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TRIASSIC GAS RESOURCES OF THE WESTERN CANADA SEDIMENTARY BASIN, INTERIOR PLAINS

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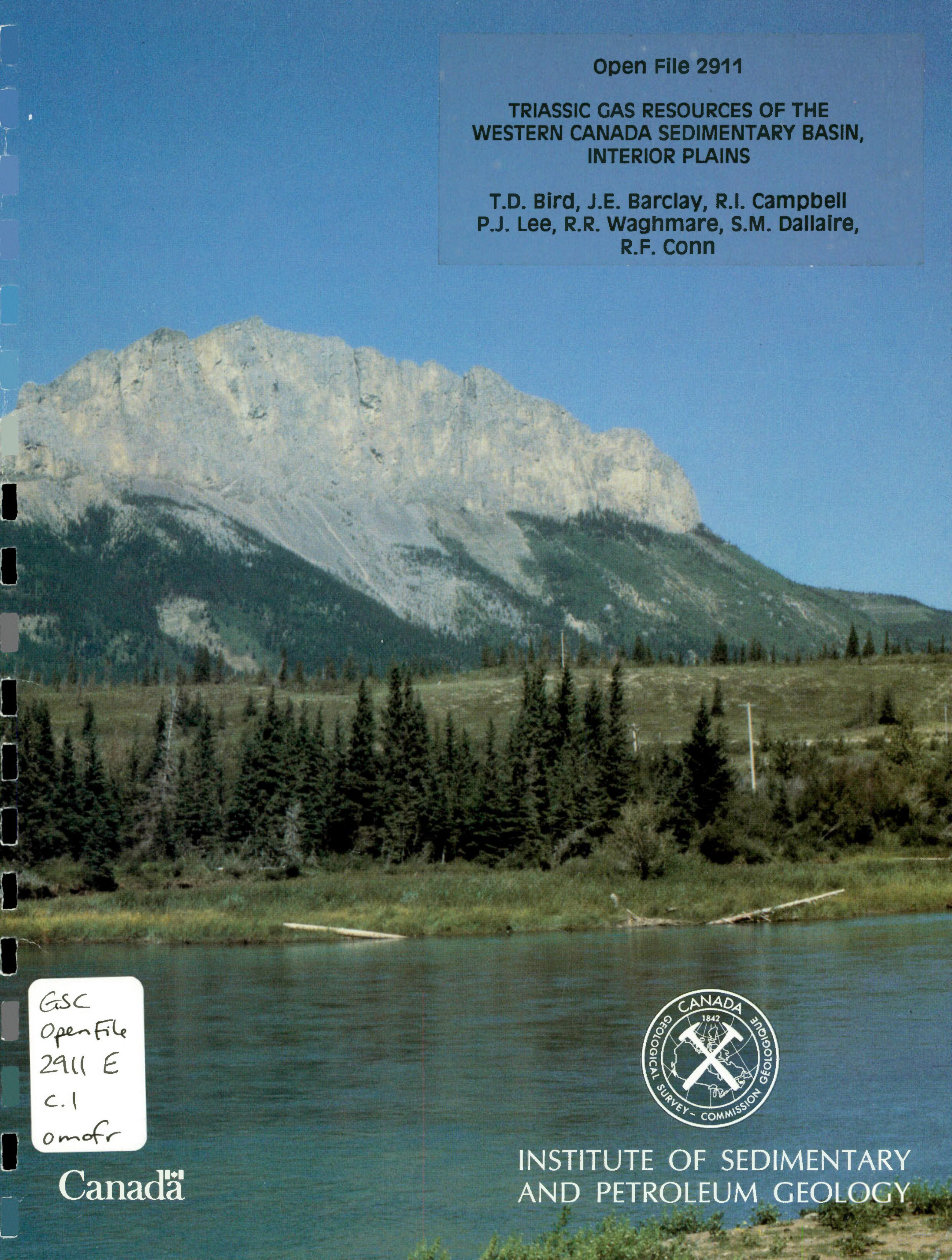

Canada

CANADA 1842 GEOLOGICAL SURVEY - COMMISSION GÉOLOGIQUE

INSTITUTE OF SEDIMENTARY AND PETROLEUM GEOLOGY

Mount Yamnuska, Alberta

Lower Paleozoic carbonates thrust over Mesozoic clastics.

Cover photo by G.D. Mossop

GEOLOGICAL SURVEY OF CANADA
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PART I: GEOLOGICAL PLAY ANALYSIS AND RESOURCE ASSESSMENT

T.D. Bird, J.E. Barclay, R.I. Campbell, and P.J. Lee

PART II: ECONOMIC ANALYSIS

R.R. Waghmare, S.M. Dallaire, and R.F. Conn

1994

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TRIASSIC GAS RESOURCES OF THE WESTERN CANADA SEDIMENTARY BASIN, INTERIOR PLAINS

PART I: GEOLOGICAL PLAY ANALYSIS AND RESOURCE ASSESSMENT

Abstract

Natural gas resource potential of Triassic strata in the Western Canada Sedimentary Basin (excluding the Foothills Belt) was evaluated using a combination of geological play analysis and statistical estimation. Triassic strata belong to a platformal succession of mixed siliciclastic, carbonate, and evaporite sediments deposited along the western portions of the basin. The thickest deposits, and most of the oil and gas, occur in the westward thickening and deepening depocentre called the Peace River Embayment.

The Triassic succession contains a total discovered in-place volume of 288 400 x $10^6 m^3$ raw gas reserves in 10 mature and 2 immature plays. Exploration plays consist of stratigraphic and stratigraphic–structural combination traps, with reservoirs in aeolian, shoreline, tidal channel, and shallow marine sandstones, coquinas, and tidal flat and marine shelf carbonates. Statistical analysis of the ten established mature plays suggests they contain a remaining potential of 272 124 x $10^6 m^3$. Three of these plays are predicted to contain over one half of the remaining gas potential: the Halfway/Doig Formation shelf sandstones play, influenced by Peace River Arch/Embayment structures (e.g., Monias field); the Baldonnel Formation subcrop play, involved in Laramide–aged gentle folds (e.g., Laprise field); and the Halfway/Doig Formation shoreline-related sandstone reservoirs, influenced by Peace River Arch/Embayment structures (e.g., Sinclair field). Statistical analysis of the mature plays indicates that a total of 13 plays are likely to exist. These include the 10 mature plays, 2 immature plays (the Montney Subcrop North–Ring play and the Montney Distal Shelf–Glacier play) with undiscovered gas in-place totalling 28 162 x $10^6 m^3$, and 1 conceptual play with 5 615 x $10^6 m^3$ gas in-place. The relatively minor amount of gas estimated to be present in the conceptual and immature plays (33 777 x $10^6 m^3$–11 per cent of the total resource) is consistent with the exploration maturity of the basin and the fact that established play definitions are sufficiently broad to include variations in trapping mechanism. Expected potential in-place gas volumes in mature, immature and conceptual plays (unencumbered by economic constraints) total 305 901 x $10^6 m^3$, indicating that over 50 per cent of the total in-place resource remains to be discovered. Triassic strata continue to offer attractive exploration targets, as shown by recent activity at Valhalla, Spirit River and Grande Prairie.

Summary

The gas resources contained in Triassic strata of the plains portion of the Western Canada Sedimentary Basin are described here in two parts. Part I contains the detailed geological play analysis and numerical assessment of undiscovered gas potential. Part II contains the economic analysis of the undiscovered potential predicted in Part I.

In Part I, 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. In-place gas reserves for mature and immature plays total 288 400 x $10^6 m^3$, discovered in 622 pools. Conceptual plays are defined as those plays without discoveries or reserves but which geological and/or statistical analysis indicates may exist. Mature plays require geological analysis to delineate the type and extent of the pool population for each play, prior to statistical analysis. In contrast, the number and magnitude of immature and conceptual plays is primarily inferred from the statistical analysis of mature plays. Geological analysis of immature plays provides subjective comparisons matching discovered resources in the modelled play population.

Geological analysis by subsurface mapping, using Alberta and British Columbia government pool-data, literature studies and discussions with government and industry geoscientists, enabled the grouping of Triassic pools into 10 mature and 2 immature plays. In each established play, pools form a natural geological population that is governed by geological controls, such as 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 is defined, quantitative analyses based on exploration discovery histories and pool size distributions were used to assess play potential.

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

1) Halfway/Doig formations: shelf-sandstone reservoirs, influenced by Peace River Arch/ Embayment structures (e.g., Monias field), with an expected potential of 88 934 x $10^6 m^3$;

2) subcropping Baldonnel Formation carbonate reservoirs, involved in gentle folds of the Laramide Orogeny (e.g., Laprise field), with an expected potential of 66 610 x $10^6 m^3$;

3) and Halfway/Doig formations: shoreline related sandstone reservoirs, influenced by Peace River Arch/Embayment structures (e.g., Sinclair field), with an expected potential of 27 036 x $10^6 m^3$.

Estimates of the potential and size of immature and conceptual plays were derived from the discovery process model using the 10 mature plays as the 'pool' database. The expected potential for conceptual and immature plays is 33 777 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 for Triassic reservoirs and the fact that mature play definitions are sufficiently broad to include most play concepts.

The expected potential from all play types (mature, immature and conceptual) is 305 901 x $10^6 m^3$ distributed in about 3 300 pools. A more speculative, probable potential value of 767 300 x $10^6 m^3$ provides a more optimistic estimate of gas remaining to be discovered in all play types.

Four conclusions can be drawn from the above numerical estimates:

1) Geological analysis and statistical assessment of Triassic gas resources in the plains portion of the Western Canada Sedimentary Basin suggest that 51 per cent of the total gas resource remains to be discovered.

2) Of the undiscovered Triassic gas potential, 89 per cent is considered to be present in established mature plays. As many as 154 pools with a volume greater than 280 x $10^6 m^3$ and 11 pools greater than 2 800 x $10^6 m^3$ remain to be discovered.

3) The most attractive mature plays with the greatest potential are: i) the Halfway/Doig Shelf (Peace River Structure)–Monias play; ii) the Baldonnel Subcrop–Laprise play; and iii) the Halfway/Doig Shore Zone (Peace River Structure)–Sinclair play. These plays make up almost 60 per cent (182 580 x $10^6 m^3$) of the total expected (undiscovered) resource.

4) Eleven per cent of the estimated expected volume study occurs in conceptual and immature plays. Of this amount, the two immature plays combine to yield over 80 per cent of the expected volume, with the remainder (up to 10 000 x $10^6 m^3$) expected in one (or more) conceptual play(s).

INTRODUCTION

Scope

Estimates of regional resource potential in 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; Reinson et al., 1993a, b). The gas assessment presented herein 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 basin (see Reinson et al., 1993a).

Seven major play groups have been identified for the Western Canada Sedimentary Basin (WCSB). Geological criteria are the basis for identification and generally are based on major stratigraphic units and/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: the Devonian, Carboniferous-Permian, Triassic, Jurassic to Lower Cretaceous (Mannville), Middle Cretaceous Colorado Group, Upper Cretaceous-Tertiary, and the Rocky Mountain Foreland Belt. About five per cent of the discovered in-place gas reserves in the Interior Plains of Western Canada is contained in Triassic rocks (Fig. 1). Two-thirds of the discovered in-place gas reserves of the Triassic are contained in the southern Interior Plains, with the remaining third in Rocky Mountain Foreland Belt of the Cordilleran Orogen (Foothills Deformed Belt).

This paper documents an assessment of Triassic gas resources in the Interior Plains of Western Canada (Fig. 2). The study area is largely confined to the Peace River Arch/Embayment (where much of the Triassic succession occurs in the subsurface). It excludes Foothills structural plays which are being evaluated with other Cordilleran structural province plays (see Osadetz et al., pers. comm.). Triassic strata in the Williston Basin are not assessed in this study since there are no gas pools or significant gas shows and the potential for gas is low.

Purpose

The objectives of this study are four-fold: i) to document and describe gas reserves in Triassic strata with respect to the plays in which they occur; ii) to outline the geology of principal gas plays in the Triassic System in a manner that enables industry to use this outline as a guide for exploration; iii) to estimate the total amount of undiscovered gas that might exist in the Triassic System 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.

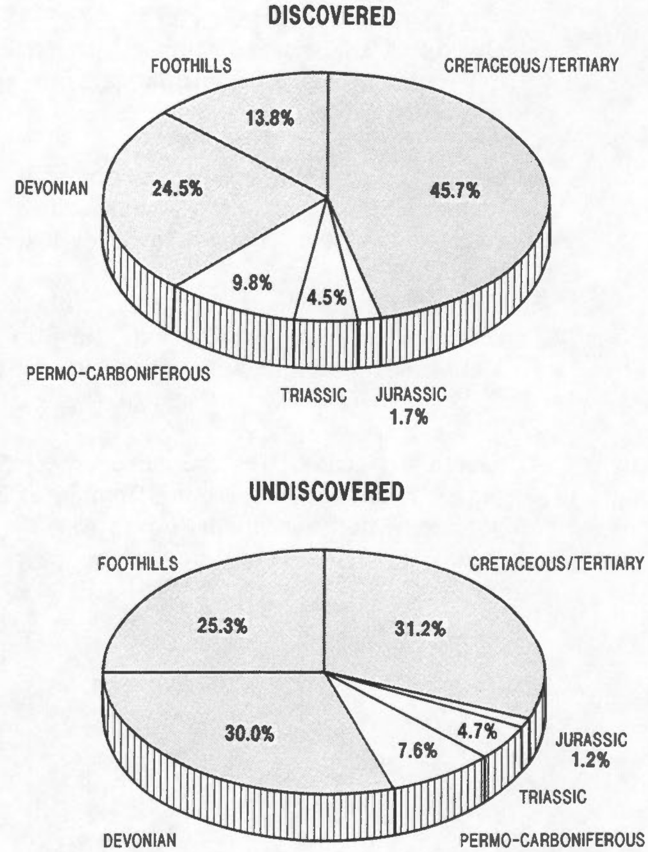

Figure 1. Distribution of Western Canada gas resources by geologic system. Based on data from the Alberta Energy Resources Conservation Board (1991), the British Columbia Ministry of Energy, Mines and Petroleum Resources Division (1991) and modified from Reinson et al. (1993a).

Terminology

The terminology and procedures used in this report follow those 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

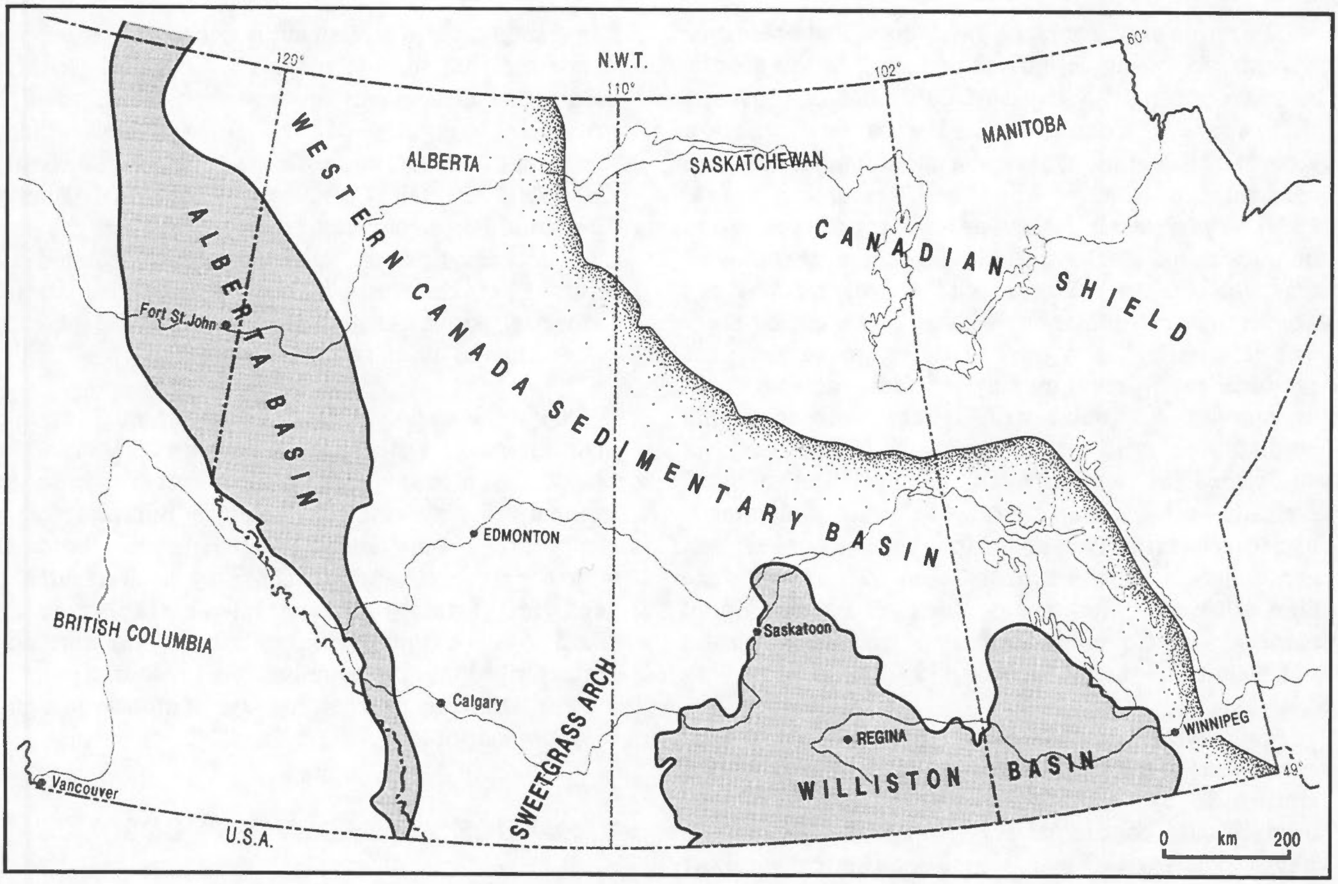

Figure 2. *Distribution of Triassic sediments in the Western Canada Sedimentary Basin (modified from Barclay, 1993).*

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. It is recognized, however, that certain components, particularly H_2S, should be accounted for in any economic analysis of potential supply from sour gas sources.

Raw gas is unprocessed natural gas, containing methane, inert and acid gases, impurities, and other hydrocarbons, some of which may be recoverable as liquids. *Sales gas* or *marketable gas* is natural gas that meets specifications for end use, usually requiring processing to remove acid gases, impurities and liquid components. *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, not sales gas or marketable 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. 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 not yet discovered. 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 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, while *initial marketable volume* is the portion of raw gas expected to be recovered with current recovery technology.

The terms *play, prospect, field, pool,* and *other area* 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). A *prospect* is defined as an untested exploration target within a single stratigraphic interval that may or may not contain hydrocarbons. A prospect may not necessarily be synonymous with an undiscovered pool. 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 another gas accumulation. In the British Columbia pool lists, the term *other area* refers to a pool not yet assigned a pool name (British Columbia Ministry of Energy, Mines and Petroleum Resources Division, 1991).

Plays were 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 were grouped further into *mature* and *immature* plays on the basis of adequacy of the play data for statistical analysis. *Mature plays* are those 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 (Lee and Tzeng, 1989; Lee and Wang, 1990; Lee, 1993). *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 Triassic strata follows that outlined by Podruski et al. (1988) but also includes more recent regional geological work published by Gibson and Barclay (1989), and Gibson and Edwards (1990).

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 British Columbia (British Columbia Ministry of Energy, Mines and Petroleum Resources, 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.

The analysis of Triassic gas potential entailed delineation and systematic evaluation of 12 established plays, 10 mature and 2 immature. These are summarized with respect to play definition, geology, exploration history and estimated resource potential, with supporting figures. Each play is designated by geological formation, reservoir or trap type, and characteristic gas pool. Conceptual and immature plays are described and their undiscovered resource potential is estimated using the mature plays to model the overall play population.

RESOURCE ASSESSMENT PROCEDURE

Numerical analysis

Several methods exist for estimating the quantity of hydrocarbons that may exist 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, 1992), which was employed 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 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 and thus, this model inherently reflects accumulated knowledge and strategy used in the exploration process. The mean volumes of undiscovered individual pools are then summed to give an estimate (expected value) of the total gas resource in that play.

The assessment procedure is illustrated by listing the various steps in the geological and numerical analysis using one of the mature plays, the "Halfway/Doig Shore Zone (Peace River Structure)-Sinclair" play, as an example.

Geological play definition

The definition of play type and play area are the primary objectives of the geological basin analysis that precedes the numerical resource evaluation because a properly defined play will possess a single population of pools and thus satisfy the assumptions required for the operation of the statistical 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* (Fig. 3). The play boundary is determined by the distribution of pools within that play and by geologic knowledge of rock distribution and prospective area. By definition, pools in a specific play form a natural geological population that is characterized by one or more of the following: age, depositional model, geographical distribution, structural style, trapping mechanism, geometry, diagenesis. In each case, a play is defined by assembling and comparing the most important characteristics and assigning each pool to the play which best describes it.

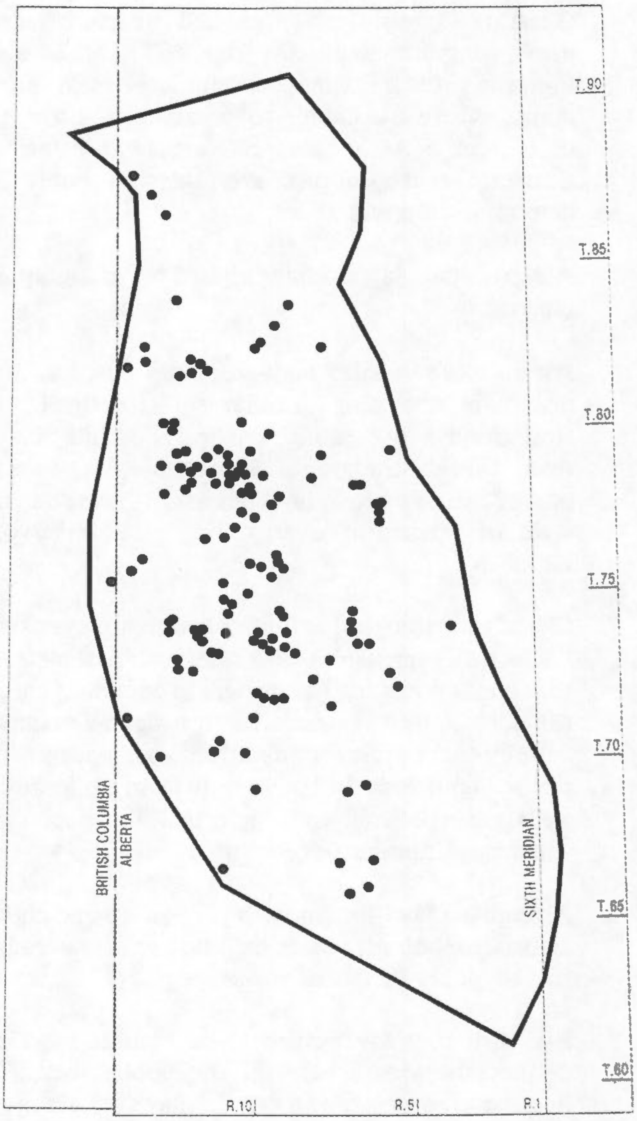

Figure 3. Example of a play boundary (play polygon) using the Halfway/Doig Shore Zone–Sinclair play. Dots show the location of the discovery wells for each pool within this play.

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 then examined to ensure that they are consistent with the play definition and play boundary.

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

1. Assemble and manipulate provincial pool and well data (Alberta Energy Resources Conservation Board, 1991; British Columbia Ministry of Energy, Mines and Petroleum Resources, Division, 1991; PETRIMES and in-house database software).
2. Search literature for publications covering regional and petroleum geology of the Triassic of Western Canada, particularly specific descriptions of Triassic plays (Barclay, 1993; McCrossan and Glaister, 1964; Nelson, 1970; Anderson et al., 1989; Rose, 1990; Mossop and Shetsen, 1994), check stratigraphic nomenclature (Glass, 1990), pool descriptions, regional setting, etc.
3. Plot "discovery" wells that identify pools and "producing" wells within pools by stratigraphic interval, in order to define broad play areas and geographic pool distribution.

4. Generate large-scale isopach and structure maps using computer databases and PETRIMES, and in-house software. Compare with large scale facies maps, where available, to create subcrop edge maps and belts of prospective reservoir facies. Generate cross-sections over selected pools to determine trapping styles.

5. Assign initial play groupings based on stratigraphic interval.

6. Assign more detailed play groupings based on the dominant trapping mechanism–structural vs. stratigraphic, separating classical Foothills plays from hybrid stratigraphic/structural plays in the plains, assign major play boundaries based on the style of structural overprinting, and reservoir facies.

7. Check for geological affinities between plays using PETRIMES crossplots of reservoir parameters; spot check pools for parameters in common; check for pools outside boundaries in order to evaluate validity of natural population assumption for pools. Significant drill-stem tests from exploratory wells may be used to supplement the pool lists when pool numbers are insufficient.

8. Assemble a pool list for each play group and check associated/non-associated–solution gas, to account for all pools in the database.

9. Establish a "play polygon" or boundary which defines the area where all the pools, including undiscovered pools, of a certain play type are most likely to exist, in order to define the natural population.

Discovery process model

Gas occurrences in a specific exploratory well may take different forms, ranging from a pool of commercial size, to a significant recovery from a drill-stem test, to a few gas bubbles in the drilling mud and/or recovery of gas-cut water. All of these "shows" of gas could be considered as a pool. In practice, a gas accumulation is considered to be a pool, if and only if, it has commercial value at the time of discovery. However, imposing such a restricted definition on the underlying pool population severely truncates the pool size distribution and may introduce errors into the resource estimate. Consequently, in some cases where there was an insufficient number of pools, wells that had significant gas shows were examined to determine whether these tests indicated a new pool.

The pools discovered in a specific play represent a sample from the total population of that play. The discovered pools are not a random sample. They are the result of a selective process because explorationists tend to drill the best, and typically the largest, prospects first. This biased nature of the sample population poses a problem for estimation of petroleum resources using standard statistical methods. The discovery process model was devised to account for the biased nature of the sample population. Lee and Wang (1985, 1990) incorporated the analysis of this bias into a probabilistic model in order to estimate the mean and variance of an underlying natural geological population. Two assumptions are inherent in this model. The first assumption is that the probability of discovering (sampling) a pool is proportional to its size. To support this assumption, the well and pool lists are used to produce an **exploration discovery time series plot,** which is a plot of the sizes of pools in their order of discovery through time (Fig. 4). The second assumption is that sampling occurs without replacement, that is, a pool will not be discovered twice. 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. A further consequence of the model is the inverse relationship between the number of pools and the mean of the pool-size distribution. That is, undiscovered pools will likely be smaller and more numerous compared to the larger, but less numerous discovered pools.

In the assessment of Triassic resources, the option of choosing the type of probability distribution for the underlying pool-size distribution was used to obtain the appropriate estimate. Both the parametric (log-normal in this report) and non-parametric (no prior probability distribution assumed) discovery process models were applied on all play data-sets. In most cases both estimation procedures yielded similar results. However, in a few cases the parametric approach failed to give a satisfactory result, due either to numerical problems associated with the computational algorithm, or to an inadequacy of the log-normal distribution in approximating the data set. A method of testing the assumptions made in the population distribution involves plotting the distribution functions against in-place pool size in a quantile–quantile plot (Lee, 1993).

It should be noted that 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

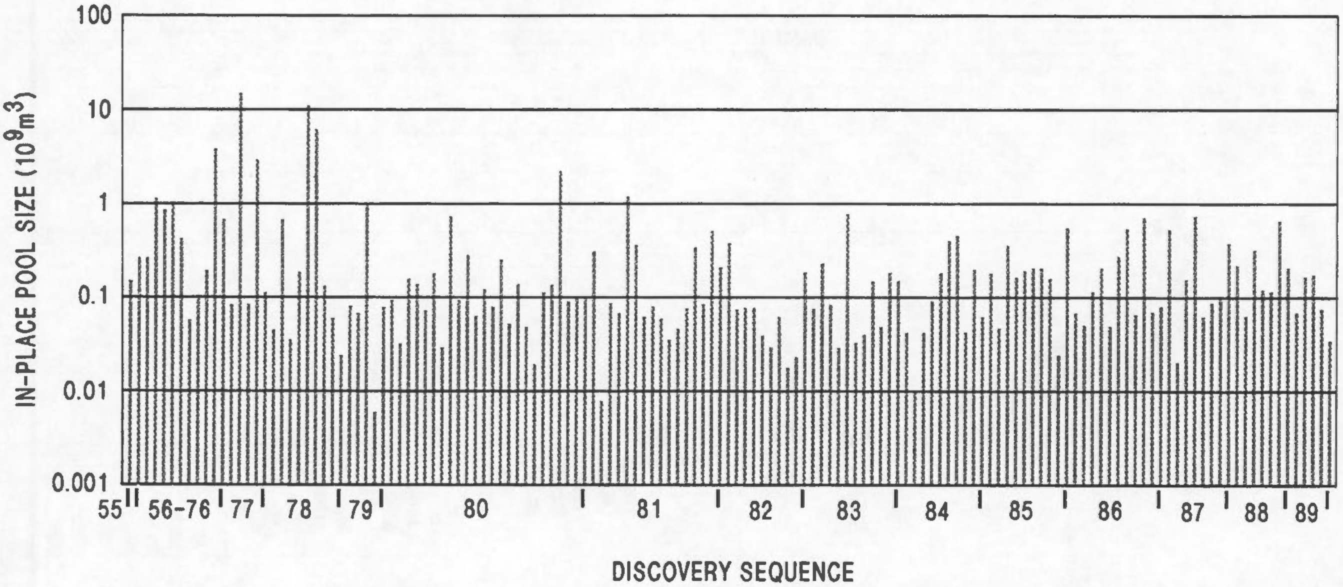

Figure 4. Exploration discovery–time series for the Halfway/Doig Shore Zone–Sinclair play. The horizontal axis is the discovery sequence by year. The vertical axis shows discovered in-place pool volume in billions of cubic metres.

existence of undiscovered pools based on that data set and does not account for appreciation in reserves of the pools within the data set.

Pool size distribution

The discovery process model generates estimates of the mean, variance, and total number of pools in the underlying pool population or play. An additional output of the model is the **beta** value which can be considered a measure of the exploration efficiency; an indicator of the strength of the relationship between pool size and discovery sequence. If beta = 0, then the discovery process is random. If beta is greater than zero, then the probability of discovering a pool is heavily dependent on the pool's size, and the size of discovered pools will decrease through time. If beta is less than zero, then the pool size will increase through time.

The model predicts individual pool size and pool rank, ordered from largest to smallest. The individual pools predicted by the model are represented in graphical form by bars which indicate the range of possible sizes of each pool (Fig. 5a). A bar with a frequency interval of 5 to 95 indicates there is a 90 per cent chance that the pool predicted 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 the estimated pool sizes. The matched pools are indicated on the plot in graphical form 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 or less than the unmatched pool (Fig. 5b).

Estimate of play potential

The play potential can be estimated from both the total number of pools and the pool size distribution. Adding the mean of all undiscovered pool sizes yields the mean of the play potential, defined as the **expected potential**.

The value of the expected potential is governed by an estimated range of values for each of the individual pool sizes, and the assigned pool ranks. Both the range of individual pool sizes and the pool ranks are controlled by the quality of the database of discovered pools. If the discovered pool sizes are incorrectly estimated in the provincial databases, or if they are appreciated or depreciated, or if the rankings are altered, then the value of the expected 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. The play potential can also be derived by estimating the total resource of a play conditional upon the resource that has already been discovered. A **probable potential** value is quoted for the mature plays using this conditional probability. This value is considered more speculative than the expected value quoted throughout the report.

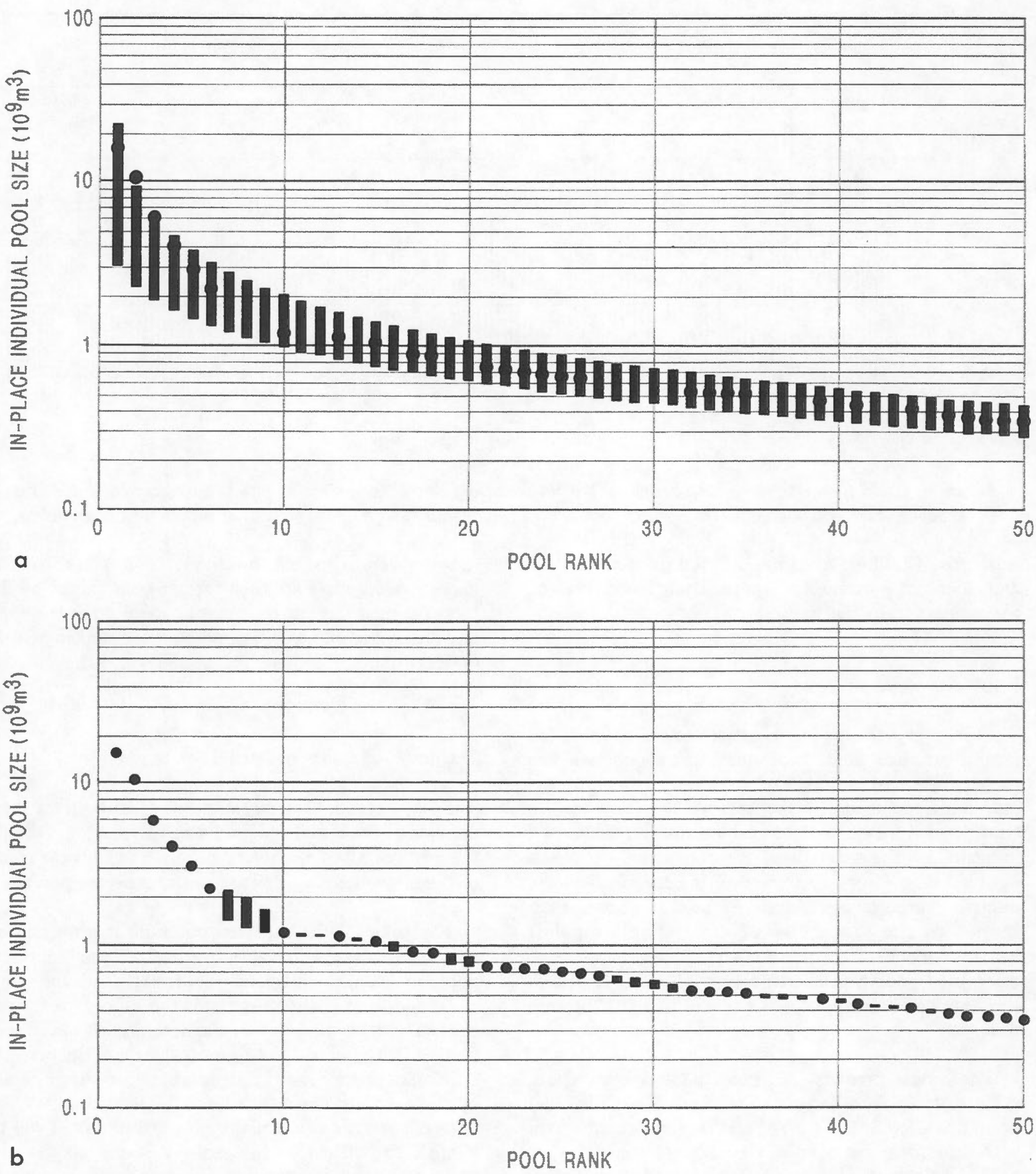

Figure 5. *Example of how a pool size-by-rank plot is generated, using the Halfway/Doig Shore-Zone-Sinclair play. a. Unconditioned pool sizes. b. Pool size-by-rank plot generated by conditioning all pool size ranges on the rank of matched discovered pools. (Dots represent the sizes of discovered pools and bars represent the estimated size ranges of undiscovered pools.)*

Estimate of conceptual play resources

Previous assessments of conceptual play potential (Roy, 1979; Lee and Wang, 1990) used an approach based on geological judgement rather than data. Reinson et al. (1993b) used the discovery process model to estimate conceptual play potential and this method is adopted here. The number and size of conceptual plays that exist in a mature basin can be estimated by the discovery process model without assuming log-normality. Thus, after compiling the total play resource (discovered plus expected potential in-place volume) for each mature play and their respective discovery dates (the date of discovery of the first pool in each play), a play resource discovery sequence was generated for all the mature plays (Fig. 6). Assuming the mature plays belong to a single, larger population, the discovery process model can be used to estimate both the number, and individual sizes, of conceptual plays within the basin (Fig. 7).

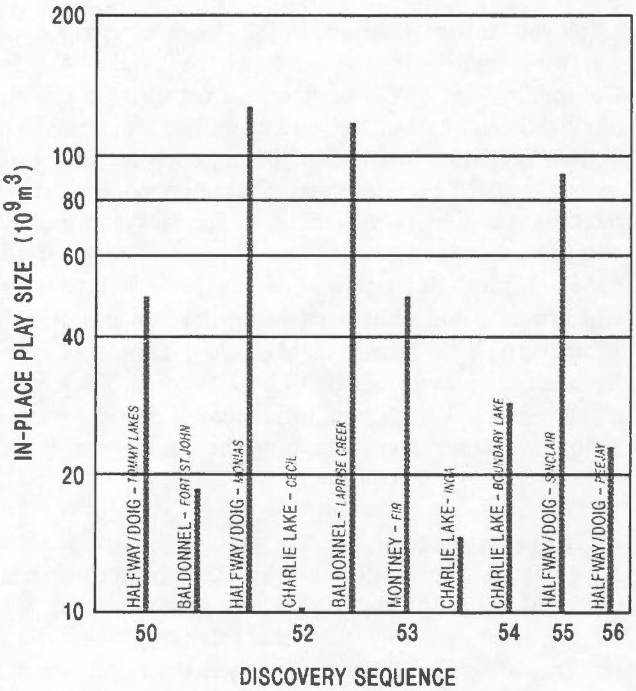

Figure 6. Discovery sequence plot of the 10 mature Triassic plays. The horizontal axis is the discovery date in sequence of the first pool within each play. The vertical axis is the sum of discovered-in-place volume plus expected potential volume or total resource.

GEOLOGICAL FRAMEWORK

Depositional setting and tectonic elements

Triassic sediments, up to approximately 1200 m thick, were deposited mainly in a major coastal embayment

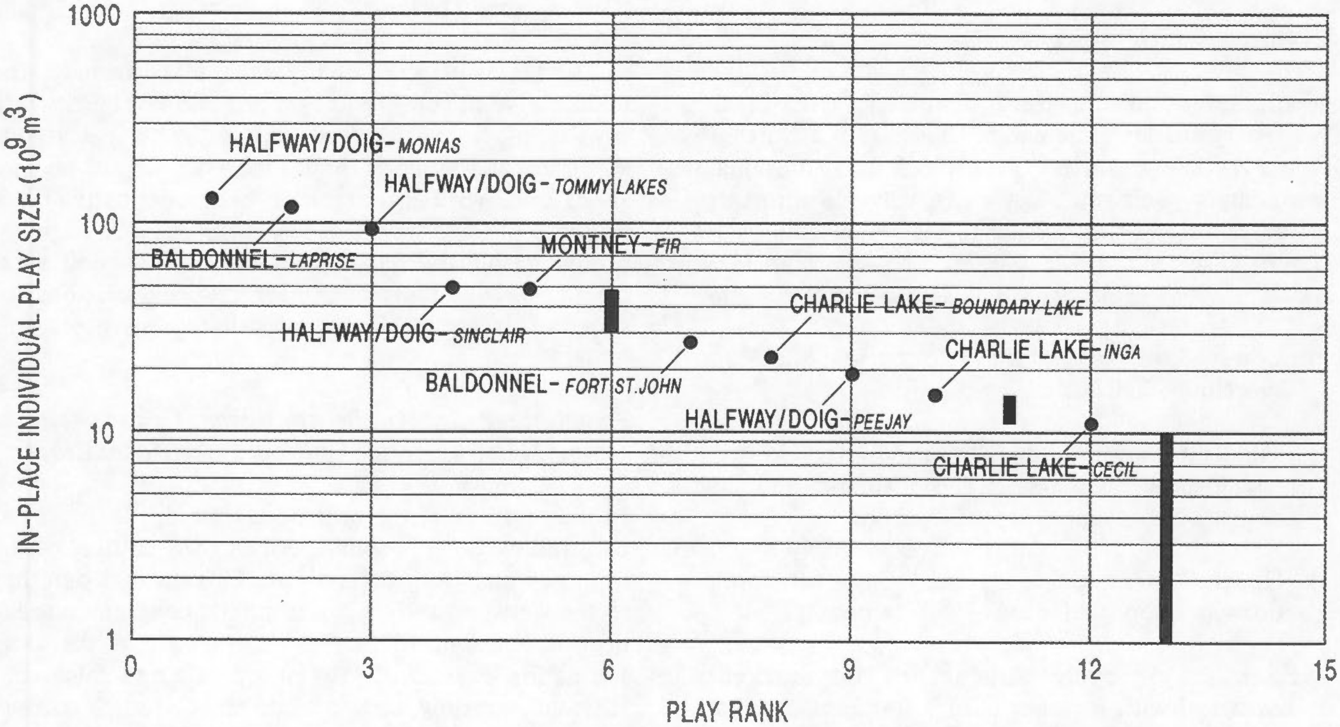

Figure 7. Play size by rank plot of the 10 mature Triassic plays. Dots show total resource of mature plays; boxes represent range in total resource of immature and conceptual plays.

along the cratonic margin, in the Peace River region of northwestern Alberta and northeastern British Columbia (Fig. 8). Triassic strata comprise a mixture of siliciclastic, carbonate, and evaporite sediments. The margin formed a broad shelf facing open oceanic water to the west. The shelf was characterized by general tectonic stability, as evidenced by the lack of lithologic variation in clastics over broad areas (Barss et al., 1964). Minor fluctuations in sea level led to small embayments and platforms being developed along the submerged shelf (Barss et al., 1964; Gibson, 1993a). Rejuvenated movement on older Paleozoic block faults in the Peace River area influenced Triassic sedimentation and petroleum trapping in the region (Cant, 1988).

The provenance of Triassic siliciclastics is thought to have been emergent Permian and Carboniferous strata east and north of the Peace River Embayment. The source area probably was characterized by relatively mature, low-relief terrain that shed multicycle quartz-rich detritus (Barss et al., 1964; Gibson, 1993a). No definitive evidence for a western provenance is evident (Gibson, 1975). Triassic strata west of the Rocky Mountain Trench are interpreted as exotic terranes accreted to the continent during later Mesozoic orogenic phases (Porter et al., 1982) and are not related depositionally to the continental shelf sediments discussed here.

Regional stratigraphy

Stratigraphic nomenclature of the Triassic in the Western Canada Sedimentary Basin is illustrated in Figure 9. The strata are subdivided into three main assemblages, which in most areas, coincide with three major regional transgressive-regressive marine cycles (Podruski et al., 1988; Gibson and Barclay, 1989; Barclay, 1993) (Figs. 9, 10). These assemblages are:

1) Lower Triassic Montney Formation shelf and shoreline siliciclastics;

2) Middle to lower Upper Triassic Doig, Halfway, and Charlie Lake formations shelf and shoreline siliciclastics, evaporites and carbonates;

3) Upper Triassic Baldonnel and Pardonet formations nearshore to distal shelf carbonates.

Each major cycle appears to be markedly asymmetrical with a rather abrupt transgressive phase being followed by prolonged overall regression (Embry, 1988). These assemblages are comparable in duration, but not necessarily correlative, with third order Triassic cycles of Vail et al. (1977). Each assemblage contains higher order transgressions and regressions which are important on a local scale, particularly as applied to petroleum exploration. The cycles are controlled by a combination of tectonic activity, variations in sediment supply, climate, eustatic sea level changes and underlying topography.

Assemblage 1. Lower Triassic Montney Formation

Assemblage 1 consists of transgressive distal shelf siltstones and shales overlain by regressive nearshore siltstones, sandstones and coquinas (Fig. 9, 10), and includes the Montney Formation and equivalents (Armitage, 1962; Gibson, 1975, 1993a; Gibson and Barclay, 1989).

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

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

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

In the subsurface, the base of assemblage 2 is marked by a radioactive phosphatic zone at the contact of the Montney and Doig formations. This contact outcrops to the west, where it is a phosphatic conglomerate lag deposit (Gibson, 1975). The lower part of the Doig Formation consists of grey phosphatic and calcareous siltstone, grading upward into calcareous siltstone, bituminous shale and argillaceous siltstone, representing deposition in a shelf to distal shoreface setting (Armitage, 1962). The upper Doig Formation

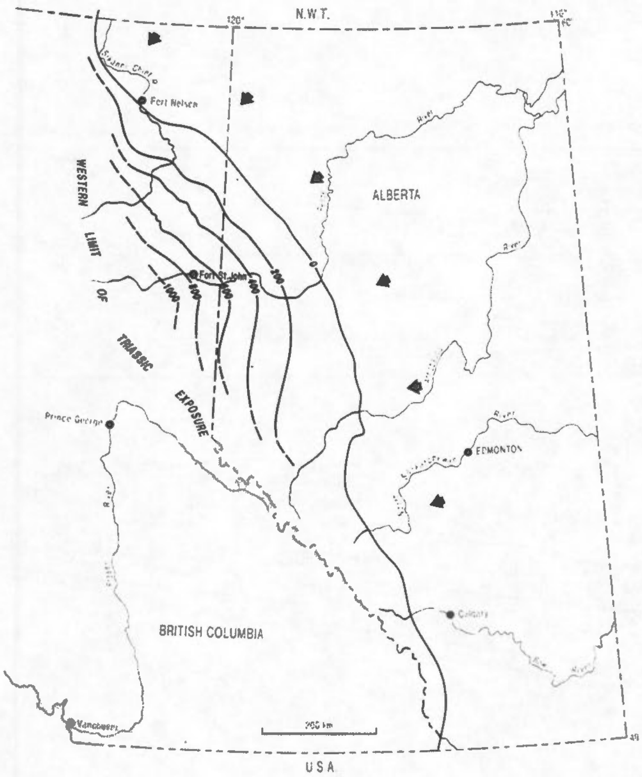

Figure 8. Isopach map of Triassic sediments in the Alberta Basin. The eastern edge is defined by the Montney subcrop. The western margin is defined by the limit of Triassic outcrop. Arrows show probable direction of sediment transport. Modified from Edwards et al. (1994) and Barss et al. (1964).

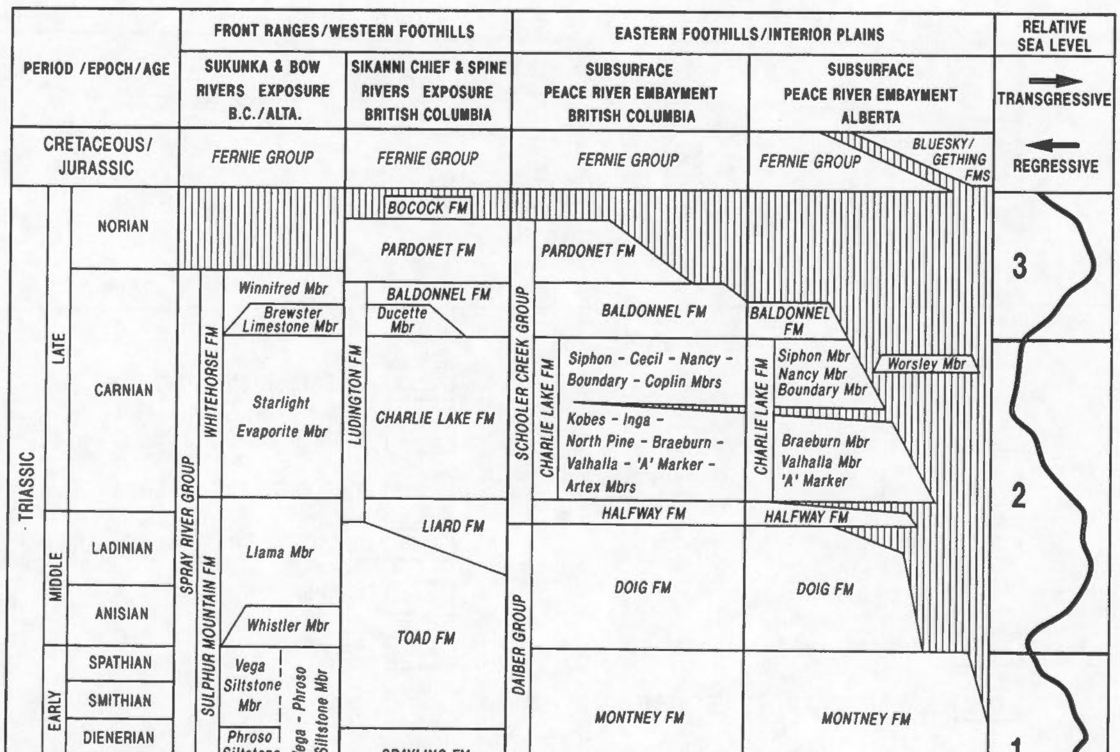

Figure 9. Table of formations, Triassic subsurface and outcrop, Western Canada Sedimentary Basin. Modified from Gibson and Barclay (1989).

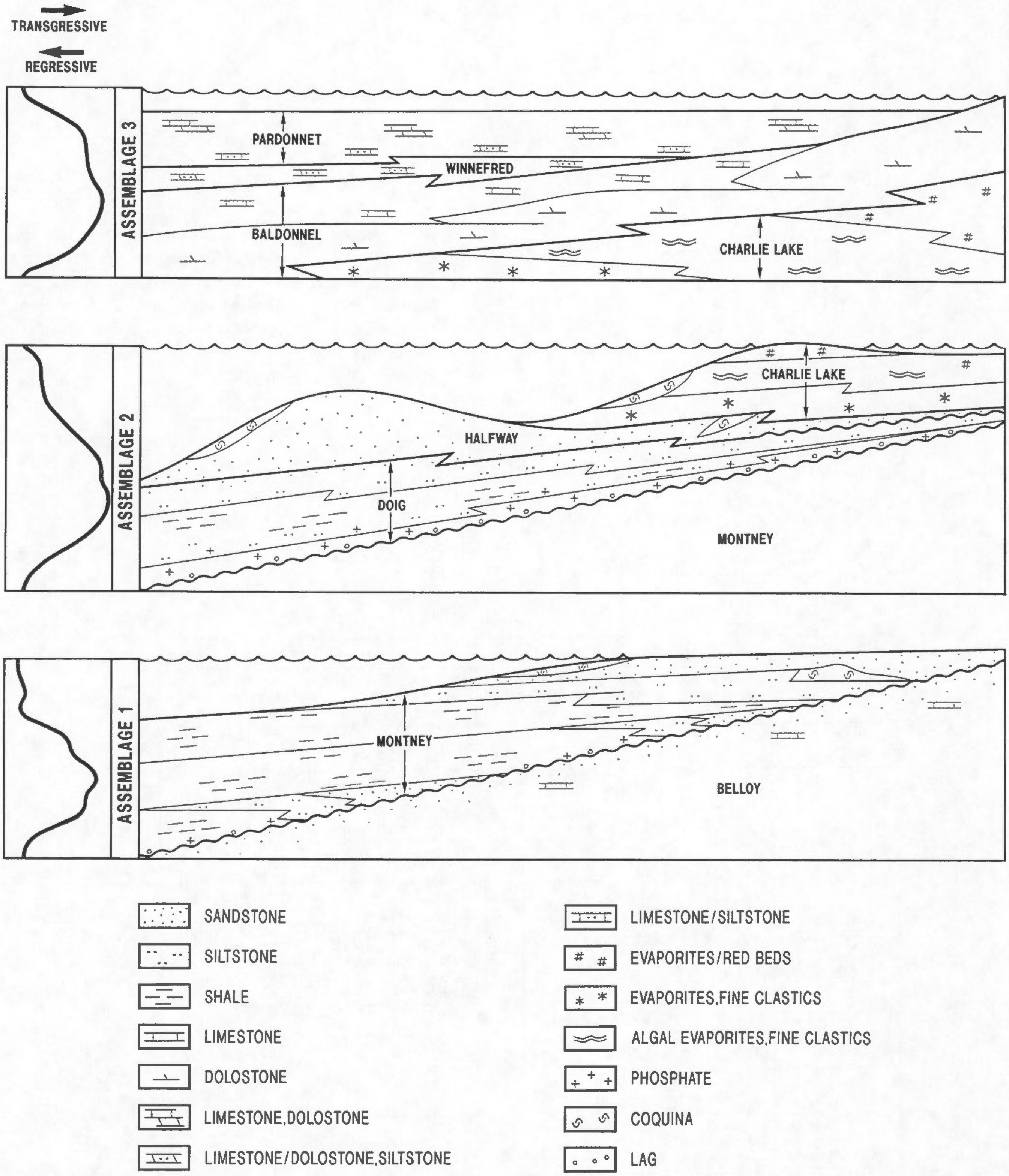

Figure 10. *Schematic cross-sections illustrating the three major Triassic assemblages. The regressive phase at the end of assemblage 1 and post-Triassic erosion has subsequently removed portions of the eastern edge of each assemblage.*

marks the beginning of the regressive phase of this assemblage and consists of a coarsening-upward sequence of shale near the base, grading upward through fine grained sandstone to coarse grained sandstone at the top (Gibson, 1968; Cant, 1986; Aukes and Webb, 1986). These strata are characterized by sandy siltstone and fine grained, phosphatic, calcareous sandstone, bioturbation, shell fragments, and acritarchs (Armitage, 1962; Cant, 1986). These shelf deposits are overlain by shoreface sandstones, commonly dolomitic and coquinoid, as well as siltstone, shale and rare limestone. Depositional environments are interpreted to be a complex of tidal and estuarine channels, barrier islands, tidal flats, and marine sheet, sand bodies (Aukes and Webb, 1986; Cant, 1986). Doig Formation sandstone and coquina reservoirs are best developed in the eastern nearshore portions of the formation, such as at Peejay–Milligan, Wembley, and Spirit River (Barss et al., 1964; Cant, 1986; Aukes and Webb, 1986). Wittenberg (1992) and Wittenberg and Moslow (1992a, b) discuss anomalously thick Doig sandstones at the Sinclair, Wembley and Valhalla fields, which they interpret to be the product of shoreface-sourced, mass wasting events occurring in an outer shelf to shelf margin setting.

Although the regional nature of the Halfway–Doig contact is controversial (Armitage, 1962; Barss et al., 1964), progressive truncation is evident from the regressive pattern of Doig Formation shelf sediments coarsening-upward into Halfway Formation shallow-marine and shoreline sandstones, which in turn, grade into overlying sabkha sediments of the basal Charlie Lake Formation. The Halfway sandstone Charlie Lake contact is distinct in the eastern subsurface, but becomes less so westward where the Charlie Lake is dominated by shallow marine sandstone (Barss et al., 1964; Armitage, 1962). The overall coarsening-upward pattern of the Halfway and Doig formations succession is locally interrupted by coquinas and sandstones thought to have been deposited in tidal inlets and channels (Cant, 1986; Barclay and Leckie, 1986; Horne et al., 1985; Munroe and Moslow, 1990). Halfway Formation lithofacies represent deposition in shoreface, barrier island, and sabkha settings (Fig. 12; Barclay and Leckie, 1986). The pattern is complicated by possible intermittent relative sea-level falls during Halfway Formation deposition, causing multiple shorelines (Hunt and Ratcliffe, 1959) and perhaps initiating multiple erosional events (Campbell et al., 1989). To the west of the shoreline units, the Halfway is a laterally extensive "blanket" deposit of fine grained sandstone representing lower shoreface to shelf deposition (Clark, 1961; Armitage, 1962; Torrie, 1973).

In eastern parts of the Peace River Embayment, Charlie Lake Formation lithofacies include anhydrite and evaporitic dolomite mudstone, shale and siltstone redbeds, stromatolitic and skeletal carbonate, dissolution breccias, sandstone, and salt (Barss et al., 1964; Gibson, 1975; Aukes and Webb, 1986; Cant, 1986; Higgs, 1990). Reservoir lithofacies occur mainly in stromatolitic skeletal carbonate (e.g., Boundary Lake, Coplin, Nancy, Braeburn, LaGlace, Demmit, Mica, and Cutbank members) and sandstone (e.g., Inga, North Pine, Siphon, Cecil, and Artex members; Torrie, 1973; Stewart, 1989; Higgs, 1990). These facies represent deposition in supratidal to intertidal environments, such as restricted lagoons and salt pans, tidal flats, aeolian dunes, barrier bars and beach shoals (Gibson, 1975; Edwards et al., 1994), and tidal channels belonging to a flat, arid coastal plain. In western parts of the Peace River Embayment, carbonate and clean sandstone intercalated with the eastern facies represents slightly deeper marine environments.

Assemblage 3. Upper Triassic Baldonnel and Pardonet formations

Marine limestones, siltstones and dolostones of the Baldonnel and Pardonet formations represent a return to transgressive shallow marine conditions, similar to lower portions of the Doig or Montney formations (Fig. 10). However, assemblage 3 differs from assemblages 1 and 2 in that it is dominated by carbonate facies. Continued transgression of the upper Baldonnel Formation is succeeded by Pardonet Formation carbonates and siliciclastics (Bever and McIlreath, 1984). The assemblage was terminated by a post-Triassic unconformity.

In assemblage 3, transgressive lower Baldonnel carbonates conformably overly Charlie Lake evaporites. The base of assemblage 3 is considered to begin above the last occurrence of anhydrite beds (Hunt and Ratcliffe, 1959; Barss and Montandon, 1981). Lithofacies in this assemblage include dolomitic mudstone to grainstone, very fine grained sandstone and argillaceous siltstone (Hunt and Ratcliffe, 1959; Gibson, 1975; Bever and McIlreath, 1984). Facies are interpreted to represent deposition in shoreface to shoreline environments.

The Pardonet Formation represents the final phase of transgressive deposition in assemblage 3 (Fig. 10). It rests conformably on the uppermost Baldonnel Formation (Armitage, 1962; Gibson, 1975, 1993b).

In the western parts of the Peace River Embayment, a lower Pardonet unit consisting of dark dolomitic and argillaceous siltstone represents transgressive deposition over the upper Baldonnel Formation (Barss and Montandon, 1981). The balance of the Pardonet Formation consists of: a clean and an argillaceous lithofacies (Barss and Montandon, 1981). The clean facies is dominated by sandy, pelletal, oolitic, bioclastic and intraclastic limestone and dolostone. The argillaceous lithofacies is dominated by argillaceous siltstone and silty carbonates. The cleaner carbonates represent foreshore to subtidal deposition and the argillaceous units indicate a deeper water, distal shelf origin (Barss and Montandon, 1981). High concentrations of carbonaceous matter in the argillaceous units suggest deposition under restricted marine to anoxic conditions (Gibson, 1975) and thus may have potential as petroleum source rocks.

The "Worsley/Tangent Dolomite", of uncertain age, rests unconformably on top of the Charlie Lake Formation (where Baldonnel and Pardonet formations are absent) in the Worsley region of northwestern Alberta (Fig. 9). Because of the lack of diagnostic fossils, the unit could possibly be an equivalent to the upper Norian Bocock Formation in the Foothills to the west. Other possible equivalents include the upper Pardonet Formation or the lower Jurassic carbonate of the Fernie Formation. Moslow and Davies (1992) suggest that the Worsley zone is laterally equivalent to the upper part of the Charlie Lake Formation, and is correlative with a restricted facies of the Baldonnel Formation.

The contact of the Triassic with overlying Jurassic Formations is unconformable throughout the region. This contact down-cuts eastward into progressively older Triassic strata, until beyond the Triassic subcrop edge, where Paleozoic strata are unconformably overlain by Jurassic units. The sub-Jurassic erosional surface merges eastward and northward with the sub-Cretaceous erosional surface, further reducing present Triassic limits.

Source rocks

Thick sequences of organic rich shales occur in the west-dipping sedimentary wedge. Source rock studies by Creaney and Allan (1990) and Riediger et al. (1990) focus on oil but their conclusions may apply also to natural gas, as summarized below. Commonly, oil and gas occur together in Triassic pools so it is likely that oil and gas source rocks are similar.

The most prolific source rock in the Peace River region is the "Phosphate Zone" at the base of the Doig Formation, which contains from 2 to 11 per cent, oil-prone (Type II), organic matter. Oils in the Halfway, Doig and Charlie Lake formations show biomarker correlation to this zone. The Lower Jurassic "Nordegg Member" is also a known source, as illustrated by biomarker correlations (Riedeger et al., 1990). Other possible sources include upper Montney Formation shales and Charlie Lake Formation mudstones and evaporites. Contributions from source rocks deeper in the section may be provided by organic-rich shales in the Carboniferous Kiskatinaw, Golata and Debolt formations (Barclay, 1988), as well as from the Devonian–Carboniferous exshaw and Besa River formations.

Organic maturation trends increase progressively westward with increasing depth of burial. Pools of associated and nonassociated gas may have been charged by gas generated from source rocks beyond the oil window and moving along extensive migration pathways. Moslow and Davies (1992) discuss the role of thermo-chemical sulphate reduction in the generation of H_2S, a major component in many carbonate-hosted pools. Reduction of sulphate in the presence of migrating hydrocarbons, with elevated temperatures generated by deep-burial or structurally-controlled thermal anomalies, is thought to form H_2S. Proximity to upper Charlie Lake Formation anhydrites as a source for the sulphate, combined with a mechanism to supply water are also important components in the reaction.

RESERVOIR AND TRAP STYLES

Structural style and degree of deformation vary across the region and stratigraphic trapping mechanisms typically involve some structural control. Laramide deformation dominates in the west, while in the east, Triassic strata are affected by vertical movements on horsts and graben blocks associated with the Peace River Arch/Embayment (see O'Connell and Bell, 1990; Fig. 11). The boundary between these two structural domains is diffuse and a spectrum of trapping mechanisms forms hybrid structural/stratigraphic traps. Plays are grouped according to dominant trapping mechanism and are outlined in Table 1.

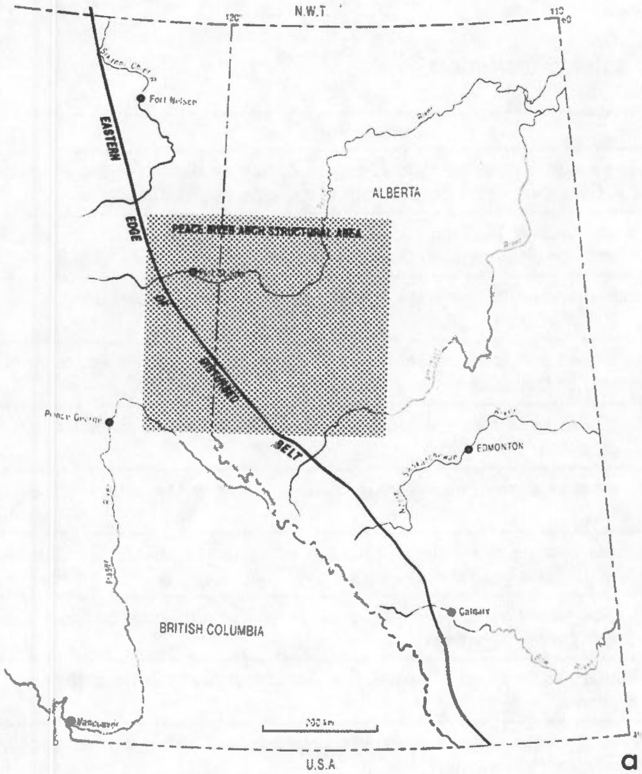

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Figure 11. Maps showing: a. the general location of the Peace River Arch structural area. b) the area influenced by Peace River Arch. Modified from Barclay et al. (pers. comm.).

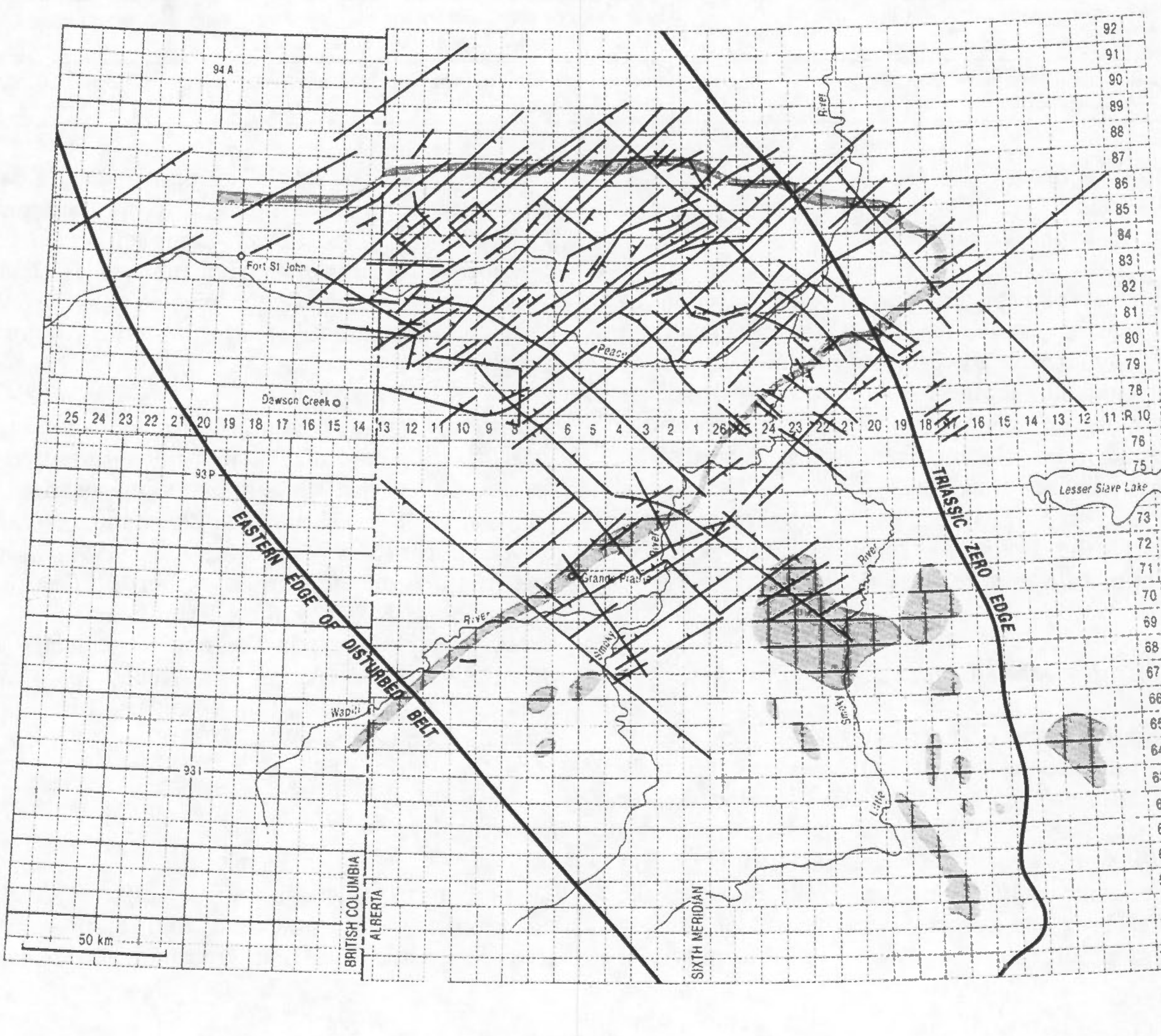

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Table 1

Triassic play list with brief description

Play #	Play name	Description
1	Montney Subcrop South – Fir play	sandstones and coquinas close to erosional edge; may also be affected by draping over Peace River Arch-related horsts or Devonian reefs, e.g., Kaybob South
2	Montney Distal Shelf – Glacier play (Immature)	sandstone lenses overlain by thick shales distant from erosional edge; may drape deeper structures, e.g., Gordondale, Boundary
3	Montney Subcrop North – Ring play (Immature)	shoreline sandstones at erosional edge affected by pre-Cretaceous and pre-Jurassic erosion, e.g., Ring/Pedigree
4	Halfway/Doig Shore Zone (Peace River Structure) – Sinclair play	shoreline sandstones and coquinas; reservoirs influenced by drape over Peace River Arch horst blocks or Devonian reefs, e.g., Valhalla, Sinclair, Wembley
5	Halfway/Doig Shore Zone – Peejay Milligan play	shoreline sandstones distant from strong Peace River Arch structural influence, e.g., Peejay, Milligan, Willow
6	Halfway/Doig Shelf (Peace River Structure) – Monias play	shelf sandstones draped over Peace River Arch horst blocks or Devonian reefs, e.g., Monias, Wilder
7	Halfway/Doig Shelf – Tommy Lakes play	shelf sandstones forming reservoirs overprinted by Laramide structural influence (gentle folds), e.g., Tommy, Cache Creek, Martin
8	Charlie Lake Clastics – Inga play	dominantly shallow marine sandstones with Laramide structural influence (gentle folds), e.g., Inga, Cache Creek, Silverberry
9	Charlie Lake Clastics (Peace River Structure) – Cecil play	dominantly sandstones draped over Peace River Arch horst blocks or Devonian reefs, e.g., Cecil, Siphon
10	Charlie Lake Carbonates (Peace River Structure) – Boundary Lake play	algal carbonates draped over Peace River Arch horst blocks or underlying topography, e.g., Boundary Lake, Pouce Coupe
11	Baldonnel Subcrop – Laprise play	coquinas and algal carbonates near erosional edge; with overprint of Laramide structural influence (gentle folds), e.g., Laprise, Nig
12	Baldonnel (Peace River Structure) – Fort St. John play	coquinas and algal carbonates draped over Peace River horst blocks, e.g., Boundary Lake, Braeburn

Stratigraphic traps

Lithofacies pinchouts

Triassic reservoirs occur typically in shoreline to shallow marine sandstone and carbonate enclosed vertically and laterally by restricted marine evaporite or offshore marine shale and siltstone seal rocks. Examples include Halfway Formation shoreface, barrier and tidal channel sandstones enclosed by offshore mudstones or sabkha evaporites. Charlie Lake Formation stromatolitic carbonate reservoirs, particularly the Boundary Member, are sealed by sabkha anhydrite and redbeds (Roy, 1972).

Unconformity related traps

Unconformity traps occur primarily at the regional angular unconformity that truncates progressively older Triassic units in a west to east direction. Lower Jurassic units overlie the top of the Triassic except toward the north where Cretaceous sediment is present on the unconformity (Armitage, 1962; Barss et al., 1964). Leaching and porosity enhancement of Triassic strata also occurred at the regional unconformity. Oil and gas pools occur in dolomitized and leached limestones along subcrop edges of the Baldonnel and Charlie Lake formations. Campbell et al. (1989) describe updip erosional truncation of Halfway and Doig formation shoreline sequences by a pre-Charlie Lake erosional event, creating a series of northwest trending subcrop belts.

Although major unconformities act as regional and local trapping controls, smaller unconformities within formations provide similar, but more localized traps. Units within the Charlie Lake Formation are affected by such unconformities. Forbes et al. (1991) discuss the role of three unconformities within the Charlie Lake Formation at Manir, Kakut, Rycroft and Cecil fields. Other examples include the outlier geometry of the Spirit River Field (Aukes and Webb, 1986) and the erosional isolation of the Boundary Member algal carbonate reservoirs (Roy, 1972).

Structural traps

Two groups of structural traps are differentiated based on geometry, location, and timing of controlling tectonic events. The first group involves underlying

Peace River Arch-related Paleozoic structures, while a second group consists of folded reservoirs associated with the Laramide Orogeny.

Traps due to structural drape are controlled by minor Paleozoic structures formed in a complex of horsts and grabens rooted in the Precambrian basement. The style of faulting is that of high-angle normal faults forming horst and graben blocks at least several kilometres in area. Faults have two principal orthogonal orientations, northwest-southeast and northeast-southwest (Sikabonyi and Rodgers, 1959; Gibson and Barclay, 1989; Gibson and Edwards, 1990; O'Connell et al., 1990; Pruden et al., 1991). Throw on the faults is in the order of several metres or less, some with a total displacement up to 60 m, such as the Boundary Lake Fault, trending northeast-southwest through the B.C. townships.

Laramide structural influence created large faulted anticlines and folds in the Foothills which become more subdued eastward in the plains region. This compressional style is important in localizing hydrocarbons by overprinting stratigraphic traps. Complex combination traps are formed where discontinuous reservoirs are involved in only portions of Laramide folds (e.g., Inga oil field; Fitzgerald and Peterson, 1967).

Another effect of structural deformation is to enhance reservoir character by creating a network of open fractures. The action of fluids migrating through these fractures can develop vuggy porosity in carbonate rocks with little primary porosity. Thus, reservoirs typically unproductive in unstructured areas have their potential productivity increased. Besides opening fracture conduits, compressional forces may modify older structures and enhance closure on pre-existing stratigraphic traps in sandstones (Pruden et al., 1991). Monias field is an example of this type of trap.

On a regional scale, the stacking of thrust plates in the Foothills and Rocky Mountains depressed the sedimentary wedge into a steeper west-dipping attitude causing maturation of source beds and allowing eventual eastward updip migration of oil and gas.

ESTABLISHED PLAYS: GEOLOGICAL DEFINITION AND RESOURCE ASSESSMENT

The combination of regional truncation of the Triassic succession updip, its internal facies variations, and complex structural history provide numerous opportunities for the entrapment of gases migrating from deep portions of the basin. A total of 10 mature and 2 immature established plays were defined within the Montney, Halfway, Doig, Charlie Lake, Baldonnel and Pardonet formations (Table 1). All plays are stratigraphic but have varying amounts of structural overprinting, either due to the Laramide Orogeny or Peace River Arch/Embayment block faulting. Plays are named using formation name, trap type and a large or characteristic pool. Each play type is discussed in sequence with respect to definition, geology, exploration history, and expected potential.

Montney Formation plays

1. Montney Subcrop South–Fir

Play definition. This play is defined to include all gas pools and prospects in stratigraphic traps in Montney Formation sandstone and coquina reservoirs. Gas is trapped in: 1) erosional truncations at the eastern subcrop edge, 2) structural drape over underlying Paleozoic features, 3) facies pinchouts, and 4) combinations of the previous three factors. The play area forms a belt up to 130 km wide, limited to the east by the Montney erosional edge, to the west and south by the depositional edge of reservoir facies sandstones, and to the northwest by the northern limit of Peace River Arch structural influence (Fig. 12). North of the arch influence, the Montney Subcrop North–Ring (immature) play continues the subcrop trend with a diagenetic and hydrodynamic trapping mechanism involving less structural influence.

Geology. Reservoirs occur in several sandstone and bioclastic dolostone units of the Montney Formation, representing progradational pulses of shoreface sediments which are interbedded with distal to proximal shelf deposits (Fig. 13). Less productive

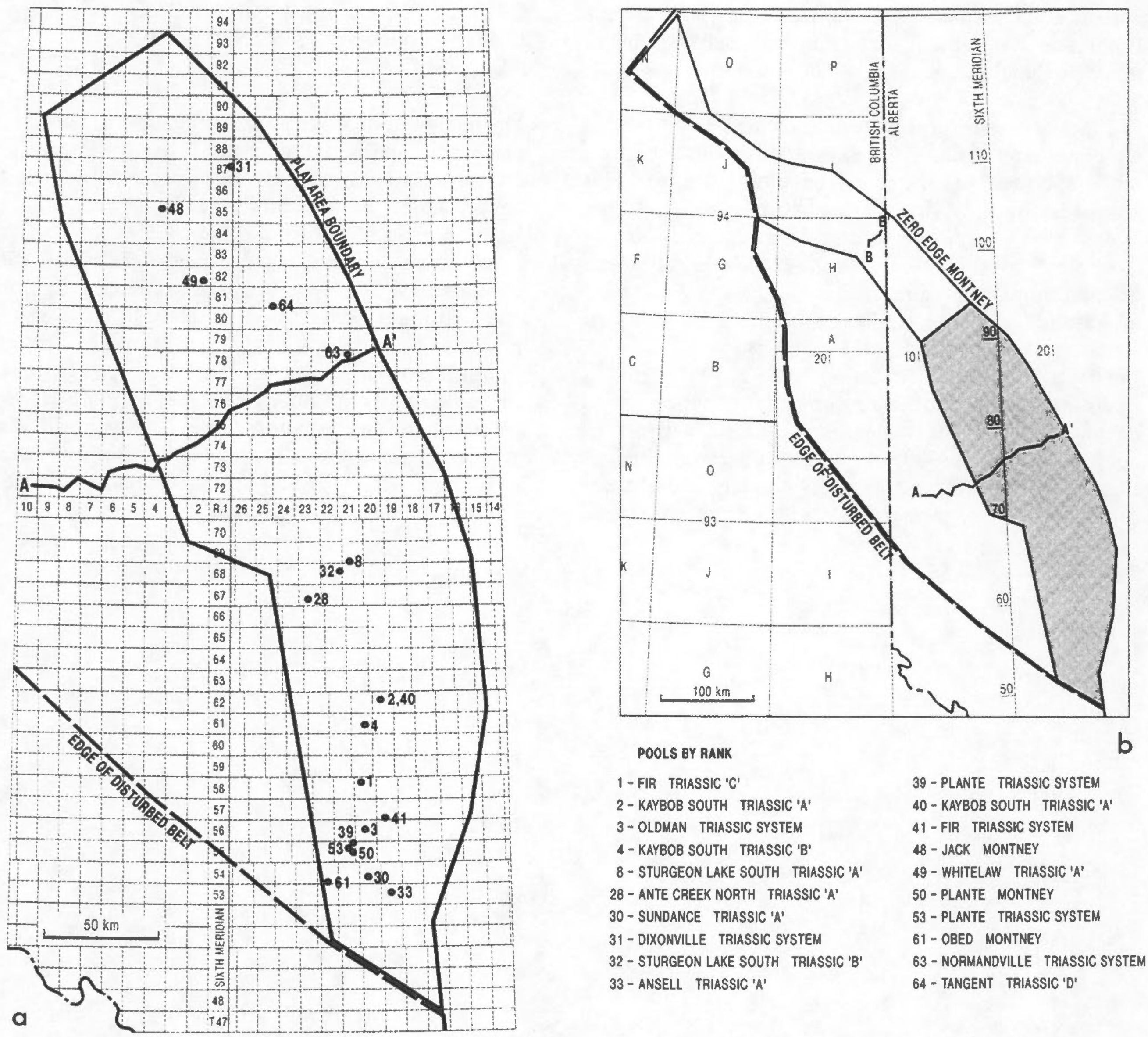


Figure 12. *a. Map of the Montney Subcrop–Fir play area. The discovery wells of the 20 largest pools and their respective ranks are shown. See Table 2 for the volumes of these pools and Figure 13 for cross-section A–A'. b. Location of this play with respect to the other Montney plays.*

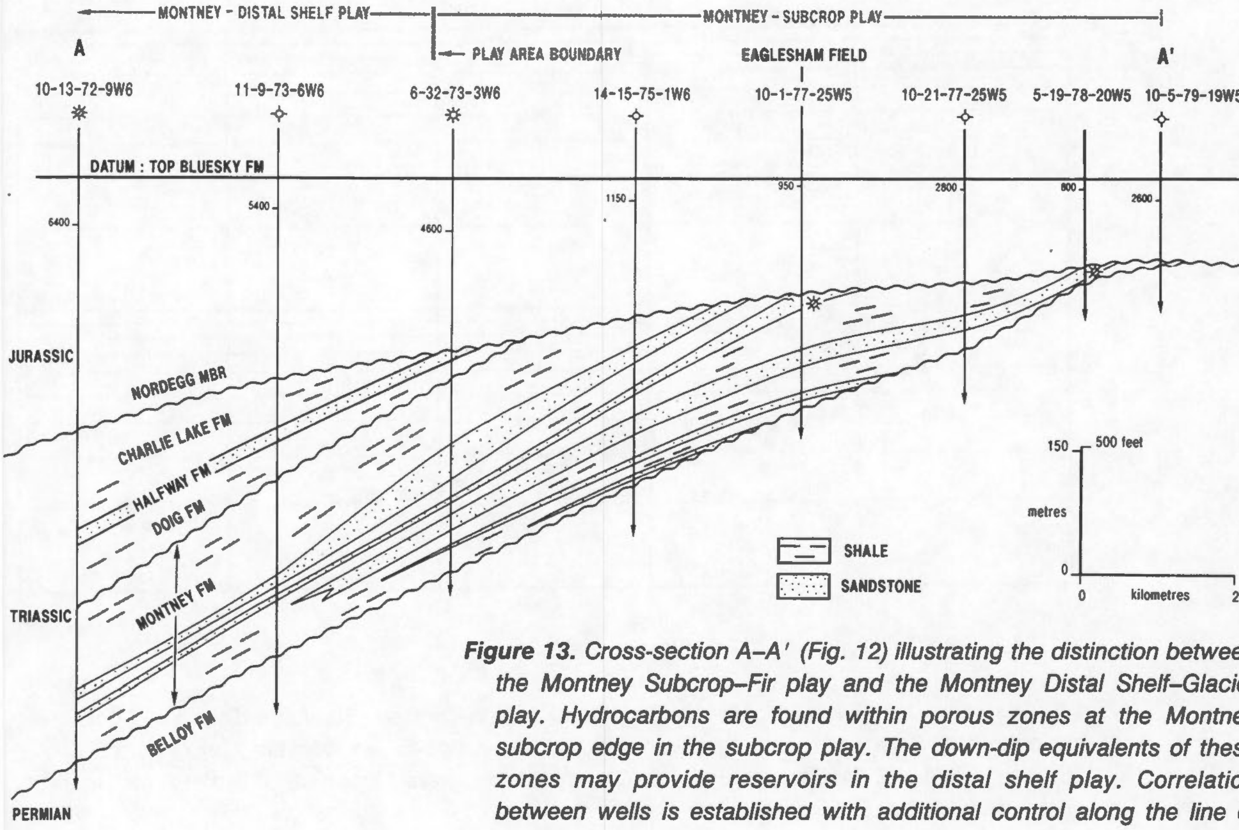


Figure 13. *Cross-section A–A' (Fig. 12) illustrating the distinction between the Montney Subcrop–Fir play and the Montney Distal Shelf–Glacier play. Hydrocarbons are found within porous zones at the Montney subcrop edge in the subcrop play. The down-dip equivalents of these zones may provide reservoirs in the distal shelf play. Correlation between wells is established with additional control along the line of section.*

reservoirs include very fine to fine grained, silty, quartzose sandstones cemented with carbonate (Metherell, 1966; Miall, 1976).

Erosional truncation is a common trapping mechanism where the post-Triassic unconformity surface truncates progressively older Triassic units eastward. Enhancement of porosity by the leaching of soluble grains at or near the erosional surface is likely to occur anywhere along the subcrop zone. Local facies changes cause variations in primary porosity. The presence of fracturing also is an important control on reservoir distribution and quality. Drape of Montney Formation reservoir facies and differential compaction over buried Leduc reef topography is the trapping mechanism for the Sturgeon Lake South pool. Facies pinch-out traps are caused by the lateral termination of sandstone and coquina, reservoir facies, where they change to siltstone and shale. Lateral and top seals, as well as source rocks are likely formed by intervening shales and siltstones within the Montney Formation and by shales in the overlying Jurassic Fernie Formation.

Exploration history. The first discoveries in this play were made in 1951 at Whitelaw and Tangent. Sturgeon Lake South, was discovered in 1956 when the Montney Formation was tested as a secondary pay zone in a Devonian Leduc reef development well (Shell Oil Company, 1956; Sproule and Boggs, 1956). The first Kaybob South Montney pool was found in 1962, again following a deeper discovery. Numerous pools were discovered through the 1970s such as Fir in 1971, and Oldman in 1977. Subsequent exploration efforts have resulted in the discovery of many small pools associated with other primary target zones. This play contains 73 pools with a total in-place volume of 25 876 x 10^6m^3. Typical values for net pay and porosity are 4 m and 15 per cent respectively (Table 2). Although Montney Formation reservoirs can be prolific gas producers, exploration efforts are hampered by the limited thickness and erratic distribution of reservoirs. Exploration is also made difficult by poor seismic resolution.

Play potential. The potential initial in-place volume for this play is 23 258 x 10^6m^3 which is likely to be discovered in 427 pools with sizes varying from 180 to 1 000 x 10^6m^3 (Fig. 14). New pools are anticipated in local facies pinch-out traps or at the erosional edge. Exploration efforts may be aided by the detailed study of faults and fracture networks in relation to diagenesis and hydrocarbon migration. Potential for undiscovered pools is in the poorly drilled northeast part of the play area close to the subcrop zone.

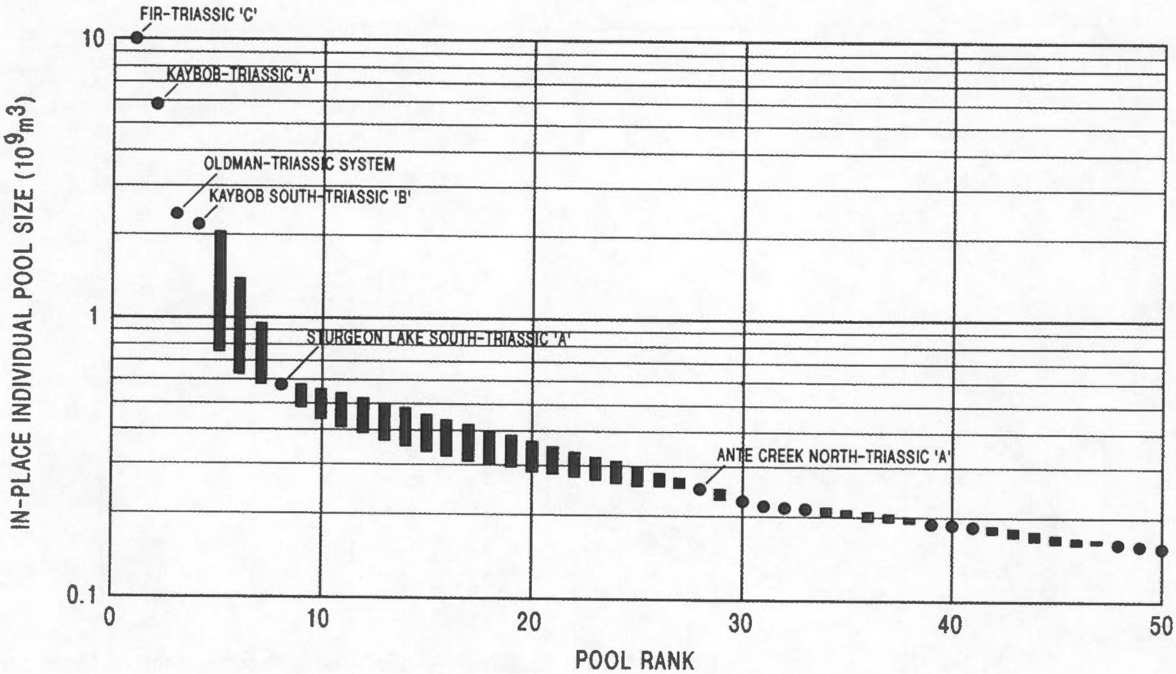


Figure 14. Pool size-by-rank plot for the Montney Subcrop-Fir play. Six large discovered pools are annotated (dots), with rectangles representing size range for undiscovered pools cut off at 50. See Figure 12 for locations of the 20 largest discovered pools and Table 2 for pool parameters.

Table 2

Montney Subcrop South - Fir play, reservoir parameters and assessment results

Rank	Field/Pool	Gas type	In-place volume (10^6m^3)	Disc. date	Net pay (m)	Area (hect.)	Depth (m)	R.F.	Por.	S.W.
1	Fir, Triassic C	NA	9 974	71/12/12	2.3	22 527	2 661	0.80	0.10	0.20
2	Kaybob South, Triassic A	AG+SG	5 552	62/12/06	*	*	2 055	0.53	*	*
3	Oldman, Tria Sys	NA	2 361	77/05/15	3.8	2 473	2 897	0.80	0.15	0.15
4	Kaybob South, Triassic B	NA	2 206	75/12/28	3.5	1 721	2 377	0.80	0.11	0.25
8	Sturgeon Lake South, Triassic A	AG+SG	578	56/11/22	1.8	335	1 498	0.75	0.15	0.35
28	Ante Creek North, Triassic A	NA	252	54/07/29	3.6	505	1 868	0.90	0.11	0.30
30	Sundance, Triassic A	NA	229	74/06/04	1.6	718	3 230	0.75	0.08	0.25
31	Dixonville, Tria Sys	NA	219	58/11/20	5.2	440	841	0.80	0.20	0.30
32	Sturgeon Lake South, Triassic B	AG+SG	217	56/02/18	1.4	607	1 539	0.75	0.14	0.45
33	Ansell, Triassic A	NA	217	77/11/10	3.7	400	3 077	0.75	0.09	0.20
39	Plante, Tria Sys	NA	188	76/12/30	3.7	200	2 981	0.80	0.15	0.40
40	Kaybob South, Triassic A	AG	187	62/12/06	1.8	782	2 091	0.75	0.10	0.25
41	Fir, Tria Sys	NA	186	78/03/10	3.3	400	2 632	0.75	0.09	0.30
48	Jack, Mont	NA	161	78/05/28	1.9	1 095	1 096	0.70	0.16	0.40
49	Whitelaw, Triassic A	NA	159	51/03/26	4.9	200	1 009	0.90	0.21	0.30
50	Plante, Mont	NA	156	80/12/11	5.2	200	3 002	0.75	0.09	0.15
53	Plante, Trias Sys	NA	148	66/02/12	2.8	128	2 914	0.80	0.20	0.25
61	Obed, Mont	NA	130	81/05/20	4.1	200	3 535	0.75	0.11	0.40
63	Normandville, Tria Sys	NA	127	81/05/21	9.0	200	910	0.75	0.13	0.30
64	Tangent, Triassic D	NA	125	51/08/02	1.5	200	868	0.75	0.23	0.25
	Total initial in-place volume (discovered)		25 876							
	Total initial in-place volume (potential)		23 258							
	Per cent play resource undiscovered		47							
	Total pools discovered		73							
	Total pool population		500							

*indicates numbers not given in data base

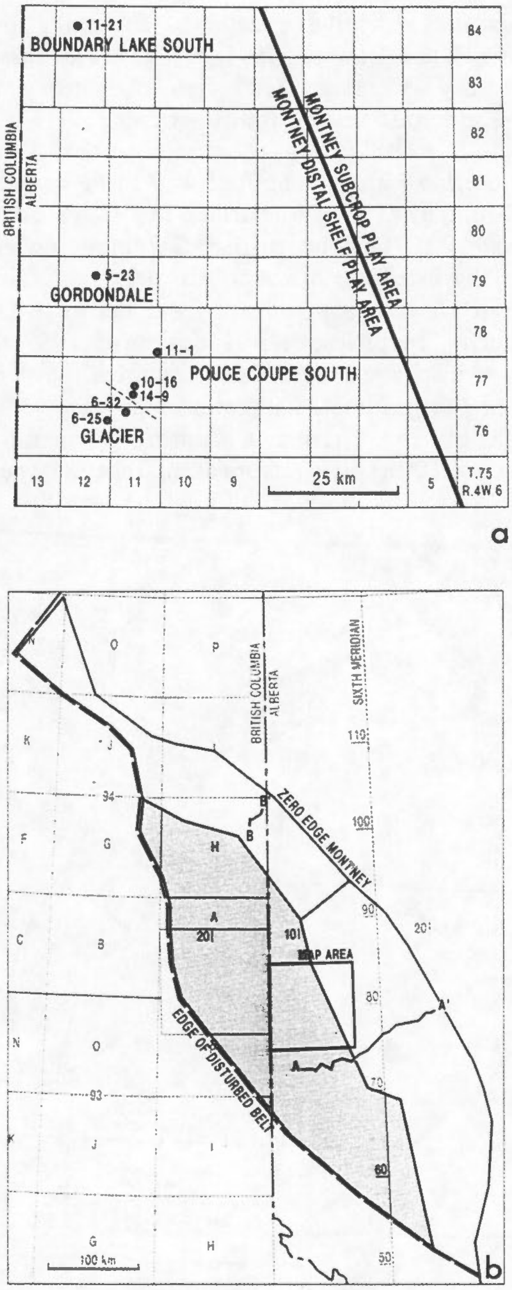


Figure 15. Maps of the immature Montney Distal Shelf-Glacier play showing: ***a.*** *the location of the discovery wells for the seven known pools.* ***b.*** *location of this play with respect to the other Montney plays.*

2. Montney Distal Shelf-Glacier (Immature)

Play definition. This immature play involves reservoir sandstones overlain by a thick sequence of shale and siltstone occurring in the lower part of the Montney Formation, west of the main subcrop edge. These fine grained sandstones may represent turbidites or transgressive lag deposits in a distal shelf setting (Fig. 15, 16). Seven gas pools with an initial in-place volume of 713 x $10^6 m^3$ form a trend from Glacier, Pouce Coupe and Gordondale northwest to Boundary Lake. Typically net pay is 4 m and porosity is 9 per cent.

Play potential. Since past drilling strategy has favoured exploration for shallower Triassic targets, this play could have significant potential. Recent drilling demonstrates the importance of this developing play. An estimate of expected potential for this immature play is given at 12 191 x $10^6 m^3$ calculated using all Triassic plays in a discovery process model (discussed later).

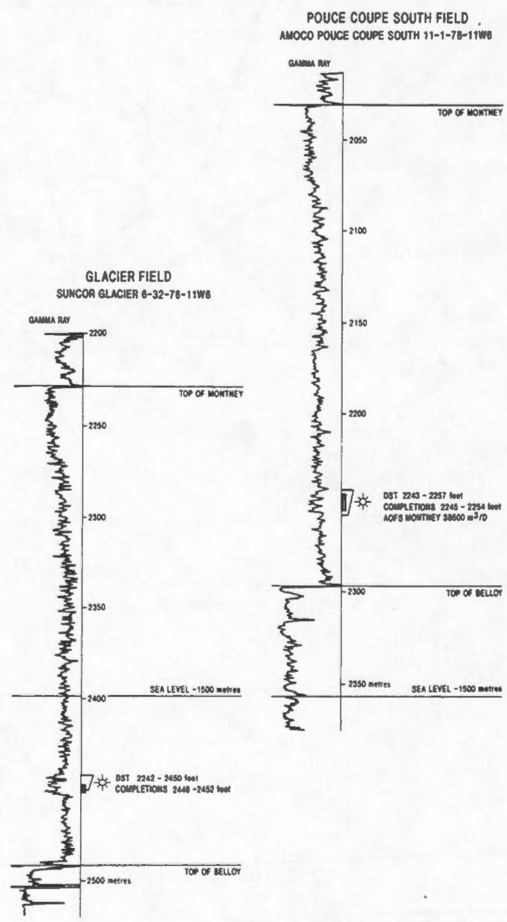


Figure 16. Representative logs showing producing zones in the lower Montney at 2 locations in the Montney Distal Shelf-Glacier play. See Figure 15 for locations.

3. *Montney Subcrop North-Ring (Immature)*

Play definition. This play is immature because there is only one discovered pool (Fig. 17). Although this play has features in common with the Montney Subcrop South-Fir play, the Ring play is controlled by a trapping mechanism which involves an underpressured reservoir in a nonconventional hydrodynamic setting (N.R. Wemyss, pers. comm., 1992). Although underlying Paleozoic structures and syndepositional structural effects do play a role in the local distribution of hydrocarbons within the pool, structure is not the dominant trapping mechanism. The key feature is the formation of reservoir quality sandstones by the leaching of detrital dolomite grains in very fine grained sandstones to give excellent secondary porosity (Sturrock and Dawson, 1991; Fig. 18). This dissolution probably is associated with proximity to the Pre-Cretaceous unconformity surface.

Exploration history. The first well to be completed in the Montney at Ring was drilled in 1978 (Sturrock and Dawson, 1991). The British Columbia government officially listed the discovery in early 1980. However, because the area was distant from known trends and gathering facilities, it was not until 1989 that an extensive drilling program demonstrated the significant size of this gas pool. Estimates of in-place volume are given by the British Columbia government at 20 409 x 10^6m^3 with approximately 85 per cent

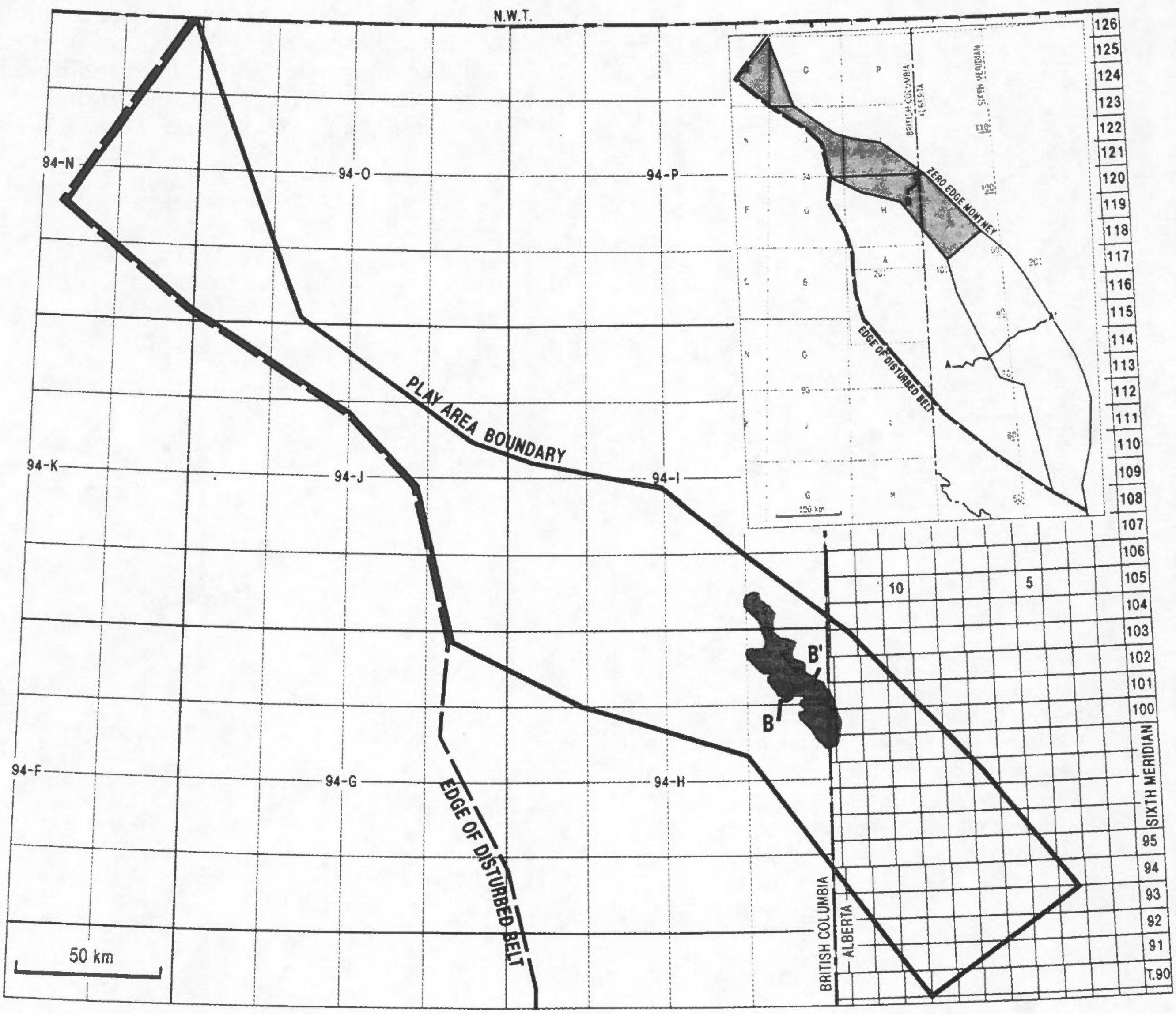


Figure 17. *Maps of the immature Montney Subcrop North-Ring play showing:* ***a.*** *the location of Ring/Pedigree (Border) Field and cross-section B-B', and* ***b.*** *the location of this play with respect to the other Montney plays. See Figure 18 for cross-section B-B'.*

(17 348 x 10^6m^3) attributed to the Montney Formation and the remaining 15 per cent attributed to the immediately overlying Cretaceous Bluesky and Gething formations. On the east side of the Alberta–British Columbia Border, the portion of reserves attributed to the Pedigree field is estimated to contribute 5 645 x 10^6m^3, to yield a total discovered in-place volume for the Ring–Pedigree pool, of 22 993 x 10^6m^3. Average porosity is 14 per cent, net pay averages 10 m, and area is approximately 50 000 ha (Sturrock and Dawson, 1991).

Play potential. Expected potential for this immature play is 15 971 x 10^6m^3, calculated using all Triassic plays in a discovery process model (discussed later). The play may have some potential to the northwest, but may be limited by a change in lithology to finer grained rocks with less detrital dolomite. There is a poorly explored region at the northern limit of the Triassic, in the Liard region of northern British Columbia, Yukon and Northwest Territories, which may have potential for gas trapped in other porous facies of the Montney Formation. To the southeast, the play may still hold some potential in undrilled areas, but the sub-Cretaceous unconformity downcuts into the reservoir leaving a thinner section that is closer to an interpreted water line.

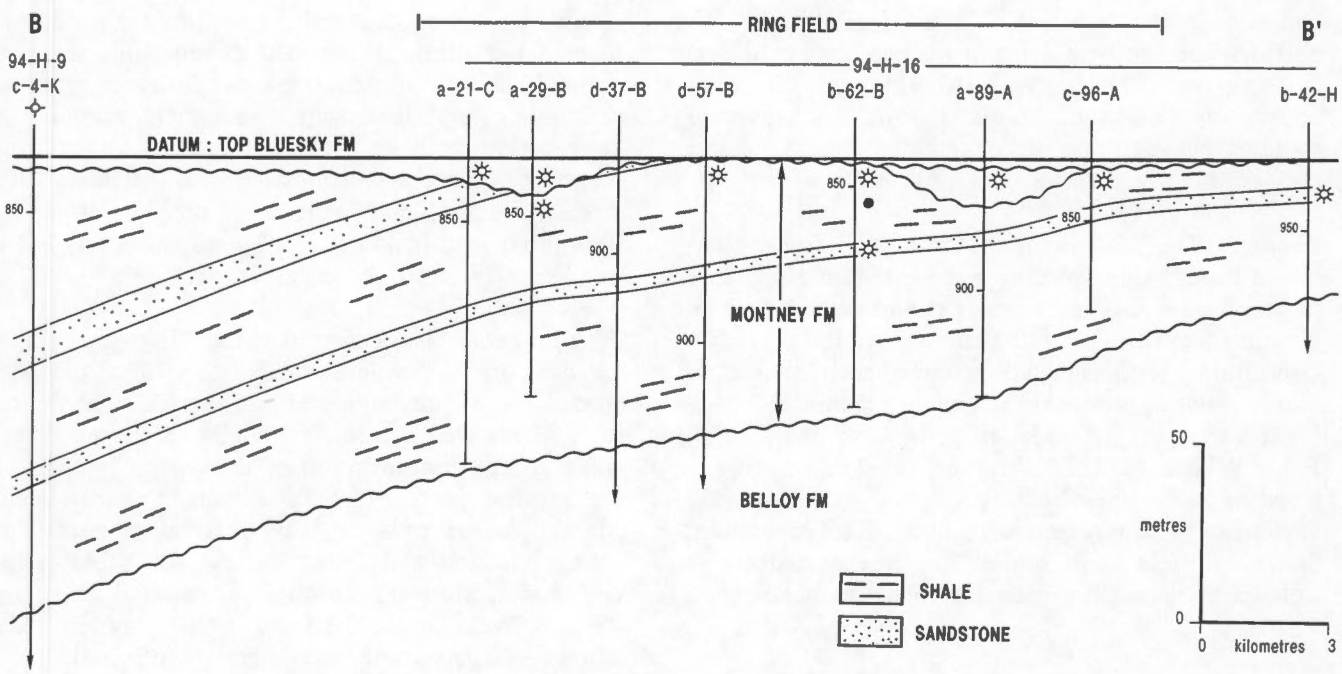


Figure 18. Cross-section B–B' (Fig. 17) showing the producing zones at the subcrop edge in the Ring/Pedigree (Border) field.

Halfway Formation and Doig Formation plays

4. Halfway/Doig Shore Zone (Peace River Structure)–Sinclair

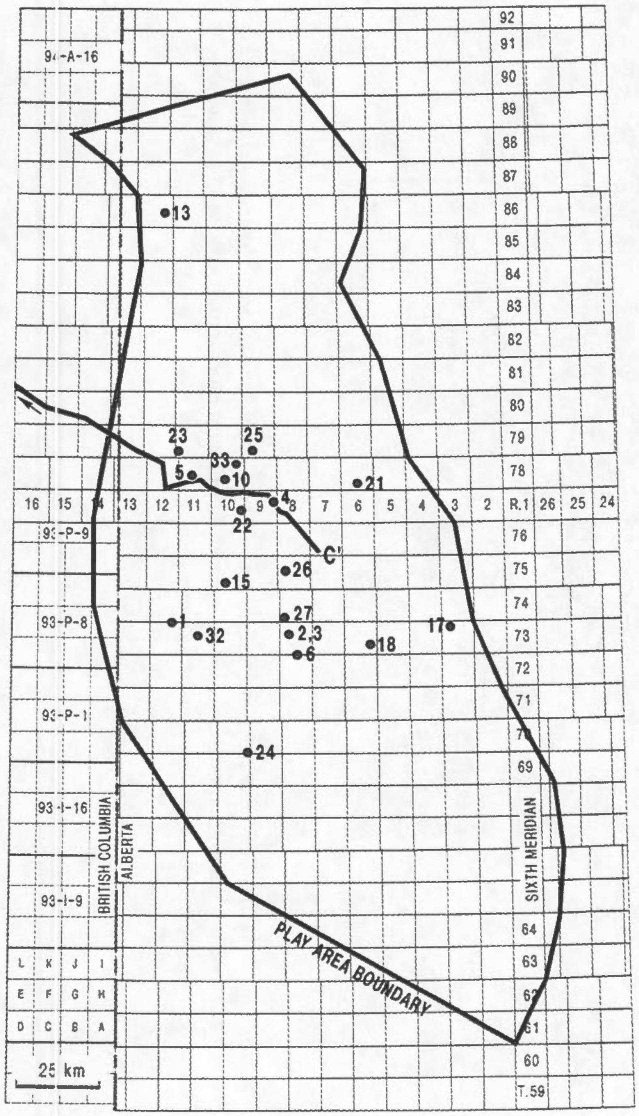
Play definition. This play includes all gas pools and prospects in facies change traps in nearshore sandstones and coquinas of the Halfway and Doig formations. Although this play is dominantly a stratigraphic play, it includes a large area that was influenced by an intermittent structural disturbance associated with the Peace River Arch/Embayment. The eastern limit of the play is defined by the erosional edges of the Halfway and Doig formations. The western edge of the play is delineated by a westward change from isolated shoreline and shoreface sand bodies to a broad, continuous shelf sandstone. The northern and southern limits of the play are established by the extent of Peace River Arch tectonic effects as defined by O'Connell et al. (1990). This play also contains gas pools in unconventional hydrodynamic traps in the Deep Basin area (Fig. 19).

Geology. The Halfway and Doig formations occur over a broad, arc-shaped area, and contain a sequence of interbedded clastics, evaporites and carbonates that dip and thicken in a southwestern direction (Fig. 20). Depositional settings include proximal shelf, shoreface, barrier island, and sabkha environments (Halton, 1981; Barclay and Leckie, 1986; Moslow and Davies, 1992; Willis, 1992). Several en echelon northwest-trending shorelines hosting oil and gas fields are attributed to progradational pulses of sedimentation. Some of these sand bodies are interpreted to be isolated by episodic erosional events (Campbell et al., 1989).

Within a belt parallel to the Halfway shoreline, bar sandstones and coquinoid storm ridge sandstones also were deposited. Bar sandstones consist of fine grained, well sorted and subrounded grains of quartz with good intergranular porosity. The coquina facies consists of a mixture of sand and dolomite with abundant molds of leached fossils. Some coquina accumulations occupy former tidal channels which intersect the bars and trend perpendicular to the shoreline. Some anomalously thick Doig sandstones may have been formed by shoreface-sourced, mass wasting events occurring near the shelf margin (Wittenberg, 1992; Wittenberg and Moslow, 1992b).

Exploration history. Exploration for Halfway Formation reservoirs resulted in the discovery of gas at Teepee Creek in 1972. Since then the area has produced a relatively continuous record of gas and oil discoveries, associated with many prolific producers. Considered mature, but still developing, the play occurs in an area of moderate well density. Exploration techniques rely on detailed geological mapping in conjunction with seismic stratigraphy and seismic mapping of structures associated with the Peace River Arch. A total in-place volume of 66 600 x $10^6 m^3$ has been discovered in 143 pools. Typically net pay is 5 m and porosity is 10 per cent (Table 3).

Play potential. The expected potential for this play is an initial in-place volume of 27 036 x $10^6 m^3$ predicted to occur in 217 remaining pools (Fig. 21). The regions with sparse well control, especially to the north and south of the concentration of discovered pools, hold the greatest potential. Targets include sandstones in longshore bars or sand waves, lagoonal bars, tidal inlets, channels and deltas, dunes, and sabkha algal carbonates. More traps along the erosional edge (e.g., Teepee Creek, Twp. 73 Rge. 3 W6M) may also exist. Limiting factors are the play's great depth in the south and the discontinuous nature of reservoirs.



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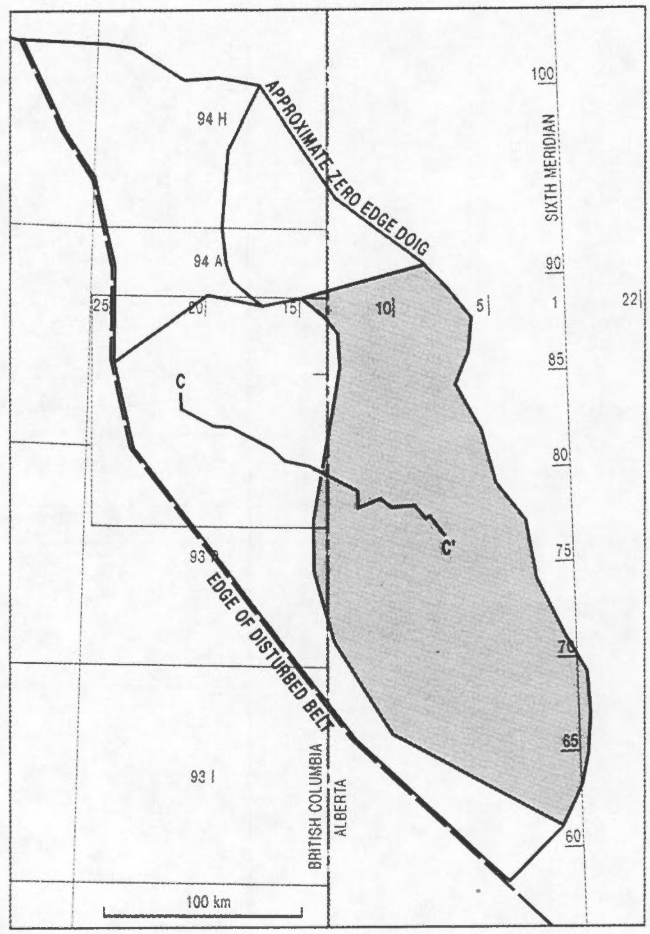

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POOLS BY RANK

1 - SINCLAIR DOIG 'A'
2 - WEMBLEY HALFWAY 'B'
3 - VALHALLA HALFWAY 'B'
4 - PROGRESS HALFWAY 'A'
5 - POUCE COUPE SOUTH DOIG 'B'
6 - WEMBLEY DOIG 'E'
10 - PROGRESS DOIG 'C'
13 - BOUNDARY LAKE SOUTH TRIASSIC 'G'
15 - VALHALLA HALFWAY 'A'
17 - TEEPEE DOIG 'A'
18 - GRANDE PRAIRIE HALFWAY 'A'
21 - SPIRIT RIVER HALFWAY
22 - PROGRESS HALFWAY 'B'
23 - GORDONDALE DOIG 'A'
24 - ELMWORTH HALFWAY 'A'
25 - PROGRESS HALFWAY 'P'
26 - VALHALLA HALFWAY 'C'
27 - VALHALLA DOIG 'D'
32 - KNOPCICK DOIG 'B'
33 - PROGRESS HALFWAY

***Figure 19.** **a.** Map of the Halfway/Doig Shore Zone–Sinclair play area. The discovery wells of the largest 20 pools and their respective ranks are shown. See Table 3 for the volumes of these pools and Figure 20 for cross-section C–C′. **b.** The location of this play with respect to the other Halfway/Doig plays.*

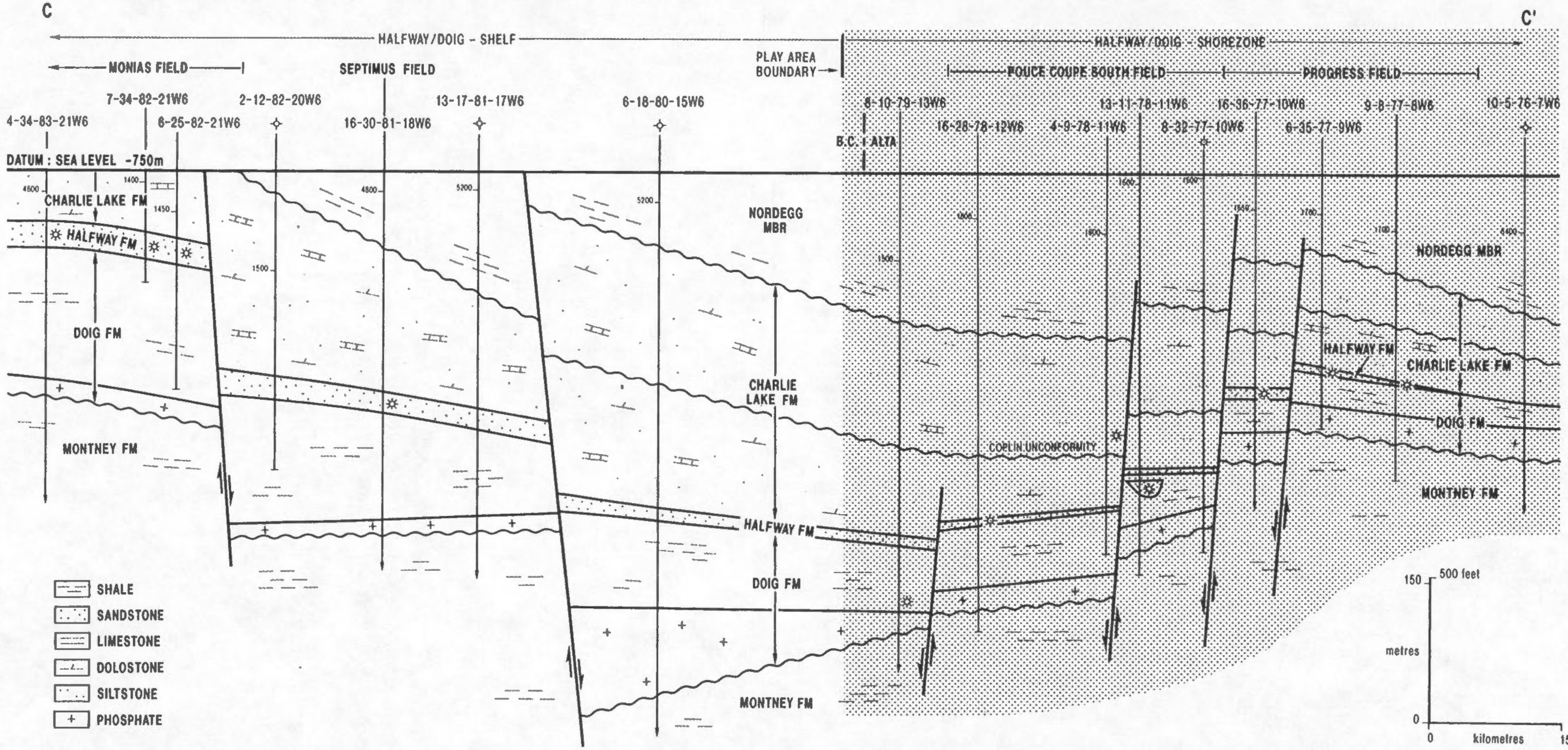

Figure 20. *Structural cross-section C–C′ (Fig. 19) through the Halfway/Doig Shelf–Monias play and the Halfway/Doig Shore Zone–Sinclair play (highlighted) showing structural control on hydrocarbon occurrence in the Halfway/Doig interval. The Shore Zone play is distinguished by discontinuous and relatively thin sands. Correlation between wells is established with additional control along the line of section (see Fig. 19).*

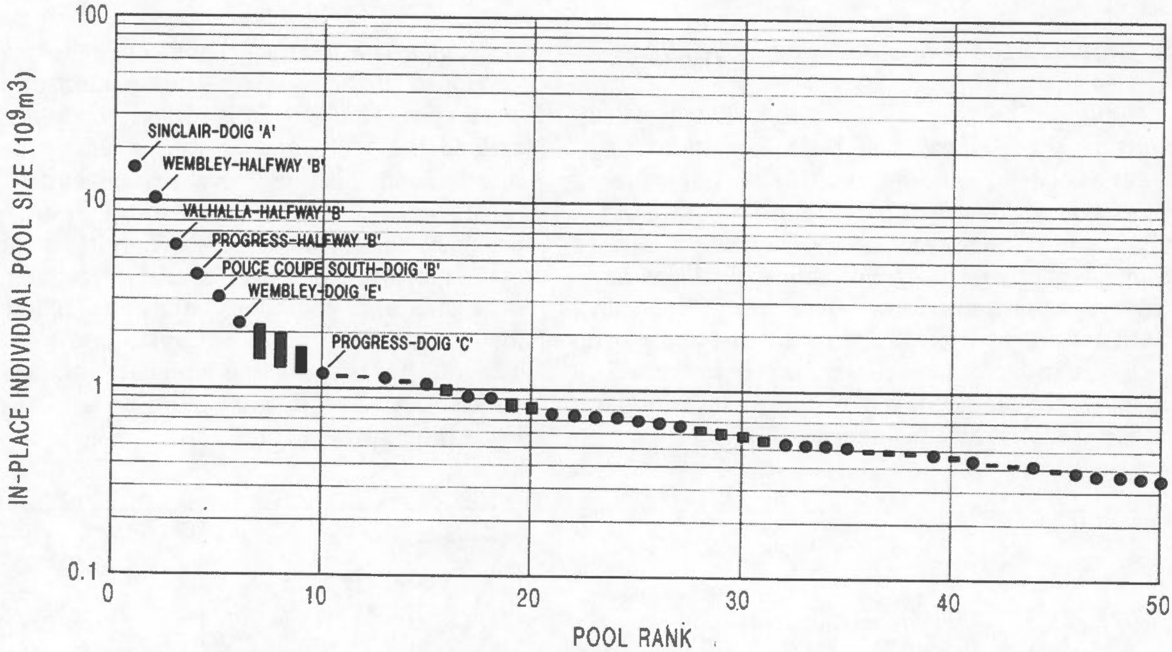

***Figure 21.** Pool size–by–rank plot for the Halfway/Doig Shore Zone–Sinclair play showing the top 50 pools (discovered and undiscovered). See Figure 19 for locations of the 20 largest discovered pools and Table 3 for pool parameters.*

Table 3

Halfway/Doig Shore Zone (Peace River Structure) - Sinclair play, reservoir parameters and assessment results

Rank	Field/Pool	Gas type	In-place volume (10^6m^3)	Disc. date	Net pay (m)	Area (hect.)	Depth (m)	R.F.	Por.	S.W.
1	Sinclair, Doig A	NA	14 815	77/06/24	11.7	7 758	2 513	0.75	0.09	0.15
2	Wembley, Halfway B	SG+AG	10 302	78/10/09	*	*	2 128	0.65	*	*
3	Valhalla, Halfway B	AG	5 885	78/10/09	3.8	5 983	2 024	*	0.14	0.15
4	Progress, Halfway A	NA	3 987	75/12/30	6.2	4 160	1 867	0.85	0.12	0.25
5	Pouce Coupe South, Doig B	NA	2 973	77/07/29	8.2	2 768	1 912	0.80	0.10	0.20
6	Wembley, Doig E	SG+AG	2 147	80/09/30	*	*	2 162	0.65	*	*
10	Progress, Doig C	NA	1 154	81/07/02	4.1	1 751	1 848	0.80	0.11	0.15
13	Boundary Lake South, Triassic G	NA	1 104	67/01/28	3.1	2 052	1 308	0.80	0.15	0.30
15	Valhalla, Halfway A	NA	1 028	73/06/25	4.5	1 934	2 142	0.75	0.09	0.30
17	Teepee, Doig A	NA	891	72/08/22	3.2	1 568	1 565	0.70	0.13	0.20
18	Grande Prairie, Halfway A	SG+AG	886	79/03/19	*	*	1 906	0.23	*	*
21	Spirit River, Charlie Lake K	SG	719	83/08/07	*	*	1 429	0.36	*	*
22	Progress, Halfway B	SG	707	76/12/10	*	*	1 909	0.65	*	*
23	Gordondale, Doig A	NA	704	80/05/27	4.9	1 340	1 751	0.85	0.08	0.20
24	Elmworth, Halfway A	NA	693	78/08/21	4.7	1 058	2 642	0.70	0.08	0.30
25	Progress, Half P	AG	667	87/09/13	4.9	574	1 653	0.90	0.17	0.15
26	Valhalla, Halfway C	SG+AG	648	86/09/22	*	*	1 954	0.65	*	*
27	Valhalla, Doig D	SG+AG	632	88/10/07	10.2	200	2 014	0.85	0.10	0.15
32	Knopcik, Doig B	NA	515	86/07/15	16.4	200	2 398	0.85	0.11	0.30
33	Progress, Halfway	NA	512	85/12/18	5.9	400	1 739	0.80	0.15	0.15
	Total initial in-place volume (discovered)		**66 600**							
	Total initial in-place volume (potential)		**27 036**							
	Per cent play resource undiscovered		**29**							
	Total pools discovered		**143**							
	Total pool population		**360**							

*indicates numbers not given in data base

5. *Halfway/Doig Shore Zone–Peejay Milligan*

Play definition. This play is defined to include isolated reservoirs in the Halfway and Doig formations that were deposited in shallow marine to nearshore environments, and overlain by evaporitic rocks of the Charlie Lake Formation. Gas is trapped in facies pinchouts. Underlying Doig Formation siltstones and fine grained sandstones form lateral seals. The play limits are defined by a zero edge to the east and north and a change in facies to shelf sandstones to the west. To the south, the play limit is defined by a transition to the more structurally-influenced Halfway/Doig-Sinclair play (Fig. 22).

Geology. The Halfway and Doig formations are developed in the northern continuation of the broad, arc-shaped Halfway/Doig Shore Zone-Sinclair play area to the south and contain a similar sequence of interbedded clastics, evaporites and carbonates (Mothersill, 1968). Depositional settings include proximal shelf, shoreface, barrier island and sabkha environments. Reservoirs consist of isolated lenses of quartzose and coquinoid sandstone filling erosional lows on the Doig surface (Caplan and Moslow 1991). The sandstones formed as elongate, southeast-trending bodies, deposited in tidal inlets on an irregular Doig Formation surface (Fig. 23).

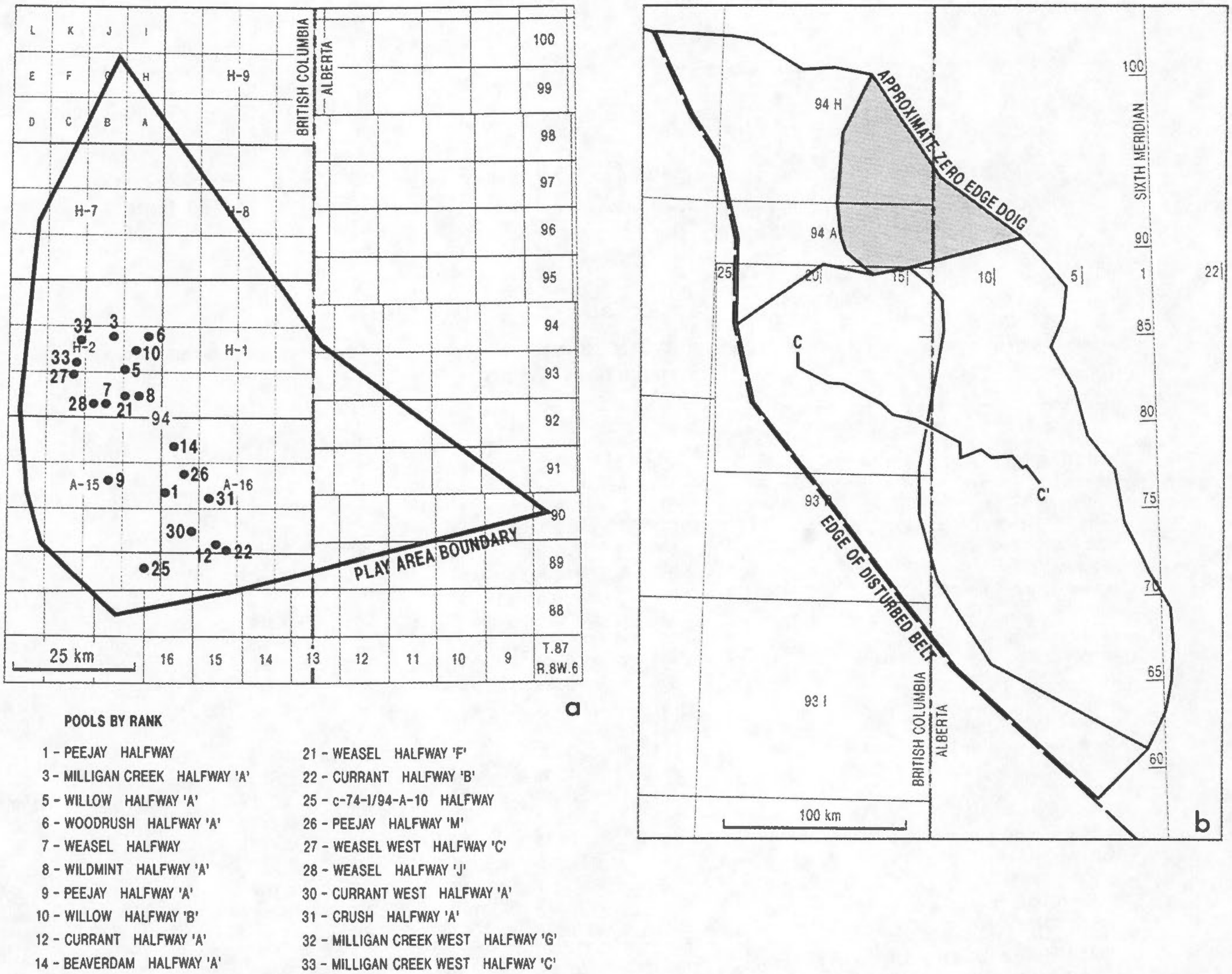

Figure 22. a. Map of the Halfway/Doig Shore Zone–Peejay Milligan play area. The discovery wells of the 20 largest pools and their respective ranks are shown. See Table 4 for the volumes of these pools. b. The location of this play with respect to the other Halfway/Doig plays.

Exploration history. Oil was discovered at Milligan Creek in the spring of 1957 in a well drilled updip of a gas show. Development of this oil-prone play proceeded slowly due to poor access and winter-only operations, until 1961 when several oil fields were connected to pipelines. Peejay, Beatton River, Wildmint and Weasel fields were subsequently discovered. Solution gas makes a significant contribution to the reserves found in this oil prone region with the most significant gas discovery made at Peejay in early 1959. Development of the area proceeded at a steady pace following construction of gathering facilities near the Willow, Weasel, Wildmint and Nettle fields. The play has initial in-place reserves of 12 731 x $10^6 m^3$ in 63 pools with the largest pool at Peejay, with 2 338 x $10^6 m^3$. Typically net pay is 5 m and porosity is 18 per cent (Table 4).

Play potential. The expected potential in-place volume is 10 839 x $10^6 m^3$ predicted to occur in 337 pools (Fig. 24). The largest remaining pool is estimated to be 1 600 x $10^6 m^3$ with most undiscovered pools less than 300 x $10^6 m^3$. Future discoveries will likely be in small pools in the immediate area of established fields. Some larger pools may be found in less explored areas to the north and east.

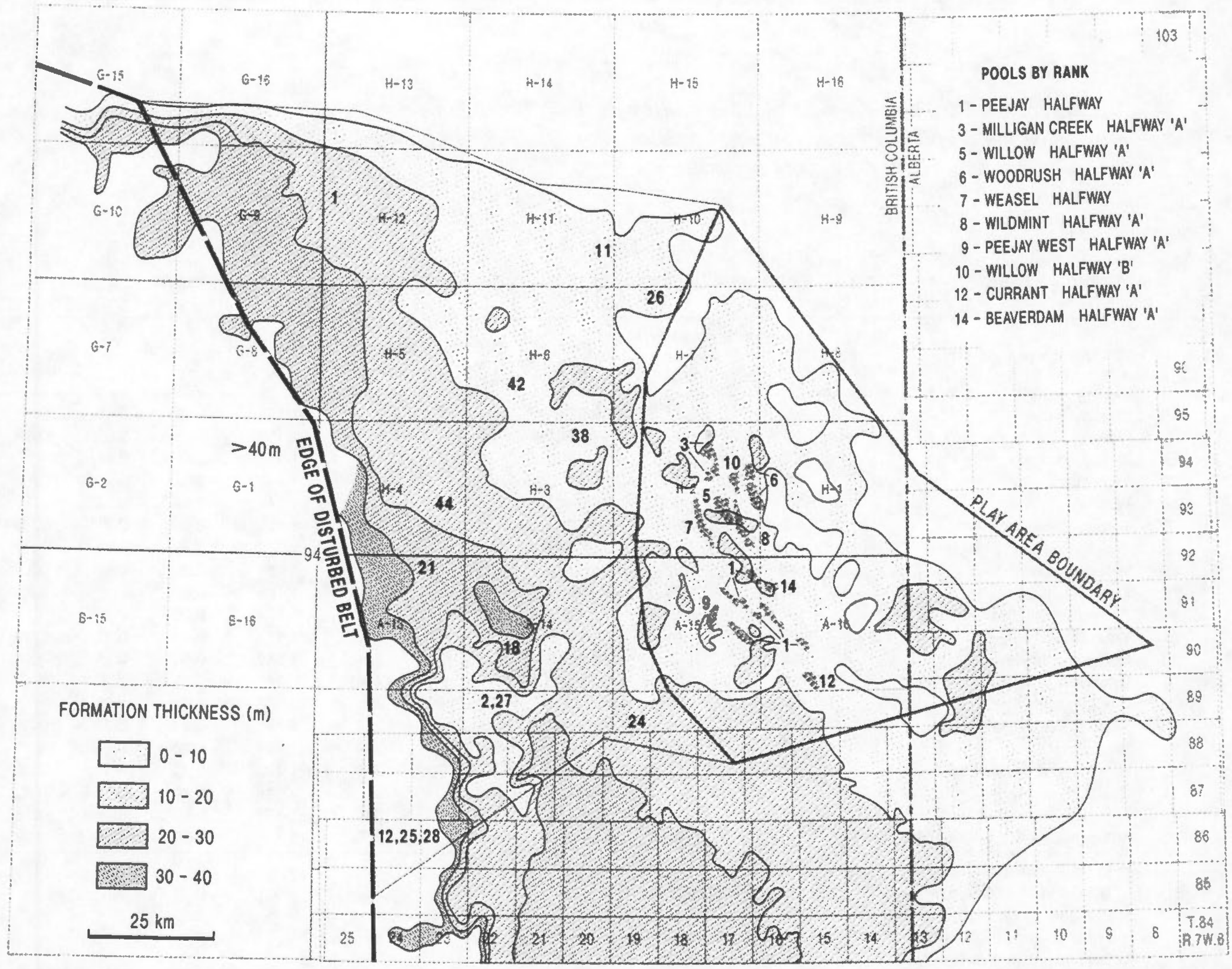

Figure 23. *Isopach map of the Halfway Formation. Highlighted area outlines the Halfway/Doig Shore Zone–Peejay Milligan play area. Outline of the largest 10 gas fields is superimposed to illustrate their position in relation to the Halfway zero edge.*

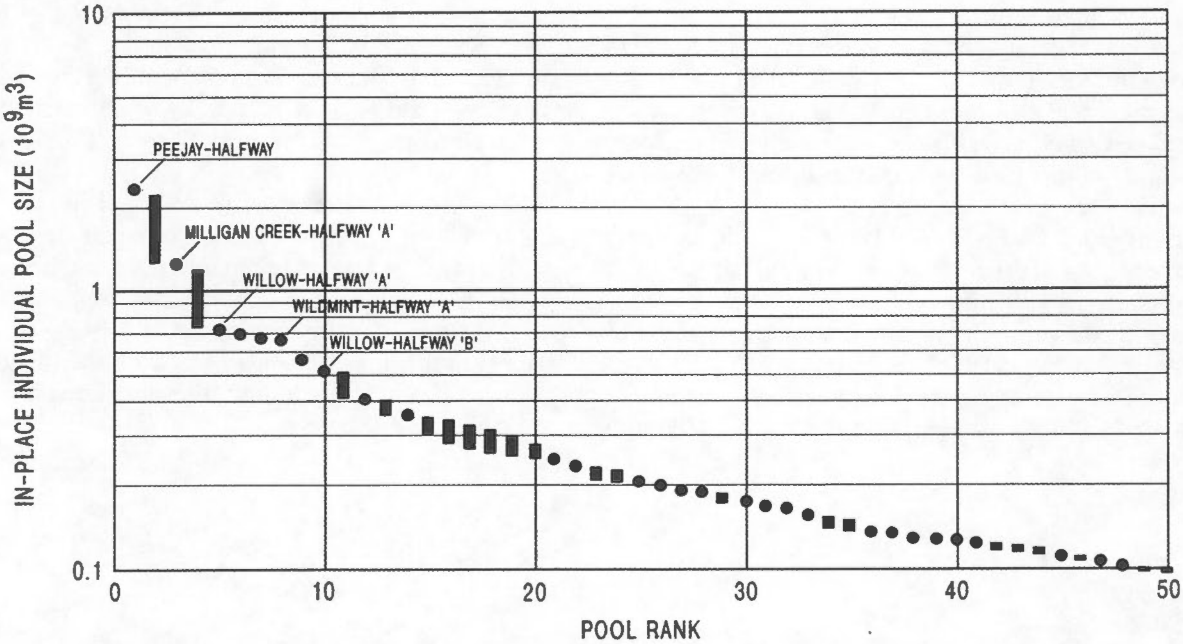

Figure 24. Pool size–by–rank plot for the Halfway/Doig Shore Zone–Peejay Milligan play showing the top 50 pools (discovered and undiscovered). See Figure 22 for locations of the 20 largest pools and Table 4 for pool parameters.

Table 4

Halfway/Doig Shore Zone – Peejay Milligan play, reservoir parameters and assessment results

Rank	Field/Pool	Gas type	In-place volume (10^6m^3)	Disc. date	Net pay (m)	Area (hect.)	Depth (m)	R.F.	Por.	S.W.
1	Peejay, Halfway	AG	2 338	59/02/21	1.7	2 835	1 143	0.72	0.16	0.18
3	Milligan Creek, Halfway A	AG	1 222	57/02/27	2.5	1 310	1 118	0.53	0.23	0.09
5	Willow, Halfway A	NA	713	61/10/25	5.6	*	1 111	0.85	0.18	0.17
6	Woodrush, Halfway A	NA	686	60/01/12	2.3	*	1 108	0.85	0.20	0.12
7	Weasel, Halfway	AG	666	65/02/15	*	*	1 149	0.80	0.22	0.21
8	Wildmint, Halfway A	AG	651	59/12/14	3.7	994	1 129	0.85	0.21	0.20
9	Peejay West, Halfway A	AG	547	62/01/17	3.6	822	1 186	0.35	0.21	0.21
10	Willow, Halfway B	NA	507	66/01/09	*	*	1 091	0.85	0.19	0.10
12	Currant, Halfway A	AG	399	65/03/05	3.7	719	1 199	0.50	0.16	0.16
14	Beaverdam, Upper Halfway A	NA	350	65/10/09	*	*	1 127	0.90	0.17	0.10
21	Weasel, Halfway F	AG	241	61/01/19	9.8	314	1 112	0.80	0.13	0.30
22	Currant, Halfway B	NA	230	65/02/08	2.7	554	1 218	0.80	0.18	0.14
25	Other area, Halfway	NA	198	87/02/21	9.0	284	1 264	0.90	0.13	0.40
26	Peejay, Halfway M	NA	196	70/02/13	7.2	259	1 153	0.95	0.23	0.15
27	Weasel West, Halfway C	NA	189	85/08/22	5.2	259	1 140	0.90	0.22	0.26
28	Weasel, Halfway J	NA	185	87/02/20	6.0	259	1 189	0.90	0.19	0.23
30	Currant West, Halfway A	NA	169	73/12/26	3.0	259	1 185	0.61	0.16	0.28
31	Crush, Halfway A	AG	164	67/02/15	0.8	*	1 145	0.90	0.12	0.25
32	Milligan Creek West, Halfway G	NA	161	56/01/31	4.6	281	1 155	0.90	0.18	0.18
33	Milligan Creek West, Halfway C	NA	153	79/08/21	3.8	259	1 144	0.90	0.20	0.09
	Total initial in-place volume (discovered)		**12 731**							
	Total initial in-place volume (potential)		**10 839**							
	Per cent play resource undiscovered		**46**							
	Total pools discovered		**63**							
	Total pool population		**400**							

*indicates numbers not given in data base

6. Halfway/Doig Shelf (Peace River Structure)–Monias

Play definition. This play is defined to include all gas pools and prospects in shelf sandstones of the Halfway and Doig formations that formed traps through draping over structures related to Peace River Arch/Embayment block faulting. The play area is centred on the British Columbia townships and includes the area southwest of Dawson Creek into the Deep Basin. It is bounded to the west by the Foothills thrust belt plays and to the east by the Halfway/Doig Sinclair Shore Zone play. To the north, the dominance of Peace River structural influence gives way to trapping mechanisms associated with Laramide tectonism and subtle facies and diagenetic variations (Fig. 25).

Geology. The reservoir rock is a carbonate-cemented, quartzose sandstone. Compared to sandstones deposited near the eastern shoreface, these shelf sandstones are finer grained, more poorly sorted, contain more interstitial clays, have fewer skeletal fragments and are generally poorer reservoirs. The Monias gas field is an example of this play, where a blanket-like sandstone reservoir, overthickened in a local structural depocentre, is trapped on the eastern updip edge of a horst block. Overprinting and inversion of earlier structures by subsequent Laramide tectonism combined to form the trap (Fig. 26). Subtle facies and diagenetic changes also are important in localizing reservoirs in these regionally continuous, fine grained sandstones.

Exploration history. This play has received only a moderate amount of exploration effort since the discovery of oil and associated gas at Wilder in 1952 and Fort St. John in 1953. The 1970s saw the discovery of several fields centered around Fort St. John. With the building of processing facilities at Taylor, many of these gas finds were put on stream. Monias, discovered in 1979, is by far the largest gas discovery in this play type. This play has in-place reserves of 39 710 x $10^6 m^3$ in 51 pools. The two largest pools are Monias and Wilder with 20 100 and 3 184 x $10^6 m^3$ respectively. Net pay for this play is typically 7 m and porosity is 10 per cent (Table 5).

Play potential. The expected potential is 88 934 x $10^6 m^3$ initial in-place volume in 449 remaining pools (Fig. 27). Although this play has received moderate exploration in the north-central part of the area, potential for this play lies to the south in deeper areas, where sparse well control allows room for new discoveries. Exploration risks are associated with difficulty in predicting subtle facies changes and diagenetic variations.

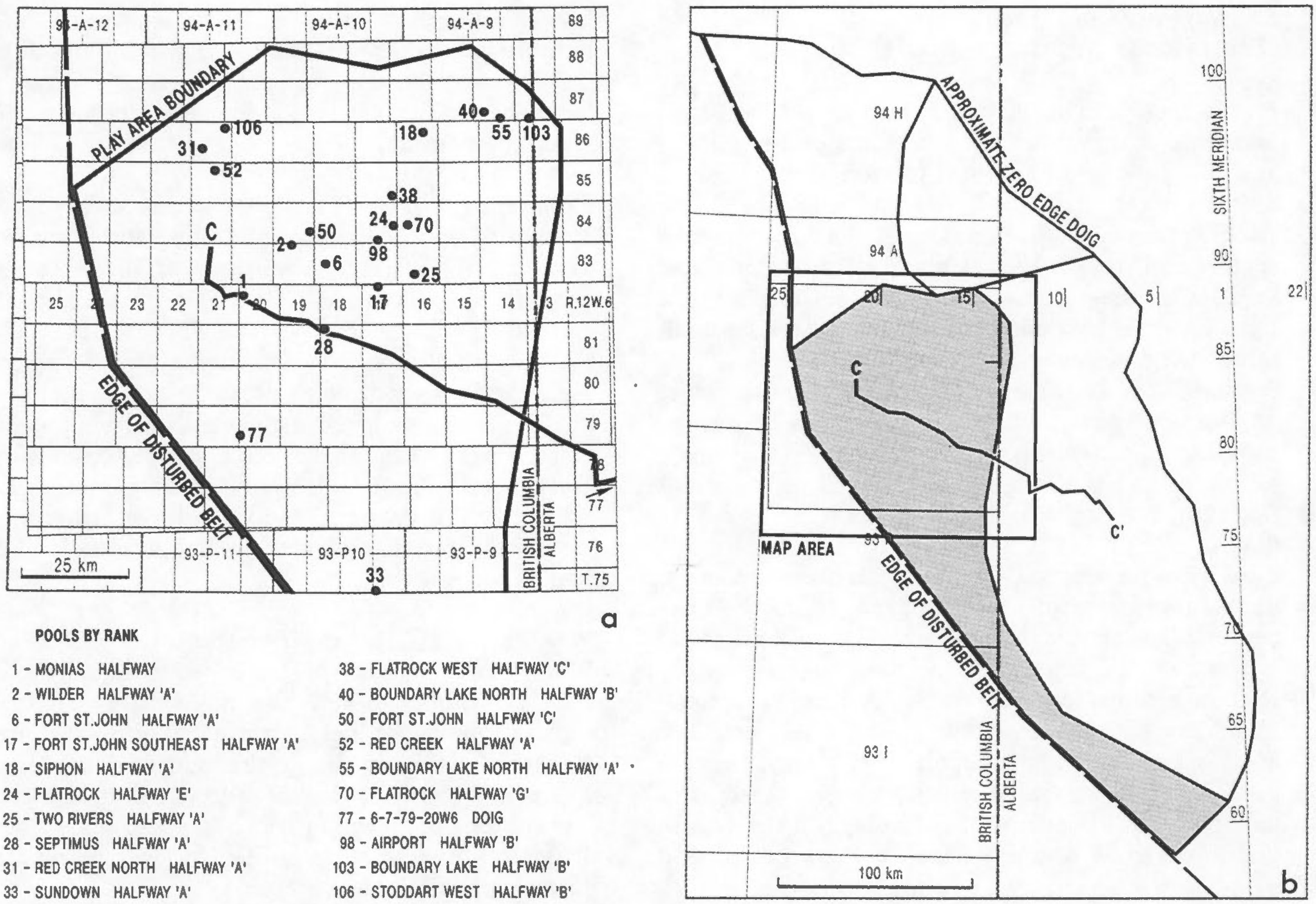

***Figure 25. a.** Map of the Halfway/Doig Shelf (Peace River Structure)–Monias play area. The discovery wells of the 20 largest pools and their respective rank is shown. See Table 5 for the volumes of these pools and Figure 26 for cross-section C–C'. **b.** The location of this play with respect to the other Halfway/Doig plays.*

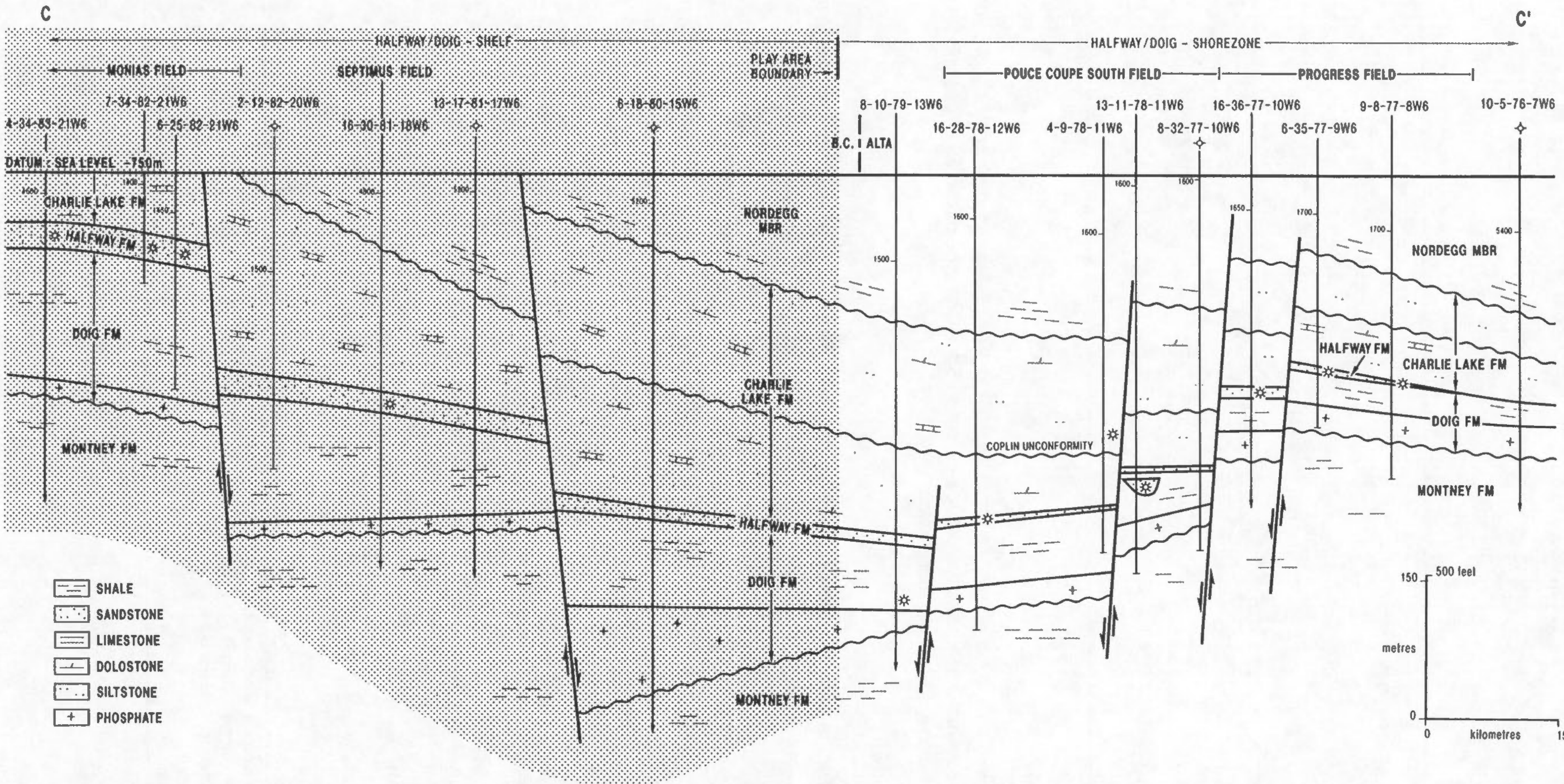

Figure 26. *Structural cross-section C–C′ (Fig. 25) through the Halfway/Doig Shelf–Monias play (highlighted) and the Halfway/Doig Shore Zone–Sinclair play showing structural control on hydrocarbon occurrence in the Halfway/Doig interval. The Shelf play is distinguished by thicker and more continuous Doig and Halfway formations. Correlation between wells is established with additional control along the line of section (see Fig. 25).*

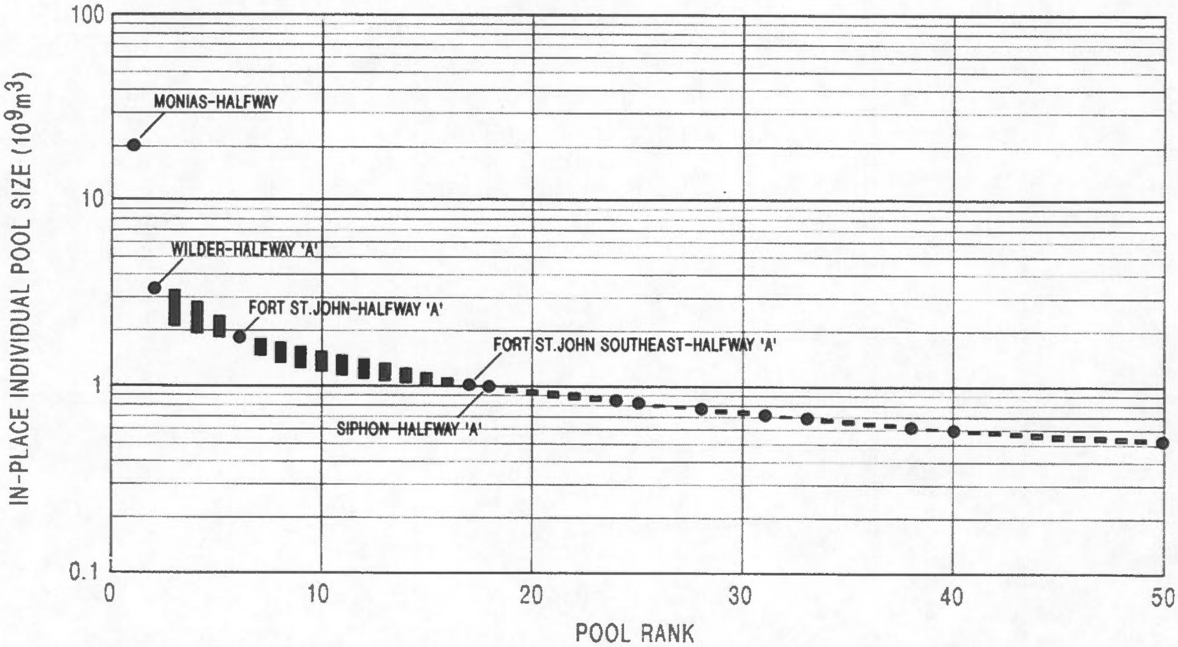

Figure 27. *Pool size–by–rank plot for the Halfway/Doig Shelf–Monias play showing the top 50 pools (discovered and undiscovered). See Figure 25 for locations of the 20 largest discovered pools and Table 5 for pool parameters.*

Table 5
Halfway/Doig Shelf (Peace River Structure) – Monias play, reservoir parameters and assessment results

Rank	Field/Pool	Gas type	In-place volume ($10^6 m^3$)	Disc. date	Net pay (m)	Area (hect.)	Depth (m)	R.F.	Por.	S.W.
1	Monias, Halfway	NA	20 100	79/07/27	21.1	*	1 450	0.90	0.09	0.30
2	Wilder, Halfway A	NA	3 183	52/05/12	9.6	3 364	1 495	0.90	0.11	0.38
6	Fort St. John, Halfway A	NA	1 780	53/08/06	8.5	*	1 463	0.90	0.11	0.25
17	Fort St. John Southeast, Halfway A	NA	1 000	53/03/08	4.9	*	1 483	0.85	0.10	0.25
18	Siphon, Halfway A	NA	997	59/02/17	4.8	1 593	1 402	0.75	0.14	0.24
24	Flatrock, Halfway E	AG	842	72/10/29	5.2	703	1 423	0.50	0.13	0.31
25	Two Rivers, Halfway A	NA	815	67/05/28	8.2	*	1 489	0.85	0.12	0.36
28	Septimus, Halfway A	NA	774	79/02/22	9.9	933	1 704	0.90	0.09	0.35
31	Red Creek North, Halfway A	NA	714	76/01/10	3.3	2 350	1 619	0.80	0.09	0.33
33	Sundown, Halfway A	NA	695	72/12/28	11.3	259	2 922	0.80	0.13	0.13
38	Flatrock West, Halfway C	NA	630	85/03/03	3.7	991	1 441	0.90	0.16	0.18
40	Boundary Lake North, Halfway B	NA	611	64/10/27	10.6	528	1 339	0.90	0.17	0.26
50	Fort St. John, Halfway C	NA	525	71/12/06	5.0	1 165	1 466	0.80	0.11	0.39
52	Red Creek, Halfway A	NA	508	54/03/28	4.6	977	1 627	0.50	0.12	0.36
55	Boundary Lake North, Halfway A	NA	490	63/11/28	9.6	446	1 372	0.50	0.15	0.27
70	Flatrock, Halfway G	NA	406	71/01/01	*	*	1 439	0.90	0.12	0.30
77	Other area, Doig (6-7-79-20W6)	NA	379	88/03/15	19.0	259	2 447	0.25	0.05	0.22
98	Airport, Halfway B	AG	308	78/08/12	7.4	259	1 474	0.50	0.16	0.31
103	Boundary Lake, Halfway B	NA	295	64/09/17	3.5	845	1 432	0.90	0.12	0.21
106	Stoddart West, Halfway B	NA	288	85/03/16	11.8	259	1 621	0.90	0.10	0.37
	Total initial in-place volume (discovered)		**38 710**							
	Total initial in-place volume (potential)		**88 934**							
	Per cent play resource undiscovered		**69**							
	Total pools discovered		**51**							
	Total pool population		**500**							

*indicates numbers not given in data base

7. *Halfway/Doig Shelf–Tommy Lakes*

Play definition. This play is defined to encompass Halfway and Doig formation sandstone reservoirs trapped in combination stratigraphic/structural traps. Gentle Laramide folds, associated with proximity to the western fold belt, overprint subtle facies change and diagenetic traps developed in shelf sandstones of the Halfway and Doig formations. The erosional edge, which forms the northern play boundary, may also be involved in the formation of traps. To the east, the play boundary abuts the primarily stratigraphic, Halfway/Doig Shore Zone–Peejay Milligan play. The southern limit marks the change in dominance of Peace River Arch structural influence to a mechanism of gentle folds associated with Laramide compression. The western limit is the Rocky Mountain foreland belt (Fig. 28).

Geology. Reservoir quality sandstones of the Halfway and Doig formations have variable compositions and occur sporadically throughout the region (Fig. 29). Doig Formation sandstones are typically in the upper part of a sequence of interbedded siltstones and shales and represent part of a regressive transition to the Halfway Formation sandstones. Doig Formation sandstones are crosslaminated, crossbedded to massive, fine grained, argillaceous, cemented with carbonate and locally coquinoid (Armitage, 1962; Fulton, 1966; Aukes and Webb, 1986). Halfway Formation shelf sandstones are fine grained and poorly sorted, have a high percentage of interstitial clay, and contain less skeletal fragments than sands deposited closer to the eastern shoreface. Consequently, reservoir quality is generally lower in this play.

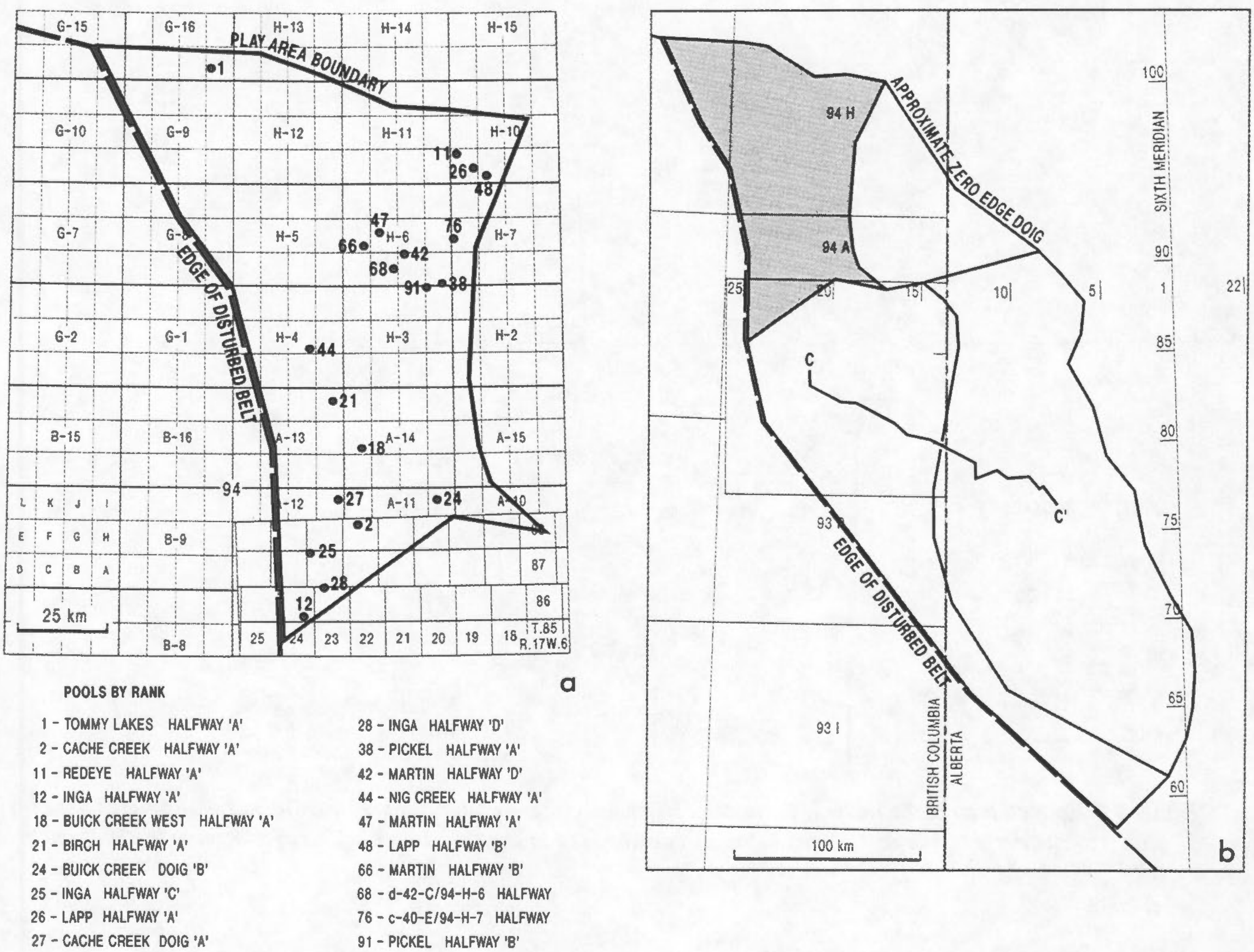

Figure 28. a. Map of the Halfway/Doig Shelf–Tommy Lakes play area. The discovery wells for the 20 largest pools with their respective rank is shown. See Table 6 for the volumes of these pools. b. The location of this play with respect to the other Halfway/Doig plays.

Exploration history. The first pool in this play was discovered at Buick Creek West in 1953. The largest pool, by volume and area is Tommy Lakes (41 969 ha), discovered in 1960, with initial in-place reserves of 19 247 x $10^6 m^3$. Since 1953, 26 pools have been discovered, establishing a total of 25 915 x $10^6 m^3$ initial in-place reserves. Typically net pay is 7 m and porosity is 10 per cent (Table 6).

Play potential. The expected potential for this play is an initial in-place volume of 23 202 x $10^6 m^3$ predicted to occur in 273 pools (Fig. 30). Although this play is immature with respect to drilling density, its potential is not high due to the relatively poor quality of reservoir sandstones.

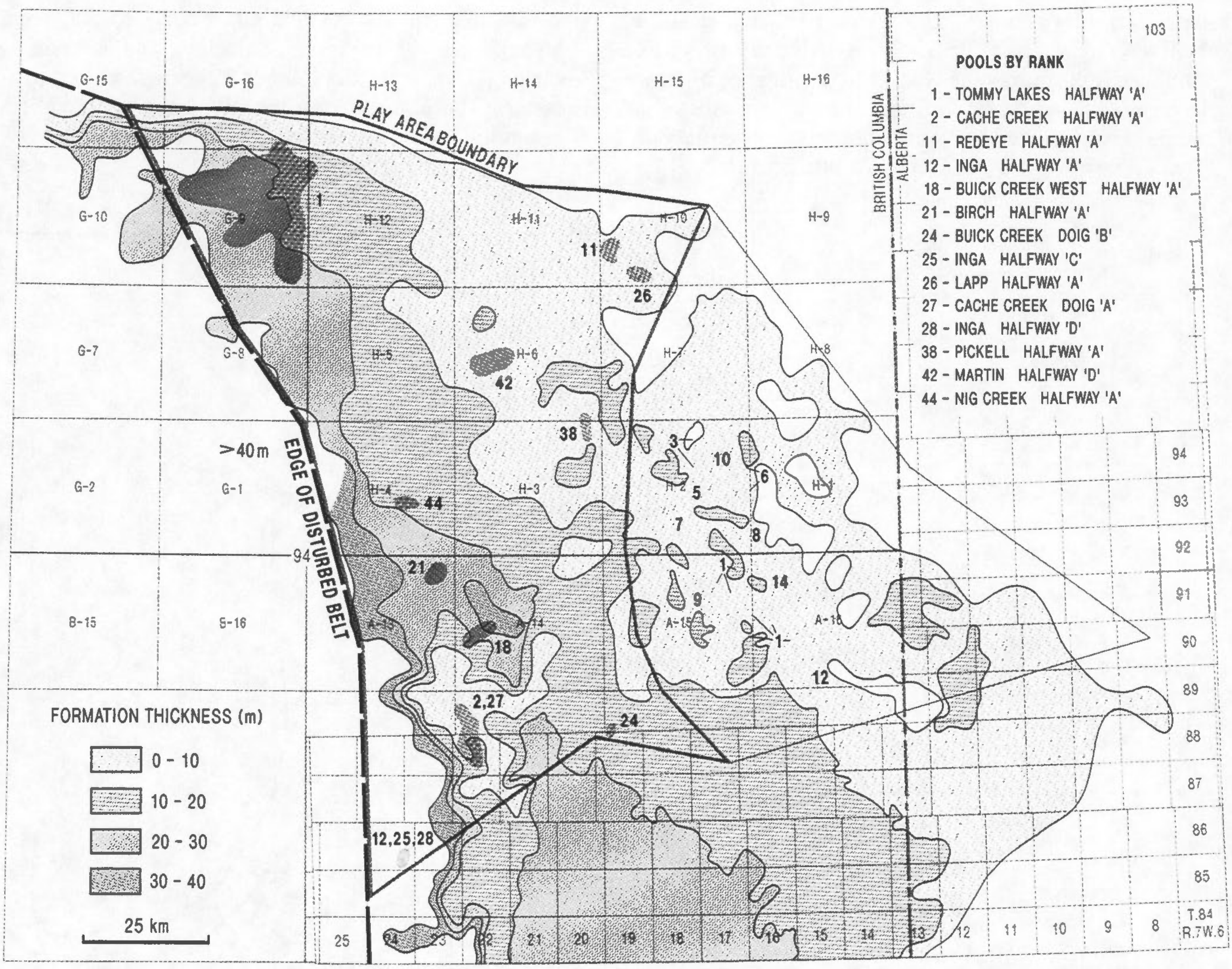

Figure 29. *Isopach map of the Halfway Formation. Highlighted area outlines the Halfway/Doig Shelf–Tommy Lakes play area. The outline of the largest 14 gas fields is superimposed to illustrate their position in relation to the Halfway zero edge.*

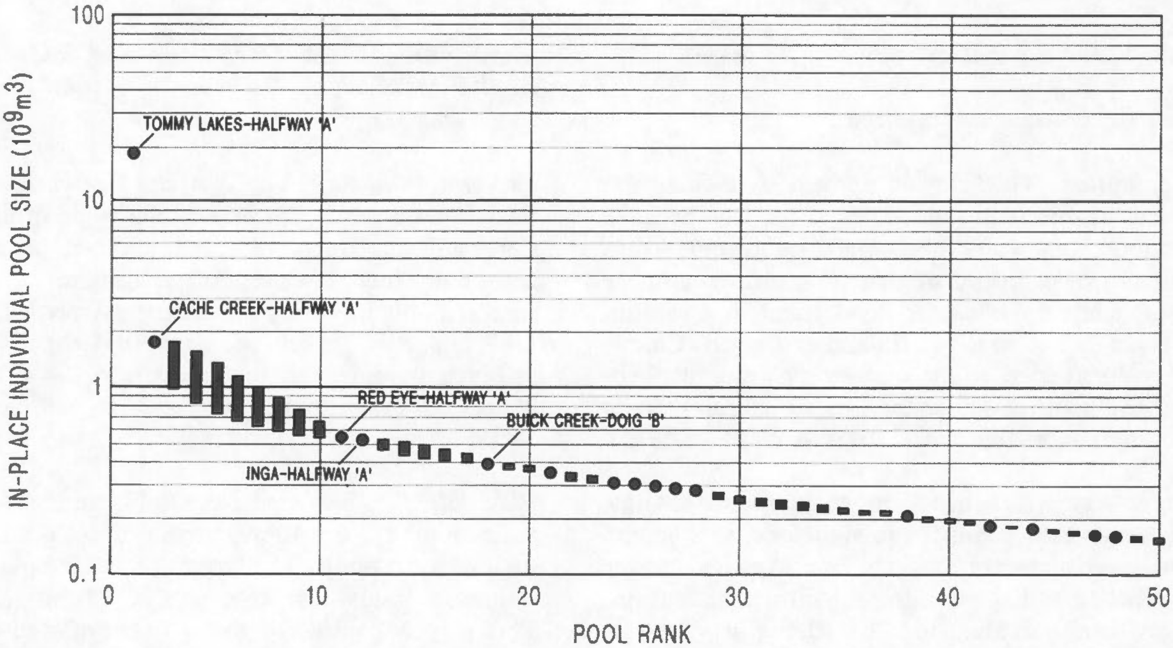

Figure 30. *Pool size–by–rank plot for the Halfway/Doig Shelf–Tommy Lakes play showing the top 50 pools (discovered and undiscovered). See Figure 29 for locations of the 20 largest pools and Table 6 for pool parameters.*

Table 6

Halfway/Doig Shelf – Tommy Lakes play, reservoir parameters and assessment results

Rank	Field/Pool	Gas type	In-place volume (10^6m^3)	Disc. date	Net pay (m)	Area (hect.)	Depth (m)	R.F.	Por.	S.W.
1	Tommy Lakes, Halfway A	NA	19 247	60/02/16	13.0	41 696	985	0.40	0.10	0.32
2	Cache Creek, Halfway A	NA	1 809	68/12/12	7.5	*	1 505	0.85	0.09	0.38
11	Redeye, Halfway A	NA	534	69/01/08	5.4	998	1 020	0.90	0.20	0.18
12	Inga, Halfway A	NA	532	80/10/12	18.8	259	1 624	0.90	0.09	0.29
18	Buick Creek West, Halfway A	NA	394	53/12/22	*	*	1 453	0.85	*	*
21	Birch, Halfway A	NA	352	74/02/10	8.5	518	1 498	0.90	0.12	0.44
24	Buick Creek, Doig B	AG	306	76/12/07	4.3	226	1 358	0.90	0.09	0.09
25	Inga, Halfway C	NA	306	89/12/14	5.0	528	1 717	0.90	0.10	0.32
26	Lapp, Halfway A	NA	296	90/02/04	5.0	556	1 021	0.90	0.24	0.29
27	Cache Creek, Doig A	NA	281	78/06/14	6.3	259	1 643	*	0.09	0.21
28	Inga, Halfway D	NA	274	89/10/12	8.6	264	1 591	0.90	0.09	0.27
38	Pickell, Halfway A	NA	208	61/02/15	1.2	1 205	1 230	0.90	0.19	0.18
42	Martin, Halfway D	NA	187	79/03/17	6.3	276	1 209	0.90	0.16	0.26
44	Nig Creek, Halfway A	NA	180	55/03/02	7.9	259	1 479	0.90	0.10	0.26
47	Martin, Halfway A	NA	164	63/03/05	2.1	1 207	1 222	0.85	0.10	0.27
48	Lapp, Halfway B	NA	162	79/03/15	5.3	278	1 023	0.90	0.23	0.31
66	Martin, Halfway B	NA	115	79/01/02	3.6	363	1 279	0.85	0.14	0.16
68	Other area, Halfway (D-42-C/94-H-6)	NA	110	80/03/22	4.3	259	1 246	0.90	0.17	0.22
76	Other area, Halfway (C-40-E/94-H-7)	NA	97	89/02/16	3.0	259	1 266	0.90	0.21	0.28
91	Pickell, Halfway B	NA	76	76/03/22	2.4	259	1 240	0.80	0.19	0.32
	Total initial in-place volume (discovered)		**25 915**							
	Total initial in-place volume (potential)		**23 202**							
	Per cent play resource undiscovered		**47**							
	Total pools discovered		**27**							
	Total pool population		**300**							

*indicates numbers not given in data base

Charlie Lake Formation plays

8. Charlie Lake Clastics–Inga

Play definition. This play is defined to include gas pools and prospects in sandstones of the Charlie Lake Formation. Reservoirs occur in stratigraphic traps which have an overprint of structural influence in the form of gentle folds caused by Laramide tectonism. The play is limited to the north and east by the Charlie Lake erosional edge, to the west by the deformed belt, and to the south by a change in structural style to block faulting on the Peace River Arch (Fig. 31).

Geology. Reservoirs occur in coastal and shallow marine sandstones deposited in shoreface, sabkha and aeolian environments. Trapping mechanisms include facies pinchouts, diagenetic traps, hydrodynamic traps, and erosional truncation by the post-Triassic unconformity or smaller scale intrasystem unconformities and diastems. Laramide structural overprinting in the form of gentle folds provides closure, especially in the western portion of the play area (Fig. 32).

Exploration history. The first and largest discovery in this play was made in 1965 at Inga while drilling for a Carboniferous Debolt Formation target on a seismic high. Since then, discoveries have been made in several smaller pools including Silverberry (Artex Member) in 1989 and Rigel (Cecil Member) in 1990. Discovered in-place volume for this play is 6 094 x 10^6m^3 in 25 pools. Typically net pay is 2 m and porosity is 12 per cent (Table 7).

Play potential. Expected potential is an initial in-place volume of 8 866 x 10^6m^3 predicted to occur in 175 undiscovered pools. The largest remaining pool has an estimated in-place volume of 200 x 10^6m^3 (Fig. 33). This play is considered to be fairly mature and it is likely that smaller gas pools will be discovered during exploratory drilling for deeper, primary targets.

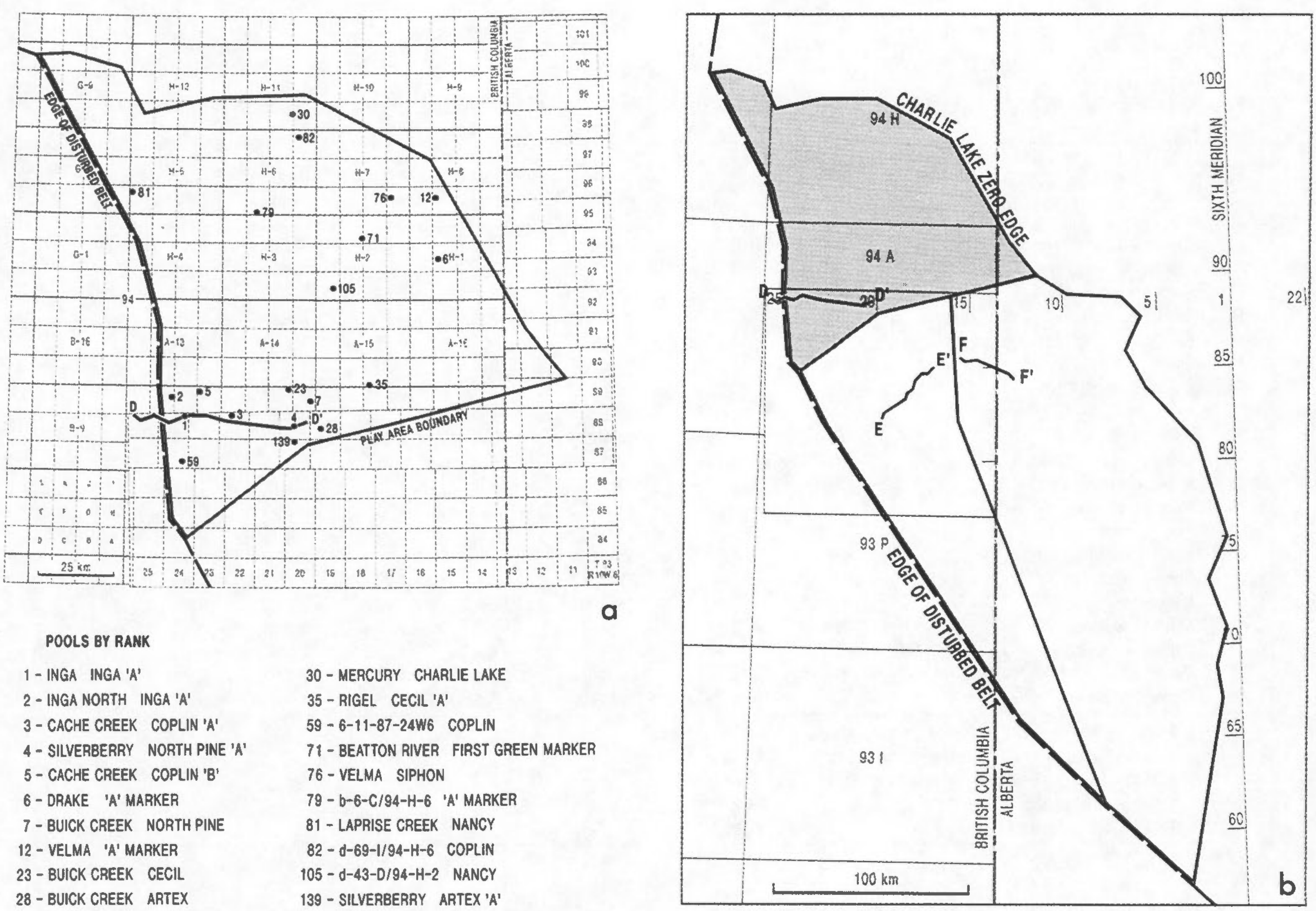

Figure 31. a. Map of the Charlie Lake Clastics–Inga play area. The discovery well locations for the 20 largest pools and their respective rank is shown. See Table 7 for the volumes of these pools and Figure 32 for cross-section D–D'. b. The location of this play with respect to the other Charlie Lake plays.

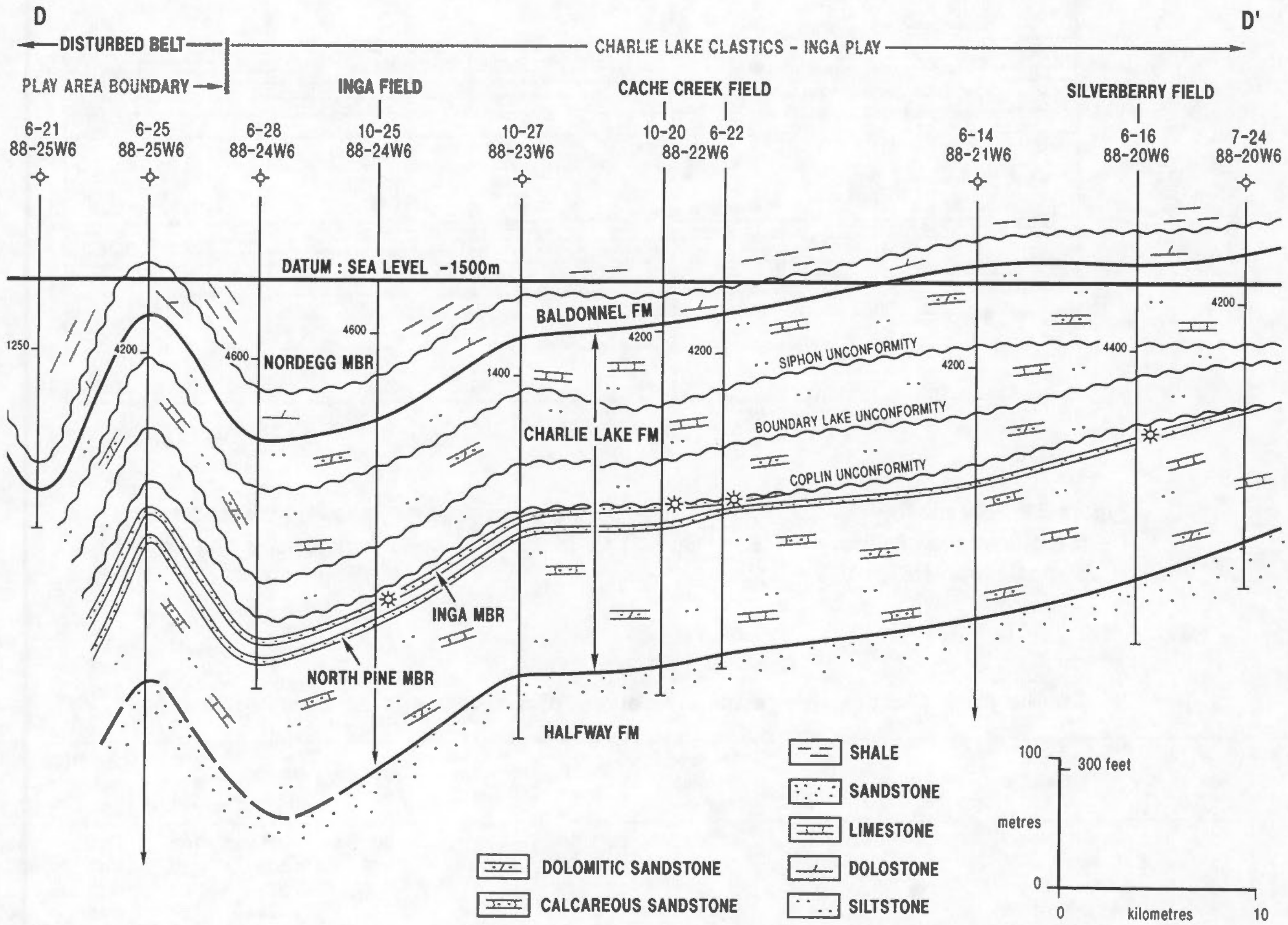

Figure 32. *Structural cross-section D–D' (Fig. 31) through the Inga field illustrating the division between the structural trapping style within the Rocky Mountain foreland (disturbed belt) and the stratigraphic trapping within the clastic North Pine and Inga members. Correlation between wells is established with additional control along the line of section (see Fig. 31).*

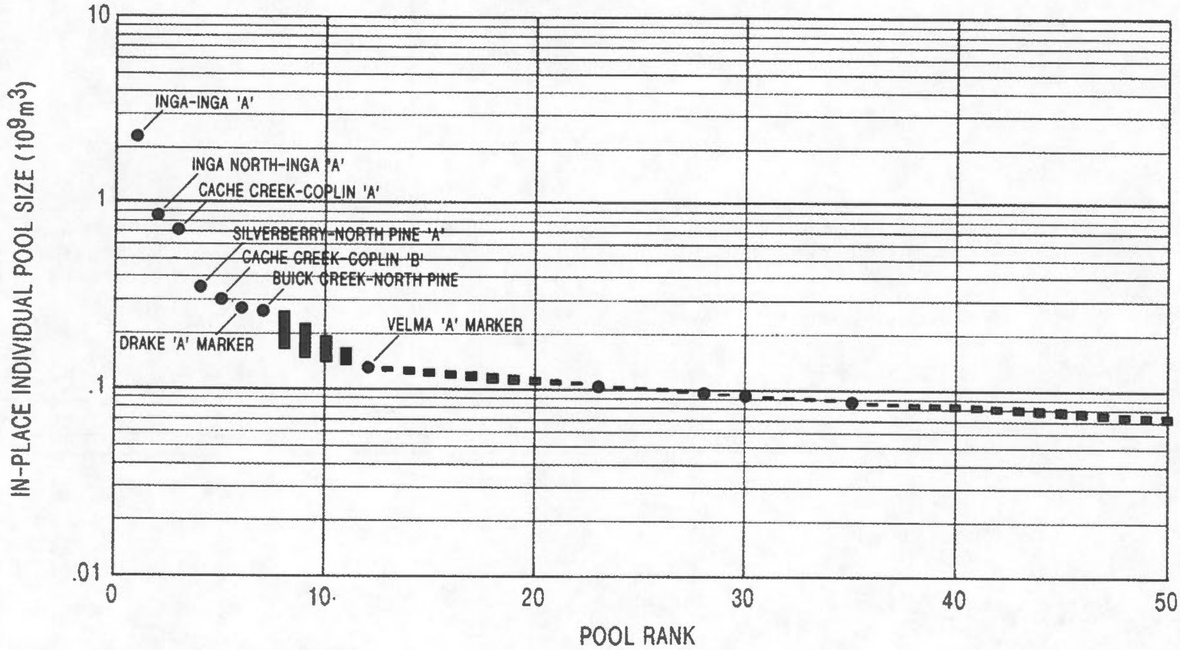

***Figure 33.** Pool size–by–rank plot for the Charlie Lake Clastics–Inga play showing the top 50 pools (discovered and undiscovered). See Figure 31 for locations of the 20 largest pools and Table 7 for pool parameters.*

Table 7
Charlie Lake Clastics – Inga play, reservoir parameters and assessment results

Rank	Field/Pool	Gas type	In-place volume (10^6m^3)	Disc. date	Net pay (m)	Area (hect.)	Depth (m)	R.F.	Por.	S.W.
1	Inga, Inga A	AG	2 302	65/11/10	1.4	900	1 595	0.62	0.10	0.18
2	Inga North, Inga A	NA	844	69/04/08	1.8	3 176	1 609	0.80	0.10	0.25
3	Cache Creek, Coplin A	NA	704	68/12/12	1.0	4 516	1 379	0.90	0.12	0.22
4	Silverberry, North Pine A	NA	353	72/02/09	2.4	*	1 404	0.95	0.29	0.10
5	Cache Creek, Coplin B	NA	300	66/11/09	0.9	*	1 450	0.90	0.08	0.28
6	Drake 'A' Marker A	NA	268	72/03/28	1.8	1 498	1 043	0.85	0.18	0.28
7	Buick Creek, North Pine A	NA	261	82/11/24	2.1	*	1 281	0.90	0.11	0.13
12	Velma 'A' Marker A	NA	132	72/01/11	2.4	791	1 067	0.80	0.14	0.26
23	Buick Creek, Cecil A	NA	104	54/06/04	1.8	*	1 267	0.70	0.13	0.33
28	Buick Creek, Artex A	NA	95	79/03/25	1.2	437	1 446	0.90	0.14	0.09
30	Mercury, Charlie Lake	NA	92	88/02/12	5.2	259	1 081	0.90	0.14	0.32
35	Rigel, Cecil A	NA	86	90/07/22	2.8	284	1 173	0.90	0.13	0.25
59	Other area, Coplin (6-11-87-24W6)	NA	65	72/01/18	1.8	259	1 411	0.80	0.13	0.29
71	Beatton River, First Green Marker A	NA	58	71/03/09	2.1	259	1 068	0.85	0.16	0.13
76	Velma, Siphon A	NA	55	66/12/06	1.8	280	1 124	0.90	0.18	0.15
79	Other area, 'A' Marker (B-6-C/94-H-6)	NA	53	82/03/19	2.0	259	1 225	0.85	0.14	0.14
81	Laprise Creek, Nancy A	NA	52	74/02/25	2.1	259	1 250	0.68	0.11	0.13
82	Other area, Coplin (D-69-I/94-H-6)	NA	52	64/12/07	2.1	259	1 198	0.80	0.20	0.36
105	Other area, Nancy (D-43-D/94-H-2)	NA	42	67/01/11	1.8	259	1 093	0.90	0.11	0.25
139	Silverberry, Artex A	NA	31	89/02/17	1.3	262	1 521	0.90	0.10	0.30
	Total initial in-place volume (discovered)		**6 094**							
	Total initial in-place volume (potential)		**8 866**							
	Per cent play resource undiscovered		**59**							
	Total pools discovered		**25**							
	Total pool population		**200**							

*indicates numbers not given in data base

9. *Charlie Lake Clastics (Peace River Structure)–Cecil*

Play definition. This play is defined to include gas pools and prospects in sandstones of the Charlie Lake Formation. Traps are formed in stratigraphic facies pinchouts similar to the Charlie Lake-Inga play to the north, but reservoirs are affected by block faulting associated with the Peace River Arch/Embayment. The eastern play boundary is defined by a lithological change to carbonates in the Charlie Lake Carbonates (Peace River Structure)-Boundary Lake play. To the west and south the play is bounded by the Rocky Mountain Foreland structural belt (Fig. 34).

Geology. Reservoir sandstones were deposited in aeolian, shoreface and shoreline environments. Trapping mechanisms include facies pinchouts, diagenetic traps, hydrodynamic traps, erosional truncation by the post-Triassic unconformity or smaller intra-formational unconformities and diastems. Structural influences include drape on Paleozoic Peace River Arch horsts and related fault-cutoff traps. Reservoirs are sealed by anhydrite, evaporitic dolomite, siltstone and mudstone (Fig. 35).

Exploration history. The first oil pool in this play was discovered in 1952 at Fort St. John, British Columbia. Since then, the oil-prone nature of the play, as well as the occurrence of multiple stacked exploration targets in the region, has encouraged continuous exploration. The first major gas pool was discovered in 1972 at Cecil Lake in a sandstone member called the North Pine Member. Recent oil discoveries in aeolian sandstones of the Artex Member at Brassey oil field have highlighted the importance of detailed geological analysis in identifying prospects (Klein and Woofter, 1989; Higgs, 1990; Jackson, 1990). Total initial in-place volume for the play is 4 529 x $10^6 m^3$ in 39 pools. Typically net pay is 3 m and porosity is 14 per cent (Table 8).

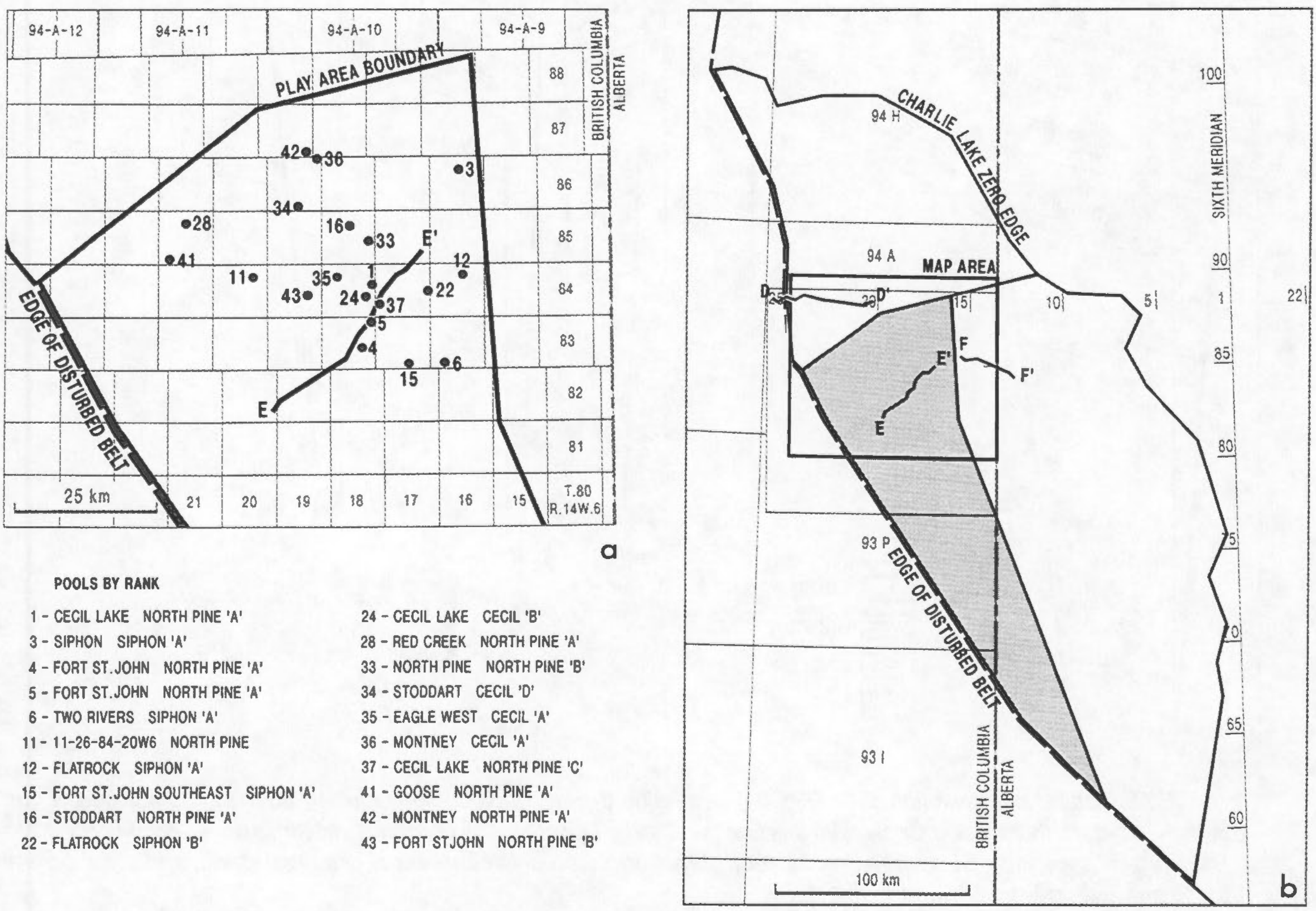

Figure 34. ***a.*** *Map of the Charlie Lake Clastics, Peace River Structure–Cecil play area. The discovery well of the 20 largest pools and their respective rank is shown. See Table 8 for the volumes of these pools and Figure 35 for cross-section E–E'.* ***b.*** *The location of this play with respect to the other Charlie Lake plays.*

Play potential. Expected potential for this play is estimated at 5 915 x $10^6 m^3$ predicted to occur in 236 pools. The largest undiscovered pool is estimated to be 700 x $10^6 m^3$, with most undiscovered pools in the range of 60 to 300 x $10^6 m^3$ (Fig. 36). Remaining pools are likely to be situated in the southern part of the play area where greater depth and the lack of multiple horizon exploration targets in other zones has resulted in limited drilling density.

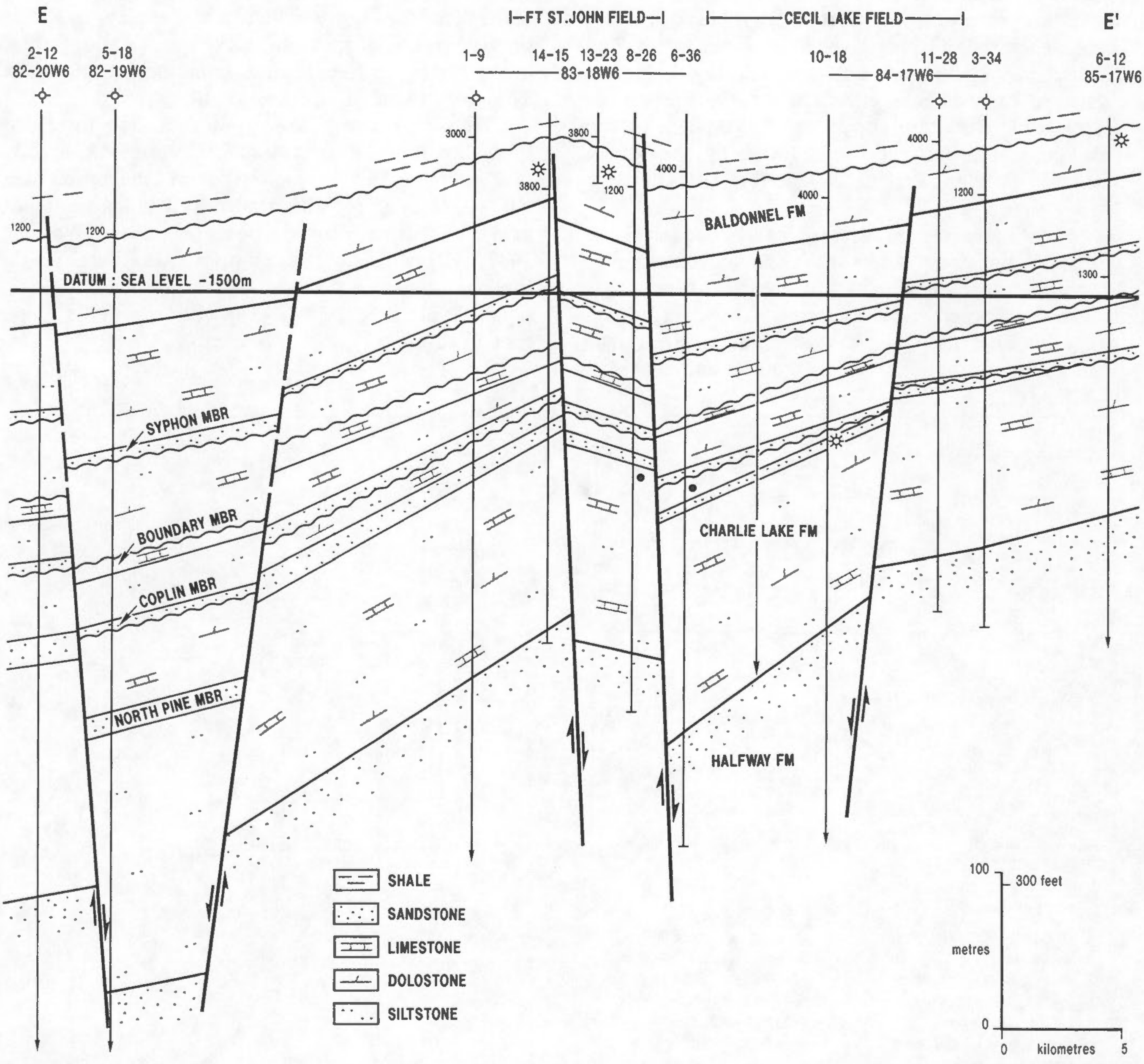

***Figure 35.** Structural cross-section E–E' (Fig. 34) illustrating the influence of block faulting on the accumulation of gas in the clastic North Pine and Coplin Members of the Charlie Lake Clastics (Peace River Structure)–Cecil Play and the Baldonnel (Peace River Structure)–Fort St. John play. Correlation between wells is established with additional control along the line of section (see Fig. 34).*

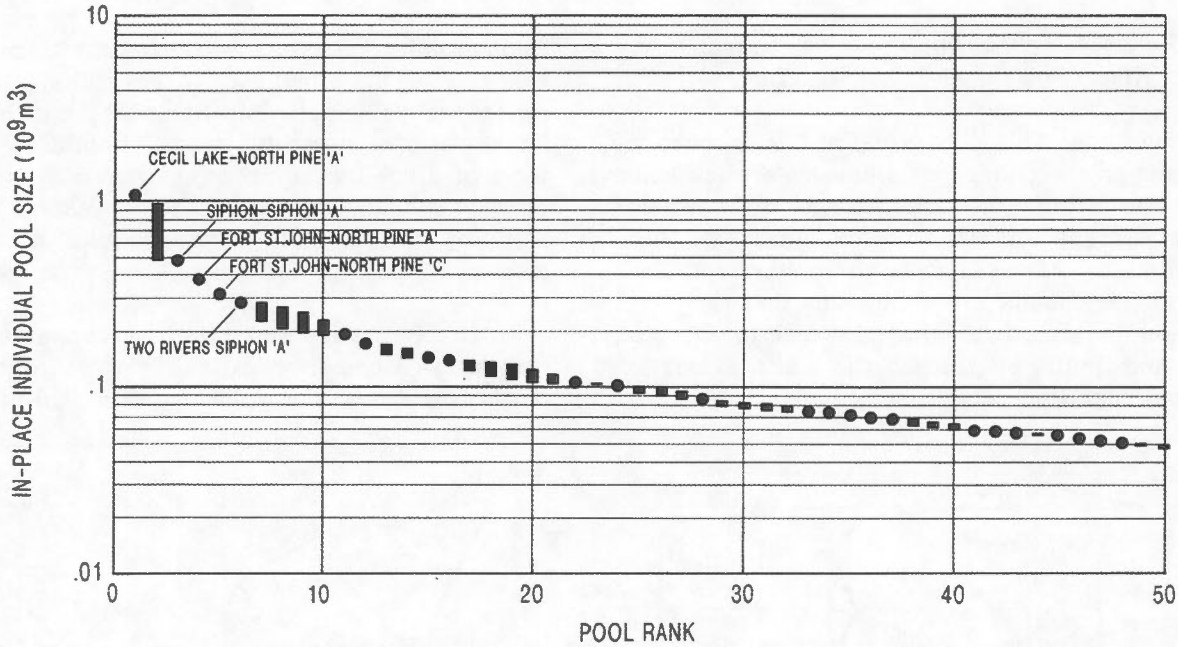

***Figure 36.** Pool size-by-rank plot for the Charlie Lake Clastics (Peace River Structure)-Cecil play showing the top 50 pools (discovered and undiscovered). See Figure 34 for locations of the 20 largest pools and Table 8 for pool parameters.*

Table 8

Charlie Lake Clastics (Peace River Structure) - Cecil play, reservoir parameters and assessment results

Rank	Field/Pool	Gas type	In-place volume (10^6m^3)	Disc. date	Net pay (m)	Area (hect.)	Depth (m)	R.F.	Por.	S.W.
1	Cecil Lake, North Pine A	AG	1 064	72/01/18	1.8	1 101	1 382	0.50	0.17	0.13
3	Siphon, Siphon A	NA	456	59/02/17	2.4	1 909	1 248	0.86	0.13	0.29
4	Fort St. John, North Pine A	AG	369	52/05/19	2.3	746	1 330	0.50	0.14	0.24
5	Fort St. John, North Pine C	AG	307	78/05/05	1.4	266	1 400	0.50	0.13	0.17
6	Twin Rivers, Siphon A	NA	285	67/01/11	*	*	1 311	0.28	0.10	0.47
11	Other area, North Pine	NA	185	79/11/19	6.5	259	1 479	0.90	0.08	0.23
12	Flatrock, Siphon A	NA	170	66/07/16	3.4	*	1 259	0.85	0.11	0.38
15	Fort St. John Southeast, Siphon A	NA	141	56/05/30	*	*	1 242	0.90	0.13	0.31
16	Stoddart, North Pine A	NA	139	66/07/17	2.7	259	1 297	0.90	0.16	0.16
22	Flatrock, Siphon B	NA	104	71/02/26	4.6	259	1 234	0.25	0.16	0.26
24	Cecil Lake, Cecil B	AG	99	72/09/01	1.8	130	1 030	0.50	0.27	0.10
28	Red Creek, North Pine A	NA	85	54/03/28	1.0	701	1 514	0.90	0.14	0.31
33	North Pine, North Pine B	NA	72	78/07/04	2.1	240	1 308	0.50	0.10	0.13
34	Stoddart, Cecil D	NA	71	78/04/04	3.0	259	1 269	0.90	0.11	0.38
35	Eagle West, Cecil A	NA	70	69/07/04	1.8	*	1 256	0.90	0.10	0.28
36	Montney, Cecil A	NA	67	54/10/12	1.5	*	1 302	0.80	0.20	0.30
37	Cecil Lake, North Pine C	AG	66	76/10/14	1.3	45	1 366	0.50	0.13	0.11
41	Goose, North Pine A	NA	58	71/10/28	1.1	334	1 529	0.49	0.21	0.43
42	Montney, North Pine A	NA	56	90/08/03	1.3	261	1 366	0.90	0.15	0.16
43	Fort St. John, North Pine B	NA	56	78/06/03	1.5	259	1 432	0.80	0.12	0.12
	Total initial in-place volume (discovered)		4 529							
	Total initial in-place volume (potential)		5 915							
	Per cent play resource undiscovered		57							
	Total pools discovered		39							
	Total pool population		275							

*indicates numbers not given in data base

10. *Charlie Lake Carbonates (Peace River Structure)-Boundary Lake*

Play definition. This play is defined to include gas pools and prospects in algal carbonates of the Charlie Lake Formation, in combination stratigraphic/structural traps and in an area which has been influenced by Peace River Arch/Embayment block faulting. Play limits are defined to the west by a transition to sandstone lithofacies and to the east, north and south by the Charlie Lake Formation erosional edge (Fig. 37).

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

In the Boundary Lake pool, carbonates of the Boundary Member consist of stromatolitic and bioclastic limestone or dolostone deposited in a tidal

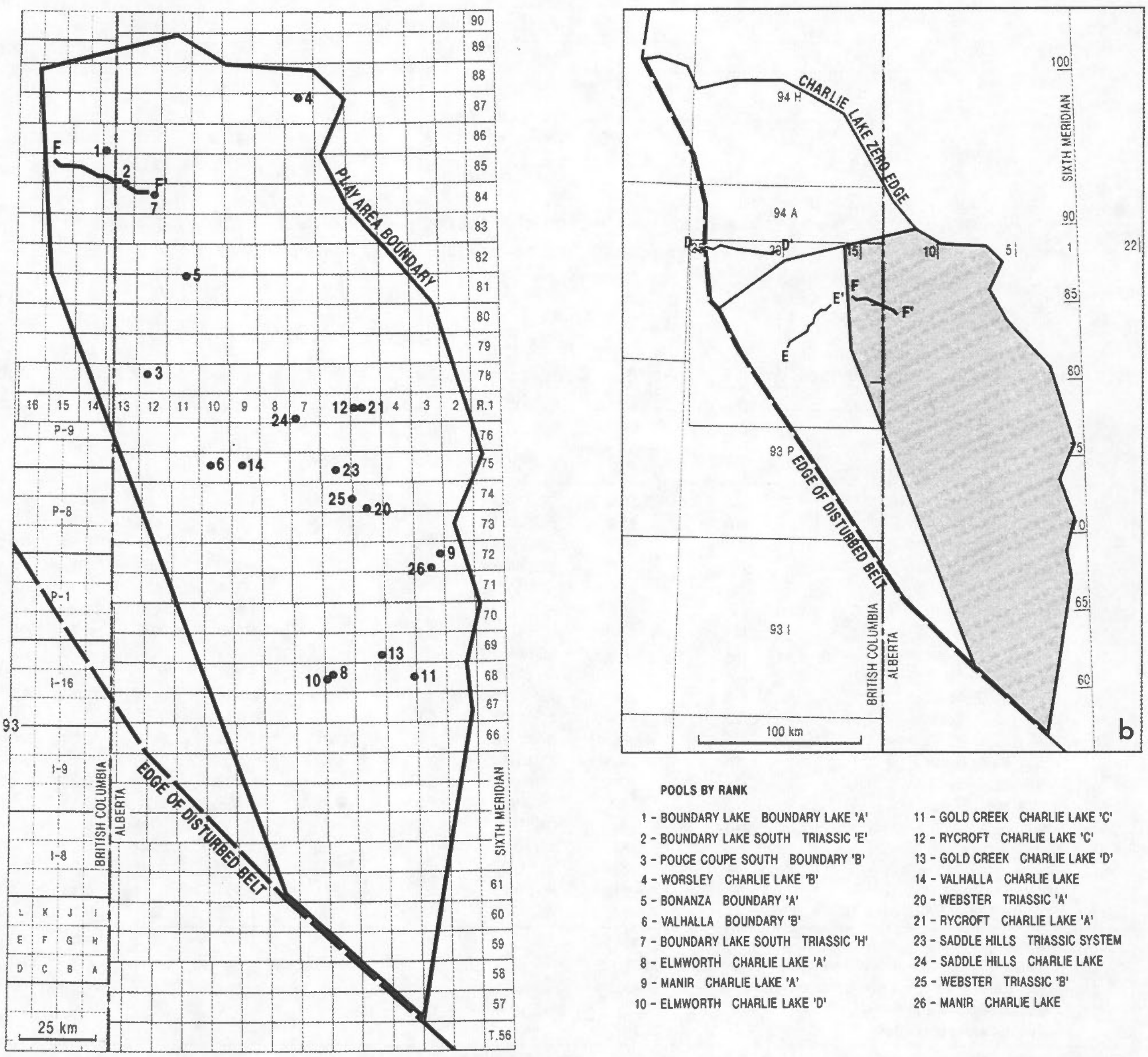

***Figure 37. a.** Map of the Charlie Lake Carbonates, Peace River Structure-Boundary Lake play area. The discovery wells for the 20 largest pools and their respective ranks are shown. See Table 9 for the volumes of these pools and Figure 38 for cross-section F-F'. **b.** The location of this play with respect to the other Charlie Lake plays.*

flat setting (Armitage, 1962; Roy, 1972; Emond, 1992). The Boundary Member remains as an erosional remnant with reservoir characteristics enhanced by exposure at the post-Boundary unconformity. The Boundary Lake pool also is intersected by high-angle normal faults (Fig. 38). Regionally, other reservoirs developed in a complex of evaporitic and redbed units, characteristic of shallow subtidal to supratidal environments.

A small number of pools in the "Worsley-Tangent Dolomite" (discussed earlier) also are included in this play because it directly overlies and resembles the Charlie Lake Formation. These reservoirs produce from algal dolomites and coquinas that occur as erosional outliers near the edge of the Charlie Lake Formation. Porosity has been enhanced by diagenesis associated with the pre-Jurassic erosional event.

Exploration history. The largest pool in this play is at Boundary Lake, drilled in 1954, where solution gas and associated gas reserves of 7 620 x 10^6m^3 were discovered. Since then, many other pools have been found while drilling for multiple-target oil prospects. The discovered in-place volume to date is 20 123 x 10^6m^3 in 120 pools, most of which are high in solution gas. Typically net pay is 4 m and porosity is 15 per cent (Table 9).

Play potential. Expected potential for this play is 9 128 x 10^6m^3 predicted to occur in 280 pools (Fig. 39). The largest undiscovered pool is estimated to be 190 x 10^6m^3. The majority of the undiscovered gas resource is likely to be found in pools less than 190 x 10^6m^3 because of the thin and discontinuous nature of the reservoirs, and the oil prone nature of the play. The greatest potential lies in the more sparsely explored areas south and north of the main pool population, especially to the south, toward the Deep Basin. Potential reservoirs exist in discontinuous outliers east of the Charlie Lake Formation erosional/subcrop edge.

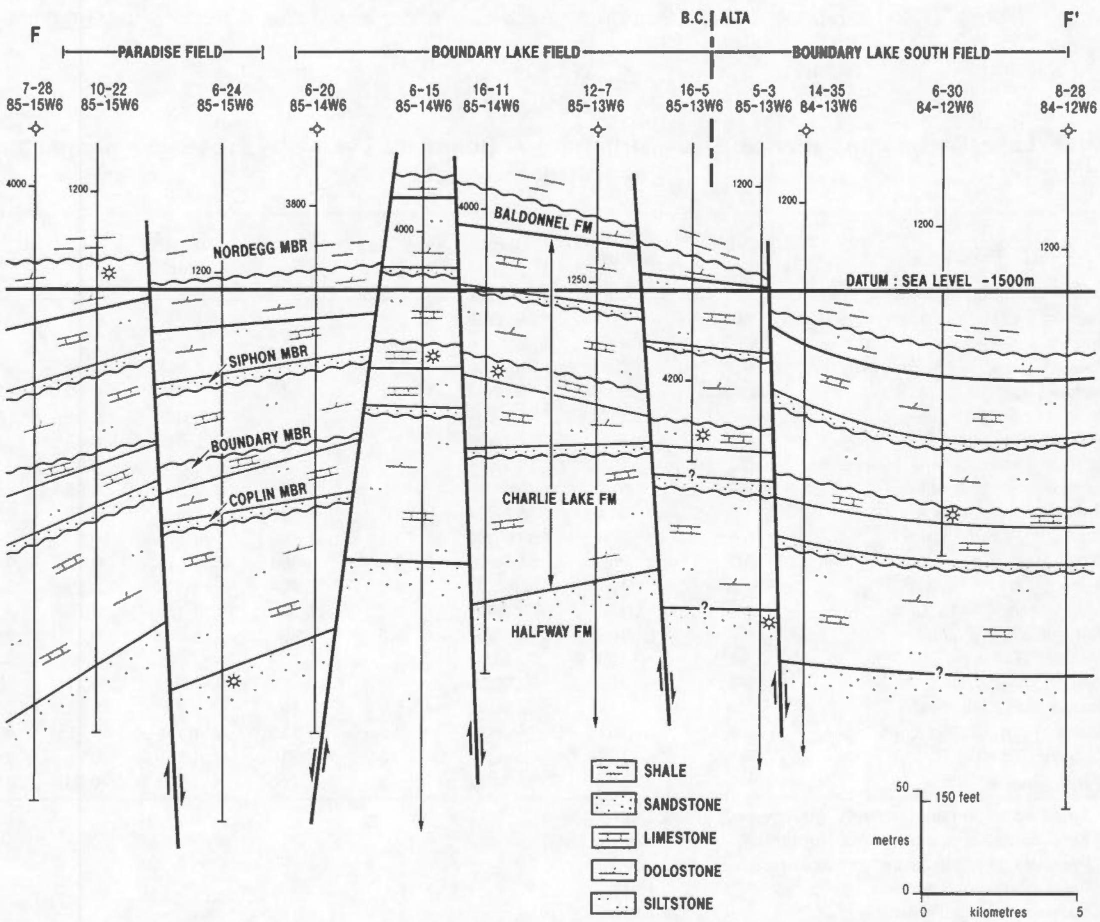

Figure 38. *Structural cross-section F–F' (Fig. 37) illustrating the influence of block faulting on the accumulation of gas in the Boundary Member of the Charlie Lake Carbonates, Peace River Arch–Boundary Lake play. Correlation between wells is established with additional control along the line of section (see Fig. 37).*

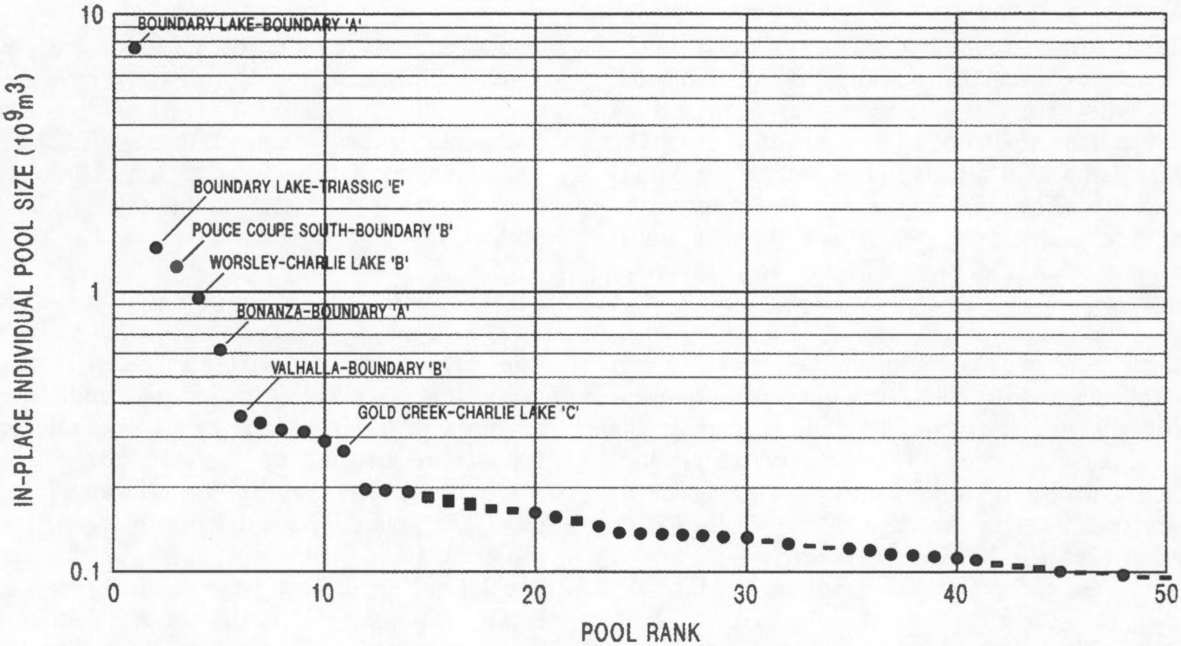

Figure 39. *Pool size-by-rank plot for the Charlie Lake carbonates, Peace River Arch Structure–Boundary Lake play showing the top 50 pools (discovered and undiscovered). See Figure 37 for locations of the 20 largest discovered pools and Table 9 for pool parameters.*

Table 9

Charlie Lake Carbonates (Peace River Structure) – Boundary Lake play, reservoir parameters and assessment results

Rank	Field/Pool	Gas type	In-place volume (10^6m^3)	Disc. date	Net pay (m)	Area (hect.)	Depth (m)	R.F.	Por.	S.W.
1	Boundary Lake, Boundary Lake A	SG	7 620	54/10/29	*	*	1 287	*	*	*
2	Boundary Lake South, Triassic E	AG+SG	1 413	70/09/26	*	*	1 331	0.45	*	*
3	Pouce Coupe South, Boundary B	SG	1 226	81/12/02	*	*	1 863	0.39	*	*
4	Worsley, Charlie Lake B	AG+SG	946	75/10/29	*	*	1 961	0.65	*	*
5	Bonanza, Boundary A	AG+SG	613	83/07/31	*	*	1 389	0.26	*	*
6	Valhalla, Boundary B	SG	356	72/12/02	*	*	2 019	0.65	*	*
7	Boundary Lake South, Triassic H	SG	336	73/07/11	*	*	1 284	0.33	*	*
8	Elmworth, Charlie Lake A	SG	317	79/01/24	*	*	2 397	0.65	*	*
9	Manir, Charlie Lake A	AG	314	85/02/04	2.8	783	1 645	0.85	0.14	0.30
10	Elmworth, Charlie Lake D	NA	289	83/07/26	3.5	400	2 404	0.80	0.12	0.15
11	Gold Creek, Charlie Lake C	AG	268	84/06/20	5.0	400	2 177	0.75	0.10	0.30
12	Rycroft, Charlie Lake C	AG+SG	195	82/08/09	1.8	400	1 383	0.80	0.16	0.15
13	Gold Creek, Charlie Lake D	AG	192	79/08/07	2.4	526	2 132	0.70	0.12	0.20
14	Valhalla, Charlie Lake	NA	189	85/11/22	4.0	200	1 969	0.75	0.18	0.20
20	Webster, Triassic A	NA	160	72/12/21	2.2	200	1 759	0.80	0.15	0.40
21	Rycroft, Charlie Lake A	SG	155	82/06/02	*	*	1 376	0.47	*	*
23	Saddle Hills, Tria Sys	NA	144	72/06/12	5.9	200	1 927	0.65	0.13	0.30
24	Saddle Hills, Charlie Lake	NA	137	84/06/18	3.1	200	1 779	0.75	0.15	0.15
25	Webster, Triassic B	NA	136	73/08/14	0.8	810	1 770	0.75	0.15	0.25
26	Manir, Charlie Lake	NA	134	88/02/12	3.3	200	1 711	0.80	0.16	0.25
	Total initial in-place volume (discovered)		**20 123**							
	Total initial in-place volume (potential)		**9 128**							
	Per cent play resource undiscovered		**31**							
	Total pools discovered		**120**							
	Total pool population		**400**							

*indicates numbers not given in data base

Baldonnel Formation plays

11. Baldonnel Subcrop–Laprise

Play definition. This play is defined to include gas pools and prospects in dominantly stratigraphic facies change traps, with a structural component, in the Baldonnel and Pardonet formations. Play boundaries to the north and east are the Baldonnel erosional edges, to the south, a change in structural influence to drape and fault traps associated with Peace River Arch/Embayment, and to the west, structural overprinting by Laramide folding (Fig. 40).

Geology. The Baldonnel and Pardonet formations consist of normal to restricted marine sediments which originally accumulated on a gently dipping carbonate shelf. Reservoir rocks consist of dolomitized skeletal calcarenites (Bever and McIlreath, 1984; Bever 1990). Reservoir quality varies considerably due to a complex interplay of stratigraphic facies changes, diagenesis and structural effects. At Laprise Creek and East Laprise Creek, the best reservoir development occurs in coquinas that have been altered by the dissolution of bioclastic detritus to form moldic vuggy porosity.

Leaching at, or near, the unconformity surface is an important part of the reservoir development mechanism. Erosional remnants of porous units preserved on paleotopographic highs localize the hydrocarbons. Seals are formed by overlying non-permeable carbonates and Jurassic Nordegg Member shales, or by the in-filling of nonporous units where the sub-Cretaceous unconformity incises deeply into the Baldonnel (Fig. 41; Fitzgerald and Peterson, 1967).

Exploration history. The largest, and the first pools in this play, Nig and Laprise, were discovered in 1953 and 1957 respectively. Both of these pools were initially drilled on structural anomalies, but subsequent drilling confirmed important stratigraphic controls. For example, East Laprise was discovered in 1978 as the result of detailed seismic mapping which was able to correctly identify it as an erosional outlier (Bever,

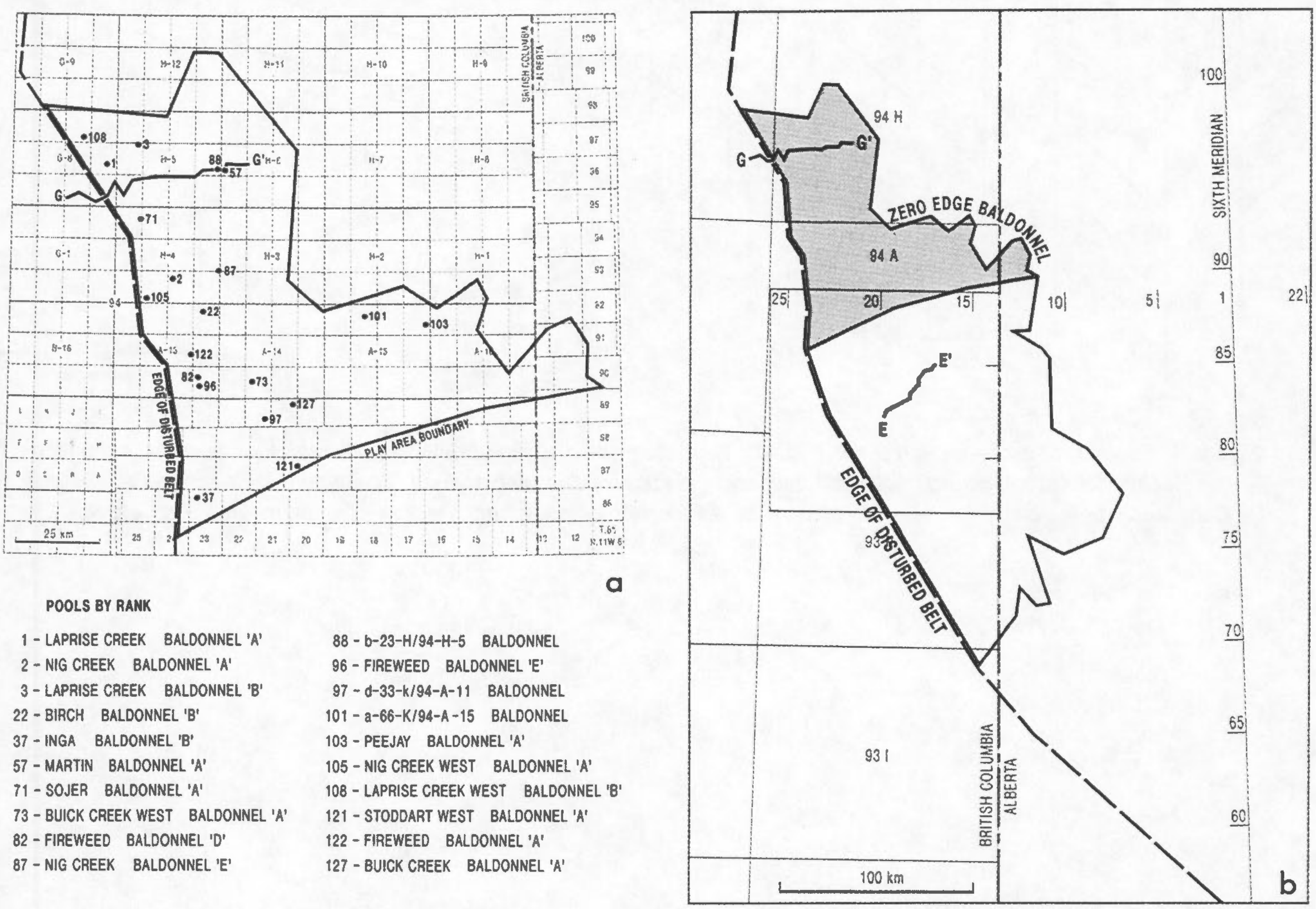

Figure 40. a. Map of the Baldonnel Subcrop–Laprise play area. The discovery wells for the 20 largest pools and their respective ranks are shown. See Table 10 for the volumes of these pools and Figure 41 for cross-section G–G'. b. The location of this play with respect to the other Baldonnel plays.

1990). Several discoveries were made in the late 1970s and early 1980s following the building of pipelines in the area. The most recent discovery was made at Fireweed in 1989, bringing the total in-place volume to 52 614 x $10^6 m^3$ in 31 pools. Typically net pay is 10 m and porosity is 10 per cent (Table 10).

Play potential. Expected potential for this play is an initial in-place volume of 66 610 x $10^6 m^3$ predicted to occur in 469 pools (Fig. 42). Smaller pools may be discovered along the erosional edge where outliers could exist. Detailed mapping of the Triassic erosional surface may provide other prospects.

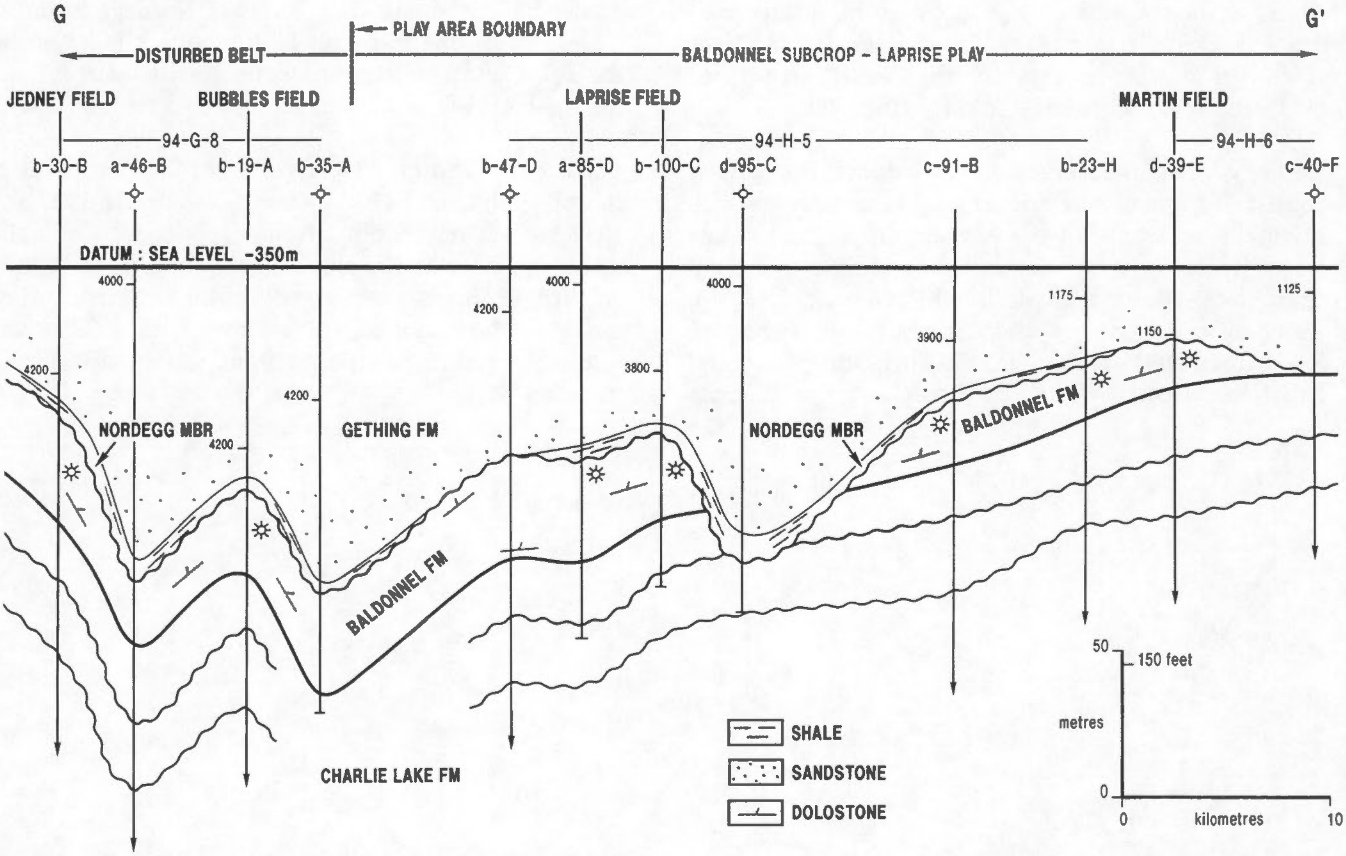

Figure 41. Structural cross-section G–G' (Fig. 40) illustrating the distinction between the structural trapping style within the Rocky Mountain foreland (disturbed belt) and the subcrop trapping style of the Baldonnel Subcrop–Laprise play. Correlation between wells is established with additional control along the line of section (see Fig. 40).

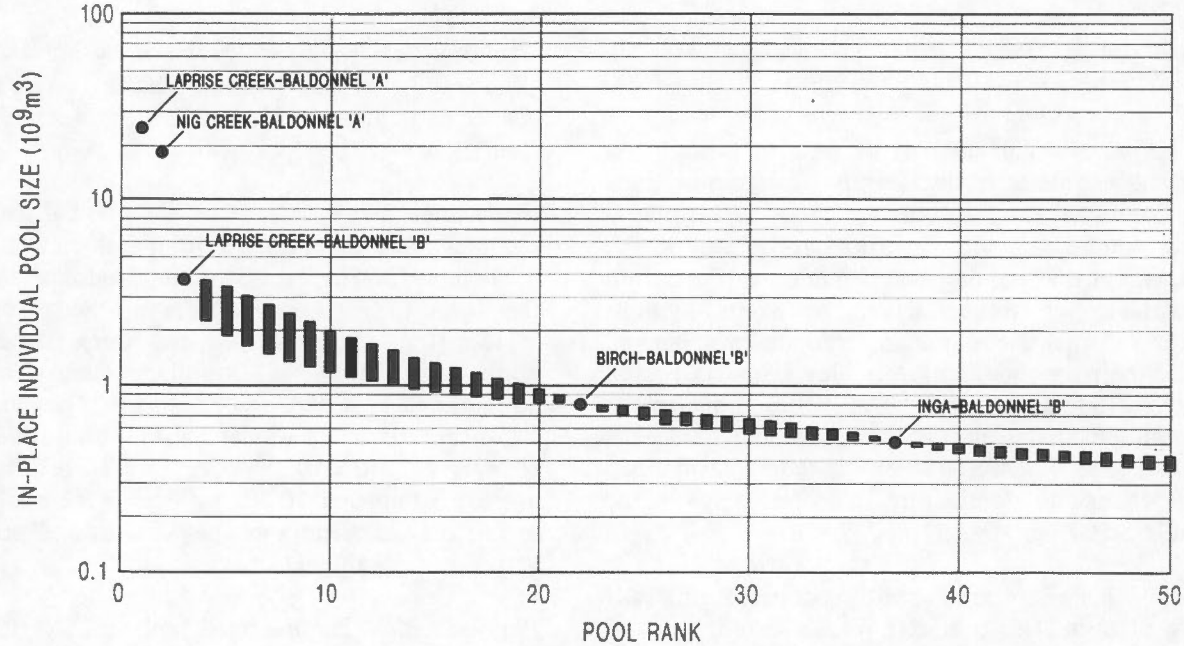

Figure 42. *Pool size-by-rank plot for the Baldonnel subcrop-Laprise play showing the top 50 pools (discovered and undiscovered). See Figure 40 for locations of the 20 largest discovered pools and Table 10 for pool parameters.*

Table 10

Baldonnel Subcrop - Laprise play, reservoir parameters and assessment results

Rank	Field/Pool	Gas type	In-place volume (10^6m^3)	Disc. date	Net pay (m)	Area (hect.)	Depth (m)	R.F.	Por.	S.W.
1	Laprise Creek, Baldonnel A	NA	25 257	57/12/30	19.0	15 642	1 358	0.85	0.10	0.19
2	Nig Creek, Baldonnel A	NA	18 477	53/04/20	11.5	*	1 331	0.70	0.10	0.24
3	Laprise Creek, Baldonnel B	NA	3 820	78/08/03	16.4	*	1 216	0.90	0.11	0.25
22	Birch, Baldonnel B	NA	790	77/12/16	10.0	1 099	1 264	0.90	0.09	0.32
37	Inga, Baldonnel B	NA	494	68/05/26	5.4	911	1 277	0.16	0.11	0.31
57	Martin, Baldonnel A	NA	326	78/07/28	15.0	279	1 156	0.85	0.13	0.26
71	Sojer, Baldonnel A	NA	258	59/07/17	5.1	840	1 380	0.80	0.08	0.26
73	Buick Creek West, Baldonnel A	NA	248	57/02/23	*	*	1 211	0.80	*	*
82	Fireweed, Baldonnel D	NA	218	78/11/12	10.0	259	1 326	0.90	0.10	0.25
87	Nig Creek, Baldonnel E	NA	203	76/08/16	14.6	259	1 249	0.10	0.09	0.43
88	Other area, Baldonnel (B-23-H/94-H-5)	NA	201	78/12/29	6.0	259	1 199	0.90	0.17	0.14
96	Fireweed, Baldonnel E	NA	180	89/07/29	11.3	284	1 329	0.90	0.07	0.28
97	Other area, Baldonnel (D-33-K/94-A-11)	NA	179	85/10/29	11.3	259	1 144	0.80	0.10	0.41
101	Other area, Baldonnel (A-66-K/94-A-15)	NA	171	87/12/17	7.6	259	1 033	0.90	0.12	0.17
103	Peejay, Baldonnel A	NA	167	76/01/09	17.1	259	1 020	0.90	0.16	0.30
105	Nig Creek West, Baldonnel A	NA	162	54/02/27	3.0	530	1 409	0.18	0.12	0.24
108	Laprise Creek West, Baldonnel B	NA	155	80/02/25	7.5	259	1 312	0.90	0.11	0.22
121	Stoddart West, Baldonnel A	NA	135	85/11/13	4.0	259	1 313	0.85	0.18	0.40
122	Fireweed, Baldonnel A	NA	134	63/10/26	2.2	860	1 337	0.70	0.09	0.35
127	Buick Creek, Baldonnel A	NA	127	54/06/04	8.5	259	1 201	0.85	0.08	0.25
	Total initial in-place volume (discovered))		**52 614**							
	Total initial in-place volume (potential)		**66 610**							
	Per cent play resource undiscovered		**56**							
	Total pools discovered		**31**							
	Total pool population		**500**							

*indicates numbers not given in data base

12. Baldonnel (Peace River Structure)-Fort St. John

Play definition. This play is defined to include gas pools and prospects in dominantly stratigraphic traps in the Baldonnel and Pardonet formations. This play is similar to the Baldonnel Subcrop-Laprise play to the north, except that the draping of Baldonnel Formation reservoirs over Peace River Arch/Embayment structures forms the dominant trapping mechanism. The northern boundary of this play is marked by a change to Laramide structural influence, while to the east and south, the play is limited by the Baldonnel erosional edge. The western edge of the play is defined by the change to dominantly structural plays in the foothills belt (Fig. 43).

Geology. The Baldonnel and Pardonet formations consist of normal to restricted marine carbonates and siltstones deposited on a broad shelf. Proximity to the pre-Jurassic unconformity provided a mechanism to enhance reservoir characteristics by the dolomitizing and leaching of primary rock fabric. The unconformity surface also formed isolated paleotopographic highs which are favourable for localizing hydrocarbons. These highs were formed by drape and differential compaction over fault blocks in the Peace River Arch/Embayment. Faults and fractures associated with normal faulting may increase permeability and provide conduits for dolomitizing fluids and hydrocarbons (Fig. 35). Seal rocks are provided by Jurassic Fernie Group and Nordegg Member shales as well as non-porous carbonates within the Baldonnel and Pardonet formations.

Exploration history. The first gas pools discovered in this play were the Fort St. John Baldonnel A and B pools in 1952. The Fort St. John Baldonnel A pool is the largest, with an initial in-place volume of 3 415 x 10^6m^3. Prior to 1960, the four next largest gas pools were found at Boundary Lake, Braeburn, Siphon, and Fort St. John Southeast. The most recent significant discovery was at Balsam in late 1987 where reserves of 210 x 10^6m^3 were found. A total initial in-place volume of 10 502 x 10^6m^3 in 42 pools occurs in this play. Typically net pay is 6 m and porosity is 15 per cent (Table 11).

Play potential. The expected potential for the play is 8 336 x 10^6m^3 predicted to occur in 438 pools. The largest pool in this play is thought to have been already discovered (Fig. 44) and based on this assumption, the majority of the remaining pools will be less than 100 x 10^6m^3. Many smaller pools are likely to be found along the erosional edge of the Baldonnel. There is some potential for new discoveries in the southern and eastern parts of the play area although increased depth may be a limiting factor. Remaining pools will probably be small and difficult to detect by seismic exploration methods.

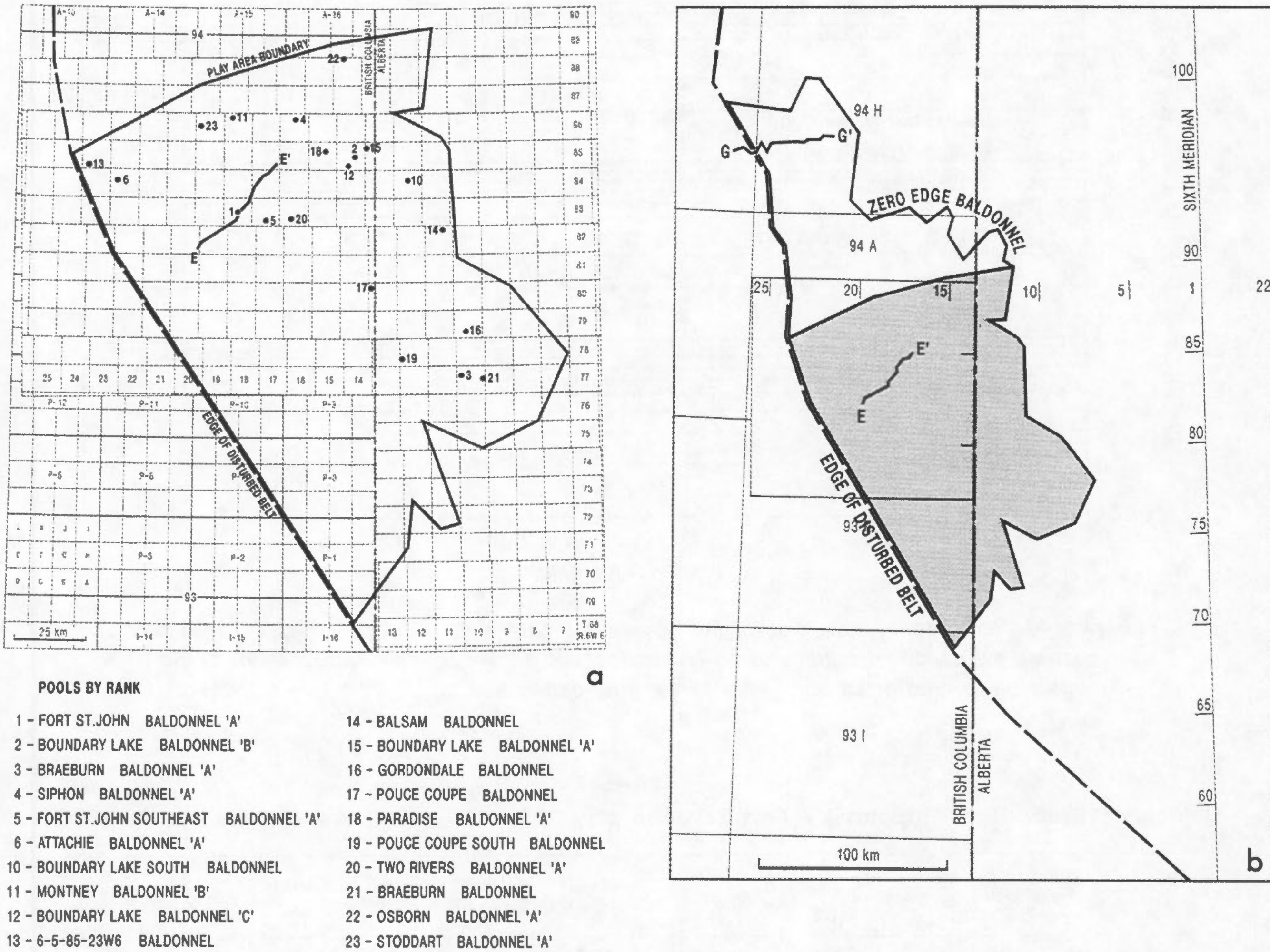

Figure 43. a. Map of the Baldonnel Peace River Structure–Fort St. John play showing the location of the discovery wells for the 20 largest discovered pools and their respective ranks. See Table 11 for the volumes of these pools. b. The location of this play with respect to the other Baldonnel plays.

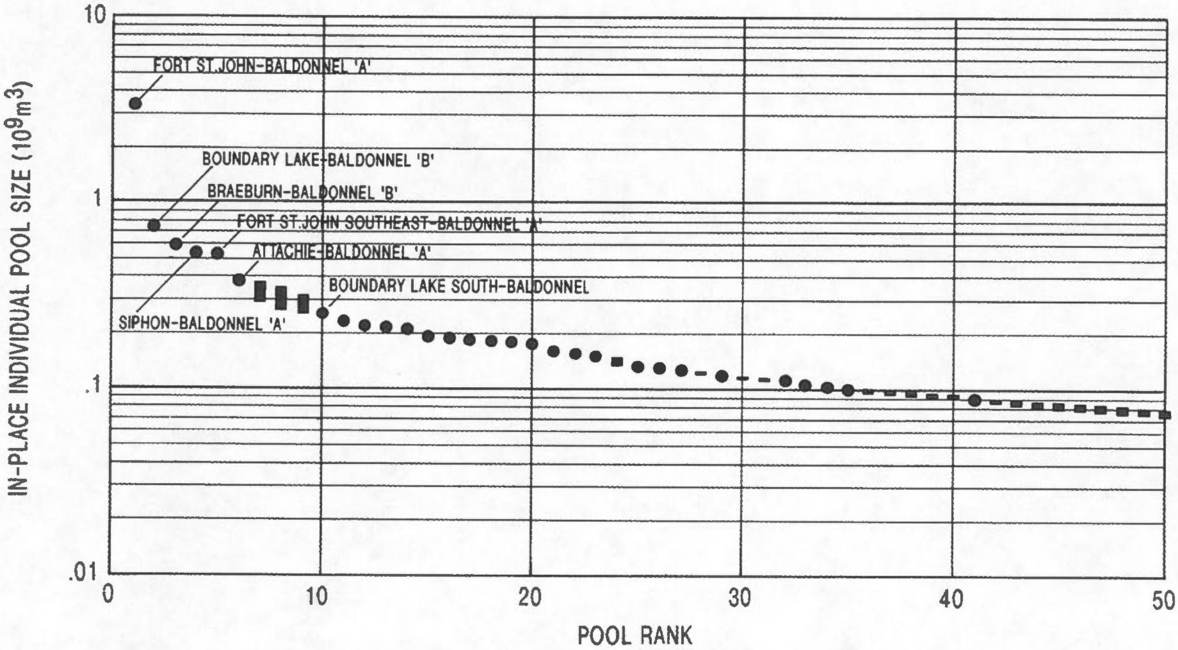

***Figure 44.** Pool size–by–rank plot for the Baldonnel (Peace River Structure)–Fort St. John play showing the top 50 pools (discovered and undiscovered). See Figure 43 for locations of the 20 largest discovered pools and Table 11 for pool parameters.*

Table 11

Baldonnel (Peace River Structure) – Fort St. John play, reservoir parameters and assessment results

Rank	Field/Pool	Gas type	In-place volume (10^6m^3)	Disc. date	Net pay (m)	Area (hect.)	Depth (m)	R.F.	Por.	S.W.
1	Fort St. John, Baldonnel A	NA	3 415	52/03/24	*	*	1 126	0.85	0.12	0.25
2	Boundary Lake, Baldonnel B	NA	744	57/06/03	6.0	755	1 207	0.90	0.14	0.34
3	Braeburn, Baldonnel A	NA	591	54/03/05	2.5	2 074	1 726	0.80	0.12	0.30
4	Siphon, Baldonnel A	NA	536	59/02/17	8.3	755	1 207	0.25	0.13	0.33
5	Fort St. John Southeast, Baldonnel A	NA	527	56/07/10	3.7	*	1 179	0.90	0.18	0.28
6	Attachie, Baldonnel A	NA	377	71/08/05	32.0	259	1 151	0.90	0.06	0.37
10	Boundary Lake South, Baldonnel	NA	254	72/03/14	3.4	440	1 235	0.75	0.25	0.40
11	Montney, Baldonnel B	NA	225	62/07/24	4.5	257	1 177	0.80	0.23	0.23
12	Boundary Lake, Baldonnel C	NA	216	77/06/21	10.4	259	1 146	0.90	0.14	0.46
13	Other area, Baldonnel (6-5-85-23W6)	NA	211	81/12/18	10.4	259	1 227	0.50	0.09	0.35
14	Balsam, Baldonnel	NA	210	87/11/27	5.4	200	1 255	0.80	0.17	0.20
15	Boundary Lake, Baldonnel A	NA	189	62/08/20	8.8	259	1 210	0.90	0.14	0.34
16	Gordondale, Baldonnel	NA	186	83/06/15	3.0	200	1 552	0.75	0.24	0.11
17	Pouce Coupe, Baldonnel	NA	184	71/07/04	5.6	200	1 420	0.80	0.15	0.25
18	Paradise, Baldonnel A	NA	182	87/02/12	6.0	259	1 231	0.90	0.15	0.23
19	Pouce Coupe South, Baldonnel	NA	180	53/08/28	3.1	440	1 778	0.70	0.13	0.22
20	Two Rivers, Baldonnel A	NA	179	67/05/28	3.7	259	1 216	0.25	0.21	0.25
21	Braeburn, Baldonnel	NA	159	85/06/13	5.0	200	1 737	0.75	0.14	0.20
22	Osborn, Baldonnel A	NA	155	63/12/26	9.1	259	1 144	0.80	0.14	0.49
23	Stoddart, Baldonnel A	NA	153	77/08/08	4.0	259	1 192	0.90	0.19	0.29
	Total initial in-place volume (discovered)		**10 502**							
	Total initial in-place volume (potential)		**8 336**							
	Per cent play resource undiscovered		**44**							
	Total pools discovered		**42**							
	Total pool population		**480**							

*indicates numbers not given in data base

MATURE PLAY RESULTS

Discovered gas volumes, and expected potential gas volumes for the 10 mature plays are listed in Table 12. The total volume for the 10 mature plays is 264 694 x $10^6 m^3$ of discovered initial in-place gas with an additional 272 124 x $10^6 m^3$ of expected potential. The total probable potential for the mature plays is 522 647 x $10^6 m^3$ offering a more speculative value based on conditional probability of the total discovered resource.

CONCEPTUAL PLAY ANALYSIS

Estimation of conceptual play potential

Conceptual plays are defined as those plays in which discoveries or reserves have not yet been proven but according to geological analysis, may exist. To assess the Triassic conceptual plays, a discovery sequence plot of the 10 mature plays was generated, each play size representing the sum of the discovered and expected potential in-place volume (Fig. 6). The discovery date of each mature play was taken as the date when the first pool in that play was discovered. A play size-by-rank plot was generated in the same manner as the pool size-by-rank plots for the mature plays. The potential and size range of immature and conceptual plays was estimated by the nonparametric discovery process model using the 10 mature plays as the database (Fig. 45). The rectangular bars in this figure represent the range in potential of 2 immature plays and at least 1 conceptual play. The 2 bars on the left match the estimated range of discovered plus potential resources for immature plays, while the remaining bar on the right represents the expected volume of conceptual plays.

The numerical analysis suggests that there is a total of at least 13 Triassic gas plays, including 10 mature, 2 immature (Montney Distal Shelf-Glacier and Montney Subcrop North-Ring), and at least one conceptual play. This conceptual play or group of plays could represent one or more plays, but it is assumed that one conceptual play will approximate the total of smaller conceptual plays if they exist.

Geological analysis of conceptual plays

The credibility of the conceptual potential estimates (Table 12) can be evaluated by examining whether it can be demonstrated geologically that enough new plays actually exist to contain the additional volume. The statistically derived idea that at least 1 new play may exist is reasonable considering the relatively long history of exploration and limited areal distribution of

Table 12

All Triassic plays, assessment results

Play Name	In-place volume ($10^6 m^3$) [TCF] Discovered	In-place volume ($10^6 m^3$) [TCF] Expected	No. of pools Discovered/Total
Mature Plays			
Montney Subcrop South – Fir	25 876	23 258	73/500
Halfway/Doig Shore Zone (Peace River Structure) – Sinclair	66 600	27 036	143/360
Halfway/Doig Shore Zone – Peejay Milligan	12 731	10 839	63/400
Halfway/Doig Shelf (Peace River Structure) – Monias	39 710	88 934	51/500
Halfway/Doig Shelf – Tommy Lakes	25 915	23 202	27/300
Charlie Lake Clastics – Inga	6 094	8 866	25/200
Charlie Lake Clastics (Peace River Structure) – Cecil	4 529	5 915	39/275
Charlie Lake Carbonates (Peace River Structure) – Boundary Lake	20 123	9 128	120/400
Baldonnel Subcrop – Laprise	52 614	66 610	31/500
Baldonnel (Peace River Structure) – Fort St. John	10 502	8 336	42/480
Subtotal	**[9.4] 264 694**	**[9.6] 272 124**	**614/3915**
Immature Plays			
Montney Subcrop North – Ring	22 993	15 971	
Montney Distal Shelf – Glacier	713	12 191	
Conceptual play(s)	NIL	5 615	
Subtotal	**[0.8] 23 706**	**[1.2] 33 777**	
Grand Total	**[10.2] 288 400**	**[10.8] 305 901**	

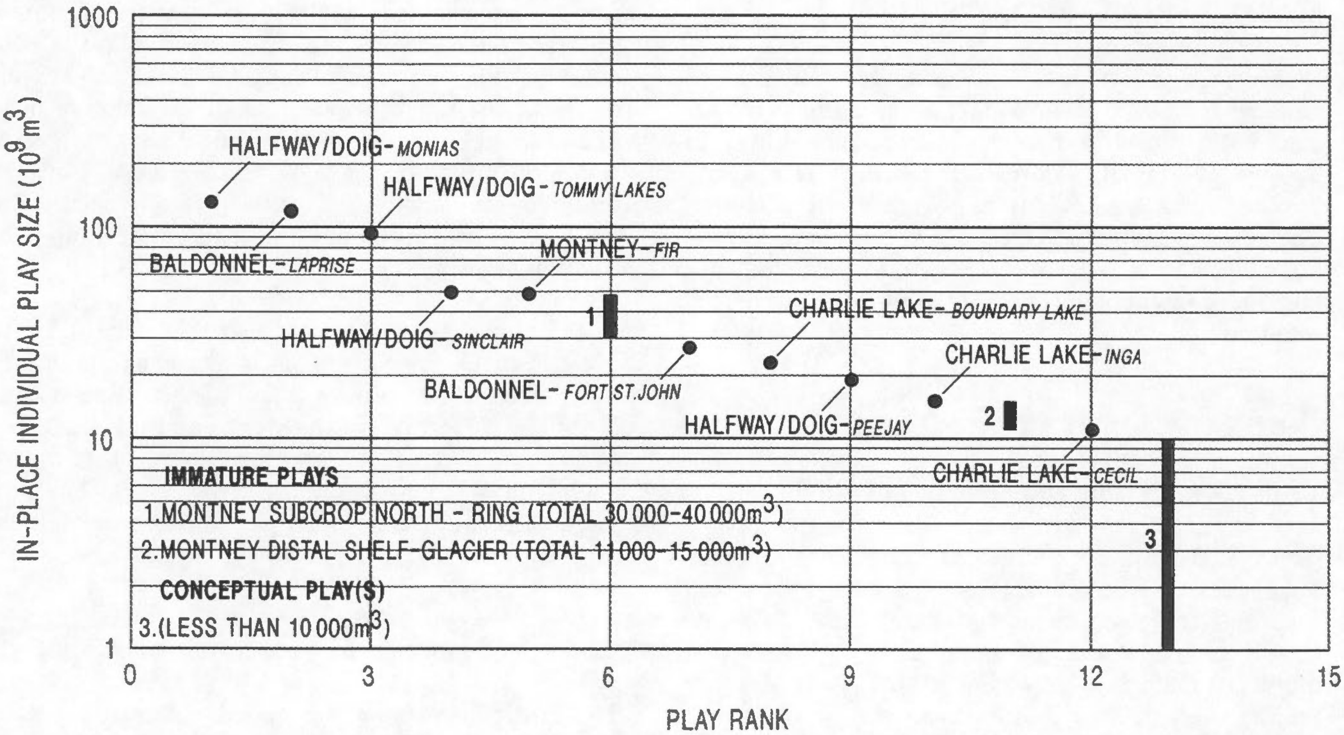

***Figure 45.** Play size-by-rank plot of the 10 mature Triassic plays. Dots show total resources (discovered plus undiscovered) of mature plays; boxes represent range of total resource for immature and conceptual plays.*

Triassic sediments in the Interior Plains. Another reason that additional conceptual plays are not thought to be numerous is that play definitions of mature plays are sufficiently broad to include most geological concepts of hydrocarbon occurrence. Assuming that the estimated volume contained in the conceptual play is realistic, several types of plays could yield the additional volume of gas.

In the western part of the region, in outcrop, distal shelf to slope facies siliciclastics and carbonates of the Ludington Formation (refer to Fig. 11) occur with coquina-filled submarine channel complexes up to 167 m thick (Gibson, 1993b) which could form reservoir units to the east in the subsurface. Debris-flow related, coquina reservoirs could be located near shelf slope-breaks and may be related to localized syndepositional block faulting. At the southern limit of Triassic strata, close to the Foothills disturbed belt, there is a possibility that stratigraphic traps could exist in porous facies of the Vega Siltstone Member of the Sulphur Mountain Formation (Gibson, 1974). Since it is the reservoir at the Basing pool in the Foothills (Osadetz et al., pers. comm.), this unit could form traps in the subsurface of the plains area.

Another conceptual play could exist in areas where there is a significant thickness of salt in the Charlie Lake Formation. It is possible to invoke a trapping mechanism which involves salt dissolution and collapse forming drape geometries or collapse breccias. This may occur in the Septimus/Wilder region (e.g., Twp. 83, Rge. 19, W6M) where the North Pine salt is known to exist.

CONCEPTUAL AND IMMATURE PLAY RESULTS

The sum of the three means of the bars on Figure 45 is the expected potential for conceptual and immature plays (33 777 x $10^6 m^3$). In the Montney Subcrop North-Ring play, a 0.9 probability gives the play resource (discovered plus undiscovered) a range from 30 000 to 40 000 x $10^6 m^3$ in-place volume. The discovered volume at Ring-Pedigree is already about 23 000 x $10^6 m^3$ which amounts to about 60 per cent of the total play resource. This high concentration in one pool suggests either the play resource may be underestimated, the play definition is too specific to that one pool, or this is a new play type and there is not enough data to be more definitive. In the Montney Distal Shelf-Glacier play, the range of potential at a 0.9 probability level gives a range of 11 000 to 15 000 x $10^6 m^3$ of which about 700 has already been discovered. A median estimate of the remaining volume is given at 12 191 x $10^6 m^3$. This is reasonable considering the lack of drilling and the size of the play area.

The estimated range for the conceptual play volume is considered to be under 10 000 x $10^6 m^3$, suggesting that the volume in the conceptual play will combine with the expected volume from the two immature plays to total 33 777 x $10^6 m^3$. Based upon this number, the expected value for the conceptual play (or plays) is 5 615 x $10^6 m^3$.

DISCUSSION

Numerical assessment of mature, immature and conceptual plays 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. The immature and conceptual play analysis used the numerical results from the 10 mature plays, matched the immature plays, and conceived at least one additional play. This difference is important when comparing the potential gas volumes for mature and conceptual plays (Table 12). All numbers quoted are for volume of gas in the ground' regardless of economic exploitability.

Mature plays: discussion

Mature plays are ranked according to discovered in-place volume, expected volume, per cent undiscovered, and largest remaining pool size in Tables 13 to 16. Comparisons yield trends which may be of use for planning exploration strategies. The play with the largest discovered gas resource is the Halfway/Doig Shore Zone-Sinclair play. This is because the play has been well explored over a large area, primarily for oil. Large volumes in the Baldonnel Subcrop-Laprise play probably reflect its gas-prone nature, with gas occurring in large individual pools. These large pools are the result of structural overprinting (in the form of gentle folding) of stratigraphic traps, giving rise to large areas of structural closure. The Halfway/Doig Shelf-Monias play shows relatively large discovered volumes also because of structural overprinting and its tendency to be gas prone. The oil-prone nature of some of the play types also downgrades their ranking for gas reserves and potential (e.g., Charlie Lake-Boundary and Halfway/Doig-Peejay Milligan).

When the mature plays are ranked according to expected potential, a different order occurs in the top three plays. The Halfway/Doig Shelf-Monias play is estimated to hold the greatest potential because it has a large, undrilled area and therefore is comparatively immature with 69 per cent of the total play resource remaining undiscovered. The Baldonnel Subcrop-Laprise play is second in this ranking also because of its relative immaturity since its large play area extends northward into an area of poor well control. The Halfway/Doig Shore Zone-Sinclair play is the third largest in the expected volume category. Since this play area is relatively mature, it is not surprising that much of the resource has already been discovered.

Estimated largest remaining pools for each mature play, when ranked according to size (Table 16), show a similar pattern which highlights the potential of the Baldonnel subcrop-Laprise play and the Halfway/Doig Shelf-Monias play. The largest undiscovered pool sizes are expected to be 3 206 and 2 635 x $10^6 m^3$. The remaining resources likely exist in many small pools.

The expected potential in-place gas volume for the 10 mature plays is 272 124 x $10^6 m^3$. Within the mature plays, the average size of the estimated largest remaining pools is 1 321 x $10^6 m^3$. The average varies significantly from play to play, but over 150 pools remain with sizes greater than 280 x $10^6 m^3$. Less than five pools remain with sizes greater than 2 800 x $10^6 m^3$.

Conceptual and immature plays: discussion

The geological and geographic location of gas resources in conceptual plays are by nature very speculative compared to mature plays. This is because the occurrence and distribution of undiscovered gas potential in mature plays is confined (by the geologically derived play boundary) to a specific type of reservoir within a constrained area. The conceptual play is not so constrained.

The total resource in conceptual plays is derived from the ten established mature and two immature plays in a discovery process model. The gas volume calculated for the conceptual play (which may include one or more plays) is a total statistical estimate of the gas volume regardless of whether it is economically exploitable. The size of the individual pools in the conceptual play will determine if exploration will take place. If the pools are too small, the play may never be identified.

The estimate for the conceptual play has a range up to 10 000 x $10^6 m^3$ with a median value of 5 615 x $10^6 m^3$ (Fig. 45). The volumetric sum of immature and conceptual plays gives an expected value of 33 777 x

Table 13

Mature Triassic plays – ordered by largest discovered volume (initial gas-in-place)

Play Name	Discovered volume	Expected potential
	(10^6m^3)	
Halfway/Doig Shore Zone (Peace River Structure) – Sinclair	66 600	27 036
Baldonnel Subcrop – Laprise	52 614	66 610
Halfway/Doig Shelf (Peace River Structure) – Monias	39 710	88 934
Halfway/Doig Shelf – Tommy Lakes	25 915	23 202
Montney Subcrop – South Fir	25 876	23 258
Charlie Lake Carbonates (Peace River Structure) – Boundary Lake	20 123	9 128
Halfway/Doig Shore Zone – Peejay Milligan	12 731	10 839
Baldonnel (Peace River Structure) – Fort St. John	10 502	8 336
Charlie Lake Clastics – Inga	6 094	8 866
Charlie Lake Clastics (Peace River Structure) – Cecil	4 529	5 915
Total	**264 694 (9.4 TCF)**	**272 124 (9.6 TCF)**

Table 14

Mature Triassic plays – ordered by largest expected volume

Play Name	Discovered volume	Expected potential
	(10^6m^3)	
Halfway/Doig Shelf (Peace River Structure) – Monias	39 710	88 934
Baldonnel Subcrop – Laprise	52 614	66 610
Halfway/Doig Shore Zone (Peace River Structure) – Sinclair	66 600	27 036
Montney Subcrop – South Fir	25 876	23 258
Halfway/Doig Shelf – Tommy Lakes	25 915	23 202
Halfway/Doig Shore Zone – Peejay Milligan	12 731	10 839
Charlie Lake Carbonates (Peace River Structure) – Boundary Lake	20 123	9 128
Charlie Lake Clastics – Inga	6 094	8 866
Baldonnel (Peace River Structure) – Fort St. John	10 502	8 336
Charlie Lake Clastics (Peace River Structure) – Cecil	4 529	5 915
Total	**264 694 (9.4 TCF)**	**272 124 (9.6 TCF)**

Table 15

Mature Triassic plays – ordered by undiscovered volume as per cent of total resources

Play Name	Discovered volume (10^6m^3)	Expected potential (10^6m^3)	% of play undiscovered
Halfway/Doig Shelf (Peace River Structure) – Monias	39 710	88 934	69
Charlie Lake Clastics – Inga	6 094	8 866	59
Charlie Lake Clastics (Peace River Structure) – Cecil	4 529	5 915	57
Baldonnel Subcrop – Laprise	52 614	66 610	56
Montney Subcrop South – Fir	25 876	23 258	47
Halfway/Doig Shelf – Tommy Lakes	25 915	23 202	47
Halfway/Doig Shore Zone – Peejay Milligan	12 731	10 839	46
Baldonnel (Peace River Structure) – Fort St. John	10 502	8 336	44
Charlie Lake Carbonates (Peace River Structure) – Boundary Lake	20 123	9 128	31
Halfway/Doig Shore Zone (Peace River Structure) – Sinclair	66 600	27 036	29
Total	264 694 (9.4 TCF)	272 124 (9.6 TCF)	

Table 16

Mature Triassic plays – ordered by largest remaining (undiscovered) pool size

Play Name	Discovered volume (10^6m^3)	Largest discovered pool (10^6m^3)	Expected potential (10^6m^3)	Largest remaining pool size (10^6m^3)
Baldonnel Subcrop – Laprise	52 614	25 257	66 610	3 206
Halfway/Doig Shelf (Peace River Structure) – Monias	39 710	20 100	88 934	2 635
Halfway/Doig Shore Zone (Peace River Structure) – Sinclair	66 600	14 815	27 036	1 806
Halfway/Doig Shore Zone – Peejay Milligan	12 731	2 338	10 839	1 577
Halfway/Doig Shelf – Tommy Lakes	25 915	19 247	23 202	1 444
Montney Subcrop – South Fir	25 876	9 974	23 258	1 204
Charlie Lake Clastics (Peace River Structure) – Cecil	4 529	1 064	5 915	607
Baldonnel (Peace River Structure) – Fort St. John	10 502	3 415	8 336	342
Charlie Lake Clastics – Inga	6 094	2 302	8 866	207
Charlie Lake Carbonates (Peace River Structure) – Boundary Lake	20 123	7 620	9 128	185
Total	264 694 (9.4 TCF)		272 124 (9.6 TCF)	

10^6m^3. When compared to mature plays, this value is relatively low due to the level of exploration maturity.

Total volumes

The total initial in-place (discovered) volume in the 10 mature plays is 264 694 x 10^6m^3. The contribution to the total discovered in-place volume from the two immature plays is 23 706 x 10^6m^3 giving a total discovered in-place volume for the established 12 plays of 288 400 x 10^6m^3 in 622 pools.

Estimates of total play potential are given at two levels, expected (Table 12) and probable. The expected values are thought to be more realistic than the probable value, because they are constrained by the discovered pool sizes. The probable potential value is derived by making the play resource distribution conditional on the total sum of the discovered resource.

The total expected in-place volume from all play types (mature, immature and conceptual) is 305 901 x 10^6m^3. This value, added to the discovered in-place volume, gives a total resource of 594 301 x 10^6m^3, indicating that about 51 per cent of the total remains to be discovered. Of the undiscovered resource, only 11 per cent is contained in immature and conceptual plays, with the remaining 89 per cent in mature plays (Fig. 46).

For all play types, the total probable potential (undiscovered) in-place volume is 767 300 x 10^6m^3.

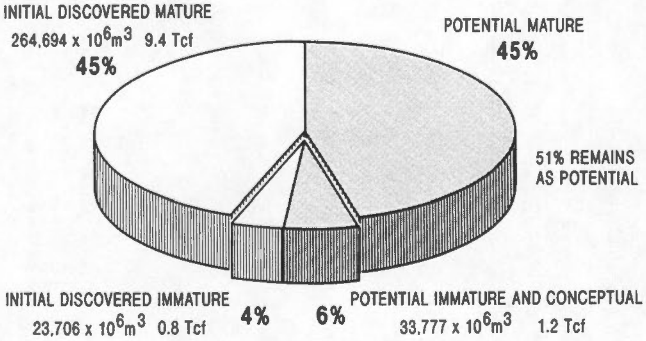

Figure 46. *Pie diagram illustrating discovered resources and potential resources of the Triassic Interior Plains, Western Canada Sedimentary Basin.*

CONCLUSIONS

1. The geological analysis and statistical assessment of Triassic gas resources in the Interior Plains portion of the Western Canada Sedimentary Basin indicates that over 50 per cent of the total gas resource remains to be discovered (not accounting for economic considerations).

2. Of the undiscovered Triassic gas potential, almost 89 per cent is estimated to be present in established mature plays. Up to five undiscovered pools have an estimated size greater than 2 800 x 10^6m^3 and over 150 pools have a size greater than 280 x 10^6m^3.

3. The most attractive established mature plays with the greatest potential are: i) Halfway/Doig Formation shelf sandstones within the area influenced by Peace River Arch/Embayment block faulting and characterized by the Monias field; ii) Baldonnel Formation carbonates situated near the northern subcrop edge, with some trapping caused by Laramide folding, for example, the Laprise field; and iii) Halfway/Doig shore zone sandstones with a component of structural influence associated with Peace River Arch/ Embayment faulting and typified by the Sinclair pool. These three plays make up almost 60 per cent (182 580 x 10^6m^3) of the total undiscovered resource.

4. Eleven percent of the total Triassic gas potential is predicted to occur in conceptual and immature plays. The range in total volume of conceptual plays is under 10 000 x 10^6m^3.

ACKNOWLEDGMENTS

The authors have drawn upon the work of, and benefited much from discussions with, many colleagues in the petroleum industry, the Institute of Sedimentary and Petroleum Geology, and other government agencies both federal and provincial. Special acknowledgments are given to G. Reinson for his encouragement and guidance in this project; P. Tzeng for her assistance with running the statistical methodology programs; J. MacRae; J. Rowling and other staff of the Petroleum Geology Branch, British Columbia Ministry of Energy, Mines and Petroleum Resources for discussions regarding plays in northeast British Columbia; N. Wemyss of Canadian Hunter and R. Jamieson of Home Oil for discussions relating to regional geology and play definitions; and G. Davies of GRDC Ltd., for valuable discussions and help with stratigraphic correlations. K. Drummond of the National Energy Board and D. Gibson reviewed the preliminary manuscript and made useful suggestions for its improvement. Editorial comments and emendations from K. Osadetz and D. Cant improved the work substantially. Note is also given to P. Gubitz for his good natured, efficient and diligent work in preparing the figures; the ISPG Cartography unit (in particular B. Ortman and J. Waddell) who assisted with cartographic and production procedures; L. Wardle and G. Edwards for photomechanical reproduction; P. Greener and M. Jacobs for typesetting and layout; and J. Monro for editorial assistance.

REFERENCES

Alberta Energy Resources Conservation Board
1991: Alberta's reserves of crude oil, oil sands, gas, natural gas liquids and sulphur, (December 31, 1990). Energy Resources Conservation Board, Calgary, Alberta, Report ST 91-18 (plus related digital tapes).

Armitage, J.H.
1962: Triassic oil and gas occurrence in northeastern British Columbia, Canada. Journal of the Alberta Society of Petroleum Geologists, v. 10. p. 35-56.

Aukes, P.G. and Webb, T.K.
1986: Triassic Spirit River Pool, northwestern Alberta. *In* 1986 Core Conference, N.C. Meijer Drees (ed.). Canadian Society of Petroleum Geologists, Calgary, Alberta, Canada, p. 3.1-3.34.

Anderson, N.L., Hills, L.V., and Cederwall, D.A.
1989: Geophysical Atlas of Western Canadian Hydrocarbon Pools. Canadian Society of exploration Geophysicists and Canadian Society of Petroleum Geologists, Calgary, Alberta, p. 344.

Barclay, J.E.
1988: The Lower Carboniferous Golata Formation of the Western Canada Sedimentary Basin, in the context of sequence stratigraphy. *In* Sequences, Stratigraphy, Sedimentology: Surface and Subsurface, D.P. James and D.A. Leckie (eds.), Canadian Society of Petroleum Geologists, Memoir 15, p. 1-14.

1993: Triassic Petroleum Geology, Western Canada Basin and neighbouring Yukon Territory and American Regions: bibliography and summary (contributions from D. Gibson). Bulletin of Canadian Petroleum Geology, v. 41, p. 437-452.

Barclay, J.E. and Leckie, D.A.
1986: Tidal inlet reservoirs of the Triassic Halfway Formation, Wembley Region, Alberta. *In* 1986 Core Conference, N.C. Meijer Drees (ed.). Canadian Society of Petroleum Geologists, Calgary, Alberta, p. 4.1-4.6.

Barss, D.L., Best, E.W., and Meyers, N.
1964: Triassic, Chapter 9. *In* Geological History of Western Canada, R.G. McCrossan and R.P. Glaister (eds.). Alberta Society of Petroleum Geologists, Calgary, Alberta, p. 113-136.

Barss, D.L. and Montandon, F.A.
1981: Sukunka-Bullmoose gas fields: models for a developing trend in the southern Foothills of northeast British Columbia. Bulletin of Canadian Petroleum Geology, v. 29, p. 293-333.

Bever, J.M.
1990: Laprise Creek and East Laprise Creek. *In* Oil and Gas Pools of Canada Series, Volume 1, M.L. Rose (ed.). Canadian Society of Petroleum Geologists, unpaginated.

Bever, J.M. and McIlreath, I.A.
1984: Stratigraphy and reservoir development of shoaling-upward sequences in the Upper Triassic (Carnian) Baldonnel Formation, northeastern British Columbia. Program and Abstracts, Canadian Society of Petroleum Geologists-Canadian Society of Exploration Geophysicists, National Convention, Calgary, 1984, p. 147.

British Columbia Ministry of Energy, Mines and Petroleum Resources Division
1991: Hydrocarbon and by-product reserves in British Columbia in 1990. Petroleum Resources Division, British Columbia, Ministry of Energy, Mines and Petroleum Resources, Victoria, British Columbia, 23 p. (plus related digital tapes).

Campbell, C.V., Dixon, R.J., and Forbes, D.M.
1989: Updip erosional truncation of Halfway and Doig shoreline sequences: a new model for exploration in west-central Alberta. Exploration Update 1989-Integration of Technologies, Program and Abstracts, Canadian Society of Petroleum Geologists Convention, Calgary, Alberta, p. 138.

Cant, D.J.
1986: Hydrocarbon trapping in the Halfway Formation (Triassic), Wembley Field, Alberta. Bulletin of Canadian Petroleum Geology, v. 34, p. 329-338.

1988: Regional structure and development of the Peace River Arch, Alberta: A Paleozoic failed-rift system? Bulletin of Canadian Petroleum Geology, v. 36, p. 284-295.

Caplan, M.L. and Moslow, T.F.
1991: Reservoir quality and characterization of the Halfway Formation, Peejay Field, northeastern British Columbia. Opportunities for the Nineties, Program and Abstracts, 1991 Canadian Society of Petroleum Geologists Convention, Calgary, p. 40.

Clark, D.R.
1961: Primary structures of the Halfway Sand in the Milligan Creek oilfield, British Columbia. Journal of the Alberta Society of Petroleum Geologists, v. 9, p. 109-130.

Creaney, S. and Allan, J.
1990: Hydrocarbon generation and migration in the Western Canada Sedimentary Basin. Classic Petroleum Provinces, J. Brooks (ed.). Special Publication of the Geological Society of London, Blackwell Scientific, p. 189-202.

Dixon, J., Morrell, G.R., Dietrich, J.R., Procter, R.M., and Taylor, G.C.
1988: Petroleum resources of the Mackenzie Delta-Beaufort Sea. Geological Survey of Canada, Open File 1926, 74 p.

Edwards, D.E., Barclay, J.E., Gibson, D.W., Kvill, G.E., and Halton, E.
1994: Triassic strata of the Western Canada Sedimentary Basin. *In* Geological Atlas of the Western Canada Sedimentary Basin, G.D. Mossop and I. Shetsen (comp.). Canadian Society of Petroleum Geologists-Alberta, Research Council, Calgary, Alberta, p. 259-275.

Embry, A.F.
1988: Triassic sea-level changes: evidence from the Canadian Arctic Archipelago. *In*. Sea-Level Changes: An Integrated Approach, C.K.Wilgus, B.S. Hastings, C.G.St.C. Kendall, H.W. Posamentier, C.A. Ross, and J.C. Van Wagoner (eds.). Society of Economic Paleontologists and Mineralogists, Special Publication No. 42, p. 249-259.

Emond, D.
1992: Upper Triassic tidal-flat carbonates of the Boundary Lake Member, northeastern British Columbia. Official Program, 1992 Annual Convention, 1992 American Association of Petroleum Geologists-Canadian Society of Petroleum Geologists-Society of Economic Paleontologist and Mineralogists, Calgary, Alberta, p. 37.

Energy, Mines and Resources Canada
1977: Oil and natural gas resources of Canada, 1976. Report EP77-1, 76p.

Fitzgerald, E.L. and Peterson, D.J.
1967: Inga Oil Field, British Columbia. Bulletin of Canadian Petroleum Geology, v. 15, p. 65-81.

Forbes, D.M., Dixon, R.J., and Hassler, G.T.
1991: Stratigraphy and exploration potential of the Charlie Lake Formation, west-central Alberta. Opportunities for the Nineties, Program and Abstracts, 1991 Canadian Society of Petroleum Geologists Convention, Calgary, p. 61

Fulton, H.B.
1966: Triassic Halfway Formation isopach, Peejay-Beatton River area, northeastern British Columbia. The Government of the Province of British Columbia, Department of Mines and Petroleum Resources, map and notes, 1 page.

Gibson, D.W.
1968: Triassic stratigraphy between the Athabasca and Smoky Rivers of Alberta. Geological Survey of Canada, Paper 67-65, 114 p.

1974: Triassic rocks of the southern Canadian Rocky Mountains. Geological Survey of Canada, Bulletin 230, 65 p.

1975: Triassic rocks of the Rocky Mountain Foothills and Front Ranges of northeastern British Columbia and west-central Alberta. Geological Survey of Canada, Bulletin 247, 61 p.

1993a: Triassic. *In* Sedimentary Cover of the North American Craton: Canada, D.F. Stott and J.D. Aitken (eds.). Geological Survey of Canada, Geology of Canada No. 5 , p. 294-320 (also Geological Society of America, The Geology of North America D-2).

1993b: Upper Triassic coquina channel complexes, Rocky Mountain Foothills, northeastern British Columbia. Bulletin of Canadian Petroleum Geology, v. 41, p. 57-69.

Gibson, D.W. and Barclay, J.E.
1989: Middle Absaroka Sequence: The Triassic stable craton. *In* The Western Canada Sedimentary Basin-A case history, B.D. Ricketts (ed.). Canadian Society of Petroleum Geologists, Special Publication no. 30, Calgary, Alberta, p. 219-232.

Gibson, D.W. and Edwards, D.E.
1990: An overview of Triassic stratigraphy and depositional environments in the Rocky Mountain Foothills and western Interior Plains, Peace River Arch area, northeastern British Columbia. *In* Geology of the Peace River Arch, S.C. O'Connell and J.S. Bell (eds.). Bulletin of Canadian Petroleum Geology, v. 38A, p.146-158.

Glass, D.J. (ed.)
1990: Lexicon of Canadian Stratigraphy, Volume 4, Western Canada, including Eastern British Columbia, Alberta, Saskatchewan and Southern Manitoba. Canadian Society of Petroleum Geologists, Calgary, Alberta, 772 p.

Halton, E.
1981: Wembley Field-facies variations in the Halfway Formation. *In* Annual Core and Field Sample Conference, F.A. Stoakes (ed.). Canadian Society of Petroleum Geologists, Calgary, Alberta, Canada, p. 9.

Higgs, R.Y.
1990: Sedimentology and petroleum geology of the Artex Member (Charlie Lake Formation), northeastern British Columbia. Petroleum Geology Branch, Province of British Columbia Ministry of Energy, Mines and Petroleum Resources, Petroleum Geology Special Paper 1990-1, 26 p.

Horne, J.C., Campbell, C.V., and Odland, S.K.
1985: Tidal-inlet fills as hydrocarbon reservoirs: example from Halfway Formation, Alberta. American Association of Petroleum Geologists, Bulletin, v. 69, p. 267.

Hunt, A.D. and Ratcliffe, J.D.
1959: Triassic stratigraphy, Peace River area, Alberta and British Columbia, Canada. American Association of Petroleum Geologists Bulletin, v. 43, p. 563-589.

Jackson, P.C.
1990: Brassey Artex Pool. *In* Oil and Gas Pools of Canada Series, Volume 1, M.L. Rose (ed.). Canadian Society of Petroleum Geologists, unpaginated.

Klein, M. and Woofter, D.
1989: The Triassic Brassey Oilfield of northeast British Columbia-a light oil discovery: its evolution from exploration to development. Exploration Update 1989-Integration of Technologies, Program and Abstracts. Canadian Society of Petroleum Geologists Convention, Calgary, Alberta, p. 134.

Lee, P.J.
1993: Two Decades of Geological Survey of Canada petroleum resource assessments. Canadian Journal of Earth Sciences, v. 30. p. 321-332

Lee, P.J. and Tzeng, H.P.
1989: The Petroleum exploration and Resource Evaluation System (PETRIMES): Working reference guide. Institute of Sedimentary and Petroleum Geology, Calgary Alberta, 258 p.

Lee, P.J. and Wang, P.C.C.
1983a: Probabilistic formulation of a method for the evaluation of petroleum resources. Mathematical Geology, v. 15, p. 163-181.

1983b: Conditional analysis for petroleum resource evaluations. Mathematical Geology, v. 15, p. 353-365.

1984: PRIMES: A petroleum resources information management and evaluation system. Oil & Gas Journal, October 1, p. 204-206.

1985: Prediction of oil or gas pool sizes when discovery record is available. Mathematical Geology, v. 17, p. 95-113.

1986: Evaluation of petroleum resources from pool size distribution. *In* Oil and Gas Assessment Methods and Applications, D.D. Rice (ed.). Studies in Geology, no. 21, American Association of Petroleum Geologists, p. 33-42.

1990: An introduction to petroleum resource evaluation methods. Canadian Society of Petroleum Geologists Short Course Notes, 1990 Canadian Society of Petroleum Geologists, Convention on Basin Perspectives, May 1990, Calgary, Alberta, Canada, 108 p.

Masters, C.D.
1984: Petroleum Resource Assessment. C.D. Masters, (ed.). International Union of Geological Sciences, Publication No. 17.

McCrossan, R.G. and Glaister, R.P. (eds.)
1964: Geological History of Western Canada. Alberta Society of Petroleum Geologists, Calgary, Alberta, 232 p.

Metherell, R.G.
1966: Kaybob South Field (Spray River Formation). *In* Oil Fields of Alberta Supplement, J.R. Century (ed.). Alberta Society of Petroleum Geologists, Calgary, Alberta, p. 59-60.

Miall, A.D.
1976: The Triassic Sediments of Sturgeon Lake South and surrounding areas. *In*. The Sedimentology of Selected Clastic Oil and Gas Reservoirs in Alberta, M. Lerand (ed.). Canadian Society of Petroleum Geologists, p. 25-43.

Moslow, T.F. and Davies, G.R.
1992: Triassic Reservoir Facies and exploration Trends: Western Canada Sedimentary Basin. Canadian Society of Petroleum Geologists, Short Course Number 7 notes, Canadian Society of Petroleum Geologists-American Association of Petroleum Geologists Conference: June 25-26, 1992, Calgary, Alberta, 166 p.

Mossop, G.D. and Shetsen, I. (Comp.)
1994: Geological Atlas of the Western Canada Sedimentary Basin. Canadian Society of Petroleum Geologists-Alberta Calgary, Alberta, 510 p.

Mothersill, J.S.
1968: Environments of deposition of the Halfway Formation, Milligan Creek area, British Columbia. Bulletin of Canadian Petroleum Geology, v. 16, p. 180-199.

Munroe, H.D. and Moslow, T.F.
1990: Reservoir quality and architecture of tidal inlet sandstones, Halfway Formation, northeastern British Columbia. Bulletin of Canadian Petroleum Geology, v. 38, no. 1, p. 174 (also in CSPG Reservoir, Canadian Society of Petroleum Geologists, v. 18, no. 9, p. 2-3).

1991: Depositional models for the Doig Formation of northeastern British Columbia. Opportunities for the Nineties, Program and Abstracts, 1991 Canadian Society of Petroleum Geologists Convention, Calgary, Alberta, p. 105.

Nelson, S.J.
1970: Historical Geology of Western Canada: Early and Middle Triassic; Late Triassic. *In* The Face of Time, The Geological History of Western Canada. Alberta Society of Petroleum Geologists, Calgary, Alberta, p. 111-113.

O'Connell, S.C. and Bell, J.S. (eds.)
1990: Geology of the Peace River Arch. Bulletin of Canadian Petroleum Geology, v. 38A, 281 p.

O'Connell, S.C., Di x , G.R., and Barclay, J.E.
1990: The origin, history and regional structural development of the Peace River Arch, Western Canada. *In* Geology of the Peace River Arch, S.C. O'Connell and J.S. Bell (eds.). Bulletin of Canadian Petroleum Geology, v. 38A, p. 4-24.

Podruski, J.A., Barclay, J.E., Hamblin, A.P., Lee, P.J., Osadetz, K.G., Procter, R.M., and Taylor, G.C.
1988: Conventional oil resources of Western Canada (light and medium), Part I: Resource endowment. Geological Survey of Canada, Paper 87-26, p. 1-125.

Porter, J.W., Price, R.A., and McCrossan, R.G.
1982: The Western Canada Sedimentary Basin. *In* The Evolution of Sedimentary Basins, P. Kent, M.H.P. Bott, D.P. Mckenzie and C.A. Williams (eds.). Royal Society of London (Philosophical Transactions), A305, no. 1489, p. 169-192.

Pruden, D.M., Jeffries, S.A., and Goetz, P.A.
1991: Structural architecture and evolution of the Dawson Creek Graben Complex, Alberta and British Columbia. *In* Canadian Society of exploration Geophysicists, Recorder, September, 1991.

Reinson, G.E., Lee, P.J., Barclay, J.E., Bird, T.D., and Osadetz, K.G.
1993a: Western Canada basin conventional gas resource estimated at 232 tcf. Oil and Gas Journal, October 25, 1993, p. 92-95.

Reinson, G.E., Lee, P.J., Warters, W., Osadetz, K.G., Bell, L.L., Price, P.R., Trollope, F., Campbell, R.I., and Barclay, J.E.
1993b: Devonian gas resources of the Western Canada Sedimentary Basin. Part I: Geological play analysis and resource assessment. Geological Survey of Canada, Bulletin 452, p. 1-128.

Rice, D.D.
1986: Oil and gas assessment-Methods and Applications. Studies in Geology, American Association of Petroleum Geologists, Tulsa, Oklahoma, 267 p.

Riediger, C.L., Brooks, P.W., Fowler, M.G., and Snowdon, L.R.
1990: Lower and Middle Triassic source rocks, thermal maturation, and oil-source rock correlations in the Peace River Embayment area, Alberta and British Columbia. *In* Geology of the Peace River Arch, S.C. O'Connell and J.S. Bell (eds.). Bulletin of Canadian Petroleum Geology, v. 38A, p. 218-235.

Rose, M.L. (ed.)
1990: Oil and Gas Pools of Canada, Volume 1, Canadian Society of Petroleum Geologists, unpaginated.

Roy, K.J.
1972: The Boundary Member: A buried erosional remnant of Triassic age in northeastern British Columbia. Bulletin of Canadian Petroleum Geology, v. 20, p. 27-57.

1979: Hydrocarbon assessment using subjective probability and Monte Carlo methods. *In* International Institute for Applied Systems Analysis, First Conference on Methods and Models for Assessing Energy Resources, M. Grenon, (ed.). Pergamon Press, New York, p. 279-290.

Shell Oil Company
1956: Sturgeon Lake South-Triassic Oil. Canadian Oil and Gas Industries, v. 9, no. 7, p. 51-54.

Sikabonyi, L.A. and Rodgers, W.J.
1959: Paleozoic tectonics and sedimentation in the northern half of the West Canadian Basin. Journal of the Alberta Society of Petroleum Geologists, v. 7, p. 193-216.

Sinclair, I.K., McAlpine, K.D., Sherwin, D.F., and McMillan, N.J.
1992: Petroleum resources of the Jeanne D'Arc Basin and environs, Part I: Geological framework. Geological Survey of Canada, Paper 92-8, p. 1-48.

Sproule, J.C. and Boggs, O.D.
1956: Sturgeon Lake-geology and reserves. Canadian Oil and Gas Industries, v. 9, no. 7, p. 43-50.

Stewart, R.
1989: Stratigraphic Correlation Chart, northeastern British Columbia and adjacent areas. Province of British Columbia, Ministry of Energy, Mines and Petroleum Resources, Victoria, British Columbia, 1 chart.

Sturrock, D.L. and Dawson, S.W.
1991: The Ring/Border Field: A significant gas discovery in the Triassic Montney Formation. Reservoir, Canadian Society of Petroleum Geologists, Calgary, Alberta, v. 18, no. 2, p. 1-2.

Torrie, J.E.
1973: Northeastern British Columbia. *In* Future Petroleum Provinces of Canada, R.G. McCrossan (ed.). Canadian Society of Petroleum Geologists, Memoir 1, p. 151-186.

Vail, P.R., Mitchum, R.M. Jr., and Thompson, S. III.
1977: Seismic stratigraphy and global changes of sea-level, Part 4: Global cycles of relative changes of sea-level. *In* Seismic Stratigraphy, Applications to Hydrocarbon exploration, C.E. Payton (ed.). American Association of Petroleum Geologists, Memoir 26, p. 83-97.

Wade, J.A., Campbell, G.R., Procter, R.M., and Taylor, G.C.
1989: Petroleum resources of the Scotian Shelf. Geological Survey of Canada, Paper 88-19, 26 p.

White, D.A. and Gehman, H.M.
1979: Methods of estimating oil and gas resources. American Association of Petroleum Geologists Bulletin, v. 63, p. 2183-2192.

Willis, A.J.
1992: Reservoir sedimentology of the middle Triassic Halfway Formation, Wembley Field, Alberta. M.Sc. thesis, University of Alberta, Edmonton, Alberta, 401 p.

Wittenberg, J.
1992: Origin and stratigraphic significance of anomalously thick sandstone trends in the Middle Triassic Doig Formation of west-central Alberta. M.Sc. thesis, University of Alberta, Edmonton, Alberta, 600 p.

Wittenberg, J. and Moslow, T.F.
1992a: Lateral facies variability and impact on reservoir heterogeneity, Middle Triassic Doig Formation, Sinclair, Wembley, and Valhalla (East) Fields, Alberta, Canada. Environments of exploration, Program and Abstracts, American Association of Petroleum Geologists and Canadian Society of Petroleum Geologists Convention, Calgary, Alberta, June, 1992, p. 144.

1992b: Origin and stratigraphic significance of several anomalously thick sandstone trends in the Middle Triassic Doig Formation of west-central Alberta, Canada. Environments of exploration, Program and Abstracts, American Association of Petroleum Geologists and Canadian Society of Petroleum Geologists Convention, Calgary, Alberta, June, 1992, p. 144.

TRIASSIC GAS RESOURCES OF THE WESTERN CANADA SEDIMENTARY BASIN, INTERIOR PLAINS

PART II: ECONOMIC ANALYSIS

Abstract

Part II consists of an economic analysis of the undiscovered Triassic natural gas resources. Estimates are made of the relation between the plant-gate price of natural gas and the volume of economically recoverable undiscovered resources. Supply curves are presented, with and without a fiscal burden, for full-cycle and half-cycle cases, and for a weighted case, which is an average of the full- and half-cycle results. The weighted case is regarded as the reference case in this study. In the weighted case, 10 per cent of the volume of recoverable gas is estimated to be economic at a price of \$44.13 per 10^3m^3 (\$1.25 per MCF), and 38 per cent at a price of \$88.25 per 10^3m^3 (\$2.50 per MCF). Prices are expressed in 1990 dollars. These percentages correspond to 8 per cent and 30 per cent, respectively, of the undiscovered initial gas-in-place volumes estimated in Part I. Estimates of the volume of economic gas potential for the entire Triassic (established and conceptual plays) are 25 x 10^9m^3 (0.9 TCF) and 92 x 10^9m^3 (3.3 TCF) at the two prices. Further analysis shows the sensitivities of economic potential to changes in total costs, exploration success ratios, distances of discoveries to gathering systems, and resource estimates. Virtually all of the economically recoverable gas resources in the Triassic are found in four plays: the Halfway/Doig Shelf–Monias, Baldonnel Subcrop–Laprise, Halfway/Doig Shelf–Tommy Lakes, and Halfway/Doig Shore–Sinclair.

Summary

In Part II, the portion of the undiscovered initial gas-in-place that can be expected to be economic over the long-term is estimated by taking into consideration the major technical and economic constraints to exploration, development and production. This constrained portion is defined as *economic potential*. It is measured as a function of the weighted full- and half-cycle estimate of the plant-gate supply price of natural gas. The weighted estimate recognizes the impact of uphole and downhole targets on the economic potential of a play. The use of a weighted estimate is appropriate in the economic analysis of resources in the Triassic System, because exploration targets are expected to exist both above and below Triassic strata. Consequently, the weighted case is regarded as the reference case for this study.

The full-cycle case is defined to include all exploration, development, production and overhead costs. The cost of land rights has been excluded from this analysis in order to estimate prospect profitability prior to acquiring land. The half-cycle case excludes all pre-development costs. Economic potential is provided for both the full-cycle and half-cycle cases in order to provide estimates at major decision points in the investment cycle, and to address single target exploration drilling.

Estimates of economic potential were prepared with and without a fiscal burden. Burdened economic potential measures potential under the existing fiscal system, while unburdened economic potential excludes the fiscal system. The difference between the burdened and unburdened cases measures the impact of the fiscal system on the discovery, development and production of marginally economic natural gas resources. For each case, two estimates of economic potential are provided: the volume of economic initial raw recoverable gas, and the percentage of the total initial raw recoverable gas that is economic.

The economic analysis was undertaken for each of the ten mature Triassic plays for which undiscovered pool size estimates and other required information were available. The undiscovered pools in each play were treated as a set of investment opportunities. Exploration, development and production costs, together with production profiles, were estimated for all undiscovered pools. The resulting cost and production schedules were then used to estimate minimum required plant-gate supply prices using discounted cash flow analysis. Supply curves, relating economic potential to prices, were constructed from the above estimates. Because of a lack of relevant information, it was not possible to undertake detailed economic analysis of the undiscovered resources in immature and conceptual plays. Results for the mature plays were, therefore, extended to the immature and conceptual plays to provide some estimate, however speculative, of their economic potential.

The supply curves prepared in this study were estimated under the following reference case conditions and assumptions: i) mean resource estimate for each undiscovered pool; ii) play-specific geological and engineering parameters; iii) play-specific economic success ratios; iv) the federal and provincial fiscal systems as of June, 1993; v) 1990 costs; and vi) a minimum required real discounted cash flow rate-of-return on investment of 10 per cent.

The reference case is based on data available at the time of analysis. It does not consider improvements in economic success ratios or upward revisions to the resource estimates due to increased knowledge of exploration plays, reductions in development costs due to expansions of pipeline networks, or possible decreases in costs due to technological changes and improvements in company practices. Consequently, economic potential for the reference case should be considered closer to the current economics of exploration. It is likely an underestimate of the long-term exploration fundamentals.

Major results and conclusions for the reference case for the ten mature plays, are:

1. In the weighted case, burdened economic potential is estimated as 22 x 10^9m^3 (0.8 TCF) at a plant-gate price of \$44.13 per 10^3m^3 (\$1.25 per MCF), and 82 x 10^9m^3 (2.9 TCF) at a plant-gate price of \$88.25 per 10^3m^3 (\$2.50 per MCF). These volumes correspond to 10 and 38 per cent, respectively, of the total initial raw recoverable gas. They represent 8 and 30 per cent, respectively, of the undiscovered initial gas-in-place volumes estimated in Part I.

2. On a full-cycle basis, burdened economic potential is 13 x 10^9m^3 (0.5 TCF) at \$44.13 per 10^3m^3, and 70 x 10^9m^3 (2.5 TCF) at a price of \$88.25 per 10^3m^3. These volumes correspond to 6 and 33 per cent of the total initial raw recoverable gas, respectively.

3. On a half-cycle basis, burdened economic potential increases to 42 x 10^9m^3 (1.5 TCF) at \$44.13 per 10^3m^3, and to 122 x 10^9m^3 (4.3 TCF) at \$88.25 per 10^3m^3. These volumes correspond to 20 and 57 per cent of the total initial raw recoverable gas, respectively.

4. The supply curves are elastic in the price range of \$35 to \$88.25 per 10^3m^3 (\$1.00 to \$2.50 per MCF). At prices higher than \$88.25 per 10^3m^3, the supply curves are relatively inelastic.

5. There is a relatively small difference between burdened and unburdened economic potential. This suggests that the combined federal and provincial fiscal systems do not significantly reduce economic potential.

Approximately one ninth of the undiscovered Triassic gas resources are estimated to be found in immature and conceptual plays. Results of the economic analysis for the ten mature plays were extended to this portion of the resource. Including the resources estimated for immature and conceptual plays increases the weighted economic potential from 22 x 10^9m^3 (0.8 TCF) to 25 x 10^9m^3 (0.9 TCF) at \$44.13 per 10^3m^3, and from 82 x 10^9m^3 (2.9 TCF) to 92 x 10^9m^3 (3.3 TCF) at \$88.25 per 10^3m^3.

Significant variability and uncertainty surround estimates of costs and other factors. Sensitivity analyses were undertaken to estimate the impact of changes in significant factors on estimates of weighted burdened economic potential. Results of the sensitivity analyses are:

1. Estimates of the weighted economic potential are sensitive to changes in total costs. An increase in total costs of 20 per cent, relative to the reference case, reduces economic potential by 52 per cent at a plant-gate price of \$44.13 per 10^3m^3 and 11 per cent at \$88.25 per 10^3m^3. A reduction in total costs of 30 per cent increases economic potential by 76 per cent at \$44.13 per 10^3m^3 and 20 per cent at \$88.25 per 10^3m^3.

2. Estimates of weighted economic potential are less sensitive to changes in the exploration success ratio. For example, doubling the exploration success ratio increases economic potential by 31 per cent at \$44.13 per 10^3m^3 and 19 per cent at \$88.25 per 10^3m^3. The greater impact occurs in the full-cycle case, where doubling the economic success ratio increases economic potential by 59 and 20 per cent, respectively.

3. Reducing the pipeline distance to the gathering system to 2.5 km increases the weighted economic potential by 23 per cent at \$44.13 per 10^3m^3 and 8 per cent at \$88.25 per 10^3m^3. Similar changes in economic potential are estimated for the half-cycle case.

4. Increases in estimates of undiscovered pool sizes have a significant impact on economic potential. A comparison of economic potential using undiscovered pool size estimates at the 10 per cent probability level with the reference case shows a 49 per cent increase at \$44.13 per 10^3m^3 and a 16 per cent increase at \$88.25 per 10^3m^3.

The supply curves are dominated by three plays in British Columbia and one play in Alberta. An examination of the economic potential estimates at the play level shows that, at prices up to \$88.25 per 10^3m^3, virtually all of the economic potential is expected to be found in the following four plays: the Halfway/Doig Shelf–Monias, Baldonnel Subcrop–Laprise, Halfway/Doig Shelf–Tommy Lakes (in British Columbia), and the Halfway/Doig Shore–Sinclair (in Alberta).

INTRODUCTION

Part I of this report provides estimates of the undiscovered natural gas resources within the Triassic System of the Western Canada Sedimentary Basin. These estimates are not constrained by engineering and economic considerations. Part II presents estimates of economic potential, which is defined as the portion of the undiscovered resource that can be expected to be profitable in the long term. By taking engineering constraints, costs and other economic factors into consideration, an estimate of the economic portion of the resource base is provided. This estimate is relevant to exploration and development decisions, strategic planning, supply forecasting and the analysis of resource management issues.

This report is the second in a series of studies on the economic potential of undiscovered gas resources in the Western Canada Sedimentary Basin. Part II of GSC Bulletin 452 examined the gas resources of the Devonian System (Dallaire et al., 1993). Since most of the methodology and assumptions used in this report are the same as those used in Bulletin 452, only a summary is provided here. Changes to the methodology used in Bulletin 452 are, however, described in detail.

Terminology

Stacked resources refers to resources found in oil and gas plays that are vertically superimposed, in whole or in part, on one another. Where stacked resources exist, oil and gas resources in shallower plays, or *uphole resources*, may be discovered with wells drilled to the target play, or discoveries in the target play may be made with wells drilled to deeper plays. In either case, total exploration costs are shared between the prospective strata. The current analysis avoids the resulting problem of double-counting costs by constructing weighted full- and half-cycle supply curves that recognize shared costs. The *full-cycle* analysis includes all exploration, development and production costs, including overhead, but excludes land acquisition costs. The exclusion of land costs from the full-cycle analysis is consistent with the practice of estimating prospect profitability prior to making expenditures for land. In the present study, exploration costs also include the completion costs incurred to produce oil or gas from discoveries in shallower strata. As will be explained later, this change in the definition of the full-cycle case from that used in GSC Bulletin 452 was necessary to account for probable exploration cost savings when stacked resources exist. The *half-cycle* analysis excludes all pre-development and land costs.

Supply price refers to the plant-gate price of natural gas and co-products required to recover all costs including a minimum discounted cash flow rate-of-return on investment. Supply price is synonymous with marginal cost. Supply prices are measured for the full-cycle and half-cycle cases. When the target play is one of a set of stacked oil and gas plays in a region, the *weighted supply price*, calculated as a weighted average of the full-cycle and half-cycle supply prices, is considered to be a more realistic estimate of the supply price of undiscovered pools in the target play. Estimates of the full-cycle and half-cycle supply prices are undertaken with and without fiscal burden. The *burdened* analysis includes net taxes and royalties, and is relevant to private sector investment decisions. The *unburdened* analysis excludes fiscal burden, and is, therefore, relevant to public sector resource management.

Initial raw recoverable gas refers to the volume of raw gas that can be extracted from pools using current technology but without explicit consideration of costs and other economic constraints. Total initial raw recoverable gas is calculated as the sum for all plays of the mean resource estimate times the average play recovery factor. *Initial marketable gas* or sales gas is the volume of natural gas that meets specifications for end use, usually requiring processing to remove acid gases, impurities and liquid components. The *economic potential*, at a given price, is the sum of recoverable resources in undiscovered pools with estimated supply prices less than or equal to the given price. The price-economic potential relation is defined as the *supply curve* or marginal cost curve. Weighted, full-cycle and half-cycle supply curves, in both burdened and unburdened contexts, are included in this report.

Scope

Total undiscovered *initial raw gas* resources in the ten exploration plays defined for the Triassic System were estimated to be 273 x 10^9m^3 (9.7 TCF), of which 213 x 10^9m^3 (7.6 TCF) were estimated to be found in seven plays located primarily in British Columbia and the remaining 60 x 10^9m^3 (2.1 TCF) in three plays located in Alberta. An additional 34 x 10^9m^3 (1.2 TCF) were estimated to exist in immature and conceptual plays.

The economic analysis was limited to the ten plays for which detailed undiscovered pool size estimates and other geological information were available. For these plays, the total *initial raw recoverable gas* was estimated to be 213 x 10^9m^3 (7.6 TCF), 169 x 10^9m^3 (6.0 TCF) of which were estimated as being in British

Columbia, and 44 x $10^9 m^3$ (1.6 TCF) in Alberta. Because of a lack of relevant information, it was not possible to undertake economic analysis for the undiscovered resources in immature and conceptual plays. Results for the mature plays were, therefore, extended to the immature and conceptual plays to provide some measure, however speculative, of their economic potential.

METHODOLOGY

A complete description of the methodology is provided in GSC Bulletin 452. A summary is provided here, together with a detailed description of significant changes.

General description

The economic analysis was undertaken at the play level. This allowed the consistent treatment of geological, engineering and economic factors. Undiscovered pools in a play were treated as a set of investment opportunities. The estimated size of an undiscovered pool in a play, together with associated geological and reservoir parameters, were basic inputs. Exploration, development and production costs for the selected pool, together with the expected production profile, were estimated. These estimates were used as inputs to subsequent discounted cash flow analysis. An initial supply price of natural gas was then used to estimate gross revenue from natural gas and co-product sales. Royalties and taxes were calculated, and a discounted net cash flow rate-of-return estimated. The price was varied until the calculated rate-of-return was equal to the minimum required rate-of-return. The supply price was estimated for each pool in the undiscovered pool array, to a maximum price of \$300 per $10^3 m^3$ (\$8.50 per MCF) in 1990 dollars. Supply prices were then sorted and economic potential calculated. Figure 47 illustrates the methodology.

Supply curves were constructed for weighted, full-cycle and half-cycle economic potential, with and without a fiscal burden. Two measures of long-term economic potential were prepared: i) the *volume* of economic initial raw recoverable gas, and ii) the *percentage* of the total initial raw recoverable gas that is economic. The number of pools containing economically recoverable resources was also calculated, at selected prices.

Non-associated/solution gas and sour/sweet gas

For most plays, natural gas is found primarily either as non-associated gas or as solution gas. In the latter case, only a subset of the costs is relevant when calculating the supply price, since exploration and development costs are more appropriately assigned to the investment in oil production. Further, natural gas may be either sour or sweet, that is, it may or may not contain hydrogen sulphide (H_2S).

Several of the ten Triassic plays have some combination of non-associated/solution gas, and sour/sweet gas. For those plays in which significant quantities of natural gas are found as both non-associated and solution gas, or as sour and sweet gas, a supply price was estimated for each case. Using these supply prices, weighted average prices were calculated for both the full-cycle and half-cycle cases, using as weights the fractions of the discovered resources having the given attributes.

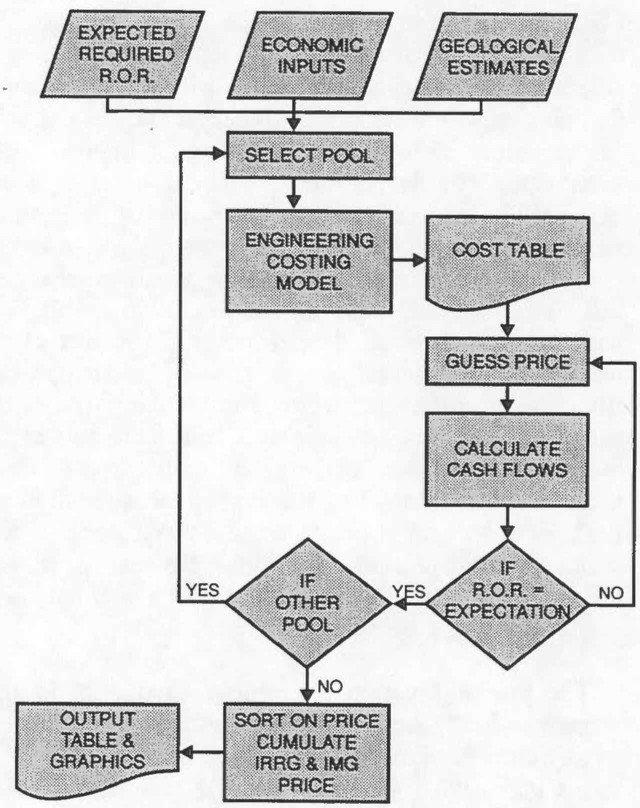

Figure 47. Flow chart illustrating the methodology used to estimate supply curves. (IRRG and IMG refer to initial raw recoverable gas and initial marketable gas, respectively.)

Analysis of stacked resources

When stacked resources are present, uphole resources may be found when drilling to target plays. Alternatively, discoveries in the target play may be found as uphole resources by wells drilled to a deeper play. For example, wells drilled to plays in the Triassic may encounter resources in the Cretaceous, and some discoveries in the Triassic may be made with wells drilled to targets in the Devonian System. When multiple targets are considered, total exploration costs can be less than the costs incurred should each play be explored separately.

It is necessary to recognize the likely savings of exploration costs in estimating economic potential when stacked resources exist. The approach adopted here requires the construction of a weighted full- and half-cycle supply curve, and a change in the definition of exploration costs. The rationale for this approach is briefly described below. Examples are provided in order to clarify the analysis.

Using a weighted supply price

Discoveries in a play may be made with wells drilled to that play or with wells drilled to deeper targets. Oil and gas resources discovered in the play of interest with wells drilled to deeper targets should be treated as half-cycle successes for the purposes of economic analysis of the play. Given that, in aggregate, there is uncertainty with regard to whether future discoveries will be found with wells drilled to the target play or with wells drilled to deeper plays, it is not clear whether undiscovered pools should be treated as full-cycle or half-cycle investments for the purposes of economic analysis. A weighted full- and half-cycle average supply price is, therefore, considered to be a more realistic estimate of the supply price required to find, develop and produce undiscovered pools when stacked resources exist. The full-cycle case is, nonetheless, relevant when decisions to drill a well having a single target are being considered.

The probability that an undiscovered pool in the target play will bear full exploration costs is calculated by dividing the number of existing discoveries in the target play *with wells drilled to the play* by the total number of pools in the play. This weight is applied to the full-cycle supply price for each pool. The weight applied to the half-cycle price is calculated by dividing the number of pools discovered in the target play *with wells drilled to deeper targets* by the total number of pools in the play.

For example, assume that a total of five discoveries were made in a Triassic play, of which two were found with wells drilled to that play and three with wells drilled to targets in deeper plays. Then the proportion of discoveries in the Triassic play made with wells drilled to that play is 2/5, or 40 per cent. This would be the weight applied to the full-cycle supply prices. The weight applied to the half-cycle supply prices is the residual, equal to 3/5 or 60 per cent.

The weighted supply curve is constructed using the weighted supply prices. It is the appropriate supply curve to use when evaluating the basin or regional economics.

It is clear that the position and slope of the weighted supply curve depend upon the relative values of the weights assigned to the full-cycle and half-cycle prices. The higher the proportion of discoveries in the target play with wells drilled to that play, the closer the weighted supply curve will be to the full-cycle supply curve, and vice-versa. To anticipate, for the Triassic plays, the weighted supply curve is closer to the full-cycle curve, indicating that Triassic plays are, in general, primary exploration targets.

Allocating exploratory drilling costs

The half-cycle prices used to calculate the weighted prices exclude exploration costs. The exploration costs for the half-cycle discoveries are assigned to deeper targets based on the following assumptions with regard to cost allocation:

- The target play for a well is considered to be the deepest play tested. Only wells drilled to the target play are considered when determining the drilling success ratio for that play.
- A well in the target play is assumed successful if uphole resources are discovered. For example, a well drilled to the Triassic is assumed to be successful even if it is dry in the Triassic but finds a pool or pools in the Cretaceous.
- All exploratory well costs, for both drilled and completed (D&C) and dry and abandoned (D&A) exploration wells, are assigned to the target play.

These assumptions imply a change in the definition of exploration costs to be assigned to the target play. In previous studies of the economic potential of Canada's undiscovered oil and gas resources, wells without discoveries in the target play were considered as D&A wells (Conn and Christie, 1988; Conn, et al., 1991; Dallaire et al., 1993). In the current study, however, wells that are unsuccessful in the target play but make discoveries in shallower strata were assumed to be completed, and the completion costs are assigned to the target play. Consequently, exploration costs for Triassic plays would include the costs of completing exploration wells in which uphole discoveries are made, in addition to completing wells with discoveries in the Triassic. In practice, incremental completion costs incurred to produce uphole resources would be wholly or more than offset by revenues generated by uphole resources. Otherwise, a decision to complete the well to produce uphole resources would, in general, not be made or would be deferred.

As an example, assume five wells were drilled to a Triassic play. In one, oil or gas resources were discovered in the Triassic, and in another, in the Cretaceous. In previous studies, only one well would have been counted as a success and subsequently completed. The remaining four would be regarded as D&A wells. In the present study, the well in the Cretaceous would be regarded as a success. Hence, the costs of two D&C wells and three D&A wells would be assigned to the Triassic play.

Technology, costs and production

The exploration, development and production requirements for natural gas pools and the associated costs depend upon variables such as the volume of gas-in-place, pool area, pool depth, drilling success ratios, gas composition, production rates, etc. The engineering and costing model developed to support the economic analysis captures the impact of these factors and also allows for economies of scale and discontinuities in development and production costs over the full range of estimated undiscovered pool sizes.

Table 17 lists the capital and operating costs used in the analysis. Wherever possible, the estimated relationships are play-specific and are based on industry experience and practices. Details regarding the selection of various technologies and the estimation of associated costs are provided in GSC Bulletin 452. The following is a brief description of some of the major items.

Well requirements. Reservoir area was estimated as a function of the original-gas-in-place. The number of production wells required was estimated by dividing the areal extent of the reservoir by the minimum well spacing. Current well densities were used to estimate minimum well spacing. The number of associated D&A wells was estimated using separate exploratory and development drilling success ratios. Capital costs for wells were estimated using separate correlations for drilling, completion and abandonment costs.

Geological and geophysical activity. Costs of geological and geophysical (G&G) activities were estimated as 40 per cent of exploratory drilling costs.

Gas processing. Gas processing costs were estimated as a function of production rate and gas composition.

Compression. Compression requirements were estimated as a function of production rate, compression ratio and number of compression stages.

Pipelines and roads. The required length and diameter of pipelines were estimated separately for flow lines, common gathering lines and a transmission line to local processing facilities. Road costs were estimated as a function of terrain and surface conditions.

Well site equipment. Well site equipment includes metering and hydrate control. Hydrate control is provided by alcohol injection, line heaters or well site dehydration.

Table 17

Summary of costs considered in engineering and costing model

	Capital cost	Operating cost
Geological and geophysical	X	N/A
Wells		
Exploration		
D&C	X	X
D&A	X	N/A
Development:		
D&C	X	X
D&A	X	N/A
Well site equipment	X	X
Pipelines		
Flow lines	X	X
Gathering lines	X	X
Transmission line	X	X
Roads		
Lease roads	X	X
Access road (optional)	X	X
Compression	X	X
Gas processing*	X	X
Corporate overhead	N/A	X

*Note: Capital cost used to estimate gas processing fee.

Overhead. Corporate overhead cost was assumed to be equal to 30 per cent of total field operating cost.

Solution gas recovery. In the economic analysis of solution gas resources, all exploration costs and many development costs were assumed to be already spent on the search for, development and production of crude oil pools. Local dehydration and compression at the oil battery and a raw gas transmission line to the local processing facility were considered to be the only cost components relevant to the economic analysis of recovering solution gas.

Production estimates. For non-associated gas pools, the raw gas production profile was defined by assigning the pool to one of five size classes, depending upon the volume of initial raw recoverable gas. A typical production profile consists of an initial period at a constant production rate, followed by a period of production on exponential decline. It was assumed that 50 per cent of the recoverable gas would be produced during the period of constant production. The time periods for constant and declining production were chosen to reflect accelerated production usually associated with smaller reservoirs. The size classes and parameters for each class are listed in Table 18. For solution gas produced from crude oil pools, gas production profiles were estimated by assuming a constant gas/oil ratio and a constant remaining-oil-reserves/production ratio of 10. In both cases, the raw gas production profiles were converted to sales gas and co-product production profiles.

Economic analysis

The economic analysis provides an estimate of the plant-gate price of natural gas and co-products that is required to recover all relevant costs, and provide a minimum required rate-of-return on investment. The required price, or supply price, was estimated using project discounted cash flow modelling and analysis.

Major economic assumptions used in this study pertain to the appropriate exploration success ratios, inflation rate, co-product prices, minimum required discounted net cash flow rate-of-return, and fiscal system.

Exploration success ratios. The number of exploratory wells required for each pool was estimated using economic success ratios instead of technical success ratios (Wilson, 1991a, b; Conn and Christie, 1988; Conn, et al., 1991; Dallaire et al., 1993).

The technical exploratory drilling success ratio for each play was determined as the ratio of the number of D&C wells to the number of exploratory tests. As noted above, wells without discoveries in the target play but in which uphole resources were discovered were assumed to be D&C wells in the target play.

Table 18

Characteristics of production profiles
by size class

Size class (10^6m^3)	≤30	>30 and ≤100	>100 and ≤400	>400 and ≤2000	>2000
Constant prod. Rate-of-take (days)	1460	2190	2920	3650	4380
No. years at initial rate	2	3	4	5	6
No. years on decline	5	7	9	11	13
Total prod. life (years)	7	10	13	16	19
Decline rate (approx. %)	38	27	21	17	15

The economic success ratio was defined as the ratio of economic discoveries to the number of exploratory tests. Economic discoveries were defined as gas pools that earn at least an after-tax-and-royalty real rate-of-return of 10 per cent at a plant-gate price of \$88.25 per 10^3m^3, on a half-cycle basis. The number of wells required to find an economic pool will be greater than or equal to the number required to simply find a pool.

As an example, suppose that the technical success ratio in a Triassic play is 1:5. This ratio implies one D&C well for every four D&A wells. In order to introduce stacked resources into the analysis, assume that in two of the four wells nothing was found in the Triassic but pools were discovered in the Cretaceous. Then, three wells would be considered as D&C wells and only two would be considered as D&A wells. Now assume that the economic success ratio, in contrast to the technical success ratio, is 1:10. The additional five wells required to find an economic pool should be regarded as D&A wells; that is, of the ten wells, three will be regarded as D&C wells and seven would be regarded as D&A wells. The rationale behind this treatment is that the additional five wells are required to find one economic pool in the play and would not, by definition, be economic half-cycle completions.

Inflation rate. Application of the fiscal system required conversion of all real costs into current values using an assumed rate of inflation. The rate of inflation was assumed to be 4 per cent per year. Inflation was subsequently removed from the estimates in order to calculate supply prices in constant 1990 dollars.

Co-product prices. Co-product prices were estimated as a function of the price of natural gas or crude oil using historical correlations.

Minimum required rate-of-return. An expected minimum after-tax-and-royalty real rate-of-return of 10 per cent was assumed. The same rate was used for the burdened and unburdened cases to facilitate comparison.

Fiscal system. The current Canadian federal and provincial (British Columbia and Alberta) fiscal systems as of June 1993 were used in the determination of fiscal burden. All companies were assumed to be fully taxable, and to claim all deductions in the year they become available. Companies were assumed to be able to take advantage of Alberta Royalty Tax Credit.

ESTIMATES OF ECONOMIC POTENTIAL

Reference case assumptions

Economic potential was estimated for a reference case using the mean resource estimate for each undiscovered pool. The reference case used play-specific geological and engineering parameters, non-associated/solution gas and sour/sweet gas weighting factors, economic exploration success ratios, and full-cycle/half-cycle weighting factors. Costs and supply prices were estimated in 1990 dollars in order to facilitate comparison with GSC Bulletin 452. The reference case data and selected cost estimates are provided in the Appendix.

The ten Triassic plays were assigned to four cost regions to reflect differences in exploration, development and production costs in different regions of British Columbia and Alberta, and the impact of different provincial fiscal systems. The play assignments were:

Eastern British Columbia: the Halfway/Doig Shore-Peejay-Milligan, Halfway/Doig Shelf-Tommy Lakes, Baldonnel Subcrop-Laprise, and Charlie Lake Clastics-Inga plays.

Northeastern British Columbia: the Halfway/Doig Shelf-Monias, Baldonnel-Fort St. John, and Charlie Lake Clastics-Cecil Lake plays.

Peace River (Alberta): the Halfway/Doig Shore-Sinclair, and Charlie Lake Carbonates-Boundary Lake plays.

West-central Alberta: the Montney Subcrop-South Fir play.

The reference case was based on data available at the time of the analysis. It did not consider improvements in economic success ratios or upward revisions to the resource estimates due to increased knowledge of exploration plays, reductions in development costs due to expansions of pipeline networks, or possible decreases in costs due to technological changes and improvements in company practices. Consequently, economic potential for the reference case should be considered closer to the current economics of exploration. It is likely an underestimate of the long-term exploration fundamentals.

Reference case

Figures 48 and 49 show *volumes* of economic initial raw recoverable gas for the burdened and unburdened cases, respectively, while Figures 50 and 51 show the corresponding *percentages* of the total initial raw recoverable gas that are economic for the two cases. In each figure, supply curves are given for the weighted, full-cycle, and half-cycle cases. Estimates of economic potential for Triassic resources at plant-gate prices of \$44.13 and \$88.25 per 10^3m^3 are given in Table 19. Also shown in Table 19 are estimates of the economically recoverable initial marketable gas, reflecting the sales gas associated with the recoverable resources.

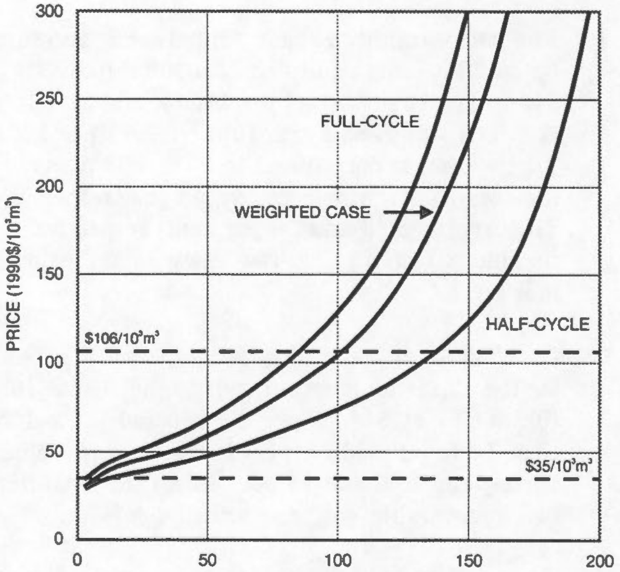

***Figure 48.** Supply curves showing the reference case estimates of burdened economic potential, measured as a volume of economic initial raw recoverable gas, for all mature Triassic plays.*

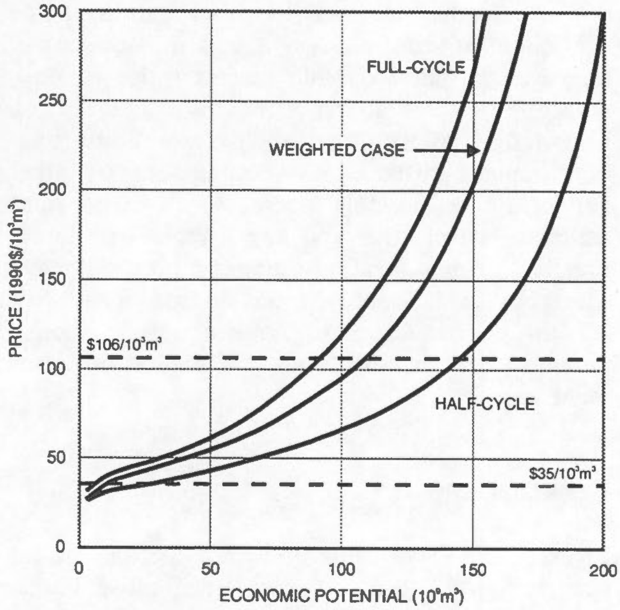

Figure 49. Supply curves showing the reference case estimates of unburdened economic potential, measured as a volume of economic initial raw recoverable gas, for all mature Triassic plays.

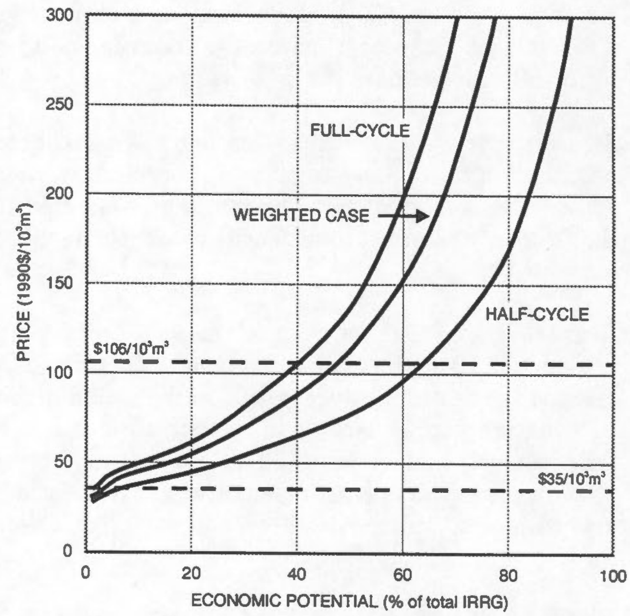

Figure 50. Supply curves showing the reference case estimates of burdened economic potential, measured as a percentage of total initial raw recoverable gas (IRRG), for all mature Triassic plays.

Similar supply curves and tables for British Columbia and Alberta are provided in the Appendix.

An analysis of Figures 48 to 51 and Table 19 leads to the following major conclusions with regard to economic potential of the ten mature plays:

1. For the weighted case, burdened economic potential is estimated to be 22 x 10^9m^3 (0.8 TCF) at $44.13 per 10^3m^3 ($1.25 per MCF), and 82 x 10^9m^3 (2.9 TCF) at $88.25 per 10^3m^3 ($2.50 per MCF). These volumes correspond to 10 and 38 per cent of the total initial raw recoverable gas, respectively. They represent 8 and 30 per cent, respectively, of the undiscovered initial raw gas volumes estimated in Part I.

2. On a full-cycle basis, burdened economic potential in the Triassic is estimated to be 13 x 10^9m^3 (0.5 TCF) at $44.13 per 10^3m^3, and 70 x 10^9m^3 (2.5 TCF) at $88.25 per 10^3m^3. These volumes correspond to 6 and 33 per cent of the total initial raw recoverable gas, respectively.

3. On a half-cycle basis, burdened economic potential in the Triassic increases to 42 x 10^9m^3 (1.5 TCF) at $44.13 per 10^3m^3, and to 122 x 10^9m^3 (4.3 TCF) at $88.25 per 10^3m^3. These volumes correspond to 20 and 57 per cent of the total initial raw recoverable gas, respectively.

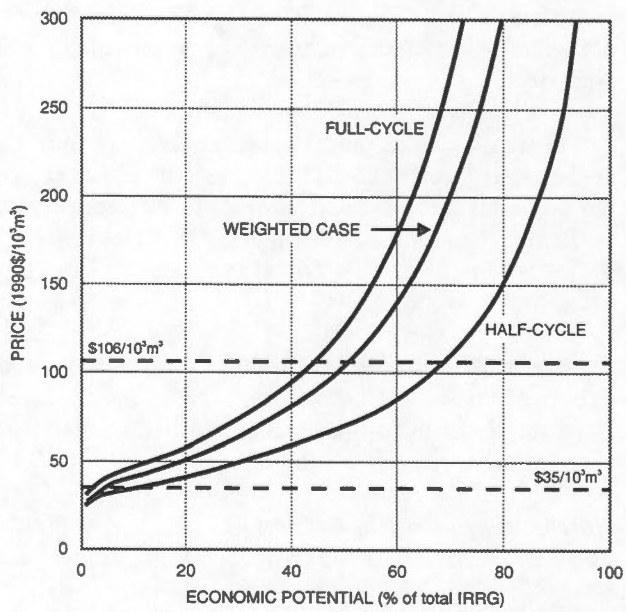

Figure 51. Supply curves showing the reference case estimates of unburdened economic potential, measured as a percentage of total initial raw recoverable gas (IRRG), for all mature Triassic plays.

Table 19

Reference case estimates of economic potential, initial marketable gas, and number of economic pools for undiscovered natural gas resources in all mature Triassic plays

Type of analysis	Economic potential				Initial marketable gas			
	Volume (10^6m^3)		% of total initial raw recoverable gas		Volume (10^6m^3)		% of total initial raw recoverable gas	
	$44.13/$10^3m^3$	$88.25/$10^3m^3$	$44.13/$10^3m^3$	$88.25/$10^3m^3$	$44.13/$10^3m^3$	$88.25/$10^3m^3$	$44.13/$10^3m^3$	$88.25/$10^3m^3$
Burdened estimates:								
Full-cycle	13 350	70 044	6	33	11 995	62 557	6	29
Half-cycle	41 883	121 707	20	57	37 466	108 564	18	51
Weighted full- and half-cycle	22 017	81 970	10	38	19 768	73 285	9	34
Unburdened estimates:								
Full-cycle	18 675	76 679	9	36	16 759	68 490	8	32
Half-cycle	51 256	129 463	24	61	45 804	115 461	21	54
Weighted full- and half-cycle	30 375	91 460	14	43	27 222	81 725	13	38

Total initial raw recoverable gas: 213238 10^6m^3

4. The weighted supply curves are closer to the full-cycle curves than to the half-cycle curves. This reflects the drilling history; the majority of Triassic discoveries have been found with wells drilled to targets in the Triassic.

5. Economic potential as a percentage of the total initial raw recoverable gas is significantly higher in British Columbia than it is in Alberta (see Appendix). This occurs because most of the economic resource in British Columbia is found in three plays with average depths between 1200 and 1600 m, while in Alberta most of the economic resource is found in a single play with an average depth of about 2000 m. Economic success ratios for the Alberta play are also somewhat poorer. Drilling costs in Alberta are, therefore, significantly higher. Since exploratory drilling costs are excluded from the half-cycle analysis, the difference is smaller in the half-cycle case.

6. There is a relatively small difference between burdened and unburdened economic potential. For example, in the weighted case, economic potential as a percentage of the total initial raw recoverable gas increases from 10 per cent in the burdened case to 14 per cent in the unburdened case at $44.13 per 10^3m^3. At $88.25 per 10^3m^3, economic potential increases from 38 per cent of the total initial raw recoverable gas in the burdened case to 43 per cent in the unburdened case. This suggests that the combined federal and provincial fiscal systems do not significantly change estimates of economic potential.

7. The various supply curves are generally elastic in the price range of $35 to $88.25 per 10^3m^3 ($1.00 to $2.50 per MCF). As shown in the figures found in the Appendix, supply curves for British Columbia are significantly more elastic relative to those for Alberta.

Extension of results to immature and conceptual plays

Approximately one ninth of the total undiscovered resources estimated for the Triassic, or 34 x 10^9m^3 (1.2 TCF), are expected to be found in immature and conceptual plays. Since geological characteristics and undiscovered pool size estimates were not available for these plays, the economic potential of these resources was obtained by simply extending the results of the mature plays to the resources estimated for the immature and conceptual plays. This was done by applying the percentage of the total initial raw recoverable gas that is economic at a given price to the resource estimate for immature and conceptual plays. An average recovery factor of 78 per cent was assumed for this resource.

Figure 52 shows the weighted economic potential for the entire Triassic System, including immature and conceptual plays. The inclusion of immature and conceptual plays in the estimates of economic potential increases the burdened weighted estimates from 22 x 10^9m^3 (0.8 TCF) to 25 x 10^9m^3 (0.9 TCF) at $44.13 per 10^3m^3, and from 82 x 10^9m^3 (2.9 TCF) to 92 x 10^9m^3 (3.3 TCF) at $88.25 per 10^3m^3.

Initial marketable gas estimates

Economic potential is calculated in terms of initial raw recoverable gas. Figure 53 shows supply curves for the volumes of economic initial raw recoverable gas and the corresponding volumes of initial marketable gas. The latter curve estimates the volume of natural gas

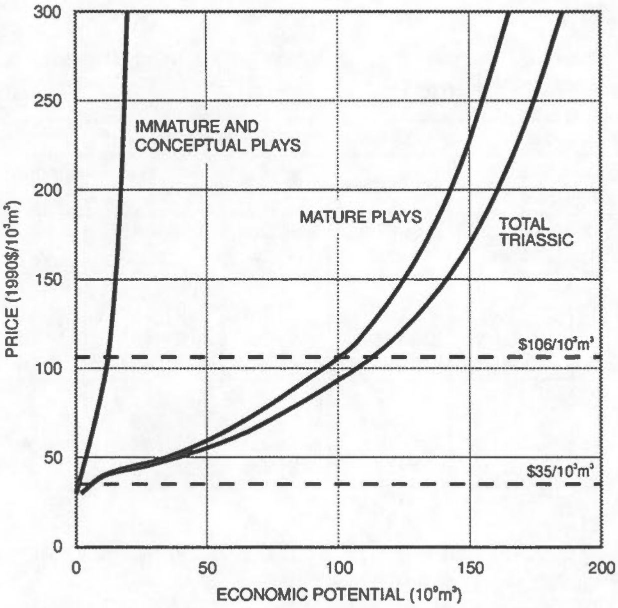

Figure 52. Supply curves showing the reference case weighted estimates of burdened economic potential, measured as a volume of economic initial raw recoverable gas, for undiscovered natural gas resources in mature, immature and conceptual plays in the Triassic.

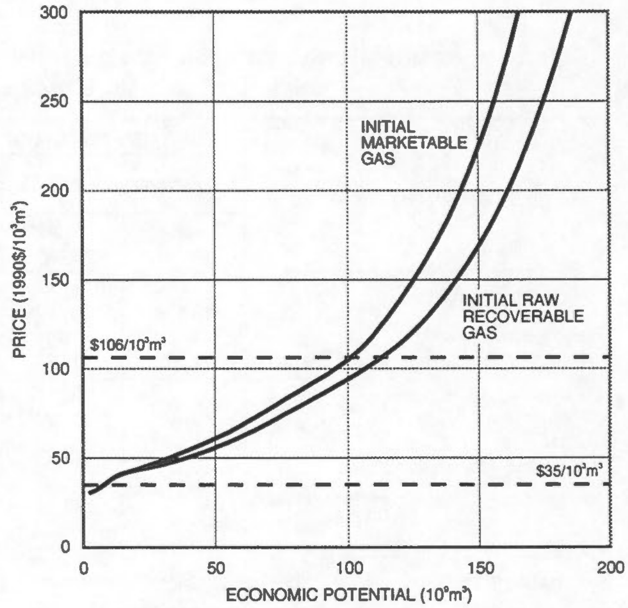

Figure 53. Supply curves showing the volumes of economic initial raw recoverable gas and initial marketable gas for the reference case weighted estimates of burdened economic potential. Recoverable gas includes co-products, while marketable gas measures the volume of sales gas. The curves represent aggregates for mature, immature and conceptual plays.

that would be available for sale to end-users at various prices, after the removal of acid gases (such as CO_2 and H_2S), impurities and liquid components (water and heavier hydrocarbons), and the use of a small portion of the processed gas as fuel in gas processing plants.

Table 19 shows that approximately 20 x 10^9m^3 (0.7 TCF) would be available for sale at a price of $44.13 per 10^3m^3, and 73 x 10^9m^3 (2.6 TCF) at a price of $88.25 per 10^3m^3.

Number of economic pools

The number of economic pools and their size distribution are important indicators of profitability for exploration companies. Figure 54 shows the number of economic pools equal to or greater than a given size at selected prices, for the burdened weighted case. The number of economic pools by size class at $44.13 and $88.25 per 10^3m^3 are provided in Table 20.

For each of the curves in Figure 54, the smallest pool size shown represents the marginally economic pool at the specified price. As expected, the marginal pool size varies inversely with price. The curves for various prices do not merge with one another to form a continuous curve because at various prices the marginally economic pool is found in different plays having different geological and cost characteristics. The "no price constraint" curve represents the distribution of pool sizes estimated in Part I.

A review of Figure 54 and Table 20 shows the following:

1. At a plant-gate price of $44.13 per 10^3m^3, 13 pools are economic. At a price of $88.25 per 10^3m^3, 114 pools are economic. The number of economic pools is, therefore, highly responsive to price, particularly in the price range of $44.13 to $88.25 per 10^3m^3.

2. Of the 13 pools that are economic at $44.13 per 10^3m^3, four pools with a size greater than or equal to 2000 x 10^6m^3 (71 BCF) are economic at prices as low as $35 per 10^3m^3 ($1.00 per MCF).

3. For pools in the size class ranging from 500 to 2000 x 10^6m^3 (18 to 71 BCF), the number of economic pools increases significantly from 7 to 78 as prices increase from $44.13 to $88.25 per 10^3m^3.

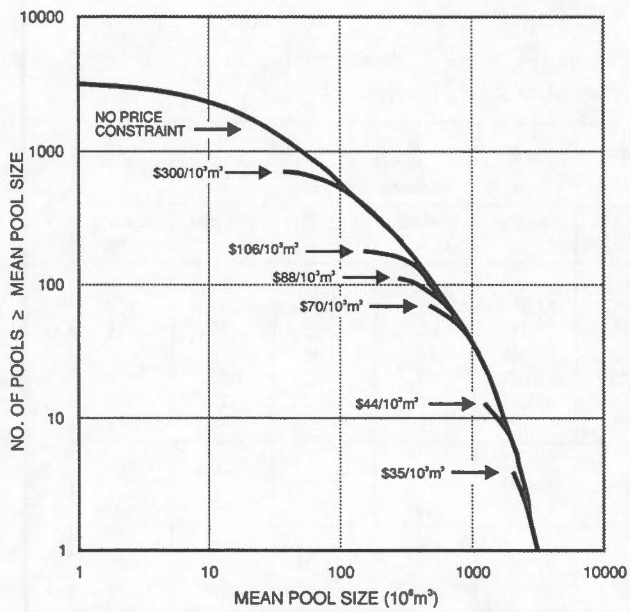

***Figure 54.** Curves showing the number of undiscovered economic pools in all mature Triassic plays, in the weighted burdened reference case, with mean sizes equal to or greater than a given size. The curves are drawn for selected prices ranging from $\$35/10^3m^3$ to $\$300/10^3m^3$. The curve without a price constraint represents the undiscovered pool size distribution. The smallest pool size shown at a given price is the marginally economic pool at that price.*

Table 20

Number of economic pools by size class
(Pool size in terms of undiscovered initial gas in place)

Price	Size class 10^6m^3			
	>2000	1000–2000	500–1000	<500
$\$44.13/10^3m^3$	6	7	0	0
$\$88.25/10^3m^3$	6	29	49	30

SENSITIVITY ANALYSIS

Significant variability and uncertainty surround estimates of costs, exploration drilling success ratios and the distance of discoveries to gathering systems. Although this analysis did not explicitly consider time, it is reasonable to expect that costs will be reduced over time, success ratios in general will increase, and gathering systems will expand. In addition, technological advancements in drilling and seismic coupled with a continuous increase of information with regard to the geology of plays have resulted, over the years, in regular upward revisions to estimates of in-place potential (Armstrong and Calantone, 1990). It is likely that current estimates of potential could again be increased in the future.

The impact of changes in these factors on economic potential was examined through sensitivity analyses. The specific sensitivities examined were: i) total costs 20 per cent above and 30 per cent below the reference case; ii) economic success ratios double those of the reference case, with a constraint that the ratio not succeed 1:2; iii) distance of pools to gathering system reduced to an average of 2.5 km for all plays; and iv) undiscovered pool size estimates at the 10 per cent probability level.

In general, sensitivity analysis was undertaken on the weighted estimates of economic potential in the reference case, with two exceptions. The first exception was with regard to the doubling of economic success. Since the weighted estimates include the half-cycle case, which excludes exploration costs, the impact of doubling the success ratio is significantly diminished. To demonstrate the maximum impact of doubling economic success, the full-cycle case is also provided. The second exception was the impact of reducing the pipeline distance to 2.5 km for the half-cycle case. This case provides a measure of the undiscovered resource that may ultimately be booked as reserves.

Table 21 compares the estimates of economic potential, in terms of volume and of the percentage of total initial raw recoverable gas, between the weighted reference case and the corresponding sensitivity case. Results are given at $44.13 and $88.25 per 10^3m^3. Similar tables for British Columbia and Alberta are provided in the Appendix.

As shown in these tables, the percentage impact is, in general, larger at the lower price and smaller at the higher price. This occurs because at higher prices, although a larger number of pools become economic, they are small in size, and have a relatively small impact on economic potential estimates.

Sensitivity to costs

Figure 55 shows the impact of cost changes on the volume of economic initial raw recoverable gas for all Triassic plays.

Given the relatively high costs of developing a majority of Triassic plays, a given percentage increase or reduction in costs dramatically affects the economics of Triassic resources. A 20 per cent rise in costs, relative to the reference case, leads to a 52 per

Table 21

Sensitivity analyses measuring impact of changes in key impact variables on estimates of economic potential for all mature Triassic plays

Type of sensitivity analysis	Economic potential (10^6m^3)		% of total initial raw recoverable gas		% Change	
	$44.13/$10^3m^3$	$88.25/$10^3m^3$	$44.13/$10^3m^3$	$88.25/$10^3m^3$	$44.13/$10^3m^3$	$88.25/$10^3m^3$
Sensitivity analyses on weighted average estimates:						
Reference case - weighted average	22 017	81 970	10	38		
20% increase in total costs	10 612	72 842	5	34	-52	-11
30% decrease in total costs	38 771	98 045	18	46	+76	+20
Drilling success ratio doubled (max. 1:2)	28 753	97 697	13	46	+31	+19
Distance to pipeline set to 2.5 km	27 186	88 831	13	42	+23	+8
Pool size at 10% probability level	32 714	95 469	15	45	+49	+16
Sensitivity analysis on full-cycle estimates:						
Reference case - full-cycle	13 350	70 044				
Drilling success ratio doubled (max 1:2)	21 212	84 157	10	39	+59	+20
Sensitivity analysis on half-cycle estimates:						
Reference case - half-cycle	42 955	121 706				
Distance to pipline set at 2.5 km	49 333	130 737	23	61	+15	+7

Total initial raw recoverable gas: 213 238 10^6m^3

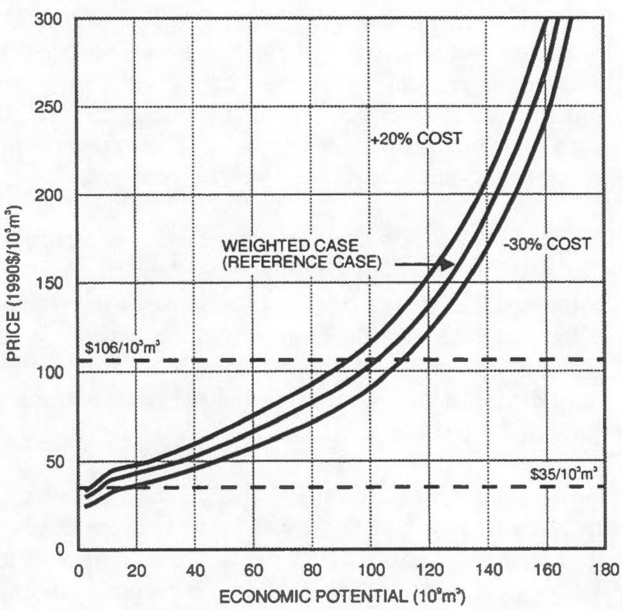

Figure 55. Supply curves showing the impact of changes in total costs on weighted estimates of burdened economic potential, for all mature Triassic plays.

cent decline in the weighted estimate of economic potential at a price of $44.13 per 10^3m^3, and an 11 per cent decline at a price of $88.25 per 10^3m^3. For a 30 per cent reduction in costs, economic potential increases by 76 and 20 per cent at the two prices, respectively.

Sensitivity to exploration drilling success ratio

Technological advances in seismic surveying, drilling, data processing, etc., together with an increased knowledge of the resource base should enable companies to find a larger proportion of economic pools for a given number of exploration wells. In order to capture the likely impact of future increases in exploration success, economic success ratios for all plays were doubled, with the constraint that the ratio not exceed 1:2. Figures 56 and 57 show the impact of doubling economic success on economic potential in the weighted and full-cycle cases, respectively.

Doubling economic success for all plays increases weighted economic potential in the burdened case by 31 per cent at $44.13 per 10^3m^3 and 19 per cent at $88.25 per 10^3m^3. As expected, the greater impact occurs in the full-cycle case, where doubling the economic success ratio increases economic potential by 59 and 20 per cent, respectively.

Sensitivity to distance to gathering systems

Estimates of average distances of future discoveries from a gathering system were based on the location of the current pipeline network. As the pipeline network expands over time, it is likely that more plays or pools, which were initially determined to be uneconomic to develop and produce due to their distance from gathering systems, would then become economic. The impact of expansion of gathering and transmission systems on economic potential was examined by assuming that the average distance of all pools from the pipeline network is reduced to 2.5 km. Figure 58 shows the impact of this change on the weighted and half-cycle estimates of economic potential.

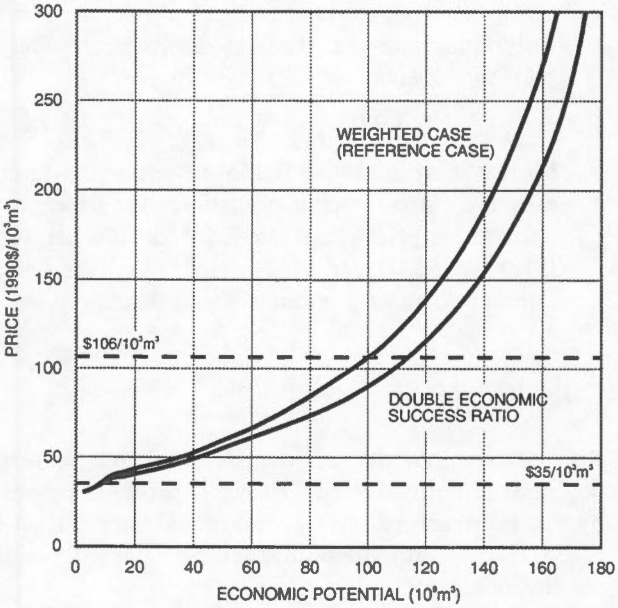

Figure 56. Supply curves showing the impact of doubling the economic success ratio on weighted estimates of burdened economic potential, for all mature Triassic plays.

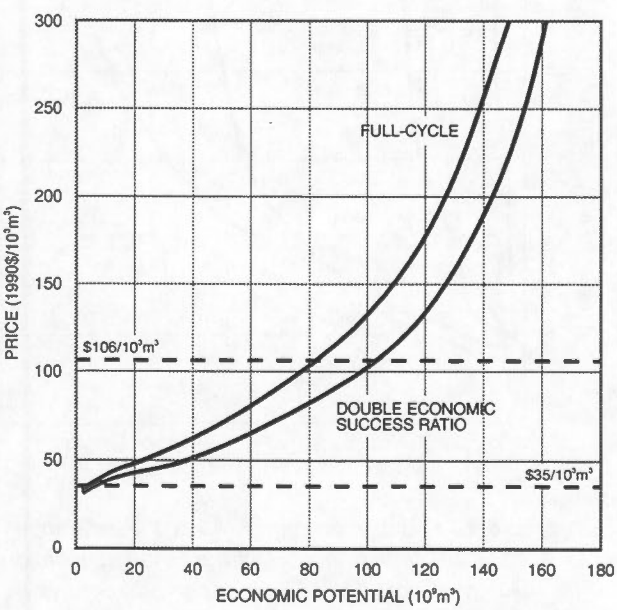

Figure 57. Supply curves showing the impact of doubling the economic success ratio on the full-cycle estimates of burdened economic potential, for all mature Triassic plays.

When the average distance from future discoveries to the gathering network is reduced to 2.5 km, weighted economic potential increases by 23 per cent at \$44.13 per 10^3m^3 and 8 per cent at \$88.25 per 10^3m^3. Similar impacts are seen in the half-cycle case.

At \$88.25 per 10^3m^3, economic potential in the Triassic for the half-cycle case is estimated to be 61 per cent of the total initial raw recoverable gas. This provides a measure of the portion of the undiscovered resource that may ultimately be booked as reserves.

Sensitivity to estimated size of undiscovered pools

Experience has shown that estimates of the resource endowment tend to increase with time, as increased exploration and development leads to a greater knowledge of the petroleum geology and the resource base. The current estimates may also increase. To measure the impact of possible upward revisions in the resource estimate, economic potential was estimated using mean pool sizes at the 10 per cent probability level. Using these estimates represents an increase in the aggregate resource estimate of approximately 7 per cent. Figure 59 shows the impact of this change.

Increases in the size of undiscovered pools have a large impact on economic potential. Increasing resource estimates by using pool sizes at the 10 per cent

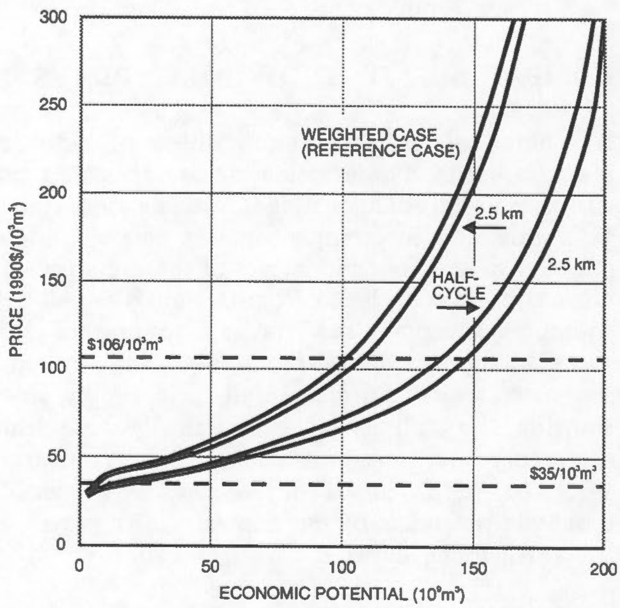

Figure 58. Supply curves showing the impact of reducing the average distance of pipelines from future discoveries to a gathering system to 2.5 km, for weighted and half-cycle estimates of burdened economic potential, for all mature Triassic plays.

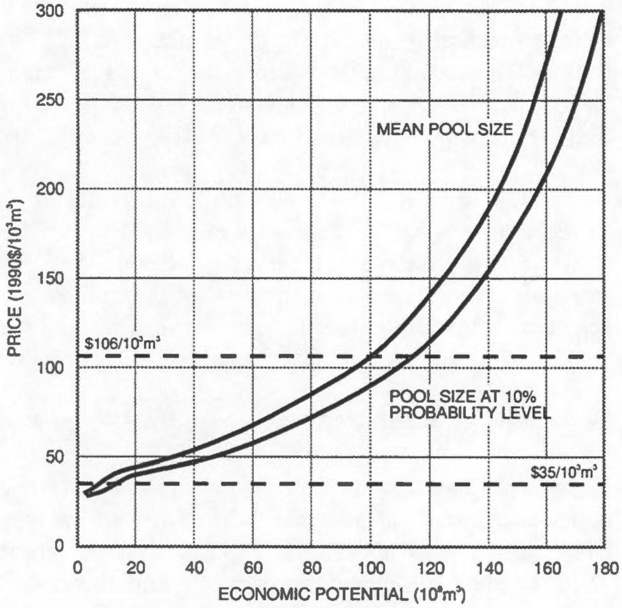

***Figure 59.** Supply curves showing the impact of an increase in the sizes of all undiscovered pools on the weighted estimates of burdened economic potential, for all mature Triassic plays.*

probability level increases economic potential by 49 per cent at \$44.13 per 10^3m^3 and 16 per cent at \$88.25 per 10^3m^3. Thus, upward revisions in the resource estimates result in a more than proportional increase in economic potential.

COMPARISON OF INDIVIDUAL PLAYS

A ranking of the economic viability of individual plays, rather than an examination of aggregate supply curves, is useful for allocating investment among plays. To ensure that the comparison was between Triassic plays only, the economic impact of resources found in other strata was excluded from this analysis. All wells without discoveries in the Triassic were regarded as dry and abandoned, even if resources were discovered in shallower strata. Burdened full-cycle supply curves showing the volume of economically recoverable resources in the more profitable plays are presented in Figure 60. Supply curves for five plays are shown. The economic potentials of the remaining five plays were too small to be illustrated on this figure.

Major observations with regard to the supply curves for these plays are:

1. The ranking of the supply curves correlates positively to the ranking of plays according to total initial raw recoverable gas, shown in Table 22.
2. The supply curves are dominated by three plays in British Columbia and one play in Alberta. An examination of the economic potential estimates at the play level shows that, at prices up to \$88.25 per 10^3m^3, virtually all of the economic potential is expected to be found in the Halfway/Doig Shelf–Monias, Baldonnel Subcrop–Laprise, and Halfway/Doig Shelf–Tommy Lakes plays in British Columbia; and the Halfway/Doig Shore–Sinclair play in Alberta.
3. Only the supply curves for Halfway/Doig Shelf–Monias play and the Baldonnel Subcrop–Laprise play are elastic over a realistic range of expected natural gas prices between \$35 and \$106 per 10^3m^3 (\$1.00 to \$3.00 per MCF). Supply curves for the remaining plays are relatively inelastic.

CONCLUSIONS

This study provides an estimate of the economic potential of undiscovered Triassic natural gas resources by placing technical and economic constraints on the resource assessment contained in Part I. Major conclusions are:

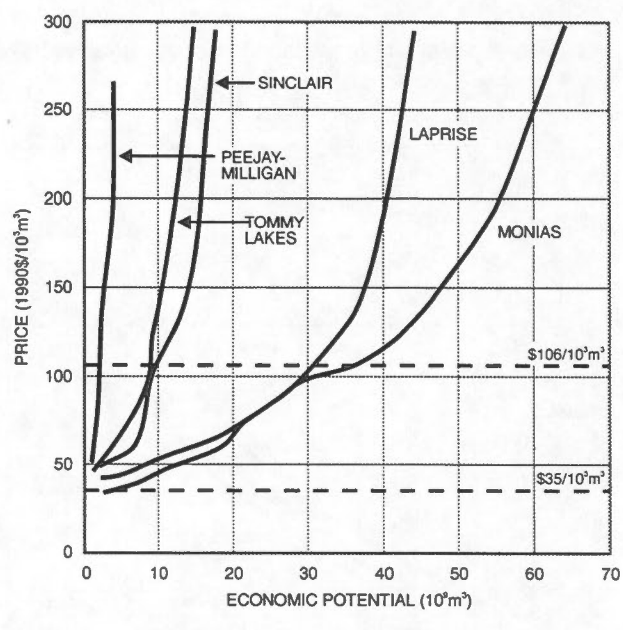

***Figure 60.** Supply curves showing the reference case full-cycle estimates of burdened economic potential for the five Triassic plays having economic potential at prices equal to or less than $106/10^3m^3$. The full-cycle analysis, in this case, excludes any completion costs incurred to produce from wells in which only uphole resources were found.*

Table 22

Triassic plays ranked by initital raw recoverable gas

Play	Initial raw recoverable gas (10^6m^3)		Economic potential (10^6m^3)	
	Total	Largest undiscovered pool	\$44.13/ 10^3m^3	\$88.25/ 10^3m^3
Halfway/Doig Shelf (Peace River Structure) - Monias	73 815	2 175	5 681	26 055
Baldonnel Subcrop - Laprise	51 796	2 435	9 311	26 085
Halfway/Doig Shore Zone (Peace River Structure) - Sinclair	20 862	1 433	0	8 802
Halfway/Doig Shelf - Tommy Lakes	19 408	1 187	1 187	7 857
Montney Subcrop - South Fir	16 446	900	0	0
Halfway/Doig Shore Zone - Peejay Milligan	7 456	1 128	0	1 759
Charlie Lake Clastics - Inga	6 761	158	0	0
Charlie Lake Carbonates (Peace River Structure) - Boundary Lake	6 458	130	0	0
Baldonnel (Peace River Structure) - Ft. St. John	6 252	253	0	0
Charlie Lake Clastics (Peace River Structure) - Cecil	3 985	438	0	0
Total economic potential	213 238		13 350	70 559

Note: Economic potential for the burdened, full-cycle reference case. For purposes of this analysis, all wells in which resources in the Triassic are not found are treated as D&A wells.

1. For the weighted case, burdened economic potential is estimated as 22 x 10^9m^3 (0.8 TCF) at \$44.13 per 10^3m^3 (\$1.25 per MCF), and 82 x 10^9m^3 (2.9 TCF) at \$88.25 per 10^3m^3 (\$2.50 per MCF). These volumes correspond to 10 and 38 per cent of the total initial raw recoverable gas, respectively. They represent 8 and 30 per cent, respectively, of the undiscovered initial raw gas volumes estimated in Part I.

2. On a full-cycle basis, burdened economic potential in the Triassic is estimated as 13 x 10^9m^3 (0.5 TCF) at \$44.13 per 10^3m^3, and 70 x 10^9m^3 (2.5 TCF) at \$88.25 per 10^3m^3. These volumes correspond to 6 and 33 per cent of the total initial raw recoverable gas, respectively.

3. On a half-cycle basis, burdened economic potential in the Triassic increases to 42 x 10^9m^3 (1.5 TCF) at \$44.13 per 10^3m^3, and to 122 x 10^9m^3 (4.3 TCF) at \$88.25 per 10^3m^3. These volumes correspond to 20 and 57 per cent of the total initial raw recoverable gas, respectively.

4. The inclusion of immature and conceptual plays in the estimates of economic potential increases the burdened weighted estimates from 22 x 10^9m^3 (0.8 TCF) to 25 x 10^9m^3 (0.9 TCF) at \$44.13 per 10^3m^3, and from 82 x 10^9m^3 (2.9 TCF) to 92 x 10^9m^3 (3.3 TCF) at \$88.25 per 10^3m^3.

5. There is a relatively small difference between the burdened and unburdened estimates of economic potential.

6. Estimates of the number of economic pools show that significant investment opportunities remain in the Triassic plays in the Western Canada Sedimentary Basin. The number of economic pools is highly responsive to price, particularly in the price range of \$44.13 to \$88.25 per 10^3m^3.

7. Sensitivity analysis has shown that economic potential is sensitive to the following factors: i) total costs; ii) increases in undiscovered pool size estimates; iii) economic success ratios; and iv) average distance of future discoveries to the gas gathering system. In general, the impact of these factors is much greater at lower prices than at higher prices.

8. The various supply curves are generally elastic in the price range of \$35 to \$88.25 per 10^3m^3 (\$1.00 to \$2.50 per MCF).

9. The supply curves are dominated by three plays in British Columbia and one play in Alberta: the Halfway/Doig Shelf-Monias, Baldonnel Subcrop-Laprise, Halfway/Doig Shelf-Tommy Lakes, and Halfway/Doig Shore-Sinclair plays.

ACKNOWLEDGMENTS

This study was undertaken by the Petroleum Resource Analysis Section of the Energy Sector of Natural Resources Canada on behalf of the Petroleum Resources Appraisal Panel. Louise Roux and Myriam Boudreault conducted the analytical work and assisted in the interpretation of results. Computer support and advice on the fiscal system were provided by colleagues in the Economic and Financial Analysis Branch.

The Energy Sector expresses its appreciation to the Small Explorers and Producers Association of Canada and the Canadian Association of Petroleum Producers, R. McLennan of R.E. McLennan and Associates Ltd., and P. Ray, B. Dickerson and G. Lore of the Minerals Management Service of the U.S. Department of the Interior, for their comments and advice on the methodology developed to estimate exploration economics of stacked plays. Special thanks are extended to R. Blakeney, who gathered the drilling statistics required to support this approach for the Triassic plays. B. Young and K. Drummond of the National Energy Board and T. Bird of the Institute of Sedimentary and Petroleum Geology provided advice to Mr. Blakeney in the conduct of his work.

REFERENCES

Armstrong, D.E. and Calantone, C.
1990: Submission to the National Energy Board in support of the ANG EXPANSION PROJECT and in Response to Information Request in letter dated 1 November.

Carlson, J.D., Cleland, N.A., and Stewart, N.T.
1991: A forecast of western Canadian gas supply and demand. Sproule Associates Ltd., Calgary.

Conn, R.F. and Christie, J.A.
1988: Conventional oil resources of western Canada (light and medium) (Part II: Economic Analysis). Geological Survey of Canada, Paper 87-26.

Conn, R.F., Dallaire, S.M., Christie, J.A., Taylor, G.C., and Procter, R.M.
1991: Natural gas resource assessment and economic potential of undiscovered natural gas resources of the Mackenzie Delta-Beaufort Sea. Geological Survey of Canada, Open File 2378.

Dallaire, S.M., Waghmare, R.R., and Conn, R.F.
1993: Devonian gas resources of the western Canada Sedimentary Basin (Part II: Economic Analysis). Geological Survey of Canada, Bulletin 452.

Independent Petroleum Association of Canada
1990: A discussion paper on oil and gas exploration economics in Alberta.

1991: Natural gas exploration economics and royalties.

Lee, P.J. and Price, P.R.
1991: Successes in 1980's bode well for western Canada search. Oil and Gas Journal, v. 89, no. 16, p. 94-97.

Robertson, J.K.
1990: A comparison of British Columbia and Alberta natural gas exploration economics using the Mississippian Debolt Formation as an example. Unpublished M.Sc. thesis, University of Calgary.

Wilson, D.L.
1991a: Knowing field size distributions crucial in estimating profitability. Oil and Gas Journal, v. 89, no. 15, p. 92-93.

1991b: Practically estimating field size, chance of success vital in U.S. Oil and Gas Journal, v. 89, no. 10, p. 99-100.

APPENDIX

Economic potential estimates and results of sensitivity analyses for British Columbia

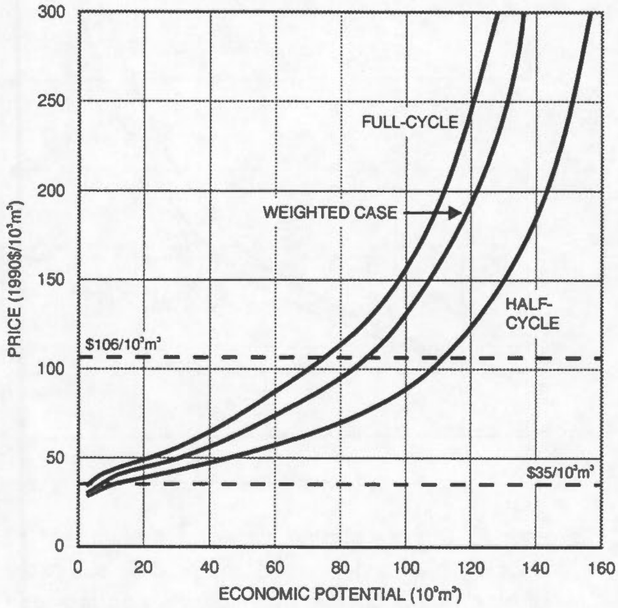

***Figure A.** Supply curves showing burdened economic potential, measured as a volume of economic initial raw recoverable gas (IRRG), for undiscovered Triassic natural gas resources in plays located primarily in British Columbia.*

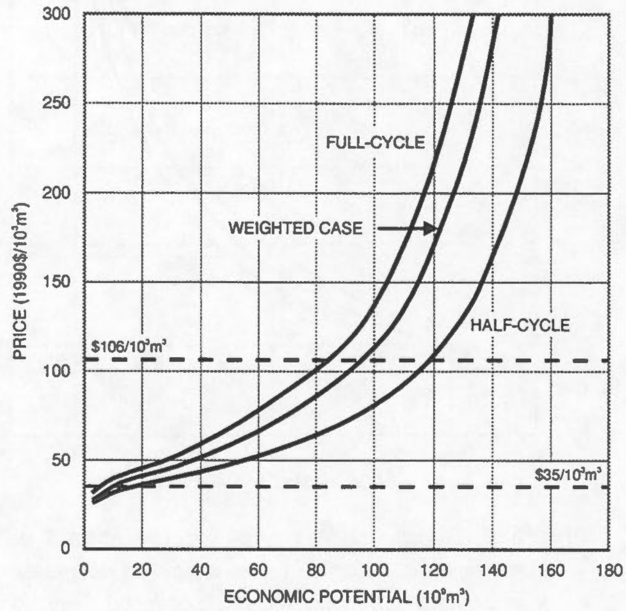

***Figure B.** Supply curves showing unburdened economic potential, measured as a volume of economic initial raw recoverable gas (IRRG), for undiscovered Triassic natural gas resources in plays located primarily in British Columbia.*

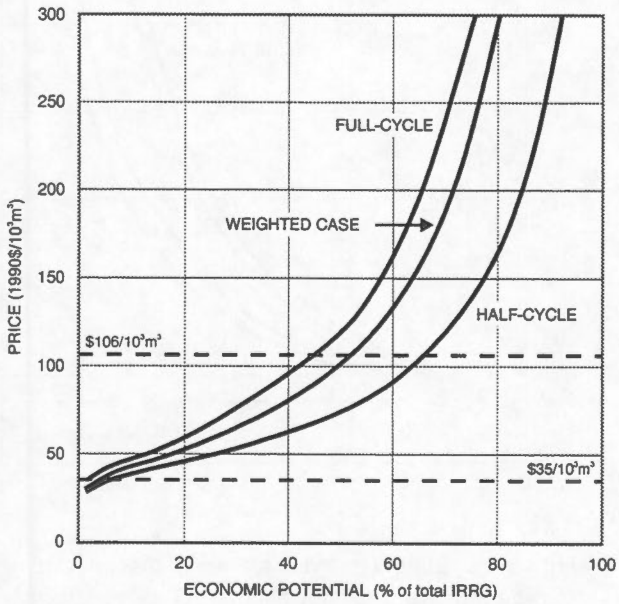

***Figure C.** Supply curves showing burdened economic potential, measured as a percentage of total initial raw recoverable gas (IRRG), for undiscovered Triassic natural gas resources in plays located primarily in British Columbia.*

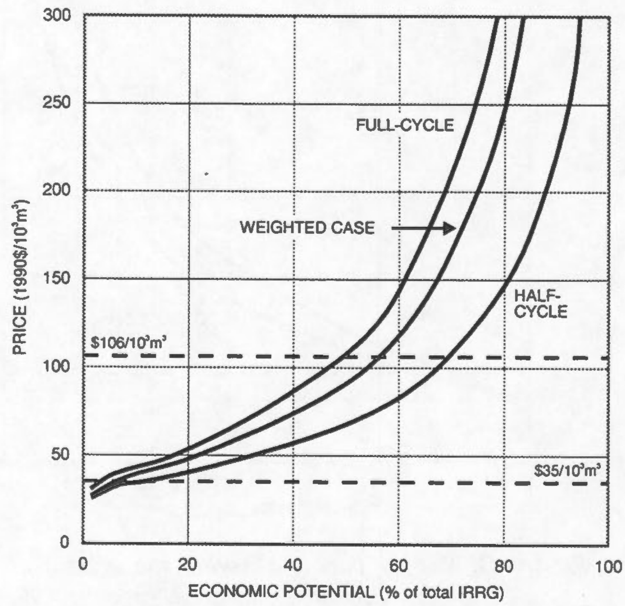

***Figure D.** Supply curves showing unburdened economic potential, measured as a percentage of total initial raw recoverable gas (IRRG), for undiscovered Triassic natural gas resources in plays located primarily in British Columbia.*

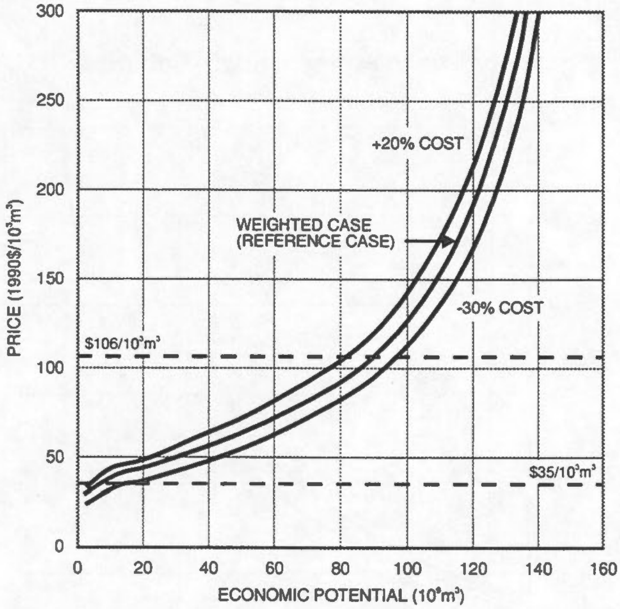

***Figure E.** Supply curves showing the impact of changes in total costs on the weighted estimates of economic potential, for undiscovered Triassic natural gas resources in plays located primarily in British Columbia.*

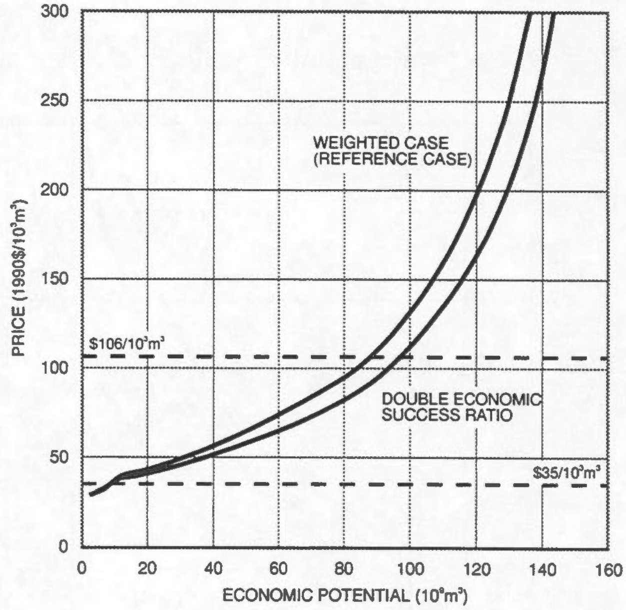

***Figure F.** Supply curves showing the impact of doubling the economic success ratio on estimates of weighted economic potential, for undiscovered Triassic natural gas resources in plays located primarily in British Columbia.*

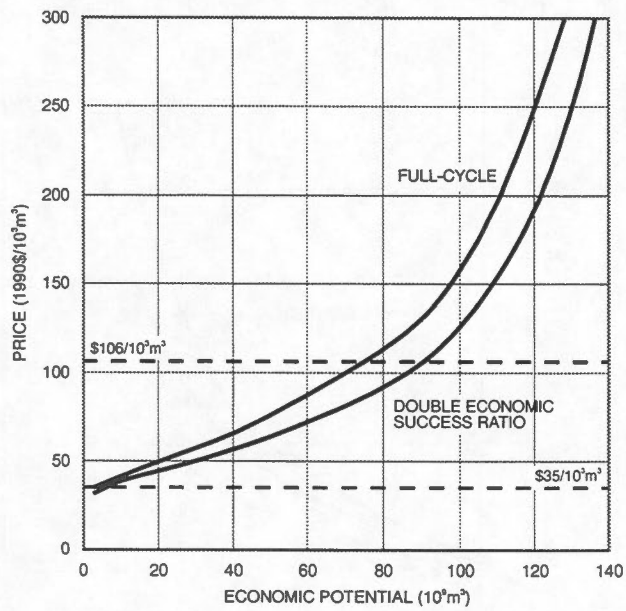

***Figure G.** Supply curves showing the impact of doubling the economic success ratio on the full-cycle estimates of economic potential, for undiscovered Triassic natural gas resources in plays located primarily in British Columbia.*

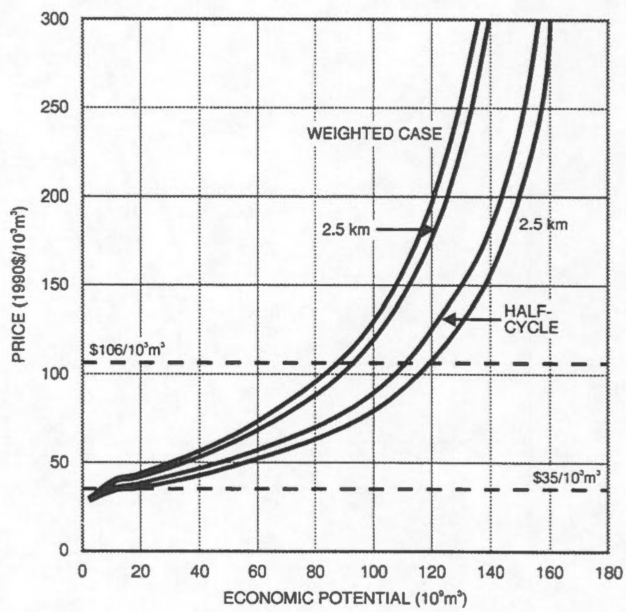

***Figure H.** Supply curves showing the impact of reducing the average distance of pipelines from future discoveries to the gathering system to 2.5 km, for both the weighted and half-cycle estimates of economic potential, for undiscovered Triassic natural gas resources in plays located primarily in British Columbia.*

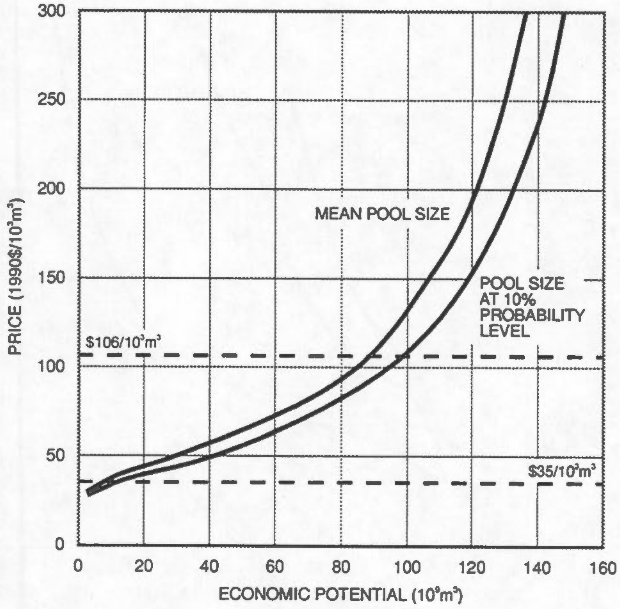

Figure I. *Supply curves showing the impact of increases in the size of undiscovered pools on the weighted estimates of economic potential, for undiscovered Triassic natural gas resources in plays located primarily in British Columbia.*

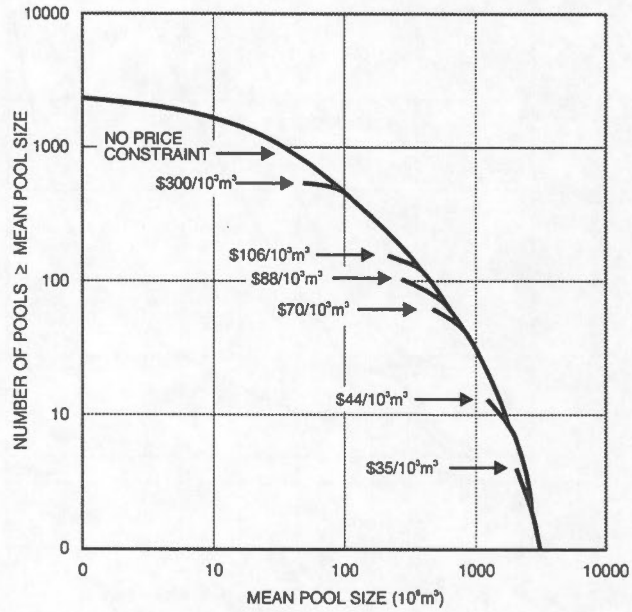

Figure J. *Curves showing the number of undiscovered pools in Triassic plays located primarily in British Columbia, which have mean size estimates are equal to or greater than a given size, and which are economic, in the weighted, burdened, reference case, at selected prices ranging from $35/10^3m^3$ to $300/10^3m^3$. The curve without a price constraint represents the undiscovered pool sizes distribution. The smallest pool size shown at a given price is the marginally economic pool size at that price.*

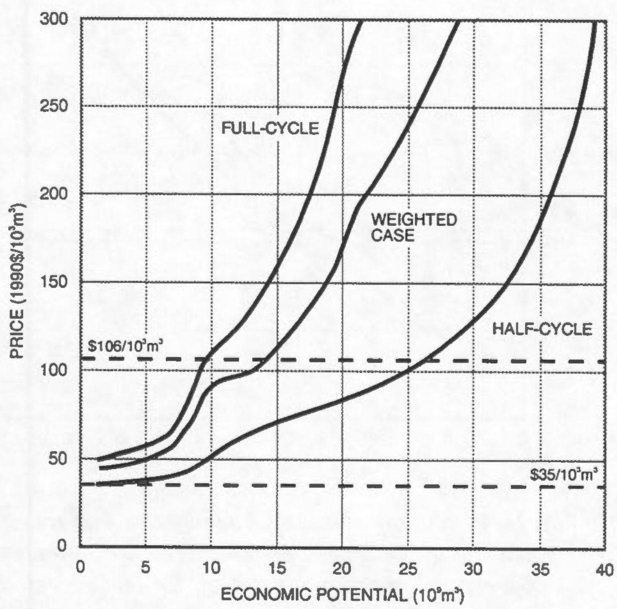

Figure K. *Supply curves showing burdened economic potential, measured as a volume of economic initial raw recoverable gas (IRRG), for undiscovered Triassic natural gas resources in plays located primarily in Alberta.*

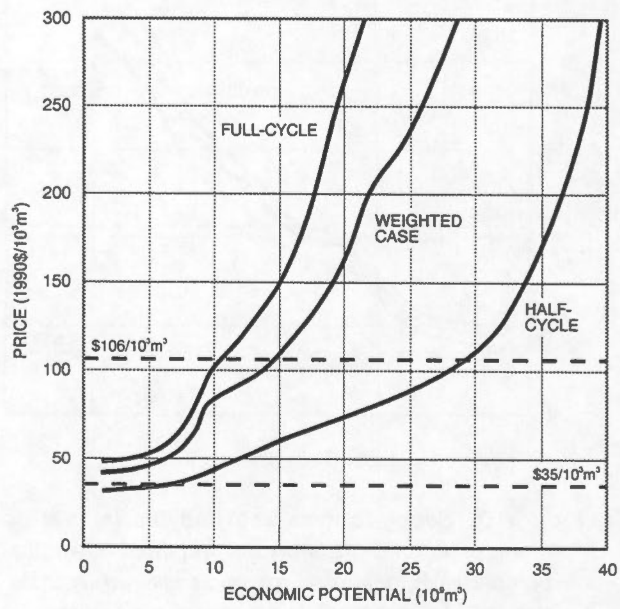

Figure L. *Supply curves showing unburdened economic potential, measured as a percentage of total initial raw recoverable gas (IRRG), for undiscovered Triassic natural gas resources in plays located primarily in Alberta.*

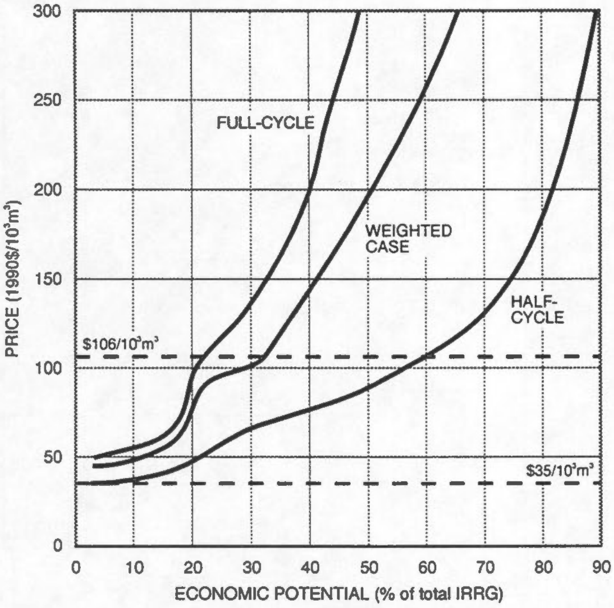

Figure M. *Supply curves showing burdened economic potential, measured as a percentage of total initial raw recoverable gas (IRRG), for undiscovered Triassic natural gas resources in plays located primarily in Alberta.*

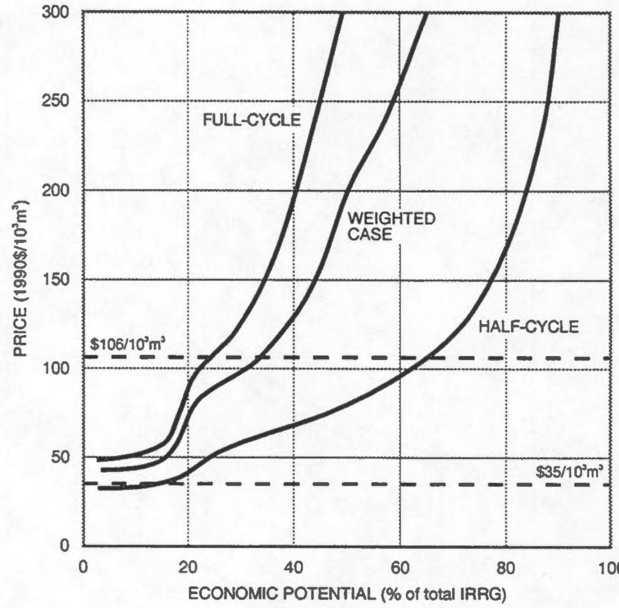

Figure N. *Supply curves showing unburdened economic potential, measured as a percentage of total initial raw recoverable gas (IRRG), for undiscovered Triassic natural gas resources in plays located primarily in Alberta.*

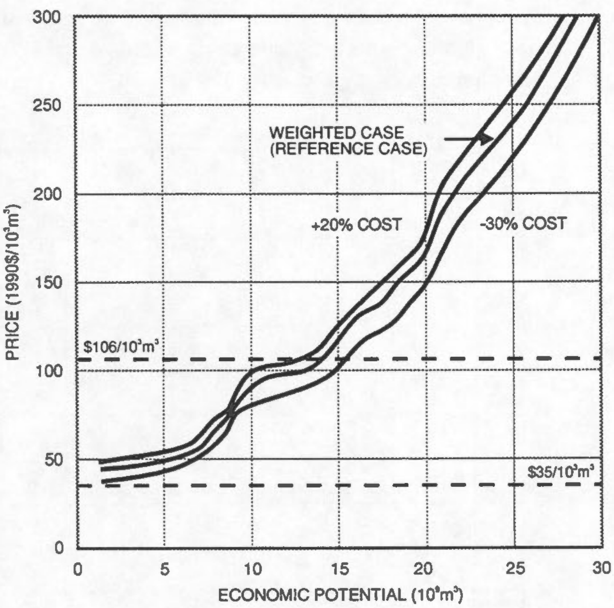

Figure O. *Supply curves showing the impact of changes in total costs on the weighted estimates of economic potential, for undiscovered Triassic natural gas resources in plays located primarily in Alberta.*

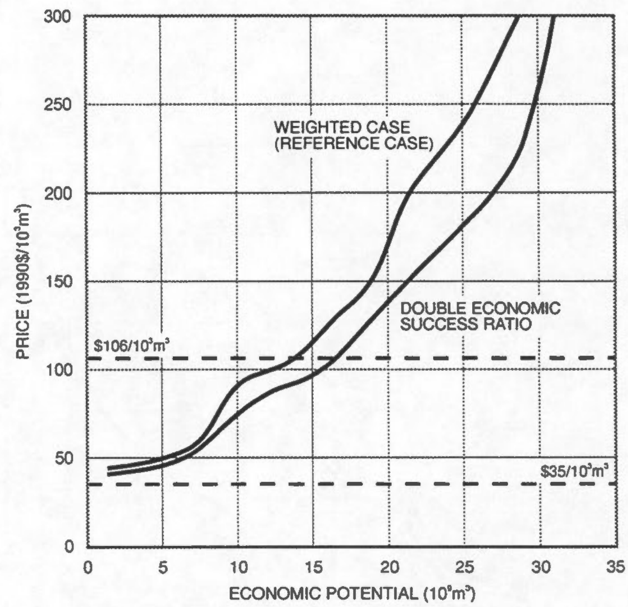

Figure P. *Supply curves showing the impact of doubling the economic success ratio on estimates of weighted economic potential, for undiscovered Triassic natural gas resources in plays located primarily in Alberta.*

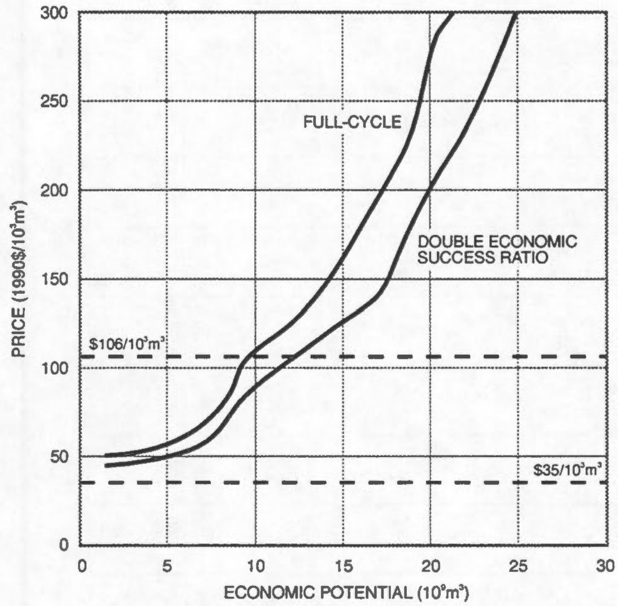

Figure Q. *Supply curves showing the impact of doubling the economic success ratio on the full-cycle estimates of economic potential, for undiscovered Triassic natural gas resources in plays located primarily in Alberta.*

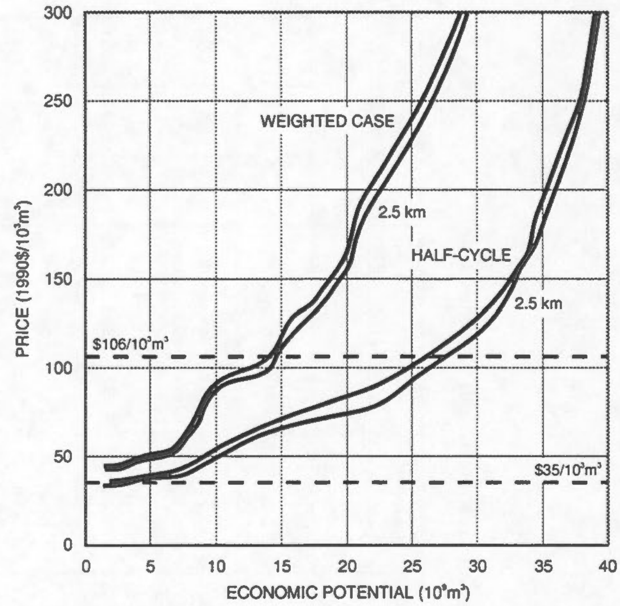

Figure R. *Supply curves showing the impact of reducing the average distance of pipelines from future discoveries to the gathering system to 2.5 km, for both the weighted and half-cycle estimates of economic potential, for undiscovered Triassic natural gas resources in plays located primarily in Alberta.*

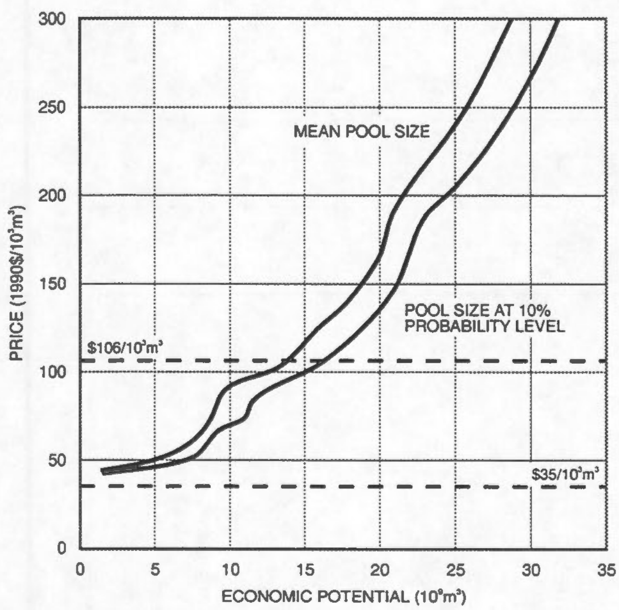

Figure S. *Supply curves showing the impact of increases in the size of undiscovered pools on the weighted estimates of economic potential, for undiscovered Triassic natural gas resources in plays located primarily in Alberta.*

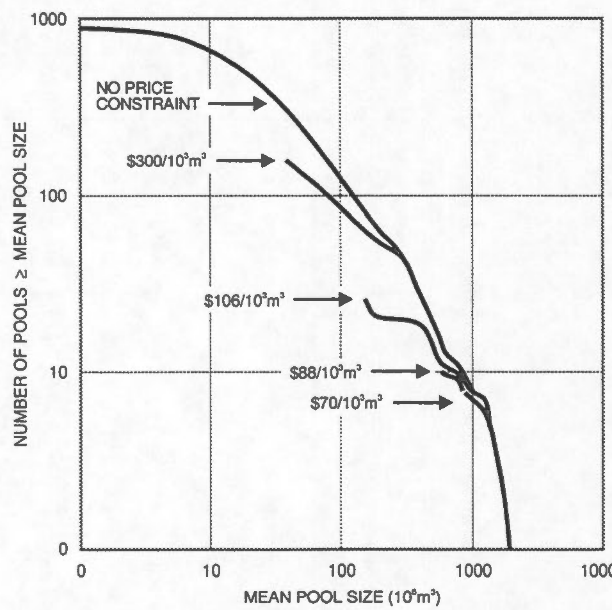

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Table A

Reference case input data and selected cost estimates for mature Triassic plays in British Columbia

Parameters	Halfway/Doig Shore Peejay-Milligan		Halfway/Doig Shelf Monias	Halfway/Doig Shelf Tommy Lakes		Baldonnel Subcrop Laprise		Baldonnel Ft. St. John		Charlie Lake Clastics Inga			Charlie Lake Clastics Cecil		
Undiscovered gas-in-place															
Undiscovered resource estimate (10^6m^3)	10 838		88 934	23 202		66 610		8 336		8 866			5 915		
Mean size of largest undiscovered pool (10^6m^3)	1 640		2 621	1 419		3 130		337		207			650		
Gas type	NA sour	SG sour	NA sour	NA sweet	NA sour	NA sweet	NA sour	NA sweet	NA sour	NA sweet	NA sour	SG sour	NA sweet	NA sour	SG sweet
Fraction of total resource	0.41	0.59	1.00	0.87	0.13	0.46	0.54	0.63	0.37	0.24	0.38	0.38	0.21	0.32	0.47
Average recovery factor	0.80	0.61	0.83	0.83	0.88	0.81	0.75	0.75	0.75	0.85	0.85	0.62	0.90	0.78	0.50
Average depth (metres)	1 185	1 144	1 465	1 238	1 578	1 200	1 270	1 400	1 250	1 182	1 388	1 595	1 389	1 273	1 351
Drilling data															
Exploratory well success rate	0.059		0.167	0.182		0.136		0.041		0.041			0.019		
Development well success rate	0.95		0.95	0.95		0.95		0.95		0.95			0.95		
Success rate in zone	0.580		0.445	0.628		0.707		0.175		0.431			0.667		
Proportion of full-cycle discoveries	0.937		0.784	0.889		0.233		0.214		0.320			0.211		
Average well spacing (ha/well)	512		512	512		512		512		512			512		
Well costs	380	NA	314	355	475	348	397	240	269	345	423	NA	268	278	NA
Costs of D&A dev. well (10^3\$)*	613	NA	499	567	771	555	643	377	429	549	688	NA	421	445	NA
Costs of D&C dev. well (10^3\$)*	4.6	NA	4.3	2.7	5.0	2.7	4.7	2.5	4.1	2.7	4.8	NA	2.6	4.2	NA
Operating costs (10^3\$/well/mo.)															
Surface facilities															
Well site equipment: Dehydration										X					
Line heaters	X		X	X	X	X	X	X	X		X		X	X	
Vapour recovery		X										X			X
Cost (10^3\$/well)	93	212	93	93	93	93	93	93	93	212	93	212	93	93	212
Roads															
Terrain	Muskeg		Parkland	Muskeg		Muskeg		Parkland		Muskeg			Parkland		
Unit costs (10^3\$/km)															
a) Lease/field roads	60	0	30	60	60	60	60	30	30	60	60	0	30	30	0
b) All-weather access	120	0	60	120	120	120	120	60	60	120	120	0	60	60	0
Pipelines															
Average distance to existing gathering system (km)	8	8	8	10	10	5	5	8	8	8	8	8	8	8	8
Unit costs (10^3\$/km) for 2″										53	68	68	52	56	
Unit costs (10^3\$/km) for 3″				81				68	73				68	73	68
Unit costs (10^3\$/km) for 4″	104	104	88	97	104	97	104								
Unit costs (10^3\$/km) for 6″			114			125	134								

*Add 10% for exploration wells

Table B

Reference case estimates of economic potential and initial marketable gas for undiscovered natural gas resources for Triassic plays in British Columbia

Type of analysis	Economic potential				Initial marketable gas			
	Volume (10^6m^3)		% of total initial raw recoverable gas		Volume (10^6m^3)		% of total initial raw recoverable gas	
	$44.13/ 10^3m^3	$88.25/ 10^3m^3	$44.13/ 10^3m^3	$88.25/ 10^3m^3	$44.13/ 10^3m^3	$88.25/ 10^3m^3	$44.13/ 10^3m^3	$88.25/ 10^3m^3
Burdened estimates:								
Full-cycle	13 350	61 242	8	36	11 995	54 798	7	32
Half-cycle	34 087	99 975	20	59	30 596	89 414	18	53
Weighted full- and half-cycle	20 585	72 281	12	43	18 506	64 744	11	38
Unburdened estimates:								
Full-cycle	18 675	67 425	11	40	16 759	60 332	10	36
Half-cycle	42 129	105 054	25	62	37 760	93 952	22	55
Weighted full- and half-cycle	26 477	80 457	16	47	23 786	72 022	14	42

Total initial raw recoverable gas: 169 472 10^6m^3

Table C

Sensitivity analyses measuring impact of changes in key impact variables on estimates of economic potential for mature plays in British Columbia

Type of sensitivity analysis	Economic potential (10^6m^3)		% of total initial raw recoverable gas		% Change	
	$44.13/ 10^3m^3	$88.25/ 10^3m^3	$44.13/ 10^3m^3	$88.25/ 10^3m^3	$44.13/ 10^3m^3	$88.25/ 10^3m^3
Sensitivity analyses on weighted average estimates:						
Reference case – weighted average	20 585	72 281	12	43		
20% increase in total costs	10 612	63 588	6	38	-48	-12
30% decrease in total costs	33 795	85 764	20	51	+64	+19
Drilling success ratio doubled (max. 1:2)	24 855	84 980	15	50	+21	+18
Distance to pipeline set to 2.5 km	24 463	78 596	14	46	+19	+9
Pool size at 10% probability level	29 658	82 979	18	49	+44	+15
Sensitivity analysis on full-cycle estimates:						
Reference case – full-cycle	13 350	61 242				
Drilling success ratio doubled (max. 1:2)	19 780	74 468	12	44	+48	+22
Sensitivity analysis on half-cycle estimates:						
Reference case – half-cycle	34 087	99 975				
Distance to pipeline set to 2.5 km	40 823	106 622	24	63	+20	+7

Total initial raw recoverable gas: 169 472 10^6m^3

Table D

Reference case input data and selected cost estimates for mature Triassic plays in Alberta

Parameters	Halfway/ Doig Shore			Charlie Lake Carbonates		Montney Subcrop South		
		Sinclair		Boundary Lake			Fir	
Undiscovered gas-in-place								
Undiscovered resource estimate (10^6m^3)		27 905		9 128			23 258	
Mean size of largest undiscovered pool (10^6m^3)		1 915		183			1 273	
Gas type	NA sweet	NA sour	SG sour	NA sweet	SG sweet	NA sweet	NA sour	SG sour
Fraction of total resource	0.13	0.55	0.32	0.25	0.75	0.24	0.53	0.23
Average recovery factor	0.77	0.77	0.70	0.76	0.69	0.76	0.76	0.53
Average depth (metres)	2 000	2 107	2 000	1 685	1 700	1 170	2 100	2 038
Drilling data								
Exploratory well success rate		0.117		0.043			0.020	
Development well success rate		0.95		0.95			0.95	
Success rate in zone		0.420		0.767			0.254	
Proportion of full-cycle discoveries		0.625		0.254			0.303	
Average well spacing (ha/well)		256		256			256	
Well costs								
Costs of D&A dev. well (10^3\$)*	380	473	NA	288	NA	257	553	NA
Costs of D&C dev. well (10^3\$)*	565	697	NA	445	NA	411	847	NA
Operating costs (10^3\$/well/mo.)	2.5	4.3	NA	2.4	NA	2.2	4.3	NA
Surface facilities								
Well site equipment: Dehydration				X				
Line heaters	X	X				X	X	
Vapour recovery			X		X			X
Cost (10^3\$/well)	81	81	184	184	184	81	81	184
Roads								
Terrain		Parkland		Parkland			Forest	
Unit costs (10^3\$/km)								
a) Lease/field roads	26	26	0	26	0	39	39	0
b) All-weather access	52	52	0	52	0	78	78	0
Pipelines								
Average distance to existing gathering system (km)	10	10	10	8	8	12	12	12
Unit costs (10^3\$/km) for 2″				39				
Unit costs (10^3\$/km) for 3″	59	64				70	76	
Unit costs (10^3\$/km) for 4″						84	91	91
Unit costs (10^3\$/km) for 6″	92	99	99					

*Add 10% for exploration wells

Table E

Reference case estimates of economic potential and initial marketable gas for undiscovered natural gas resources for Triassic plays in Alberta

Type of analysis	Economic potential				Initial marketable gas			
	Volume (10^6m^3)		% of total initial raw recoverable gas		Volume (10^6m^3)		% of total initial raw recoverable gas	
	$44.13/ 10^3m^3	$88.25/ 10^3m^3	$44.13/ 10^3m^3	$88.25/ 10^3m^3	$44.13/ 10^3m^3	$88.25/ 10^3m^3	$44.13/ 10^3m^3	$88.25/ 10^3m^3
Burdened estimates:								
Full-cycle	0	8 802	0	20	0	7 759	0	18
Half-cycle	7 796	21 732	18	50	6 870	19 150	16	44
Weighted full- and half-cycle	1 432	9 689	3	22	1 262	8 541	3	20
Unburdened estimates:								
Full-cycle	0	9 254	0	21	0	8 158	0	19
Half-cycle	9 127	24 409	21	56	8 044	21 509	18	49
Weighted full- and half-cycle	3 898	11 003	9	25	3 436	9 703	8	22

Total initial raw recoverable gas: 43 765 10^6m^3

Table F

Sensitivity analyses measuring impact of changes in key impact variables on estimates of economic potential for mature plays in Alberta

Type of sensitivity analysis	Economic potential (10^6m^3)		% of total initial raw recoverable gas		% Change	
	$44.13/ 10^3m^3	$88.25/ 10^3m^3	$44.13/ 10^3m^3	$88.25/ 10^3m^3	$44.13/ 10^3m^3	$88.25/ 10^3m^3
Sensitivity analyses on weighted average estimates:						
Reference case – weighted average	1 432	9 689	3	22		
20% increase in total costs	0	9 254	0	21	-100	-4
30% decrease in total costs	4 976	12 281	11	28	+247	+27
Drilling success ratio doubled (max. 1:2)	3 898	12 717	9	29	+172	+31
Distance to pipeline set to 2.5 km	2 723	10 235	6	23	+90	+6
Pool size at 10% probability level	3 056	12 490	7	29	+113	+29
Sensitivity analysis on full-cycle estimates:						
Reference case – full-cycle	0	8 802				
Drilling success ratio doubled (max. 1:2)	1 432	9 689	3	22	NA	+10
Sensitivity analysis on half-cycle estimates:						
Reference case – half-cycle	7 796	21 732				
Distance to pipeline set to 2.5 km	8 511	24 265	19	55	+9	+12

Total initial raw recoverable gas: 43 765 10^6m^3