. OIL AND GAS RESOURCE POTENTIAL OF THE KOOTENAY AREA OF BRITISH COLUMBIA

by

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April, 1993

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SUMMARY

There are sixteen exploration hydrocarbon plays identified in the Kootenay area of southeastern British Columbia. The plays are:

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The Waterton Colorado, Waterton Mannville Oil and Gas, Rocky Mountain Trench Gas, and Belt-Purcell Oil and Gas Plays are all immature and have minor historical production. The Waterton Rundle/Wabamun Gas Play is a mature play with abundant production principally in Alberta. The remaining nine plays have no established reserves or production and are, therefore, conceptual. The Belt-Purcell Conceptual and Speculative Oil and Gas Plays were not assessed here because of the lack of relevant information. All other plays were assessed using current practices employed at the Petroleum Resources Subdivision of the Geological Survey of Canada.

The Waterton Colorado Foothills Gas Play is located in the Foothills Belt of the Western Canada Sedimentary Basin. The play covers an area of southwestern Alberta, northwestern and west-central Montana as well as southeastern British Columbia. Two gas pools have been discovered in deformed Colorado Group sediments in the play. A total mean play resource of $6.7x10^9$ m^3 (238 BCF) of raw gas in place is inferred.

Similarly, the Waterton Mannville Foothills Oil and Gas Play is found in the Foothills Belt of Alberta, British Columbia and Montana. Three gas and two oil pools have been discovered in Alberta. These pools have been delineated within deformed Lower Cretaceous rocks. Total mean play resources for oil and gas is $78x10^6$ m^3 (491 million barrels) and $11.9x10^9$ m^3 (422 BCF), respectively.

Sufficient production has been attained in the Waterton Rundle/Wabamun Play to classify it as a mature play. The play virtually covers the same area as the previous Foothills plays. Deformed Paleozoic carbonates prove to be excellent reservoir rock for the accumulation of gas. The total expected resource is 225.9×10^9 m^3 (8 TCF) of gas. The largest pool has already been discovered in the play (79.5×10^9 m^3 (2.8 TCF)).

There is a distinct risk attached to the existence of each of the conceptual plays. The Kishenehn Tertiary Graben Oil and Gas Plays are located in the valleys of the Middle and North Forks of the Flathead River in southeastern British Columbia and northwestern Montana. A high probability that this play exists is illustrated with a play-level risk of 0.90. If the play exists, a mean play potential of 17.9×10^9 m^3 (632 BCF) and 60.7×10^6 m^3 (382 million barrels) have been computed for gas and oil, respectively. The largest inferred median pool sizes in these plays are 3.1×10^9 m^3 (109 BCF) and 9.1×10^6 m^3 (57 million barrels) respectively.

The deformed sediments that are incorporated within the MacDonald Paleozoic Structural Gas Play underlie the Tertiary sediments in the Kishenehn Graben and outcrop to the west of the graben. There is a 0.50 probability that the play does not exist, as reflected in potential problems associated with seal due to outcropping of potential reservoir material and timing of deformation with respect to hydrocarbon generation. The mean play potential has been predicted to be 3.4×10^9 m^3 (121 BCF) while the median of the largest pool size is calculated to be 1.8×10^9 m^3 (64 BCF).

The Fernie-Elk Valley Mesozoic Structural Gas Play consists of Mesozoic sediments that are found in the Fernie Basin and Elk Valley of southeastern British Columbia. There is a 0.20 probability that this play does not exist principally due to seal problems as a consequence of the outcropping of potential reservoir material. The ultimate mean play potential is 203×10^6 m^3 (7 BCF) of gas. The median of the largest pool size has been predicted to be 81.4×10^6 m^3 or 3 BCF.

The Paleozoic play in the Fernie Basin and Elk Valley is located in southeastern British Columbia as well. A 10% chance that the play does not exist has been assigned here, principally due to problems associated with the timing of hydrocarbon generation with respect to structure formation. Seal is less of a risk because the Paleozoics are less likely to outcrop. The expected mean play potential is 5.1×10^9 m^3 (182 BCF) while the median of the largest pool size is expected to be 1.5×10^9 m^3 (53 BCF).

The Cenozoic gas play in the Rocky Mountain Trench has been classified as an immature play because minor production of biogenic gas has been recorded near Flathead Lake in Montana. The ultimate mean play potential is $849x10^6$ m^3 (30 BCF). It is expected that the play is not significant because the gas pools would be very small.

The Belt-Purcell Immature Structural Oil and Gas Plays constitute one of the oldest exploration plays in Western Canada. Oil was produced at one time from Oil City in Waterton National Park. Although the play-level risk is non-existent, individual prospects would have much higher risks because production seems to be exclusively involved with secondary fracture porosity. Primary porosity has been eliminated due to Precambrian metamorphism. The ultimate mean play potential is estimated to be $4.5x10^6$ m^3 (28 million bbls.) for oil and $622x10^6$ m^3 (22 BCF) for gas. The largest median pool sizes are $8x10^5$ m^3 (5 million bbls.) and $118x10^6$ m^3 (21 BCF) respectively.

The total oil and gas potential for the entire Kootenay area is $143x10^6$ m^3 (901 million bbls.) and $272.7x10^9$ m^3 (9.6 TCF), respectively.

INTRODUCTION

In October 1992, John MacRae, Director of the Petroleum Geology Branch of British Columbia's Ministry of Energy, Mines and Petroleum Resources requested that the Institute of Sedimentary and Petroleum Geology of the Geological Survey of Canada assess the hydrocarbon potential of certain sedimentary basins in British Columbia. Consequently, an assessment of the sedimentary basins surrounding Vancouver Island was completed and submitted to the Ministry in January, 1993. That work constituted Phase I of the information requested by the Ministry. This report deals with Phase II, which describes the results obtained from an oil and gas assessment of the Kootenay area of southeastern British Columbia. Results from these assessments are to be employed by British Columbia's Commission on Resources and Environment, which is currently performing a detailed land-use planning study of selected areas in the Province.

G.S.C. hydrocarbon resource assessments are computer-generated by an internally formulated statistical program known as PETRIMES (Lee and Wang, 1990). These assessments can be applied to mature, immature and conceptual hydrocarbon plays. A play is defined as a family of hydrocarbon pools or prospects with similar histories of hydrocarbon generation and migration as well as similar trapping mechanisms and reservoir configurations. A mature play has sufficient discoveries and pool definitions for analysis by the "discovery process model" while an immature play has too few discoveries to allow analysis by this method. A conceptual play has no defined pools, just prospects.

Most of the plays in this assessment were defined as either conceptual or immature and the pool-size distributions were generated using probability distributions of geological variables substituted into the standard pool-size equation.

Following compilation of pertinent geological information in the Kootenay area as well as adjacent Montana (see reference list), 16 potential geological plays were recognized. Five of these plays have oil potential while the remainder have gas prospects. In addition, four of the plays have been defined as occurring within the Foothills Belt of the Western Canada Sedimentary Basin. The boundaries of these Foothills plays are illustrated in Figures 1-3. As illustrated on these play maps, only a small wedge of territory in southeastern British Columbia is included in the areal extent of the Foothills plays. The Foothills plays described in this report are the Waterton Colorado Gas, Waterton Mannville Oil and Gas and the Waterton Rundle/Wabamun Gas. The major proportion of the area covered by these plays is found in Alberta and Montana.

The Foothills Belt within the Western Canada Sedimentary Basin consists of a large volume of sediments occupying the area directly east of the Cordillera from southwestern Northwest Territories through northeastern British Columbia, west-central and southwestern Alberta, and northwestern and west-central Montana.

There are also five intermontane sedimentary basins in the Kootenay region which accommodate the remaining eleven exploration hydrocarbon plays (Figures 1-3).

Two plays in Tertiary sediments are recognized in the intermontane sedimentary basin called the Kishenehn Graben which is located in the Flathead River Valley in B.C. and northwestern Montana (see Figure 1).

Paleozoic sediments occurring in the hangingwall of the Flathead normal fault are basinal deposits. The sediments filled a Paleozoic basin and subsequent to thrusting now underlie the Kishenehen Tertiary sediments and outcrop west of the Graben in the MacDonald Dome. One potential gas play has been recognized in these rocks (Figure 2).

Another sedimentary basin occupied by both Mesozoic and Paleozoic sediments is known as the Fernie and Elk Valley Basin. This basin occurs north of the Kishenehen Graben in the vicinity of the town of Fernie and north into the Elk River Valley. Two potential gas plays are present (Figures 1&2).

Further west is another major graben feature known as the Rocky Mountain Trench that contains potential hydrocarbon-bearing sediments (Figure 1).

The largest sedimentary basin in the Kootenay area occupies a very large area of southeastern British Columbia, extreme southwestern Alberta, a large portion of western Montana and parts of northern Idaho. These sediments are of Proterozoic age and are known as the Belt-Purcell Series of rocks (Figure 3).

Sixteen plays were defined in this area. They are the:

1) Immature Waterton Colorado Foothills Gas Play,
2) Immature Waterton Mannville Foothills Gas Play,
3) Immature Waterton Mannville Foothills Oil Play,
4) Mature Waterton Rundle/Wabumun Foothills Gas Play,
5) Conceptual Kishenehn Tertiary Graben Gas Play,
6) Conceptual Kishenehn Tertiary Graben Oil Play,
7) Conceptual MacDonald Paleozoic Structural Gas Play,
8) Conceptual Fernie-Elk Valley Mesozoic Structural Gas Play,
9) Conceptual Fernie-Elk Valley Paleozoic Structural Gas Play,
10) Immature Rocky Mountain Trench Cenozoic Graben Gas Play,
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GEOLOGICAL SETTING AND PLAY PARAMETERS

Waterton Colorado Foothills Gas Play

This play is located in the Foothills Belt of southwestern Alberta, extreme southeastern British Columbia, and northwestern and west-central Montana (see Figure 1). The stratigraphic interval of interest includes Lower to Upper Cretaceous sediments within the Colorado Group and equivalents.

During compilation of geological information for the study of the oil and gas potential of the Foothills Belt at the ISPG, it was recognized that there are five major geographic areas. Oil and gas pools that exhibit similar gross structural characteristics were grouped into a single geographic area. The southernmost geographic area defined within the Foothills Belt is called the Lewis Thrust Geographic Area. Sediments east of and/or directly related to the Lewis Thrust in Canada and Montana as well as the Eldorado and Lombard Thrusts in Montana are considered to occur in the Lewis Thrust Geographic Area. The four Foothills plays in this assessment are found in the Lewis geographic area.

The eastern limit of Colorado Group thrusting defines the eastern boundary of the Waterton Colorado Play. The Waterton Colorado Foothills Gas Play covers an area of approximately 35075 square kilometres of which about 1540 square kilometres is located in British Columbia (4.4% of the total area)(see Figure 1). Three hundred and nineteen exploratory and development wells have penetrated the Colorado Group rocks in the play. Two gas pools have been defined which would classify the play as immature. These pools were fortuitously discovered in the Waterton Field of southwestern Alberta since the major target was deeper Mississippian and Devonian carbonates. The gas was found in Cardium sands and total raw gas in place of the two pools has been calculated to be 199 million cubic metres (ERCB, 1990). Hall's study of the Waterton Field (1969) illustrates the overthrusting of Mississippian sediments onto younger rocks consequently forming hydrocarbon traps in the Mississippian carbonates. The younger Cardium sands would also be affected similarly, thus forming hydrocarbon traps in the sands. Bruce and Frey, 1982 indicate thrusting of Cretaceous rocks in their structural geological cross-sections in the Waterton Field. Simple and complex thrust faulted anticlines seem to be the principal trapping regime in the Foothills of southern Alberta.

The Colorado Group sediments vary greatly in thickness throughout the Waterton Colorado Play. In the Crowsnest Pass area, Colorado or Alberta Group sediments range from 378 to 830 metres thick of which the principal reservoir sand (Cardium) varies from 3 to 90 metres (Norris, 1971). Therefore, potential reservoir sands would make up approximately 1 to 25% of the total succession.
Herr, 1967, Wall and Rosene, 1977, Rice and Cobban, 1977, and Vielle and Harris, 1965 all discuss the stratigraphy of the Upper Cretaceous succession in the play area. Structural studies of these rocks are found in Bruce and Frey, 1982, Price, 1962a, 1965, Bally, Gordy and Stewart, 1966, and Dahlstrom, 1970.

Geological risks are important components in immature and conceptual play assessments. Play-level risks consider the existence of adequate source rocks, seals, migration conduits, and the timing of trap formation with respect to hydrocarbon generation. The fact that two gas pools have been defined would indicate that all play-level risks have been satisfied and the play exists. The above risk factors can be assigned to individual prospects, however.

Waterton Mannville Foothills Gas Play

The Waterton Mannville Play essentially occupies the same area as the previous play but involves older rock of Lower Cretaceous age (Mannville or Blairmore Group sediments)(see Figure 3). The eastern boundary is located west of the eastern boundary of the Colorado play. The westward movement of the eastern boundary down-section characterizes the Foothills Belt in this area. Thrusting associated with the Laramide orogeny pushed older rocks in an easterly or cratonward direction over top of younger sediments. Since these thrusts cut up-section in the direction of transport, the boundary limiting deformed rocks in the Foothills from flat-lying rocks in the Plains would move west as one goes down-section. The Waterton Mannville Play occupies an area of 33850 square kilometres of which 1540 or 4.5% is found in southeastern British Columbia (Figure 3).

A total of 280 exploratory and development wells have intersected the Mannville Group succession in this play area. Three gas pools have been defined in the play, all in Alberta (ERCB, 1990). Two pools were discovered in the Todd Strike Area while the other was found in the Waterton Field. Douglas, 1950 notes abundant thrust faults in Lower Cretaceous rocks in his structural cross-sections. Total raw gas volume recorded in this play is 459 million cubic metres (ERCB, 1990).

The Mannville or Blairmore Group of Lower Cretaceous clastic strata varies widely in thickness. For example, in the Crowsnest Pass area of Alberta, thickness varies from 375 to 2015 metres. Important reservoir examples are the Home sandstone member and the Dalhousie Formation (equivalent to Cadomin). One gas pool was defined in the Cadomin in the Waterton Field. The two remaining pools at Todd were listed as Blairmore accumulations. A general discussion of the stratigraphy and sedimentology of the Cadomin Formation is presented in McLean's paper, 1977. A discussion of Cretaceous stratigraphy in Glacier National Park is found in Rice and Cobban's paper (1977).

The existence of three gas pools satisfies all of the play-level risk factors so the play definitely exists. Any risk should be assigned to the prospect level only. The play is classified as immature.

Waterton Mannville Foothills Oil Play

This play covers the same area as the Mannville gas play and involve the same package of rocks. Two oil pools have been discovered and defined in the play. The oil pools were found in the same discovery well in the Pincher Creek Field in the Lower Mannville succession. Oil in place is 454.6×10^3 m^3 (2.86 million bbls). These oil pools are gas-free and structurally-controlled. The Dalhousie sand of the Mannville Group is probably the main reservoir sand in the Cretaceous clastic succession.

The discovery and definition of two oil pools in the play classifies it as immature.

Waterton Rundle/Wabamun Foothills Gas Play

This Foothills play covers approximately the same area as noted previously in the other Foothills plays (Figure 2). It occupies an area of approximately 31750 square kilometres with 1540 square kilometres occurring in southeastern British Columbia (about 4.9% of the total area). A total of 232 exploratory and development wells penetrated the Mississippian and/or Devonian succession. Twenty-six gas pools in eight fields were defined in the play. Included are two large carbon dioxide-rich gas pools discovered by Shell in the Sage Creek area of British Columbia. The total in-place raw gas reserves defined in British Columbia is $17x10^9$ m^3 (600 BCF) while the total reserve for the entire play is $185.6x10^9$ m^3 (6555 BCF).

Porous Paleozoic carbonates are the principal target for gas exploration in the Foothills Belt of southern Alberta and western Montana. Dolomites found in the Mississippian Turner Valley Formation are the dominant reservoirs in the area. Trap configuration is commonly represented by structural thrust-faulted anticlines. Possible source beds are found in Devonian rocks generally associated with reef complexes, the Lower Mississippian Exshaw Formation, the Jurassic Fernie Formation and shales in the Cretaceous succession. Migration of hydrocarbons has occurred in the play through fault pathways. Seal is provided by the numerous interbeds and overlying sequences of shale and non-porous limestones. Average pay thickness in the Pincher Creek Field is 116 metres. At the Waterton Field, it averages 46 metres. Average porosity at Pincher Creek is 4.2% while at Waterton it averages 5.7% (Norris and Bally, 1972).

Sufficient discoveries have been made in this exploration play to classify it as mature. Therefore, the "discovery process model" can be used for retrieving the gas potential (Lee and Wang, 1990).

Kishenehn Tertiary Graben Gas Play

The Kishenehn Tertiary sediments fill a half-graben that occupies the valleys of the North Fork of the Flathead River in southeastern British Columbia and the Middle Fork in northwestern Montana along the western boundary of Glacier National Park (Figure 1). It covers an area of 1350 square kilometres of which 235 square kilometres or 17% of the territory is found in British Columbia. Possible targets for hydrocarbon accumulations include Early to Late Oligocene rocks. These rocks were deposited in fluvial and lacustrine depositional environments.

A total of nine wells have been drilled to date in the basin. At least four gas shows have been reported in four of the wells. Frequently, the old drilling reports are not quantitively accurate in the exact number of shows discovered in the wells. Therefore, the number of shows indicated in this report may err on the low side.

The total thickness of the Tertiary succession has been estimated up to 5000 metres (Constenius et al, 1989, R.D. McMechan, 1981, Curiale and Sperry, 1987). P.B. Jones, 1969a cites a thickness of 4700 metres. Sediments where sands and conglomerates are sufficiently porous and permeable to be classified as reservoir material seem to occur in the upper 1500 metres of the Oligocene sedimentary package.

Prospects can be found in traps formed by small-scale antithetic normal and reverse faulting within the Kishenehn extensional basin. Sandstone and conglomerate pinchouts and facies changes may produce stratigraphic traps as well. The lack of available seismic data made the inference of the area of closure as well as vertical relief of the traps poorly constrained. Appraisals of area of closure were made by using geological analogues. The largest closure estimated in this play was 5 square kilometres while the smallest could be 0.5 square kilometres (see Appendix 1). The total area under closure in the basin is gauged to be in the order of 700 square kilometres.

Porous sands and conglomerates are both thick and thin and usually stacked. These porous zones range in thickness between one to thirty metres. The proportion of potential reservoir material varies widely within the basin (1 to 45%). Porosity in reservoir zones seem to vary between 8 to 25% with average values in the 8 to 12% range. There seems to be no evidence for secondary fracture porosity in this play.

Excellent source rock potential for gas is present in the Kishenehn Basin. Organic-rich shales are the predominant gas source in the area. Type I, II and III kerogens have been observed throughout the basin (Curiale, 1987). Vitrinite reflectance (Ro) ranges from 0.27 to 0.51 in the basin. The TOC ranges from 0.1 to 50% with an average of 6%. The average HI has been observed to be 550 mg/g. These organic geochemistry values indicate that the potential for source rock in the basin is excellent, though thermally immature. Although thermal maturity data signifies that temperatures were not high enough for hydrocarbon generation on the western border of the basin (Curiale et al, 1988), burial by a thick succession of sediments in the centre would provide sufficiently high temperatures for the generation of hydrocarbons.

Most of the deformation that established the general framework of the intermontane basins in the area occurred during the Upper Cretaceous to Paleocene time interval (Constenius, 1982, and Mudge, 1982). The Kishenehn basinal structure was formed as a consequence of Lewis thrusting. Subsequent to thrusting, the Flathead listric normal fault system developed along the eastern margin of the basin. Sedimentation of the Oligocene Kishenehn Formation then occurred within the basin. There is a pervasive dip eastward of the Kishenehn sediments toward the Flathead fault system. Also, drag folding of the Kishenehn occurs along the eastern basin margin. This suggests that extension in the basin continued subsequent to sedimentation possibly to Recent times (Constenius, 1982). Therefore, the major deformation producing the basin occurred previous to sedimentation while further extensional forces operated during and subsequent to sediment deposition. The presence of many normal and thrust faults in this geological setting provide abundant opportunity for hydrocarbon migration. Numerous interbedded and overlying shales would provide sufficient seal.

Kishenehn Tertiary Graben Oil Play

The oil play occupies the same area as the Kishenehn Gas in southeastern British Columbia and northwestern Montana. The play parameters described for the Kishenehn Gas would thus be similar to this play for the most part.

At least four oil shows have been recorded within the 9 wells drilled in the basin. In addition, oil shales were recognized in various parts (Curiale, 1987a, Constenius and Dyni, 1983), principally in the lacustrine sediments as opposed to the fluvial segment. Excellent oil-prone, though thermally immature, source rocks are present in the basin. Abundant oil shales and sapropelic coals have been found in the basin. Type I kerogen is commonly present, especially in the northern part of the basin. As noted above, the sediment succession is sufficently thick that burial metamorphism would produce temperatures high enough so that both liquid and gaseous hydrocarbons could form. Trap formation, migration and seal are all present.

MacDonald Paleozoic Structural Gas Play

This conceptual petroleum play consists of the Paleozoic sequence occupying the hangingwall of the Flathead normal fault. This would place the play immediately west of and underlying the Flathead Graben (Figure 2). The total area of play is 7400 square kilometres of which 900 or 12% of the area is found in southeastern British Columbia. The MacDonald Dome located in B.C. gives the play its name (Price, 1965). A thick Paleozoic succession of carbonates as well as clastic sediments provide an age range of targets from Permian to Middle Cambrian.

Only 2 wells have been drilled into the Paleozoics in this play and no hydrocarbon shows have been reported.

Stratigraphic thicknesses recorded in this area produce a total Paleozoic sediment succession of 1600 to 1850 metres. The actual prospect succession thickness would be the same since reservoir material was found at both end-members of the sequence.

Structure types found in this play are large-scale drape folds related to listric normal faulting, simple compressional folds, thrust faults and some unconformity truncations. These structures developed during the Maastrichtian as a consequence of Lewis thrust faulting and were modified in the Oligocene during which normal faulting of the Flathead fault system produced the Flathead Graben. Compressional structures that were developed during the Laramide orogeny were modified by extensional forces functioning in the Flathead epeirogeny.

The largest area of closure recognized in the play is 100 square kilometres under the MacDonald Dome. The second largest structure observed is the Trail Creek Structure in Montana with an area of 78 square kilometres (Fritts & Klipping, 1987b). The minimum area of closure is probably 0.5 square kilometres. There are at least two prospects since two wells were drilled. However, it is felt that there should be about 100 prospects in the play. Vertical closure is estimated to be 800 metres in the MacDonald Dome and 300 metres at Trail Creek. Average relief is probably 300 metres while minimum vertical closure could be five metres.

The potential reservoir interval ranges from the Upper Mississippian Etherington Formation to the Middle Cambrian Elko Formation. Both thick and thin carbonate reservoirs occur in reef buildups, edges of marine shelves or interiors of carbonate shoals. Estimated thickness of porous and permeable material compared to total thickness varies from 2 to 6%. Secondary fracture porosity is present as exhibited by occasional water flows below the depth of 1350 metres. Primary and secondary porosity is estimated to range from 8 to 30% with an average of 15% in porous strata.

Possible source rocks for gas in the MacDonald Paleozoic Structural Play are shales in the Fernie Group and the Exshaw Formation as well as coal seams found in the Jurassic-Cretaceous Kootenay Group (Clayton et al, 1982 and Meissner et al, 1984). Solid pyrobitumens were noted in geological well logs in the Mississippian Mount Head, Livingstone, and Banff Formations as well as the Devonian Fairholme Group.

The main episodes of orogenic and epeirogenic folding postdate the peak organic maturation produced after normal burial metamorphism. The relative timing of maturation and hydrocarbon generation with respect to trap formation is considered to be unfavourable in this play. Similar timing relationships exist throughout the Foothills of western Canada without appreciably depleting the hydrocarbon content of Laramide structures. The presence of large volumes of hydrocarbons in the structures suggest that either a subsequent period of hydrocarbon generation occurs after the structures form or a redistribution of predeformational stratigraphically-trapped hydrocarbons into later structures has occurred. A substantial play-level risk is assigned to reflect this timing problem. The fact that extensional forces that predominate in the graben could generate open fractures, implies that gas leakage could occur.

Numerous normal and thrust faults and fractures present in the area provide abundant opportunity for hydrocarbon migration. The presence of overlying and interbedded shales may provide seal in some cases. However, seal may be breached if faults intersect porous Kishenehn strata overlying the Paleozoics. The gas column could come in contact with this porous material and thus be lost. The seal risk-factor would in this case be prospect-level. Seal at a play-level would also be a problem in some cases since a large portion of the Paleozoic succession outcrops to the west of the Graben.

Fernie - Elk Valley Mesozoic Structural Gas Play

This play encompasses the Fernie Basin as well as the Elk River Valley north of the Basin (Figure 1). The play area is about 2100 square kilometres of which 99% of the territory is found in southeastern British Columbia. This hydrocarbon-bearing sedimentary basin is well-known as a coal mining area and numerous articles describe the geology with the coal and coal-bed methane potential (Gibson, 1985, Grieve and Kilby, 1989, Johnson and Smith, 1991, for example). There are many other papers as well (see reference list). The age range of possible hydrocarbon targets is Late Cretaceous to Late Triassic. Thin reservoir sands have been observed throughout the Mesozoic sequence.

Four wells have penetrated the Mesozoic succession in this play area. All wells penetrated coal seams but three were classified as dry holes. Coal-bed methane potential was realized in the fourth hole in the Elk River valley. The thickness of the prospect succession as well as the total succession varies from 1370 to 4500 metres depending on its location.

Hydrocarbon traps can form as a result of simple compressional folding, normal and reverse faulting, and extensional slumping that produce accommodation structures. It has been estimated that these structures were formed from Upper Cretaceous (Maastrichtian) to Oligocene time. Structural closure area varies from 15 to 1 square kilometre while vertical closure has been estimated to range from a maximum of 400 metres down to a minimum of 5 metres. Fifty prospects were estimated in this area.

Thin reservoir sands are found interspersed throughout the stratigraphic succession. It has been estimated that only 1% of the total succession would have suitable characteristics to be classified as reservoir. Secondary fracture porosity is possible due to open fractures occurring downhole in the wells drilled in the play. Porous sands and fracture zones vary in porosity from 8 to 36% while the average porosity noted in the sands would range from 10 to 15%.

Abundant source-rock material for gas is present in the coal seams of the Mist Mountain and Elk Formations as well as dark marine shales in the Wapiabi, Blackstone, and Rock Creek Formations. Type III and lesser amounts of Type II kerogens have been recognized within these sediments. Vitrinite reflectance values range from 0.6 to 1.6.

Generally, structure formation occurs subsequent to deposition of both reservoir and source rocks. This would suggest that primary hydrocarbons produced by normal burial maturation would not be trapped during the Laramide orogeny. Structures postdate the peak organic maturation episode but as demonstrated in the previous play this sequence of events does not preclude the existence of substantial hydrocarbon resources.

Migration should be no problem because of the abundance of faults that would provide pathways for fluid passage. Seal, however, is a problem in some instances since Mesozoic rocks outcrop throughout the play area. It has been estimated that there may be at least 30% communication of hydrocarbon-bearing sediments with the surface which would imply that these hydrocarbons would leak out and be lost. However, other prospects could have seal if there are enough interbedded and overlying shales to provide impermeable layers.

Structural characteristics are very similar to the Foothills Turner Valley Blairmore mature gas play. The lognormal discovery process model was used in evaluating this Foothills play. The mean and variance of the lognormal conditional pool size distribution was retrieved and used for the statistical input parameters for the evaluation of the Fernie - Elk Valley Mesozoic play. The mean of the conditional pool size distribution is 2.96 while the variance is 1.50.

Fernie - Elk Valley Paleozoic Structural Gas Play

The Paleozoic succession generally underlying the Mesozoic sediments in the Fernie Basin and Elk Valley constitute another structural gas play in the area (Figure 2). The play area is estimated to be 1850 square kilometres with 99% of the area in

British Columbia. Three wells penetrated the Paleozoic sequence in the play. No hydrocarbon shows were reported in the wells. Stratigraphic studies indicated that the Paleozoic succession varies in total thickness from 1980 to 3050 metres. The thickness of the prospect succession ranges from 1745 to 2540 metres.

Structure characteristics would be similar to those affecting the Mesozoic succession. Area of closure would again range from 15 to 1 square kilometre. Vertical relief is unknown, however. Age of structure formation would also range from Maastrichtian to Oligocene. There may be 50 prospects in this play as well.

Prospective reservoir rock is found in the Upper Mississippian Etherington Formation and continues intermittently down the stratigraphic column to the Middle Cambrian Elko Formation. The most important reservoir occurs in the Mississippian Turner Valley Formation. The majority of the reservoirs are both thick and thin carbonate porous intervals found in reef buildups, shelf edges, and shoal interiors. Reservoir thickness compared to thickness of the total Paleozoic succession ranges from 0 to 3.5%. Minor open-fracture zones may produce secondary fracture porosity. Porous carbonates and open-fracture zones vary in porosity from 8 to 35%. The average porosity in the reservoirs is 15%.

The gas source in this play is present in the coal seams of the Kootenay Group and the marine shales of the Fernie Group and Exshaw Formation. Solid pyrobitumens were noted in geological well logs in the Tunnel Mountain, Mount Head, Livingstone, and Banff Formations.

Structure generation postdates the hydrocarbon generation that would be produced during the peak organic maturation event. Similar episodes throughout the Foothills did not severely depreciate the hydrocarbon potential in Laramide traps. Migration would be easily facilitated due to the presence of numerous fault pathways. Seal would be accomplished in part with the presence of numerous interbedded and overlying siltstones and shales. Less risk would be assigned to seal in this play than the Mesozoic since most of the Paleozoic rocks do not outcrop.

This play was identified as being very similar in character to the Burnt Timber Wabamun/Palliser Foothills Play. The lognormally-derived pool size distribution from this Foothills play was used for the evaluation of the Fernie Paleozoic play. The mean and variance used was 5.719 and 1.192.

Rocky Mountain Trench Cenozoic Graben Gas Play

This play includes the Cenozoic sedimentary succession that has accumulated in the Rocky Mountain Trench of southeastern

British Columbia and northwest Montana (see Figure 1). The Cenozoic sediments include both the Tertiary clastic sediments as well as the Quaternary glacial drift. Insufficient information was available in order to segregate the Quaternary and Tertiary sequences. Therefore, the age range of prospects ranges from Pleistocene to Paleocene. The play encompasses an area of 5100 square kilometres of which 1325 or 26% of the area is found in British Columbia.

Fifteen wells have penetrated these sediments in this play. Two of the wells in the Flathead Lake produced small amounts of biogenic gas at one time.

The total succession as well as the prospect succession varies in thickness from 370 to 1830 metres depending on location in the Trench.

Hydrocarbon trap type are small-scale antithetic and synthetic normal and reverse faults within extensional grabens in the Trench, stratigraphic sandstone and conglomerate pinchouts in the sediments, and small drape folds in the graben. The structures noted above developed post- and syn-Oligocene, subsequent to and synchronous to sedimentation.

Many of the reservoir parameters in this play are unknown, such as area of closure, vertical closure, porosity and proportion of reservoir rock to total sediment thickness. Parameters associated with the Kishenehn Graben play can be used because of the similarity of tectonics and sedimentation in the two plays. The number of prospective structures estimated in this play are estimated to be four times the Kishenehn Play due to play area. Eight hundred structures were estimated compared to 200 at Kishenehn.

Thin sands and gravels constitute the reservoir fraction in the play.

The biogenic gas source in this play would be swamp and glacial drift gas pockets as well as peat deposits. Dark marine shales could produce some thermogenic gas.

Structure formation would generally predate or be synchronous with sedimentation and primary hydrocarbon generation due to normal burial maturation. The presence of reservoir is risky in this play since the potential reservoir material is found in channel deposits which would be quite local and unpredictable. Migration would be no problem because of the many fault pathways in the play. At a play-level, the risk of seal would be small because of the presence of numerous impermeable boulder clays and shales. At a prospect-level, seal could have a greater risk since these boulder clays and shales do not occur everywhere in the play.

It has been proven that this play would be classified as immature because of minor previous gas production. The significance of this play should be downgraded because the pools are probably very small.

Belt - Purcell Structural Oil and Gas Play

This play encompasses the oldest known sedimentary succession on the North American miogeocline. Six separate geological plays are recognized within these Proterozoic sediments. An eastern, central and western subdivision are proposed because of the widely varying amount of geological and petroleum information available throughout the basin. It was decided that the Belt - Purcell Basin should be divided into an immature, conceptual, and speculative zone respectively, in order to illustrate this information contrast. In addition, each of these divisions are assigned an oil and gas potential component.

Belt - Purcell Immature Structural Oil Play

This immature oil play is one of the oldest exploration plays discovered in western Canada. The first well drilled in Alberta was spudded beside some oil seeps in Proterozoic rocks in 1901 in what is now Waterton Park. This eastern division of the Belt - Purcell Basin covers an area of 19800 square kilometres in southeastern British Columbia, southwestern Alberta and west-central and northwestern Montana (Figure 3). Six hundred square kilometres of this play is found in B.C.(3%). Ninety-seven wells have been completed in the Proterozoic sediments and at least 52 oil shows in 24 of the wells were found. About 1000 barrels of oil had been produced at one time in this play (159 cubic metres). Numerous oil seeps are found in this play especially around the International Boundary (Boberg, 1984, Darrow, 1955, Hume, 1964, and Link, 1932). The thickness of the total sediment succession as well as prospect thickness varies from 2200 to 7200 metres.

Trap types in this play would involve compressional folding, drape folding of Precambrian strata over duplex structures in the the Lewis Plate, and traps produced by normal and reverse faults. Duplex structures and drape folds would have been formed during thrusting episodes. The largest area of closure observed over one of these duplex structures is approximately 800 square kilometres. The minimum area would be in the order of 0.5 square kilometres possibly associated with simple fault traps. The large areal extent of the play implies that a very large number of structures probably exists. Five thousand was chosen as the maximum number possible while 250 denotes the lower limit. Vertical closure of the largest structure was estimated to be about 300 metres while the smallest could be 10 metres.

The prospective zone considered in this play ranges from the Upper Proterozoic Horsethief Creek Group to the Middle Proterozoic Waterton Formation. All sediments in this succession have been metamorphosed to the lower greenschist facies which destroyed all primary porosity. The clean sandstones and carbonates in this play are brittle, so fracturing is probable and secondary fracture porosity could be present. There is a relatively small percentage of clays in this succession so many of the fractures should remain open or be sparsely cemented. The mean porosity estimate considering the whole rock volume is 0.1%. If hydrocarbons are present in these fractures, the hydrocarbon saturation should be relatively high.

Source rock has been speculated to be the Colorado Group Speckled Shales. Migration could be a significant risk factor because there is a substantial thickness of stratigraphic section through which fluids must migrate vertically before they encounter any Belt - Purcell sediments. During migration, the hydrocarbons would most likely enter Belly River and Cardium reservoir sands before invading any Proterozoic rocks. Seal would have some risk as well because extensional fractures could form in the brittle rock over hydrocarbon-bearing antiformal drape structures and leakage could occur. Fractures over synformal structures can form as well. In other circumstances, seal could be a positive risk factor if one considers that since all primary porosity has been removed from these rocks, the resultant dense sediments would act as impermeable barriers. Formation of structures postdate the hydrocarbon charge produced by normal burial maturation. The fact that many Laramide structures are filled to spill-point with hydrocarbons in the Foothills of western Canada implies that timing is not necessarily an unfavourable factor for accumulation of significant resources of hydrocarbons. No play-level risk would be assigned because the play is known to exist with the presence of former oil producers and oil seeps.

Belt - Purcell Immature Structural Gas Play

An immature gas play would occupy the same position in the eastern section of the Belt - Purcell Basin (Figure 3). In the 97 wells drilled to date in the play, at least 33 gas shows were logged in 11 wells. Most of the play parameters described in the oil section would apply to the gas component. However, gas source would more likely be the Exshaw shale which would be buried much deeper than the oil sources. The deeper burial would suggest a higher risk for source and migration because any gas produced at source would have to vertically migrate past a larger number of potential reservoirs before it arrives at the uppermost Belt - Purcell sediments. In addition to diversion of gas into the reservoir sands of the Belly River and Cardium Formations, migrating gas could also be deflected into the Paleozoic carbonates found in duplexes in the footwall of the Lewis Thrust as illustrated by the Waterton Field. Gas saturation would be relatively high varying from 70 to 95% in the open fractures.

Belt - Purcell Conceptual Structural Oil Play

The central portion of the basin was called the conceptual play because there are few wells and minor oil and gas shows. The play area is 45000 square kilometres located in southeastern British Columbia, west-central and northwestern Montana (Figure 3). Twenty- three wells were completed in the Proterozoic succession and at least 4 oil shows were encountered. Structure-type and closure components are similar to the previous Belt - Purcell plays. In this portion of the basin, duplex structures involving Precambrian sediments are prevalent and these structures would provide an additional trapping mechanism. There would be a very high risk factor for source rock because there are no underlying Phanerozoic rocks west of the Flathead normal fault. Seal would be a problem because much of the Proterozoic outcrops in this area.

Belt - Purcell Conceptual Structural Gas Play

Play parameters would be identical to the oil play. One gas show was identified in one of the 23 wells drilled in this play. Risk factors would be similar to the previous play.

Belt - Purcell Speculative Structural Gas Play

The western portion of the Belt - Purcell basin is found in southeastern British Columbia, northwestern and west-central Montana, and northwestern Idaho (see Figure 3). The play area is 62000 square kilometres. Only 2 wells in this huge area have been drilled. The lack of petroleum information available makes any assessment of this area highly speculative. At least 3 gas shows were identified in the 2 wells. Presumably, the play parameters would be very similar to the previous Belt - Purcell plays. Source- rock and migration as well as seal would again have high risk factors.

Belt - Purcell Speculative Structural Oil Play

One minor oil show was observed in the Paul Gibbs well in northwestern Montana (Boberg et al, 1989). This play is highly speculative in that thermal maturity characteristics suggest that these sediments should be in the gas window well out of the oil window.

The last four plays cited above were not assessed due to the lack of information as well as the very high risk associated with source, migration and seal. All these factors would be classified as play-level risks. The oil and gas potential is possible in these plays but it is highly speculative.

ASSESSMENT TECHNIQUE

After compilation of relevant material for each hydrocarbon play, an assessment committee assigned subjective and objective probabilities and risk factors for eight of the plays (see Appendix 1 for probabilities and risk factors and Appendix 2 for the statistical data retrieved). The risk factors were defined by discussing the geological characteristics of various play parameters and then deciding upon reasonable limits for these parameters. Analogous geological plays with similar tectonic settings were also considered. Once the probabilities and risk factors were compiled, Monte Carlo and lognormal approximation options in PETRIMES were used for the immature and conceptual plays (Lee and Wang, 1990). For the mature play, that is, the Waterton Rundle/Wabamun Gas Play, the "discovery process method" of PETRIMES was invoked.

The three remaining Foothills immature exploration plays required a separate assessment technique using empirical relationships. All mature Foothills plays were taken into consideration in order to derive the mean play potential for each of these immature plays. First of all, a linear regression was performed on a plot of volumetric proportion of resources discovered versus the number of pools discovered for all the Foothills plays (see Figure 4). The volumetric proportion of the resources discovered is defined as the ratio of discovered resource to total resource. If one calculates an error on this regression line, one can then retrieve an upper and lower limit for the volumetric proportion discovered for a given number of pools. One can also graphically retrieve the total number of pools expected (N) by plotting the proportion of pools discovered (n/N) versus the number of exploratory wells for the mature Foothills plays (see Figure 5). One can infer the proportion discovered from a regression analysis to the number of exploratory wells. Knowing n, (the number of pools discovered) and the number of exploratory wells drilled in each of the immature plays, one can then analytically retrieve N (the number of pools discovered). More work is required in order to determine the largest pool size of the immature plays. The pool sizes will be quite small compared to the mature Rundle/Wabamun Foothills play and should not affect the planning study.

A substantial portion of the area covered by the Waterton Foothills plays have not been explored in Montana due to park and wildlife land restrictions. This geographic bias may substantially affect the resource estimates. However, this is not expected to affect the portion of reserves located in British Columbia significantly because of the small area involved (about 4.5% of the total area in each play) (see Figures 1,2 & 3).

RESOURCE APPRAISAL

Following is a discussion of statistical results obtained for each play (see Appendix 2 for output data).

Waterton Colorado Foothills Gas Play

As described above, empirical and graphical techniques are used to obtain the mean play potential and expected number of pools for each of the immature Foothills plays in this assessment.

The total mean play resource, that is, the reserves discovered and the expected resource, is 6.7×10^9 m^3 or 238 BCF. The expected number of pools is 20. The gas resource figures cited above are raw gas-in-place values, not recoverable or marketable gas.

A small percentage of the areal extent of this play is found in British Columbia (4.4%). Therefore, the total mean play resource in British Columbia would be 296×10^6 m^3 or 10.5 BCF, assuming the resources are roughly evenly distributed. However, there is no reason that all or part of the largest pool cannot be found in B.C.

Waterton Mannville Foothills Gas Play

The expected number of pools is 33. The total mean play resource is 11.9×10^9 m^3 or 422 BCF of gas.

Again, a very small percentage of the areal extent of the play is located in British Columbia (4.5%). Therefore, the total play resource in B.C. would be 537×10^6 m^3 or 19 BCF. However, all or part of the largest pool could occur in B.C.

Waterton Mannville Foothills Oil Play

The play exists since two oil pools have been defined, specifically in the Pincher Creek Field. The expected number of pools is 33. The total mean play resource over the full areal extent is 78×10^6 m^3 or 491 million bbl.

In British Columbia, there would be expected a total mean play resource of 3.5×10^6 m^3 or 22 million bbl, assuming the resource is evenly distributed.

Waterton Rundle/Wabamun Foothills Gas Play

This mature play has been assessed using the "discovery process model" (Lee and Wang, 1990). Including updated information on the carbon dioxide-rich gas pools found in southeastern British Columbia, the discovered resource is 185.6×10^9 m^3 or 6.6 TCF. The mean play potential is 40.3×10^9 m^3 or 1.4 TCF. Therefore, the total expected resource in this play would be the sum of the discovered and mean play potential, that is, 225.9×10^9 m^3 or 8 TCF. The largest pool has already been discovered according to the model (see Figure 6). This pool is found in the Waterton Field and its size is 79.5×10^9 m^3 or 2.8 TCF. The expected number of pools in the play is estimated to be 80 so with 26 pools already discovered, 54 more gas pools are yet to be found.

The two pools discovered in British Columbia probably form the largest part of the available resource in the Province. The total expected resource in B.C. if the resources are evenly distributed throughout the play is 11.1×10^9 m^3 cubic metres or 390 BCF. However, as noted in the previous section of this report, 17×10^9 m^3 have already been discovered in B.C. This implies therefore, that the resource is not evenly distributed in this play. This may be explained by observing the relative size of the Flathead duplex compared to the Waterton duplex to the east. The Flathead duplex is larger in size and thus, may contain larger reserves of gas. It is suggested that the remaining resource yet to be discovered in British Columbia is at least 2×10^9 m^3 or 70 BCF of gas. It should be emphasized that all the gas discovered in the Province is carbon dioxide-rich rather than hydrocarbon-rich. This resource could be used for enhanced oil recovery.

Kishenehn Tertiary Graben Gas Play

The overall play risk assigned to this play is 90%. The prospect-level risk is estimated to be about 50%. The greatest risk at a prospect-level was assigned to the presence of closure and source. The median of the largest pool size was calculated to be 3.1×10^9 m^3 or 109 BCF (see Figure 7). Fifty pools are expected to exist in this play. The total mean play potential is 17.9×10^9 m^3 (632 BCF).

In British Columbia, 17% of the areal extent of the play is present. Therefore, 3×10^9 m^3 (107 BCF) can be potentially present, assuming the resources are roughly evenly distributed.

Kishenehn Tertiary Graben Oil Play

The overall play- and prospect-level risks in this play would be identical to the gas play. The median of the largest pool size is 9.1×10^6 m^3 or 57 million bbl (Figure 8). There are expected to be 50 oil pools in the Kishenehn Basin. The total mean play potential would be 60.7×10^6 m^3 (382 million bbl).

Seventeen percent of the mean play potential would be 10.3×10^6 m^3 (65 million bbl). This figure would represent the potential in B.C. if the resources are evenly distributed throughout the play.

MacDonald Paleozoic Structural Gas Play

Timing of structure formation compared to hydrocarbon generation was considered to be a large play-level risk in this area. The probability that the play exists was estimated to be 0.5. Another important risk identified in the play is the presence of adequate seal. On a prospect-level, seal was identified to have a risk of 25%. The overall exploration risk was calculated to be 13%. The mean play potential estimated in this play is 3.4×10^9 m^3 (121 BCF) of gas. Five gas pools are expected to exist in this play. The largest pool size has a median value of 1.8×10^9 m^3 (64 BCF) (Figure 9).

Twelve percent of the areal extent of the play is found in British Columbia. If the resources are evenly distributed, the mean play potential in the Province should be 411×10^6 m^3 (14.5 BCF) of gas.

Fernie - Elk Valley Mesozoic Structural Gas Play

Risk was assigned principally to seal in this play since the Mesozoic outcrops in a large proportion of the area. The probability that leakage of hydrocarbons could occur is 0.30. Along with a less severe risk assigned to closure, the overall prospect-level risk is estimated to be 27%. The calculated mean play potential of the Fernie Mesozoic area is 203×10^6 m^3, that is 7 BCF of gas. Note that this gas figure is for conventional natural gas and is in addition to any coal-bed methane that may be present in the area. Five gas pools are expected to exist with the largest pool size at 81×10^6 m^3 (3 BCF) (Figure 10).

Virtually all of the play is located in British Columbia, so the above figures can be used as gas potential in the Province.

Fernie - Elk Valley Paleozoic Structural Gas Play

Seal risk was upgraded to 50% in this play because the Paleozoic sediments are less likely to outcrop. The overall play-level risk was estimated to be 90% while at the prospect-level, risk is 45%. Nine expected gas pools with a potential of 5.1×10^9 m^3 (182 BCF) are present in this play. The median of the largest pool size is $1.5x10^9$ m^3 million cubic metres (53 BCF) (Figure 11). These figures would apply for the potential of this play in British Columbia.

Rocky Mountain Trench Cenozoic Graben Play

The play-level risk assigned to this play is 100%. This means that the play definitely exists. Previous gas production in two water wells near Flathead Lake confirms the existence of the play. It must be pointed out, however, that this play is probably not very significant because of very small pool sizes. Prospect-level risk was estimated to be in the order of 38%. Seal and source are considered to be the major factors affecting overall exploration risk in the play. One hundred and seventy small pools are expected to exist here with a total mean potential of $849x10^6$ m^3 (30 BCF). The largest pool size is expected to be $79.2x10^6$ m^3 (3 BCF) of gas (Figure 12). Twenty-six percent of the play is located in British Columbia. Therefore, the potential in the Province is $221x10^6$ m^3 (8 BCF).

Belt - Purcell Immature Structural Oil Play

This play exists with the presence of former producers as well as numerous oil seeps. Prospect-level risk would be severely affected by seal considerations in that a large proportion of the Proterozoic succession outcrops. Migration risk and closure risk pose less a problem for hydrocarbon potential in this play. The median of the largest pool size expected is $8x10^5$ m^3 (5 million bbl.) (Figure 13). The expected number of pools is 55. The total mean potential is estimated to be $4.5x10^6$ m^3 (28 million bbl).

Only 3% of the total area of the play is found in British Columbia. Assuming the potential oil resource is evenly distributed in the play, the resource should be $13.5x10^4$ m^3 (850,600 bbl).

Belt - Purcell Immature Structural Gas Play

Equivalent risk factors used in the previous play would apply to the gas play. The median of the largest pool size would therefore, be $118x10^6$ m^3 (4 BCF) while the expected number of pools would be 35 (Figure 14). The total mean potential of gas in this play is $622x10^6$ m^3 (22 BCF). Again, British Columbia contains 3% of the area of this play. Therefore, the mean play potential in the Province should be $18.7x10^6$ m^3 (0.7 BCF).

SUMMARY AND CONCLUSIONS

1. The discovery of two gas pools in the Waterton Colorado

Foothills Gas Play classifies it as an immature play. Graphical solutions employing data from the Foothills mature plays are used to obtain total potential resources in the immature plays. The mean ultimate play resource derived is $6.7x10^9$ m^3 (238 BCF).

2. The Waterton Mannville Foothills Gas Play is an immature play because of the presence of 3 defined gas pools. It was determined that the ultimate mean play resource is $11.9x10^9$ m^3 (422 BCF).

3. The Waterton Mannville Foothills Oil Play has 2 defined oil pools. The mean ultimate play resource is $78x10^6$ m^3 (491 million bbl).

4. The mature Waterton Rundle/Wabamun Foothills Gas Play has 26 discovered pools. Total potential in this play is $40.3x10^9$ m^3 or 1.4 TCF of gas. In British Columbia, the total expected resource is $11.1x10^9$ m^3 (390 BCF) of gas if the resource is evenly distributed throughout the total play area. However, $17x10^9$ m^3 of gas has already been discovered in the Province. This implies that the gas resource is not evenly distributed and it is thus estimated that at least $2x10^9$ m^3 (70 BCF) is yet to be found in B.C.

5. The conceptual Kishenehn Tertiary Graben Gas Play is an excellent prospective geological configuration as reflected in play-level risks, 90%. Hydrocarbons are noted in other similar configurations around the world (southern Junggar Basin, China, or Orcadian Basin, North Sea area)(Carroll et al, 1992, Parnell, 1985). The total mean gas potential of this play is $17.9x10^9$ m^3 (632 BCF).

6. The conceptual oil play in the Kishenehn Graben is an excellent prospective site as well. Abundant oil shales in the basin guarantee oil source. The total mean oil potential in this basin is $60.7x10^6$ m^3 (382 million bbl).

7. In the MacDonald Paleozoic Structural Gas Play, both play and prospect risk are significant in the potential gas resource assessment. Seal is a major problem here because a large majority of the Paleozoic reservoir rocks outcrop. In addition, the Paleozoics underlying the Tertiary sediments in the Kishenehn Graben may abut against porous sediments where leakage can also occur. A total mean potential of $3.4x10^9$ m^3 was estimated in this area (121 BCF).

8. The Fernie - Elk Valley Mesozoic Structural Gas Play has a total mean potential of $203x10^6$ m^3 (7 BCF) of gas. Seal is a major risk because a large proportion of the Mesozoic sediments outcrop in the basin. Coal- bed methane is a separate resource and is not included in this report.

9. In the Fernie - Elk Valley Paleozoic Structural Gas Play, both play and prospect-level risk are somewhat less and the total mean gas potential is $5.1x10^9$ m^3 (182 BCF).

10. The Rocky Mountain Trench Cenozoic Graben Gas Play tectonically is similar to the Kishenehn Graben. Play parameters identified in the Kishenehn were incorporated into the Trench resource analysis. Play-level risk is non-existent because production occurred at one time. The ultimate mean play potential is $849x10^6$ m^3 (30 BCF) in very small pools.

11. The Belt - Purcell Immature Structural Oil Play is the oldest play recognized in western Canada. The first oil well was drilled in this play in 1901. Former oil production and numerous oil seeps prove that this play exists. The total mean oil potential in this play is $4.5x10^6$ m^3 (28 million bbl).

12. The Belt-Purcell Immature Structural Gas Play is also known to exist. The total mean gas potential is $622x10^6$ m^3 (22 BCF).

13. The Belt - Purcell Conceptual and Speculative Oil and Gas Plays are conceptual plays in Proterozoic sediments that are found in areas where little or no geological information is available. Also, source and seal have very high risk factors at the play-level which implies a very speculative hydrocarbon potential computation would result. It was decided for these reasons that insufficient information is available to properly assess the hydrocarbon potential of these plays.

14. The total gas potential for all plays in this assessment is $272.7x10^9$ m^3 or 9.6 TCF. If the gas resources are evenly distributed throughout the total area of the Kootenay assessment, the total potential resource in British Columbia is $20.9x10^9$ m^3 (739 BCF).

15. The oil potential for the entire Kootenay assessment area is $143x10^6$ m^3 (901 million bbl.). In British Columbia the total oil potential is $13.9x10^6$ m^3 (88 million bbl.) if the resources are evenly distributed.

Statistical results for twelve plays identified in the Kootenay area of British Columbia suggest a significant undiscovered oil and gas potential.

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APPENDIX 1: PROBABILITY DISTRIBUTIONS AND RISK FACTORS
(INPUT DATA)

APPENDIX 2: STATISTICAL OUTPUT

FIGURE CAPTIONS

Figure 1: Hydrocarbon play map (Waterton Colorado (Gas), Kishenehn Tertiary Graben (Oil & Gas), Fernie - Elk Valley Mesozoic Structural (Gas), and Rocky Mountain Trench Cenozoic Graben (Gas))

Figure 2: Hydrocarbon play map (Waterton Rundle/Wabamun (Gas), MacDonald Paleozoic Structural (Gas), and Fernie - Elk Valley Paleozoic Structural (Gas))

Figure 3: Hydrocarbon play map (Waterton Mannville (Oil & Gas), Belt - Purcell Structural Immature (Oil & Gas), Belt - Purcell Structural Conceptual (Oil & Gas), and Belt - Purcell Structural Speculative (Oil & Gas))

Figure 4: Plot of volumetric proportion of resources discovered versus number of pools discovered, WCSB Foothills gas plays

Figure 5: Plot of proportion of pools discovered versus number of exploratory wells, WCSB Foothills gas plays

Figure 6: Pool size by rank diagram of the Waterton Rundle/Wabamun Foothills Gas Play

Figure 7: Pool size by rank diagram of the Kishenehn Tertiary Graben Gas Play

Figure 8: Pool size by rank diagram of the Kishenehn Tertiary Graben Oil Play

Figure 9: Pool size by rank diagram of the MacDonald Paleozoic Structural Gas Play

Figure 10: Pool size by rank diagram of the Fernie - Elk Valley Mesozoic Structural Gas Play

Figure 11: Pool size by rank diagram of the Fernie - Elk Valley Paleozoic Structural Gas Play

Figure 12: Pool size by rank diagram of the Rocky Mountain Trench Cenozoic Graben Gas Play

Figure 13: Pool size by rank diagram of the Belt - Purcell Immature Structural Oil Play

Figure 14: Pool size by rank diagram of the Belt - Purcell Immature Structural Gas Play