a marine seaway (Taylor et al., 1964). The surface exposures represent only the preserved portion of an

Figure 61. *Play area for Paskapoo Formation, Basal sandstone play.*

originally continuous blanket up to 1750 m thick in southwestern Alberta, thinning to 90 m thick in Manitoba (Taylor et al., 1964). The base of the wedge is probably disconformable (Lerbekmo et al., 1990), with minor erosional bevelling of underlying units to the east.

The lower Paskapoo Formation is characterized by erosively based, thick channel deposits of calcareous, well sorted, medium to coarse grained sandstone, with minor conglomerate lenses and thin mudstone interbeds (Williams and Dyer, 1930; Allan and Sanderson, 1945). Channels are typically multi-storied, 5 to 10 m thick, and pinch out laterally over about 100 to 150 m. The sandstones are typically fine grained, well sorted, uniform and trough crossbedded. Paleocurrent data indicate northeastward dispersal (Jerzykiewicz and Labonte, 1991). Meyboom (1960) noted that Paskapoo sandstones have an average porosity of 7 per cent, with good permeability.

The very thick Paskapoo Formation is present at surface over most of west-central Alberta, with the thick, lower sandstone units present in the subsurface, from Twps 25 to 55, west of the Fifth Meridian, to the disturbed belt. The overlying nonmarine, fine grained deposits of greenish siltstone with paleosols, interbedded with minor silty, very fine grained sandstone would serve as the vertical seal for potential pools in fluvial channel, stratigraphic traps. The source of hydrocarbons may be the underlying coal-bearing strata of the Scollard Formation.

Exploration history

There are no discoveries in this conceptual play, although minor anecdotal evidence (local gas seeps) suggests that gas is present, even at surface.

Play potential

Estimates of the potential for this conceptual play are not possible due to the limited data available.

Conceptual play analysis

The geologically derived idea that at least one new play may exist is reasonable, considering the relatively short history of concerted exploration and vast areal distribution and stratigraphic thickness of uppermost Cretaceous, post-Colorado sediments in the Interior Plains. The geological and geographic location of gas resources in this conceptual play are, by nature, very speculative compared to mature plays. However, additional conceptual plays are not thought to be numerous because play definitions of mature plays are sufficiently broad to include most geological concepts of hydrocarbon occurrence.

DISCUSSION OF RESULTS

Numerical assessment of 12 mature plays and one immature play was undertaken with the discovery process model, using the size and discovery sequence of individual pools and plays within a natural geological population of pools and plays. Established mature plays required geological analysis to delineate the type and extent of the pool population for each play. Analysis of one immature play (Foremost Formation ("Basal Belly River"), Cycle 1 Shoreline) employed the numerical results from six related mature plays (Foremost Formation ("Basal Belly River"), Cycles 2 to 7 shorelines). Numerical assessment is not yet possible for one additional immature, and one conceptual, play. The expected potential of in-place gas volume for the 12 mature and 2 immature plays is 130 448 x 10^6 m^3 (4.6 TCF).

Mature plays

Mature plays are ranked in Tables 15 to 19 according to discovered in-place volume, expected potential volume, probable potential volume, percent of expected total resource, and largest remaining pool size. Comparisons yield trends that may be of use for planning exploration strategies. The predicted potential of five plays, in particular, warrant comment here.

The play with the largest discovered gas resource, by far, is the Milk River/Medicine Hat play (Table 15). This is because the play is very close to surface, and has been well explored throughout a large area, over a very long time. However, little potential is expected in this largely well explored play (Tables 16, 17). Nevertheless, this composite play is very complex, and the controls on trapping and production capability are poorly understood. With improvements in detailed reservoir delineation, location of infill sites, and completion techniques, this play ultimately may yield a much greater resource than predicted here.

The Foremost Formation ("Basal Belly River") Cycle 4 Shoreline play is ranked third in discovered in-place volume, third in expected potential, first in probable potential, and second in largest undiscovered pool size (Tables 15, 16, 17, 19). This play, with 45 per cent of the undiscovered resource (Table 18), clearly is

a very significant play in post-Colorado strata. The updip pinchout of thick reservoir facies in this cycle approximately coincides with the crest of the Sweetgrass Arch and covers a very large area in southeastern Alberta. The most prospective area is in Twp 25-50, Rges 10W4 to the Fifth Meridian. This combination of subtle structural and stratigraphic controls perhaps make this play the most attractive of the "Basal Belly River" plays for further exploration.

The Foremost Fluvial play is ranked second in discovered in-place volume, second in expected potential, third in probable potential, and third in largest undiscovered pool size (Tables 15, 16, 17, 19). This play, with 44 per cent of the undiscovered resource (Table 18), contains the most discovered pools to date, and has the potential for a large number of medium to small pools. However, many of these pools result from serendipitous discoveries in wells drilled for deeper targets, and this will likely continue. Models for predicting the location and trend of fluvial channel bodies in the vast wedge of strata behind (west of) the shoreline trends of the Foremost Formation are still in their infancy.

The Oldman Fluvial play is ranked tenth in discovered in-place volume, fourth in expected potential, and fourth in probable potential (Tables 15, 16, 17). This play, with 83 per cent of the undiscovered resource (Table 18), generally has not been recognized in the past and has not been the subject of concerted exploration efforts. The work of Hamblin (1994a, b) suggests a vast play area and significant thicknesses of mappable potential reservoir facies. However, expected pool size is small, distribution of known pools is not obviously related to thickness trends of clean sandstones, and the controls on reservoir productivity may be complex. Nevertheless, attention to this additional target zone may yield significant results in the future.

The Dinosaur Park play is ranked seventh in discovered in-place volume and eleventh in expected pool size, but first in expected potential, and second in probable potential (Tables 16, 17). This play contains a significant number of known pools, although about 84 per cent of the total resource is still undiscovered (Table 18). It has not been recognized as a significant play type in the past and has not been the subject of concerted exploration efforts. The work of Eberth and Hamblin (1993) and Hamblin (1994c, d) suggests a vast play area and significant thicknesses of mappable potential reservoir facies. Discovered pools are typically associated with clean sandstones that have thicknesses of 15 m or more, especially in the area of Twp 20-40, Rges 15W4 to the Fifth Meridian. The present analysis suggests that attention to this newly recognized play promises to yield encouraging results in the future.

The above discussion suggests that the Foremost Formation Cycle 4 Shoreline and the Dinosaur Park plays are the most attractive targets for exploration effort in the post-Colorado strata.

Total volumes

The total initial in-place (discovered) volume in the 12 mature plays is 554 395 x 10^6 m^3 (19.6 TCF). The contribution to the total discovered in-place volume from one immature play that can be analysed is 1885 x 10^6 m^3 (0.2 TCF), giving a total discovered in-place volume for the established 14 plays of 556 280 x 10^6 m^3 (19.8 TCF) in 1400 pools.

Expected and probable potential for the 14 established plays are 130 448 x 10^6 m^3 (4.6 TCF) and 175 858 x 10^6 m^3 (6.2 TCF), respectively. The expected values are thought to be more realistic, because they are constrained by the sizes of discovered pools. The probable potential value is derived by making the play resource distribution conditional on the total sum of the discovered resource. These estimates suggest that about 19 per cent of the total resource available in these strata remain to be discovered.

Table 15

Mature post-Colorado plays ranked in order of discovered in-place gas volume (x 10^6 m^3)

Rank	Play	In-place volume
1	Medicine Hat/Milk River	455 493
2	Foremost Fluvial	23 252
3	Foremost Cycle 4 Shoreline	21 513
4	Foremost Cycle 2 Shoreline	19 997
5	Foremost Cycle 3 Shoreline	12 295
6	Foremost Cycle 5 Shoreline	6 147
7	Dinosaur Park	4 686
8	Foremost Cycle 6 Shoreline	4 281
9	Foremost Cycle 7 Shoreline	3 552
10	Oldman Fluvial	3 179
11	Edmonton Shoreline	1 237
12	Edmonton Fluvial	532
13	Foremost Cycle 1 Shoreline*	116
	Total	556 304 (19.8 TCF)

*immature play

Table 16

Mature, post-Colorado plays ranked in order of expected potential in-place gas volume (x 10^6 m^3)

Rank	Play	In-place volume
1	Dinosaur Park	25 283
2	Foremost Fluvial	18 547
3	Foremost Cycle 4 Shoreline	17 733
4	Oldman Fluvial	15 691
5	Edmonton Shoreline	9 714
6	Foremost Cycle 2 Shoreline	7 404
7	Foremost Cycle 7 Shoreline	6 666
8	Foremost Cycle 3 Shoreline	6 615
9	Edmonton Fluvial	5 834
10	Foremost Cycle 5 Shoreline	5 088
11	Medicine Hat/Milk River	4 862
12	Foremost Cycle 1 Shoreline*	3 605
13	Foremost Cycle 6 Shoreline	116
	Total	130 448 (4.6 TCF)

*immature play

Table 17

Mature, post-Colorado plays ranked in order of probable potential in-place gas volume (x 10^6 m^3)

Rank	Play	In-place volume
1	Foremost Cycle 4 Shoreline	27 484
2	Dinosaur Park	26 502
3	Foremost Fluvial	22 812
4	Oldman Fluvial	15 691
5	Foremost Cycle 2 Shoreline	15 267
6	Foremost Cycle 3 Shoreline	14 180
7	Foremost Cycle 7 Shoreline	11 543
8	Edmonton Shoreline	10 070
9	Foremost Cycle 1 Shoreline*	7 390
10	Foremost Cycle 5 Shoreline	7 114
11	Foremost Cycle 6 Shoreline	6 109
12	Edmonton Fluvial	5 834
13	Medicine Hat/Milk River	4 862
	Total	175 858 (6.2 TCF)

*immature play

Table 18

Mature, post-Colorado plays ranked in order of per cent of expected total resource

Rank	Play	%Undiscovered
1	Foremost Cycle 1 Shoreline*	97
2	Edmonton Fluvial	92
3	Edmonton Shoreline	89
4	Dinosaur Park	84
5	Oldman Fluvial	83
6	Foremost Cycle 7 Shoreline	65
7	Foremost Cycle 4 Shoreline	45
8	Foremost Cycle 5 Shoreline	45
9	Foremost Fluvial	44
10	Foremost Cycle 6 Shoreline	44
11	Foremost Cycle 3 Shoreline	35
12	Foremost Cycle 2 Shoreline	27
13	Medicine Hat/Milk River	1

*immature play

Table 19

Mature, post-Colorado plays ranked in order of largest undiscovered pool size

Rank	Play	In-place volume
1	Foremost Cycle 2 Shoreline	1 606
2	Foremost Cycle 4 Shoreline	1 128
3	Foremost Fluvial	882
4	Foremost Cycle 7 Shoreline	789
5	Foremost Cycle 5 Shoreline	365
6	Edmonton Fluvial	335
7	Edmonton Shoreline	324
8	Oldman Fluvial	323
9	Foremost Cycle 3 Shoreline	295
10	Medicine Hat/Milk River	200
11	Dinosaur Park	197
12	Foremost Cycle 6 Shoreline	189

CONCLUSIONS

1. The geological analysis and statistical assessment of gas resources in uppermost Cretaceous–Tertiary, post-Colorado strata of the Interior Plains portion of the Western Canada Sedimentary Basin indicates that over 19 per cent, and perhaps as much as 64 per cent, of the total gas resource of these strata remains to be discovered. The expected potential from all play types analysed is 130 448 x 10^6 m^3 (4.6 TCF), distributed in about 7000 pools.

2. Of the undiscovered gas potential, almost 99 per cent is estimated to be present in established mature plays. Only one percent of the total gas potential is predicted to occur in immature and conceptual plays.

3. The most attractive established, mature plays with the greatest potential are: i) Dinosaur Park Formation, Valley-fill (e.g., Carbon field, Belly River C pool) with an expected potential of 25 283 x 10^6 m^3; ii) Foremost Formation Cycle 4 Shoreline (e.g., Bashaw field, Belly River No. 3 pool) with an expected potential of 17 733 x 10^6 m^3; iii) Foremost Formation Fluvial (e.g., Bashaw field, Belly River C pool), with an expected potential of 18 547 x 10^6 m^3; iv) Oldman Formation Fluvial (e.g., Nevis field, BR C No. 1 pool), with an expected potential of 15 691 x 10^6 m^3. These four plays make up about 59 per cent (77 254 x 10^6 m^3 or 2.7 TCF) of the total undiscovered resource.

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