

**OIL AND GAS RESOURCE POTENTIAL OF THE
BOWSER-WHITEHORSE AREA OF BRITISH COLUMBIA**

by Peter Hannigan, P. J. Lee, and K. G. Osadetz

Petroleum Resources Subdivision
Geological Survey of Canada - Calgary
3303 - 33 Street N. W.
Calgary, Alberta
T2L 2A7
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SUMMARY

Syntectonic Jura-Cretaceous sediments represent the principal basin fill in three strongly-deformed intermontane basins (Bowser and Sustut Basins and Whitehorse Trough). These basins are mainly gas-prone with smaller areas exhibiting oil generation characteristics. The hydrocarbon plays defined in this assessment incorporate variably preserved Permian to Recent strata. The development of reservoir occurs in fractured Late Paleozoic siliceous carbonates, Triassic reefal mounds and associated shallow-water platformal carbonates, Jura-Cretaceous non-marine fluvial and marginal to deep-water marine clastics, and in unconsolidated Quaternary till and alluvium. Seal is principally provided by Jura-Cretaceous shale in these basins although fine-grained volcanics and tight carbonates also contribute to the sealing potential in some instances. Source material has been identified within Jura-Cretaceous and Jurassic shales, Lower Permian black shales and minor interspersed coal seams. The most important trapping mechanism for hydrocarbon accumulations are anticlinal structures that have been complicated further by at least four episodes of intense faulting. Stratigraphic traps are also recognized throughout the sequence. Structural traps were formed both contemporaneously and subsequent to hydrocarbon generation. All of these basins are very immature with respect to exploration. Two wells have been drilled in the Bowser Basin while no exploratory drillholes have been attempted in the other two basins.

Seventeen hydrocarbon plays have been identified in the Bowser-Whitehorse area of north-central British Columbia and southern Yukon. The plays are:

1. Bowser Skeena Structural Gas Play,
2. Bowser Skeena Structural Oil Play,
3. Bowser Mid-Jurassic-Lower Cretaceous Structural Gas Play,
4. Sustut Upper Cretaceous Structural Gas Play,
5. Sustut Upper Cretaceous Structural Oil Play,
6. Northern Rocky Mountain Trench Sifton Structural Gas Play,

7. Whitehorse Cenozoic Stratigraphic Gas Play,
8. Whitehorse Tantalus Structural Gas Play,
9. Whitehorse Tantalus Structural Oil Play,
10. Whitehorse Takwahoni Structural Gas Play,
11. Whitehorse Takwahoni Structural Oil Play,
12. Whitehorse Takwahoni Stratigraphic Gas Play,
13. Whitehorse Takwahoni Stratigraphic Oil Play,
14. Whitehorse Inklin Structural Gas Play,
15. Whitehorse Lewes River Structural Gas Play,
16. Whitehorse Lewes River Stratigraphic Gas Play, and
17. Whitehorse Taku Fractured Carbonate Gas Play.

The Bowser Skeena, Bowser Mid-Jurassic-Lower Cretaceous, Sustut Upper Cretaceous, Northern Rocky Mountain Trench Sifton, Whitehorse Tantalus, Whitehorse Takwahoni, Whitehorse Inklin, and Whitehorse Lewes River Structural Oil and Gas Plays have no established reserves or production and, therefore, are conceptual. The remaining five plays are classified as speculative, meaning insufficient petroleum geological information was available to properly assess potential hydrocarbon reserves. The conceptual plays were assessed using current practices employed at the Geological Survey of Canada.

The total oil and gas potential for the entire Bowser-Whitehorse assessment area is 4.0×10^8 m³ (2.52 billion barrels) and 3.89×10^{11} m³ (13.7 TCF), respectively.

Good hydrocarbon potential is recognized in Skeena and Upper Cretaceous clastic sediments deposited in the Bowser and Sustut Basins. Laberge Group basin-fill sediments in the Whitehorse Trough are favourable areas for hydrocarbon accumulation.

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. This work constituted Phase I of the information requested by the Ministry. Phase II, which involved the oil and gas potential of the Kootenay area of southeastern area of British Columbia, was submitted in April of 1993. An oil and gas assessment was then performed for the Nechako-Chilcotin area of south-central British Columbia. That report was presented in September 1994 representing Phase III. This report deals with the final phase which describes the results obtained from an oil and gas assessment of the Bowser-Whitehorse region of northern British Columbia and southern Yukon. 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.

All of the plays analyzed statistically in this assessment were defined as conceptual and the pool-size distributions were generated using probability distributions of geological variables substituted into the standard pool-size equation. Prospect-level and play-level risks were assigned to each play prior to analysis.

Following compilation of pertinent geological information in the Bowser-Whitehorse area of British Columbia as well as adjacent Yukon Territory (see reference list), seventeen geological hydrocarbon plays were recognized. Five of these plays have oil potential while the remainder are gas prospects. The play boundaries are illustrated on Maps 1 to 5.

Basins included in this study are the Bowser Basin, Sustut Basin, Whitehorse Trough and the Northern Rocky Mountain Trench.

Immediately apparent on the tectonic map of the Cordillera is the vast area covered by the Bowser Lake Assemblage of sediments in the Bowser Basin (Wheeler and McFeely, 1991). Very limited well control and complex tectonic and structural histories complicate the definition of the physical boundaries of the basins. Before defining any petroleum plays, it was necessary to compile and analyze the numerous tectonic and orogenic episodes and depositional events in the Intermontane

Belt of the Cordillera. The affiliation of basins with exotic terrane as well as the timing of accretion onto the continent were important elements used in interpreting the tectonic histories of each basin. Transgressive and regressive cycles were significant events in the formulation of depositional histories. Thicknesses of sedimentary and volcanic successions and identification of major unconformities were important geological criteria required to properly establish petroleum exploration plays.

Prior to the beginning of the Mesozoic Era, widely scattered volcanic arcs with associated oceanic plateaus in Panthalassa were separated from the west coast of ancestral North America by back-arc basins. In the study area, the arc is represented by the Nicola calc-alkaline assemblage in Quesnellia and the Hazelton low-alkali calc-alkaline volcanic succession in Stikinia. The Cache Creek assemblage represents an oceanic platform succession in the fore-arc that formed as an accretionary prism above a subduction zone (Souther, 1991). Overlap sedimentary successions such as the Bowser Lake, Skeena and Laberge Groups represent accretionary response assemblages that were derived from the amalgamation of Stikinia, Cache Creek and Quesnellia terranes forming the Intermontane Superterrane. This amalgamation episode could have occurred as early as the Late Triassic. These three terranes were at least loosely amalgamated by Pliensbachian time in the Whitehorse area due to the interfingering of Lower Jurassic sediments derived from separate terranes. The Intermontane Superterrane was formed previous to accretion to the North American continent. A thrusting episode commencing in Bajocian time, where the Cache Creek Terrane is thrust southwestward over Stikinia in northern British Columbia, may represent the accretion of the Intermontane Superterrane on to the continent. In southern B. C., accretion is represented by thrusting of the Cache Creek Terrane eastwards over Quesnellia in Late Jurassic time.

The Early Jurassic embraces a fundamental shift from terrane-specific geological processes of plutonism, volcanism and sedimentation to the development of overlap assemblages starting in the Middle Jurassic.

Lower to Middle Jurassic volcanic and volcanoclastic Hazelton Group rocks comprise a complex of island arcs surrounding Bowser, Sustut and Nechako Basins (Gabrielse and Yorath, 1991c). The development of the Skeena and Stikine Arches in the Early Jurassic influenced Jurassic deposition and tectonics in Stikinia. These arches separated and delineated the proto-Bowser, Nechako and Whitehorse basins. The Whitehorse Trough developed to the north of the Stikine Arch while the ancestral Bowser shale basin lies between the two arches. All of these basins, arches and volcanic belts are interrelated as one complex island arc terrane. However, the stratigraphic continuity is lacking between the various elements; thus the separation of Whitehorse and Bowser basins. Accretion of the Intermontane Superterrane onto North America most likely terminated in the mid-Jurassic.

Cordillera-wide erosion with the development of a major unconformity occurred in the Early Cretaceous before another episode of uplift in the Cordillera assisted in the deposition of the marine Aptian to Cenomanian Skeena Group assemblage in the Cordillera and equivalent Blairmore Group in the Rocky Mountain foredeep. Thick clastic marine and non-marine sediments

were shed eastward from the Omineca Belt into the Sustut and Skeena Basins (Gabrielse and Yorath, 1991c). Post-accretionary deposition of Late Cretaceous to Paleocene marine and non-marine sediments are represented by westerly-derived rocks in the Sustut and Nechako Basins and the Brazeau Assemblage in the foredeep of the Rocky Mountain Foreland Belt. Extensional tectonics commenced in the mid-Eocene and continued to Recent time with concomitant block-faulting producing fault-bounded valleys where non-marine sediments have accumulated (Sifton and Tantalus Formations).

The Bowser Basin, located in north-central British Columbia, contains three oil and gas plays defined in Jurassic to Cretaceous sediments (Maps 1-3).

The Sustut Basin has two hydrocarbon plays defined in the Sustut assemblage. The older Tango Creek Formation of the Sustut Group is equivalent in age to the upper Skeena Group. (Maps 1-2).

Eleven oil and gas plays in Late Paleozoic to Quaternary sediments have been proposed within the Whitehorse Trough (Maps 1- 5).

One biogenic gas play has been defined in Paleocene sediments in the Northern Rocky Mountain Trench (Map 1).

Seventeen oil and gas plays have been designated in the area. They are the:

- 1) conceptual Bowser Skeena Structural Gas Play,
- 2) conceptual Bowser Skeena Structural Oil Play,
- 3) conceptual Bowser Mid-Jurassic-Lower Cretaceous Structural Gas Play,
- 4) conceptual Sustut Upper Cretaceous Structural Gas Play,
- 5) conceptual Sustut Upper Cretaceous Structural Oil Play,
- 6) conceptual Northern Rocky Mountain Trench Sifton Structural Gas Play,
- 7) speculative Whitehorse Cenozoic Stratigraphic Gas Play,
- 8) conceptual Whitehorse Tantalus Structural Gas Play,
- 9) conceptual Whitehorse Tantalus Structural Oil Play,
- 10) conceptual Whitehorse Takwahoni Structural Gas Play,
- 11) conceptual Whitehorse Takwahoni Structural Oil Play,
- 12) speculative Whitehorse Takwahoni Stratigraphic Gas Play,
- 13) speculative Whitehorse Takwahoni Stratigraphic Oil Play,
- 14) conceptual Whitehorse Inklin Structural Gas Play,
- 15) conceptual Whitehorse Lewes River Structural Gas Play,
- 16) speculative Whitehorse Lewes River Stratigraphic Gas Play, and
- 17) speculative Whitehorse Taku Fractured Carbonate Gas Play.

The Whitehorse Tantalus Structural Oil and Gas Plays, the Whitehorse Takwahoni Structural and Stratigraphic Oil Plays, and the Whitehorse Lewes River Stratigraphic Gas Play are

located entirely within the Yukon Territory (Maps 1-4). These plays are described and the results are presented in a separate addendum at the end of this report. The hydrocarbon resources statistically determined in these plays may be of interest with respect to transportation corridors needed for export through the Province.

GEOLOGICAL SETTING AND PLAY PARAMETERS

Bowser Skeena Structural Gas Play

The Skeena Group of marine and non-marine sediments are preserved around the southern margin of the Bowser Basin. Skeena Group-equivalent sediments have also been mapped in the interior of the basin in the Groundhog coal field (MacIntyre et al, 1994) and have been included in the play. A regular orthogonal pattern of block faults on the margin represent domal uplifts that preserve these sediments on horst structures (Gabrielse et al, 1991a). The Skeena Group rests unconformably on the Hazelton Group and paraconformably on the Bowser Lake Group. A marine transgression in Albian time provided marine to nearshore depositional sites. Mid-Cretaceous uplift of the Omineca Belt resulting from the collision of Stikinia with the Cache Creek Terrane provided the source material for deposition of Skeena Group sediments in the Sustut Basin and Bowser Basins in northern British Columbia (Gabrielse et al, 1991d). Skeena Group sedimentation is thus characterized as an accretionary response assemblage. The boundaries for this play are illustrated on Map 1.

The play encompasses an area of 9400 square kilometres. No wells have been drilled and no hydrocarbon shows have been reported. Total succession thicknesses vary from 300 to 2800 metres (Gabrielse et al, 1991d; Hunt, 1992; Koch, 1973).

Petroleum trap-types that have developed in the play reflect the compressional tectonic regime associated with terrane accretion taking place from mid-Jurassic to mid-Eocene and subsequent extensional tectonic structures developed from mid-Eocene to Recent time. Structure trap-types encountered in the play are simple compressional anticlinal folds, folds associated with thrust faults, and normal block fault traps. Compressional tectonics form the anticlinal and thrust fault traps while block fault structures are associated with extensional tectonics. Both the Sustut Basin located to the northeast of Bowser Basin and the Nechako Basin to the south were used as analogues in identifying and limiting trap sizes and estimating number of prospects. The largest structure found in the Nechako Basin was an anticlinal fold with an area of closure of 175 square kilometres and a vertical closure of 1000 metres. These dimensions were used in this assessment. Average estimated closure area varies from 10 to 90 square kilometres as measured on the structural map of the Sustut Basin (Eisbacher, 1974). Block fault and thrust fault traps have a minimum area of closure of 1 square kilometre. The estimated mean amplitude for the numerous

folds identified in the Sustut Basin varies from 100 to 300 metres (Eisbacher, 1974). Minimum vertical closure is interpreted to be one metre. If one determines the number of structures present in the Sustut Basin and apply it proportionately by play area in the Bowser Basin, a mean of 500 prospects is estimated. The maximum number of structures for the play is inferred to be 1000.

Thin reservoir sands within the marine and non-marine shale and sandstone succession are characteristic of this play. Estimated proportion of reservoirs compared to total thickness varies from 0 to 7%. Porosity ranges from 5 to 15% in the porous sands with an average of 10%. Secondary fracture porosity does develop in parts although most fractures are plugged with cementing material.

Vitrinite reflectance on surface outcrops of Skeena Group rocks vary from 0.35 to 5.60 (Hunt, 1992; Ryan 1992; Ryan and Dawson, 1994). In coal exploration drillholes at the Telkwa coal field, vitrinite reflectance varies from 0.80 to 1.55 (Ryan, 1992). In outcrop, TOC varies from 0.00 to 55.19. Nine out of 108 samples show very good TOC values ranging from 2.03 to 55.19 (Hunt, 1992). In outcrop, seven out of 108 samples show moderate to good gas-generating potential. Coal-bed methane is present in the Telkwa coal field. The estimated resource is 3.7 billion cubic metres or 131 BCF (Ryan and Dawson, 1994). Organic matter is dominantly classified as Type III material, with lesser amounts of Type I and II. Source rocks consist of carbonaceous and bituminous shales and sandstones, along with coal in parts.

Trap-forming structures in the play developed from mid-Jurassic to Recent time. These structures thus evolved previous to, contemporaneously and subsequent to hydrocarbon generation. The presence of numerous faults and fractures, some of which are open, produce opportunities for migration of fluids in these sediments. Geochemical maturity factors in numerous individual samples indicate that migration has taken place. In these samples, Tmax values of greater than 435°C. are indicative of mature source rocks while production index values (S1/S1+S2) of <0.1 represent immature source material. Low production index values imply that migration of earlier formed S1 hydrocarbon away from the source strata has occurred. A significant area of Skeena Group sediments outcrop in the play so some risk to seal is applied even though numerous overlying and interbedded shales may provide a seal in some instances. Risk has also been assigned to the preservation of hydrocarbons that reflect the possibility of the breaching of structures (Appendix 1).

Bowser Skeena Structural Oil Play

The oil play occupies a somewhat smaller area compared to the gas due to the exclusion of the Groundhog area found in the centre of basin (compare Maps 1 and 2). Rocks are overmature with respect to oil generation and preservation, in the Groundhog coal field. In the remainder of the basin, the two play areas coincide. The reduced play area is now 7500 square kilometres. No oil shows have been reported in this play. Reservoir parameters are similar to the previous play. One sample out of 108 collected, show moderate oil-generating potential.

Bowser Mid-Jurassic-Lower Cretaceous Structural Gas Play

The Bowser Lake Group of sediments of mid-Jurassic to Lower Cretaceous age occupies a very large proportion of the Bowser Basin (see Map 3). The Bowser Basin encompasses the area between the Stikine and Skeena Arches on Stikinia Terrane. A play area of 54,200 square kilometres has been interpreted. The Bowser Lake Assemblage consists of clastic sediments that represent a foredeep where coarse-grained non-marine molasse progrades over fine-grained marine basinal flysch (Gabrielse et al, 1991d). Delta and pro-delta channel deposits and turbidites are overlain by alluvial and paralic deposits. The source for Bowser Lake Group sediments in the northern part of the basin was the marine Cache Creek Assemblage found in the Cache Creek Terrane that is situated to the north and east. The emergent Skeena Arch provided the source material for Bowser rocks in southern Bowser Basin. No contribution of sedimentary material from the Omineca or Coast Belts have been reported during Bowser deposition. Early to Middle Jurassic volcanics and volcanogenic sediments of the Hazelton Group surround the Bowser Basin. The upper and thickest part of the Bowser succession contains coal seams of anthracite rank. The Bowser Group is overlain unconformably by the non-marine Sustut Group on the northern and eastern margins of the basin and the marine and non-marine Skeena Group on the southern margin and in the central Groundhog area. Two hydrocarbon exploration wells have been completed in the play and both wet and dry cuttings gas was reported from one of the boreholes. The Bowser succession is up to 3500 metres thick. However, prospect thickness is interpreted to vary from 0 to 800 metres thick.

Most of the deformation in the Bowser Basin occurred in the mid-Jurassic to Tertiary interval while hydrocarbon generation arose in the Late Mesozoic. Therefore, structures developed before, contemporaneously, and subsequent to hydrocarbon generation. Simple compressional folding producing broad en echelon folds generates the main trap-type of the play; the large anticlinal structures. The folds are variable in this play; ranging from concentric to chevron and open to closed (Gabrielse et al, 1991a). In addition, drag folds associated with thrust faults are potential sites for hydrocarbon accumulation in this play. Often the thrusts are hard to recognize due to the lack of marker horizons and the presence of faults parallel to bedding planes. Normal block fault traps are also present, especially near the Skeena Arch. The underlying Hazelton Group which is deformed into broad warps is separated from the Bowser Group rocks by a decollement surface. Compressional tectonics in the mid-Jurassic to mid-Eocene interval generated the folds and thrust fault folds, while the extensional block faulting episode occurred post mid-Eocene. The largest area of closure has been identified as the Owegee Dome at 180 square kilometres. Another significant structure is the Ritchie Anticline with an area of closure of 65 square kilometres. The two wells in the play were drilled on this structure. The estimated mean area of structural closure is 10 square kilometres while the minimum is one square kilometre. Vertical closures range from 20 to 1000 metres with a mean of 100 metres. Structures occur up to 2000 metres below surface. Number of prospects range from 300 to 6000 with a mean of 3000.

A major risk associated with this play is the general lack of porosity in outcrop and in wells. Interspersed very thin porous sandstones and conglomerates represent the reservoir facies in the

play. Reservoir is represented in <1% of the total succession. Secondary fracture porosity is not known in the Bowser Lake Group rocks.

Geochemical studies give vitrinite reflectances with a range of 1.43 to 5.80% in Bowser Lake Group rocks. Paleotemperatures range from 220 to 260°C. implying the hydrocarbon generated would be methane only. Black, organic-rich shale of the Early Jurassic Spatsizi Group underlies the Bowser Group in northern Bowser Basin and represents potential source material. Organic-rich shales and coal seams are also interbedded within the Bowser Lake succession. One geochemical sample at the southern margin of the basin revealed good gas-generating potential. However, most of these rocks show prehnite-pumpellyite to subgreenschist-grade metamorphism which is indicative of dry gas or no hydrocarbon potential.

The presence of numerous faults and fractures in the play provide some opportunity for migration of hydrocarbons. Abundant overlying and interbedded shales may provide seal in some cases. Immense areas of Bowser Group rocks do outcrop which may contribute to leakage of hydrocarbons in certain areas due to breaching of structures or removal of seal by erosional processes.

Sustut Upper Cretaceous Structural Gas Play

The petroleum play defined as the Sustut Upper Cretaceous Structural Gas Play is found within the Sustut Basin which is located northeast of the Bowser Basin (Map 1). The interval of interest incorporates the Sustut Group of rocks ranging in age from Cenomanian to Maastrichtian (possibly to Eocene(?)). The oldest sediments are equivalent in age in part to the Skeena Group. The Sustut interval ranges in thickness from 300 to 2600 metres. No wells or shows have been reported in this play. Play area is estimated to be about 9825 square kilometres.

In the basin, the Sustut Group sediments reveal a record of mid-Cretaceous uplift of the Omineca Belt to the east and mid- to Late Cretaceous uplift of the Coast Belt and the western part of the Bowser Basin to the west (Gabrielse et al, 1991d). The metamorphic terranes of the Omineca source is represented by ubiquitous muscovite in the Sustut sediments. Mid- to Late Cretaceous magmatism associated with uplift in the Coast Belt and the Skeena Arch is also revealed in these sediments. The non-marine Sustut Group consists of the older Tango Creek Formation overlain conformably and unconformably by the Brothers Peak Formation. The fluvial Tango Creek Formation rests unconformably on the Bowser Lake Group in the western part of the basin and on the Hazelton Group on the eastern and northern margins. Interbedded sandstone, conglomerate and mudstone with local lenses of lignite make up the formation. The Tango Creek Formation is sourced by two principal river systems from the Omineca Belt. The younger Brothers Peak Formation has a basal conglomerate that represents a significant uplift of the Coast Belt and western side of Bowser Basin to the west. The overlying pebbly sandstones and mudstones are introduced to the basin from the northeast and then transported to the southwest and south along the main axis of the basin by fluvial processes (Gabrielse et al, 1991d).

The Tuya and Nahlin Basins on the lower reaches of the Tuya and Tanzilla Rivers and along the Nahlin River have been included in this play. These coarse, non-marine Eocene rocks are roughly located along trend with the Sustut Basin but separated by a fault. No direct paleogeographic evidence links these basins, however. The sequence contains conglomeratic sandstones, shale and carbonaceous shale along with abundant seams of lignite (Gabrielse et al, 1991d).

In the Sustut Basin, there are two fundamentally different structural zones; the eastern part of the basin resting unconformably on the Hazelton-Takla volcanic and plutonic terrane and the western section resting on the Bowser Lake Group. Broad, open folds with gentle dips characterize the eastern side of the basin while tight commonly thrust faulted anticlines and synclines deform the Sustut sediments to the west (see GSC map 14-1973, Eisbacher, 1974). Structural analysis of the western margin of the Sustut Basin infers that tight folds existed in the underlying Bowser Lake Group before deposition of the Sustut Group. Deformation and sedimentation related to the Coast Belt uplift overlapped the deposits resulting from uplift of the Omineca Belt to the east. Trap-types recognized in the play are simple compressional anticlinal structures and smaller-scale folds related to thrust faults. These structures developed both previous to, and contemporaneous with hydrocarbon generation. Area of closure range from 1 to 175 square kilometres with a mean of 10 square kilometres. Vertical closure varies from 20 to 1000 metres with a mean of 100.

The reservoir fraction in the play consists of thin porous and permeable sands within the clastic succession. The estimated thickness of reservoir material compared to total thickness varies from 0.5 to 5%. Porosity range is estimated to vary between 5 and 15% with an average of 10%, with secondary fracture porosity possible in localized zones.

Vitrinite reflectance on surface outcrops varies from 0.36 to 1.22% (Read et al, 1991). Total organic carbon in outcrop ranges from 0.0 to 67.79 and two out of nine samples have very good TOC values (13.11, 67.79). These two samples indicate good gas-generating potential. Type III kerogens dominate with lesser amounts of Type I and II. Carbonaceous and bituminous shales and sandstones with minor coal are probable source rocks in the play.

Open faults or fractures provide opportunities for hydrocarbon migration. Interbedded and overlying shales occur locally and these beds may provide seal in some cases. Significant areas of Sustut Group rocks do outcrop, however, which may indicate risk on seal. Preservation of hydrocarbons may not be attained because of breaching of structure due to erosion of the outcropping succession.

Sustut Upper Cretaceous Structural Oil Play

This play incorporates the same package of rocks as the gas component and encompasses the same play area. Play parameters are similar and the number of prospects probability distribution coincides with the gas play. In outcrop, one out of the nine geochemical samples analyzed indicate moderate to good oil-generating potential.

Northern Rocky Mountain Trench Sifton Structural Gas Play

A clastic non-marine assemblage of Upper Cretaceous to Paleogene sediments deposited in and along the northern Rocky Mountain Trench constitute the Northern Rocky Mountain Trench Sifton Structural Play (Map 1). Large dextral transcurrent displacements deform the sediments deposited in this fault-controlled basin. The Sifton Assemblage of rocks in the play extend from Williston Lake in the south to Watson Lake in the Yukon Territory. The play area is 2280 square kilometres. The rocks consist of conglomerate, sandstone, siltstone, and mudstone with minor lignite (Gabrielse, 1991a).

These rocks are characteristically highly deformed. Locally, this sequence is quite thick due to syndepositional faulting. Paleocurrent data indicate that the major drainage direction is to the south. The Sifton Formation probably occupied a much broader alluvial plain than the present floor of the trench.

Two episodes of deformation affected the Sifton sediments. Initial uplift of the Omineca Belt in mid-Cretaceous time resulted in extension and normal faulting in the basin. This phase of normal faulting precedes the deposition of the Sifton Formation. A later pulse of brittle and compressional deformation produced kink-folding and disruption along high-angle reverse faults (Eisbacher, 1974). Likely traps would be small-scale antithetic and synthetic normal and reverse fault structures. These traps were formed previous to and contemporaneous with hydrocarbon generation. Area of closure was estimated to range from 0.5 to 10 square kilometres, averaging about one square kilometre in area. Range of vertical closure varies from one to 150 metres. The number of prospects vary from 15 to 50 with a mean of 25.

Thin reservoir sandstones and conglomerates are expected in the succession. Reservoirs constitute between zero and 5% of the total thickness in the Sifton play. There is little evidence of fracturing in these rocks so secondary porosity is unlikely. The thin reservoir intervals have an estimated porosity range of 7 to 14%.

Coal seams within the basin range in rank from lignite to high-volatile bituminous A. Source rocks within the succession include these coal seams as well as carbonaceous and bituminous shales and sandstones. Biogenic gas is the most likely hydrocarbon generated in the play.

Migration and seal are adequate for hydrocarbon accumulations in some prospects.

Whitehorse Cenozoic Stratigraphic Gas Play

The Whitehorse Cenozoic Stratigraphic Gas Play is classified as speculative due to insufficient geological and petroleum reservoir information. Biogenic marsh gas is probably present in Quaternary to Recent unconsolidated alluvium and till in the Whitehorse Trough owing to reports of ignition of gaseous hydrocarbons at the tailpipes of vehicles to the north of Whitehorse

(Koch, 1973). Fractures and/or faults in underlying bedrock may provide migration corridors for thermogenic gas buried deep within the succession with subsequent accumulation in stratigraphic porous lenses interspersed within the alluvium and till. These gas saturated lenses can range in size from 10 to 500 metres long and vary in thickness from 10 to 50 metres. Alluvium and/or till is interpreted to cover the major portion of the Trough (see Map 5) (19,400 sq. km.). Gas pools, if present, are very small and they may represent a geotechnical hazard in exploiting hydrocarbons in this basin. No assessment was performed due to insufficient information and very low resource potential.

Whitehorse Takwahoni Structural Gas Play

The Jurassic rocks comprising the Laberge Group and subdivided into the Inklin and Takwahoni Formations define the extent of the Whitehorse Trough. The Trough was mainly developed on the Cache Creek Terrane but also on bordering parts of Stikinia and Quesnellia. These rocks are therefore an accretionary response assemblage. It has been observed in the northern part of the Trough that the Inklin rocks derived from Quesnellia interfinger with Takwahoni material sourced from Stikinia. This implies that Stikinia, Cache Creek, and Quesnellia were at least loosely amalgamated by Early Jurassic time. The Takwahoni Formation of Pliensbachian to Bajocian age represents the proximal facies derived from Stikinia to the southwest. The Formation consists of interbedded conglomerate, greywacke, siltstone and shale. Volcanic and plutonic clasts found in the conglomerate are derived from the Stikine Arch to the south and the Coast Belt to the west. The Takwahoni Formation disconformably overlies the Lewes River Group.

The gas play encompasses an area of 6040 square kilometres (Map 3). No wells have been drilled and no shows have been reported in the play. Thickness of the Takwahoni Formation varies from 1600 to 3350 metres.

Three major structural hydrocarbon trap-types have been identified. Compressional deformation episodes produce the simple anticlinal structures along with traps associated with thrust faulting. Normal block fault traps were formed in the post-mid-Eocene extensional tectonic regime. Folds and thrusts were developed from Late Paleozoic to mid-Eocene. Hydrocarbon generation occurred in the Late Mesozoic so structures were developed previous to, contemporaneously, and subsequent to the generation. Area of closure of significant structures are estimated to vary from 10 to 60 square kilometres. The amplitude of folds in this play range from 200 to 300 metres with an absolute maximum of 1000 metres. It is estimated that structures have developed at surface to the 3000 metre depth. Number of prospects vary from 40 to 750 with a mean of 375.

Thin porous sandstones and conglomerates in the Laberge Group is recognized as the primary reservoir in the Whitehorse Trough. Even though most of the Laberge Group has little or no porosity, there are occasional thin layers with excellent porosity. Porosity probability distribution range from 5 to 20% with a 10% mean.

The most probable source rocks for the play are dark grey to black shales and siltstones of the Jurassic Richthofen Formation. There are also coal seams and lenses present with ranks varying from high-volatile bituminous C to high-volatile bituminous A. Total organic carbon ranges from 0.11 to 30.5, HI from 0.0 to 58.71, and Ro max from 0.6 to 2.59 (Gunther, 1985). A potential for wet gas is present in the northwest corner of the Trough while dry gas potential occurs in the remainder of the basin.

Abundant overlying Jura-Cretaceous shales provide seal in some parts. However, significant outcrop areas of Laberge Group rocks may increase the risk on seal and hydrocarbon preservation.

Whitehorse Takwahoni Stratigraphic Gas Play

This speculative play incorporates stratigraphic hydrocarbon traps within the Takwahoni Formation adjacent to the King Salmon and Llewellyn Fault Systems in northern British Columbia and south-central Yukon, respectively (see Map 3, this report; and Fig. 8.75, Monger et al, 1991). Three distinct pulses of arkosic sandstone and conglomerate sediments were deposited in the Trough from the west and southwest and juxtaposed against Nordenskold dacite and tuff in the northern part of the Trough and against Inklin Formation sediments in northern B. C. Insufficient information on reservoir parameters precludes the assessment of the play.

Whitehorse Inklin Gas Play

The Whitehorse Inklin Structural Gas Play embodies the rocks of the Laberge Group in the eastern part of the Trough that constitute both a proximal facies derived from Quesnellia to the east and a distal facies obtained from Stikinia to the west. The Inklin Formation contains interbedded turbiditic greywackes, shales and siltstones. The play covers an area of 10,000 square kilometres in northern British Columbia and southern Yukon Territory. The rocks range in age from Hettangian to Bajocian. No wells or shows are encountered. Thickness of the sedimentary succession varies from 0 to 3000 metres.

Structure-type, area and range of vertical closures along with timing of structure formation with respect to hydrocarbon generation is similar in this play to the parameters in the Whitehorse Takwahoni play. Coal ranks in Inklin rocks vary from high-volatile bituminous C to high-volatile bituminous A. Total organic carbon ranges from 0.31 to 0.95. The hydrogen index varies from 0 to 11.11 and the vitrinite reflectance from 1.55 to 2.93 (Gunther, 1985). These geochemical values show that this play is dry gas prone. The Jurassic Richthofen Formation of dark grey to black shales and siltstones is the probable source rock for gas in the play. Although there is abundant overlying and interbedded tight shales, siltstones and conglomerates that may provide seal in some cases, significant outcrop areas of Inklin rocks may increase the risk on seal and/or preservation.

Whitehorse Lewes River Structural Gas Play

The carbonates and clastics of the Late Triassic Lewes River Group and Sinwa Formation are included in this play. These rocks are found in the Whitehorse Trough which is developed on both the Cache Creek and Stikinia Terranes. In southern Yukon on the Cache Creek Terrane, there is interbedded greywacke and radiolarian chert with conodonts of Late Triassic age. The greywacke is similar compositionally to clastics of the Lewes River Group in the Whitehorse Trough. This may represent the link between the Whitehorse Trough partly found in Stikinia and the Cache Creek Terrane (Monger et al, 1991). The Sinwa Formation located in northern B. C. consists of massive to thickly-bedded limestone up to 250 metres thick. This formation occurs on both sides of the King Salmon Fault separating the Cache Creek and Stikinia Terranes. Amalgamation of Cache Creek and Stikinia must have occurred previous to Sinwa deposition. The Lewes River Group in the southern Yukon contains interbedded clastics, volcanics and carbonates up to 3000 metres thick (Wheeler, 1961). Prominent reefal mounds are found within the carbonates. The reefoid masses are principally made up of carbonate muds with a lesser proportion of organism-generated framework structures (Reid and Templeman-Kluit, 1987). The Lewes River Group is overlain disconformably by the Jurassic Laberge Group in the western portion of the Whitehorse Trough while to the east the contact becomes gradational (Monger et al, 1991).

This gas play covers an area of 14,000 square kilometres in northern British Columbia and southern Yukon (Map 4). No wells have been drilled but a gas seep has been reported at Takhini Hot Springs north of Whitehorse.

In northern Stikinia, there was Late Permian to Early Triassic deformation that produced tight northerly-trending folds. Overprinted on these structures are southeasterly-trending Jurassic folds and thrust faults (Monger et al, 1991). Pre-Triassic structures were indicative of both easterly subduction of the Cache Creek Terrane and northeast-directed thrusting of Quesnellia onto North America. Jurassic structures reflect collision of Stikinia, Quesnellia and Cache Creek Terranes. In the early Cenozoic, extensional tectonics prevailed affecting Mesozoic structures with right-lateral transform motions (Monger et al, 1991). Structures developed before, during and subsequent to hydrocarbon generation in the Lewes River and Sinwa intervals. The main hydrocarbon trap in the play is simple compressional anticlinal folds. Another compressional trap-type is folds associated with thrusting. Extensional structures are represented by normal block fault traps. Folded structures developed from Late Permian to mid-Eocene while block faults were formed post-mid-Eocene. Major structures vary in area closure from 10 to 60 square kilometres. Vertical closures range from 200 to 1000 metres. It is estimated that the mean of number of prospects is 800 with a range of 80 to 1600.

There is a distinct lack of primary porosity and permeability in these carbonates. Porosity, if present, is secondary with the development of fractures in the carbonates in brecciated zones. Vuggy porosity was noted in outcrop. Estimated mean for the fracture porosity is 4% with a range of 3 to 10%. A risk factor of 0.50 was applied to the presence of porosity at a play level.

Vitrinite reflectance in outcrop varies from 0.53 to 2.93% Romax. The hydrogen index ranges from 8.93 to 20.24 and total organic carbon varies from 0.17 to 0.84. These numbers

suggest that these rocks are generally overmature, lean and gas-prone (Gunther, 1985). Carbonaceous material in the limestones and organic-rich shales provide an adequate source for hydrocarbons.

The presence of numerous faults and fractures in the play provide adequate conditions for migration. Seal is sustained by abundant overlying and interbedded shales. However, large areas of Lewes River Group outcrop in the play may breach structures and provide opportunities for hydrocarbon leakage. Risk is assigned to seal and preservation to reflect this possible loss of hydrocarbon.

Whitehorse Taku Fractured Carbonate Gas Play

Map 4 illustrates the area covered by the Whitehorse Taku Fractured Carbonate Play. Massive carbonates of the Permian Taku Formation are an integral part of the Nakina and French Range Subterranean in northwestern British Columbia and south-central Yukon Territory. These subterranean represent the westernmost and easternmost facies belts of the oceanic Cache Creek Assemblage of the Cache Creek Terrane (Monger, et al, 1991). Shallow-water massive carbonates are the dominant lithological units in these marine assemblages. These limestone bodies have developed as atoll reefs on basal volcanic strata. Algalaminated dolostones frequently form in the back-reef environment, particularly in the Nakina Subterranean. There are infrequent pillowed mafic flows and tuff layers within the carbonate. Prominent carbonate in the French Range Subterranean consists of algalaminated dolostones similar to the lagoonal facies in the Nakina terrane. Fractures in the massive tight carbonates are interpreted as the principal site for gas accumulation. Dark argillaceous limestone containing organic matter with a fetid odour when broken, may represent source material in these rocks. Gas may form, migrate along the fracture system until it is trapped against the unconformity juxtaposing Permian rocks and overlying Jurassic Laberge Group sediments. Insufficient geological information for the play precludes an assessment analysis in this case. Gas potential is small and the play is a minor component in the overall basin assessment analysis.

ASSESSMENT TECHNIQUE

After compiling relevant material for each hydrocarbon play, an assessment committee assigned objective and subjective probabilities and risk factors for the play (see Appendix 1 for probabilities and risk factors and Appendix 2 for the statistical data retrieved). The risk factors were defined by analyzing the geological characteristics of various play parameters, comparing them to analogous settings, and then deciding upon reasonable limits for these parameters. Once the probabilities and risk factors were compiled, lognormal approximation and pool-size-by-rank options in PETRIMES were used to model the conceptual plays (Lee and Wang, 1990).

RESOURCE APPRAISAL

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

Bowser Skeena Structural Gas Play

Overall, the play-level risk is 1.0, which signifies total confidence in the existence of this conceptual hydrocarbon play. At the prospect-level, adequate preservation of hydrocarbons is assigned the greatest risk, because of the extensive outcrop exposure of Skeena Group sediments which may provide opportunities for leakage of hydrocarbons (see Appendix 1). Timing of hydrocarbon generation with respect to trap formation has been interpreted to be unfavourable in some cases, and the play has been appropriately risked. Risk has also been applied to the presence of closure in some prospects. An overall prospect-level risk of 0.04 has been calculated for the Bowser Skeena Structural Gas Play.

Complicated tectonic histories with numerous depositional episodes prevail in the Bowser assessment area of north-central British Columbia. Structural deformation is inferred to have occurred previous to, contemporaneous with, and subsequent to hydrocarbon generation and accumulation depending on location. Some hydrocarbon accumulations may have been affected by these deformation episodes. Such accumulations may have been cut by many faults and subsequently remigrated. Fields, rather than pools, are interpreted as representing these composite structurally-complex hydrocarbon accumulations. Thus, the largest undiscovered hydrocarbon accumulation in this assessment is considered to be a field, rather than a pool. We emphasize that readers consider the range of possible sizes for the largest recoverable field size (90% confidence interval) rather than simply quoting the median of the largest field size. This range more accurately describes the largest field size.

In this assessment, the mean of the expected number of fields present in the play is recorded. In addition, values representing the probability of one or more fields existing in a play and the number of fields at 1% are presented. The number of fields at 1% indicate the probable maximum of expected number of fields in a play and it would be 99% certain that no greater number of fields exists.

The total mean play potential of in-place resources in the Bowser Skeena Structural Gas Play is $7.19 \times 10^{10} \text{ m}^3$ (2.54 TCF) of gas (see Appendix 2). Recoverable mean potential is $5.03 \times 10^{10} \text{ m}^3$ (1.78 TCF). The in-place resource estimate for the largest field size varies from 3.25×10^9 to $5.05 \times 10^{10} \text{ m}^3$ (114 to 1783 BCF)(Figure 1). The median of the largest in-place field is $1.47 \times 10^{10} \text{ m}^3$ (519 BCF)(Figure 1). Using a recovery factor of 0.70, we suggest that a largest recoverable field size of 2.28×10^9 to $3.53 \times 10^{10} \text{ m}^3$ (80 to 1248 BCF) occurs in the play. A mean of 19 gas fields is expected to occur in the play. It is 99% certain that no more than 45 gas fields are expected.

All plays in the Bowser and Sustut Basins are located entirely in British Columbia. Therefore, all potential resources quoted in the two basins occur in British Columbia.

Bowser Skeena Structural Oil Play

Similar reservoir parameters between the oil and gas plays are indicated by identical probability distributions (see Appendix 1). Geological risk factors are similar as well. The reduced play area signifying the rocks that are interpreted to occupy the oil window, is reflected in the diminished probability distribution for the number of prospects.

The Bowser Skeena Structural Play has a mean in-place oil potential of $2.01 \times 10^8 \text{ m}^3$ or 1264 million barrels. Figure 2 indicates that the largest undiscovered in-place field size varies from 1.00×10^7 to $1.42 \times 10^8 \text{ m}^3$ or 63.1 to 893.3 million barrels. The median of the largest undiscovered field is $4.36 \times 10^7 \text{ m}^3$ (274.4 million barrels). The range of the largest undiscovered recoverable field size is 2.01×10^6 to $2.89 \times 10^7 \text{ m}^3$ (12.6 to 181.5 million barrels). The mean number of fields expected to occur is 16. No more than 37 fields are expected in the play with a 99% certainty.

Bowser Mid-Jurassic-Lower Cretaceous Structural Gas Play

A play-level risk of 0.12 has been assigned. Regional metamorphism of these rocks was the main contributing factor in elevating risk at the play level. The substantial degree of metamorphism in the rocks probably has destroyed most of the petroleum which is indicated in the adequate preservation risk. Metamorphism also may destroy the primary porosity which is reflected in the elevated reservoir facies risk (see Appendix 1). Adequate seal at the prospect-level is risked to reflect the erosion of cap-rock where Bowser Group outcrops. Erosion may also breach structure and trapped hydrocarbons may have escaped.

The total mean in-place gas potential of the play is $5.78 \times 10^{10} \text{ m}^3$ or 2.0 TCF. The median of the largest undiscovered field (in-place) is statistically determined to be $1.80 \times 10^{10} \text{ m}^3$ (637 BCF). The median has been extracted from a range of 8.04×10^9 to $4.26 \times 10^{10} \text{ m}^3$ (284-1505 BCF) for the largest undiscovered field (Figure 3). The recoverable range of largest field size is 6.43×10^9 to $3.41 \times 10^{10} \text{ m}^3$ (227-1204 BCF). If gas fields do exist, the expected mean number of fields is 173. It is extremely unlikely that more than 2473 fields exist.

Sustut Upper Cretaceous Structural Gas Play

Adequate preservation of hydrocarbons is assigned the greatest prospect-level risk in the play due to extensive outcrop of Sustut Group rocks. This outcrop exposure may provide opportunities for leakage of hydrocarbons. Timing of hydrocarbon generation with respect to trap formation is unfavourable in some prospects and in such instances the parameter is appropriately risked. An overall prospect-level risk of 0.1 has been calculated. However, a play-level risk of 1.00 has been assigned which implies total confidence in the existence of the play.

The mean play potential (in-place) is $5.27 \times 10^{10} \text{ m}^3$ or 1.86 TCF of gas. The largest undiscovered field (in-place) according to the field-size-by-rank diagram (Figure 4) within the 90% interval varies from 2.54×10^9 to $4.48 \times 10^{10} \text{ m}^3$ (90 to 1581 BCF). The median of the largest field size is determined to be $1.24 \times 10^{10} \text{ m}^3$ (438 BCF). The recoverable largest field size range is 1.78×10^9 to $3.13 \times 10^{10} \text{ m}^3$ (63-1106 BCF). The expected number of fields in the play is 14, and it is extremely unlikely that no more than 34 gas fields are present.

Sustut Upper Cretaceous Structural Oil Play

Play conditions in this play are similar to the gas component. The mean in-place play potential is $1.84 \times 10^8 \text{ m}^3$ (1158 million barrels). The range of the largest undiscovered field (in-place) according to the field-size-by-rank diagram (Figure 5) within a 90% interval is 9.57×10^6 to $1.38 \times 10^8 \text{ m}^3$ (60 to 865 million barrels). The median of the largest field size is determined to be $4.17 \times 10^7 \text{ m}^3$ or 262 million barrels. Recoverable largest undiscovered field size range is 1.92×10^6 to $2.79 \times 10^7 \text{ m}^3$ (12 to 176 million barrels). The mean of the expected number of fields in the oil play is the same as the gas (14).

Northern Rocky Mountain Trench Sifton Structural Gas Play

An overall play-level risk of 0.90 has been assigned. This risk indicates the high confidence for the existence of gas in the play. At the prospect-level, however, a risk factor of 0.25 is specified, indicating a one in four chance in encountering hydrocarbons. The mean number of fields expected to exist is 7, and it is extremely unlikely that more than 16 fields are present.

The mean play potential is $1.46 \times 10^8 \text{ m}^3$ or 5 BCF of gas in-place. The largest undiscovered in-place gas field according to the field-size-by-rank diagram (Figure 6) varies from 8.34×10^6 to $2.92 \times 10^8 \text{ m}^3$ (0.3 to 10 BCF). The median of the largest field size is $5.03 \times 10^7 \text{ m}^3$ (1.8 BCF). Recoverable largest field size ranges from 5.84×10^6 to $2.04 \times 10^8 \text{ m}^3$ or 0.2 to 7 BCF.

This particular play extends into the Yukon Territory near Watson Lake (Map 1). Ninety-two percent of the play area is located in British Columbia so if gas resources are distributed evenly, the mean play potential for B.C. is $1.34 \times 10^8 \text{ m}^3$ (4.7 BCF).

Whitehorse Takwahoni Structural Gas Play

An overall play-level risk of 1.00 implies the absolute confidence in the existence of the play. A marginal probability of 0.04 at the prospect-level reflects the high risk in encountering hydrocarbons in individual prospects. The mean of the expected number of gas fields in the play is 14. There is a 99% chance that no more than 34 fields are present.

The in-place mean play potential is statistically determined to be $8.07 \times 10^{10} \text{ m}^3$ or 2.85 TCF of gas. Figure 7 illustrates the range of the largest undiscovered gas field in a field-size-by-rank diagram. The largest field varies from 4.17×10^9 to $5.92 \times 10^{10} \text{ m}^3$ or 147 to 2092 BCF. The median of the largest field is $1.82 \times 10^{10} \text{ m}^3$ (642 BCF). The recoverable range for the largest field extends

from 3.13×10^9 to $4.45 \times 10^{10} \text{ m}^3$ or 110 to 1571 BCF of gas.

The Whitehorse Takwahoni Structural Gas Play is located to the northwest of the Bowser Basin in northern British Columbia and extends further north into the Yukon Territory. Approximately 27% of the play area is found in British Columbia. Therefore, assuming gas resources are evenly distributed, the in-place mean potential within the Province is $2.18 \times 10^{10} \text{ m}^3$ or 770 BCF of gas.

Whitehorse Inklin Structural Gas Play

The structural gas play that incorporates the Inklin Formation also has a play-level risk of 1.00 implying total confidence in the existence of the play. Again, significant risk has been assigned at the prospect-level to produce an overall risk of 0.03. The expected mean number of gas fields in the play is 20. It is 99% certain that no more than 45 fields are present.

It has been determined that the in-place mean potential is $2.21 \times 10^{10} \text{ m}^3$ or 779 BCF of gas. The range for the largest undiscovered in-place gas field varies from 1.04×10^9 to $1.36 \times 10^{10} \text{ m}^3$ (37 to 480 BCF) (Figure 8). The median of the largest undiscovered field is $4.29 \times 10^{10} \text{ m}^3$ (151 BCF). Applying a recovery factor, the range for the largest recoverable undiscovered field is 7.79×10^8 to $1.02 \times 10^{10} \text{ m}^3$ (28 - 361 BCF).

The Inklin play is found in northern British Columbia and southern Yukon. Seventy-one percent of the play area is found in northern British Columbia. If gas resources are distributed evenly throughout the play, then the expected resource in B. C. is $1.57 \times 10^{10} \text{ m}^3$ (557 BCF) of gas.

Whitehorse Lewes River Structural Gas Play

A risk of 0.50 was assigned for the presence of porosity at a play-level. Relatively-high prospect-level risks were attributed to the presence of closure, adequate seal and timing as well as adequate preservation (see Appendix 2). If any gas fields do exist, the mean expected number is 10, and it is extremely unlikely that no more than 42 are present.

The mean play potential is $1.02 \times 10^{11} \text{ m}^3$ (3.6 TCF)(in-place). The largest undiscovered field according to the field-size-by-rank diagram (Figure 9) ranges from 9.78×10^9 to $1.25 \times 10^{11} \text{ m}^3$ (345 - 4398 BCF). The median of the largest field size is $3.97 \times 10^{10} \text{ m}^3$ (1.4 TCF). Recoverable largest undiscovered field size varies from 5.87×10^9 to $7.47 \times 10^{10} \text{ m}^3$ or 207 to 2639 BCF of gas.

Even distribution of resources indicates that 15% of the mean potential occurs in British Columbia. Therefore, the mean play potential in B. C. is $1.53 \times 10^{10} \text{ m}^3$ (540 BCF).

HYDROCARBON POTENTIAL DISTRIBUTION

Map 6 illustrates a qualitative interpretation of the distribution of potential for hydrocarbon accumulation in the Bowser-Whitehorse assessment area. Good potential is indicative of favourable locations for hydrocarbon accumulations and should be the major focus for any future exploration activities. Medium potential signifies secondary and less important areas for oil and gas prospects but significant resources may occur. Poor potential marks areas where little or no hydrocarbon reserves are expected and would likely not be of interest to oil companies.

Sediments belonging to the Skeena Assemblage are included in areas of good hydrocarbon potential due to favourable reservoir parameters. The oil and gas components of both the Bowser Skeena and Sustut Upper Cretaceous Structural plays encompass areas of good potential since Skeena rocks are involved (Maps 1, 2 and 6). Good potential is also recognized in Jurassic Takwahoni sediments of the Laberge Group (Maps 3 and 6).

Medium potential areas include the Bowser Group sediments in north-central British Columbia and the Jurassic Inklin Formation rocks to the north. In addition, the carbonates in the Triassic Lewes River Group is classified as having medium hydrocarbon potential.

Areas of poor potential include the Whitehorse Taku Fractured region, the Whitehorse Tantalus and the Northern Rocky Mountain Trench Sifton play areas.

SUMMARY AND CONCLUSIONS

The Bowser Skeena Structural Gas Play incorporates an accumulation of Early Cretaceous clastic sediments in a near-shore to marine environment. Skeena sedimentation occurs subsequent to collision of the exotic Stikinia and Cache Creek Terranes with the North American continent. The Skeena Group of rocks is thus characterized as an accretionary response assemblage. Regular orthogonal block faults have preserved Skeena Group sediments in horst-type structures. The mean potential for this conceptual play is determined to be $7.19 \times 10^{10} \text{ m}^3$ (2.54 TCF). These figures represent in-place petroleum resources. Similar geological and reservoir parameters can be applied to the Bowser Skeena Structural Oil Play. The total mean play potential is $2.01 \times 10^8 \text{ m}^3$ or 1264 million barrels.

In the conceptual Bowser Mid-Jurassic-Lower Cretaceous Structural Gas Play, potential gas prospects are found in a marine to non-marine clastic sequence where the coarse-grained non-marine molasse progrades over the fine-grained marine flysch. Major risks associated with the play involve the general lack of porosity and permeability along with the effects resulting from metamorphism of the sedimentary package from prehnite-pumpellyite to subgreenschist grade. At best, methane would be found in these rocks. These significant play-level risks are reflected in the marginal probability that the play exists (0.12). This play has a total mean gas potential of $5.78 \times 10^{10} \text{ m}^3$ (2.04 TCF).

The Sustut Upper Cretaceous Structural Oil and Gas Play represents the single assemblage of sediments recognized as having hydrocarbon potential in Sustut as well as Tuya and Nahlin Basins. Deposits of terrestrial fluvial Sustut rocks are included in the play. The total mean play potential for gas is $5.27 \times 10^{10} \text{ m}^3$ or 1.86 TCF. The mean potential of the Sustut Upper Cretaceous Structural Oil Play is $1.84 \times 10^8 \text{ m}^3$ (1158 million barrels).

A potential hydrocarbon play is present to the east in the Rocky Mountain Trench. Biogenic gas probably occurs in Sifton clastics of Upper Cretaceous to Paleogene age. This shallow gas has a total mean potential of $1.46 \times 10^8 \text{ m}^3$ (5 BCF).

Within the Whitehorse Trough, numerous oil and gas plays of Permian to Cenozoic age have been proposed. The most significant reservoir encountered within the Trough is found in the Jurassic Laberge Group that has been divided into the proximal Takwahoni Formation clastics to the west and the eastern proximal and distal Inklin Formation.

The coarse-grained westerly-derived proximal facies of the Laberge Group is represented in the Trough by the Takwahoni Formation. Several kilometres of marine interbedded conglomerate, greywacke, siltstone and shale along with minor flows and tuffs constitute the Takwahoni sequence. The Whitehorse Takwahoni Structural and Stratigraphic Gas Plays represent potential hydrocarbon accumulations in these rocks. The total mean play potential for the Whitehorse Takwahoni Structural Gas Play is $8.07 \times 10^{10} \text{ m}^3$ (2.85 TCF).

The finer-grained easterly- and westerly-derived Inklin Formation belongs to the Laberge Group as well. Interbedded turbiditic greywacke, shale and siltstone is found in the Whitehorse Inklin Structural Gas Play. The ultimate mean play potential for these rocks is $2.21 \times 10^{10} \text{ m}^3$ or 779 BCF of gas.

The Whitehorse Lewes River Structural Gas Play incorporates clastics, volcanics, radiolarian chert and carbonates of the Lewes River and Sinwa Groups. These rocks are tight so the presence of porosity was considered to be high-risk at the play level. There is a 50% chance that the play exists. If gas is present, then the total mean in-place play potential is $1.02 \times 10^{11} \text{ m}^3$ (3.6 TCF).

The speculative Whitehorse Taku Fractured Carbonate Gas Play consists of shallow-water massive carbonate forming the main component of the reef on a basaltic substrate. A back-reef facies composed of algalaminated dolomite is also present. The speculative nature of this conceptual play; principally, the lack of information on possible shows, the absence of primary porosity, and increased levels of metamorphism which may have destroyed petroleum and volatiles, reduces the likelihood that the play exists and, consequently no assessment was attempted.

The Whitehorse Cenozoic Stratigraphic Gas Play does exist but no assessment was performed because of insufficient geological and reservoir information.

The total gas potential for all plays in this assessment is 3.87×10^{11} m³ or 13.7 TCF. Oil potential total is 3.85×10^8 m³ or 2.42 billion barrels.

Good hydrocarbon potential is recognized in areas occupied by the Bowser Skeena, Sustut Upper Cretaceous, and Whitehorse Takwahoni Structural plays. Secondary or medium potential is interpreted in the Bowser Mid-Jurassic-Lower Cretaceous, Whitehorse Inklin and Lewes River Structural Gas Plays. The Whitehorse Taku Fractured Carbonate and the Northern Rocky Mountain Trench Sifton Structural Gas Plays are areas of poor to fair hydrocarbon potential.

ADDENDUM

INTRODUCTION

In this section, interpreted hydrocarbon plays identified within the Whitehorse Trough that are located entirely within the Yukon Territory is discussed. This information may be useful if sufficient interest is generated for the exploitation of resources and the subsequent need for development of a transportation corridor through the Province to market.

Plays discussed in this section are the:

- 1) conceptual Whitehorse Tantalus Structural Gas Play,
- 2) conceptual Whitehorse Tantalus Structural Oil Play,
- 3) conceptual Whitehorse Takwahoni Structural Oil Play,
- 4) speculative Whitehorse Takwahoni Stratigraphic Oil Play, and the
- 5) speculative Whitehorse Lewes River Stratigraphic Gas Play.

GEOLOGICAL SETTING AND PLAY PARAMETERS

Whitehorse Tantalus Structural Gas Play

Non-marine, coal-bearing fluvial clastic rocks occupy northwest-trending small partly fault-bounded pull-apart basins partially related to the Teslin Fault system (Gabrielse, 1991a). These sediments belong to the Late Jurassic to Early Cretaceous Tantalus Formation. The basins are located in the northwestern part of the Intermontane Belt in south-central Yukon near Carmacks (Map 1). Lowey and Hills, 1988 interprets the clastic material south of Dawson on the Indian River as correlative to the Tantalus Formation. The play area is quite limited; 610 square kilometres. No wells or shows have been reported. The succession varies in thickness from 200 to 1500 metres. In the lower part of the sedimentary succession, interbedded sandstones and shales prevail. Carbonaceous shale occurs irregularly along with discontinuous coal seams. The upper portion of the sequence consists of chert-pebble conglomerate. Southerly to southwesterly-flowing fluvial systems constitute the dominant control for sedimentation in the basins.

Tight folds and normal block fault traps represent the main trapping mechanisms in this play. Folding occurred contemporaneously and subsequent to deposition until the mid-Eocene. Post mid-Eocene extensional tectonics produce the antithetic and synthetic small-scale fault traps. Area of closure is estimated to range from 0.5 to 10 square kilometres while vertical closure varies from 1 to 1000 metres. Number of prospects is estimated to range from 25 to 100.

Thin reservoir sands and conglomerates are interspersed within the Tantalus sedimentary succession. Up to 7% of the succession constitutes the reservoir fraction. Trap fill ranges from 1.5 to 30% of the succession. The porous material varies in porosity from 5 to 15%, with a 10%

average. Secondary fracture porosity probably exists in the play.

Source rocks within the succession are carbonaceous and bituminous shales and sandstones along with some coal seams. Coal rank varies from high-volatile bituminous C to low-volatile bituminous at Carmacks, and low-volatile bituminous to anthracite rank at Whitehorse. Total organic carbon values in surface outcrop range from 0.72 to 42.99 (Gunther, 1985). Hydrogen index varies from 0.09 to 75.33 and vitrinite reflectance ranges from 0.53 to 3.45% implying the basin is gas-prone throughout (Hunt and Hart, 1994).

Numerous faults and fractures, some of which are open, may provide opportunities for migration of gas in the play. Abundant overlying and interbedded shales may provide seal in some cases.

Whitehorse Tantalus Structural Oil Play

In the northwest corner of the Whitehorse Trough at Carmacks, there exists a fairly-rich oil-prone zone in the Tantalus rocks. This 160 square kilometre play area constitutes the Whitehorse Tantalus Structural Oil Play (Map 2). Play parameters are similar to the gas play. The number of prospects is estimated to range from 1 to 10 with a 50% probability that 8 prospects are present.

Coal ranks range from high-volatile bituminous C to low-volatile bituminous in the area. Vitrinite reflectance (Romax) varies from 0.53 to 2.14% revealing that at least some of the material sampled is found within the oil window (Gunther, 1985). No oil shows are reported, however.

Whitehorse Takwahoni Structural Oil Play

The Whitehorse Takwahoni Structural Oil Play occupies an area of 1160 square kilometres within the Miners Range and the Anticline Mountain area northwest of Whitehorse (Map 3). The Takwahoni Formation of Pliensbachian to Bajocian age represents the western proximal facies of the Jurassic Laberge Group. This facies consisting of interbedded conglomerate, greywacke, siltstone, and shale is derived from the accreted Stikinia Terrane to the southwest. Volcanic and plutonic clasts within the conglomerates also indicate derivation from the Coast Belt to the west. To the east within the Trough, is a proximal to distal facies of the Laberge Group known as the Inklin Formation which is derived from both Quesnellia to the east and Stikinia to the west. The fact that the Inklin and Takwahoni Formation interfinger in the northern portion of the Trough implies that Quesnellia, Cache Creek and Stikinia were at least loosely amalgamated by Jurassic time. The Takwahoni Formation ranges in thickness from a few metres up to 3000 metres.

Three trap-types have been identified in the structural play. They are anticlinal traps formed by simple compressional folding, traps produced by normal block faulting, and anticlinal structures constructed as a result of thrust faulting. The compressional structures were developed during the mid-Jurassic to mid-Eocene interval when accretion of exotic terranes to the North American continent was taking place. Extensional tectonics prevailed in the post-mid-Eocene, when the

block faulting was propagated.

Major structures range in size from 10 to 80 square kilometres with vertical closure varying from 40 to 200 metres. The estimated mean for the number of prospects is 75 with a minimum of 10 and a maximum of 150.

Thin porous sandstones and conglomerates within the succession represent the reservoir fraction. There is little or no porosity in most of the Laberge Group. However, there are minor sandstone and conglomerate layers with excellent porosity. These porous sands range from 5 to 20% porosity, with a 10% average. It is estimated that about 7% of the fill in traps is considered to be reservoir quality material. Secondary fracture porosity may be present in parts.

Dark grey to black shales and siltstones and possible oil shales of the Jurassic Richthofen Formation are most likely the major source for oil in the basin. Petro-Canada's geochemical survey in 1985 revealed that total organic carbon varies from 2.66 to 11.69 within the play area. Hydrogen index ranges from 13.25 to 58.71 and the vitrinite reflectance (Romax) from 0.6 to 1.6% (Gunther, 1985). These values imply an oil window is present in this area of the Whitehorse Trough, with indications of a relatively rich oil source in some samples.

Abundant Jura-Cretaceous overlying shales provide seal in some parts. However, significant outcrop areas of Laberge Group rocks may increase the risk on seal.

The formation of structure has been interpreted to occur both contemporaneously and before the generation of hydrocarbons. A risk of 0.5 was assigned to timing to reflect this interpretation.

Whitehorse Takwahoni Stratigraphic Oil Play

Small-scale stratigraphic hydrocarbon traps within the Takwahoni Formation adjacent to the Llewellyn Fault System in south-central Yukon constitute this oil play. Map 3 shows the extent of the play. This play has been classified as speculative due to the lack of geological information required to set reservoir parameters. Oil resources in the play are a minor component in the overall analysis. No assessment was performed on the play.

Whitehorse Lewes River Stratigraphic Gas Play

Map 4 shows the areal extent of the stratigraphic play starting just south of Whitehorse and continuing to the north along the western side of the Trough to Carmacks. Prominent reefal masses in the Lewes River limestones represent the dominant stratigraphic trapping mechanism in the play (Koch, 1973, Reid and Templeman-Kluit, 1987). These masses are principally made of carbonate muds with a lesser proportion of reefal framework organisms (Reid and Templeman-Kluit, 1987). The reefs lack good porosity and permeability but fracture porosity may occur. Brecciation has been observed in outcrop and cavernous to vuggy porosity is present in weathered material. The reefs range in thickness up to 150 metres. No assessment was performed on this play because of the lack of pertinent geological information for proper evaluation of reservoir.

RESOURCE APPRAISAL

Whitehorse Tantalus Structural Gas Play

It is almost certain that this play exists, but individual prospects embody a much greater risk in identifying hydrocarbon accumulations. Adequate timing and preservation are the highest risk factors at the prospect-level in the play. The expected number of undiscovered fields has a mean value of 5 while it is 99% certain that no more than 13 fields are expected in the play.

The mean potential for gas in the Whitehorse Tantalus Structural Play is 1.36×10^9 m³ or 48 BCF. According to Figure 10, the range of the largest in-place undiscovered field at the 90% interval varies from 3.30×10^7 to 3.40×10^9 m³ (1 to 120 BCF). The median of the largest undiscovered field (Figure 10, in-place) is 3.97×10^8 m³ or 14 BCF of gas. The largest recoverable undiscovered field ranges in size from 2.60×10^7 to 2.72×10^9 m³ (1 to 96 BCF).

Whitehorse Tantalus Structural Oil Play

There is a 38% chance that this oil play exists within the oil window in the northwest of the Whitehorse Trough. Substantial risk has been applied to adequate timing and preservation while lesser risk was assigned to adequate seal, all at the prospect level. The mean of the number of expected fields is less than 1 and it is 99% certain that no more than 3 oil fields are present in the Whitehorse Tantalus Structural Oil Play.

Mean play potential is 1.75×10^6 m³ or 11 million barrels of oil. Figure 11 illustrates that the largest undiscovered in-place field ranges in size from 5.66×10^5 to 1.23×10^6 m³ in the 90% interval (3.6 to 77.5 million barrels). The recoverable largest undiscovered field varies in size from 2.00×10^6 to 2.90×10^7 m³ (13-182 million barrels).

Whitehorse Takwahoni Structural Oil Play

The probability that the Takwahoni Structural Oil play exists is 0.86. The mean in-place oil potential is determined to be 1.3×10^7 m³ or 83 million barrels. The field-size-by-rank diagram for the play (Figure 12) indicates that the largest undiscovered in-place field ranges in size from 8.77×10^5 to 2.84×10^7 m³ or 5.5 to 179 million barrels. Applying the recovery factor probability distribution in Appendix 1, the recoverable largest undiscovered field varies in size from 1.30×10^5 to 4.0×10^6 m³ (0.8 to 28 million barrels). The median of the largest undiscovered in-place field is 6.0×10^6 m³ or 37.5 million barrels (Figure 12).

HYDROCARBON POTENTIAL DISTRIBUTION

A favourable location for hydrocarbon accumulation is the area covered by the Whitehorse Takwahoni Structural Oil Play. Good potential is thus interpreted in the area (Map 6). Poor potential is assigned to the Whitehorse Tantalus Structural Oil and Gas Plays due to the limited areal extent with the reduced likelihood of encountering hydrocarbons. Note that the Tantalus plays are not shown on Map 6 since the favourable potential of the underlying Takwahoni Formation is illustrated in the area.

SUMMARY AND CONCLUSIONS

A Cretaceous coal-bearing fluvial clastic sedimentary succession represents the rocks associated with the Whitehorse Tantalus Structural Gas Play. This play has a mean in-place gas potential of $1.36 \times 10^9 \text{ m}^3$ or 48 BCF. The oil window is restricted to the Carmacks area in the same package of rocks. The mean potential of oil in-place is $1.75 \times 10^6 \text{ m}^3$ or 11 million barrels in the Whitehorse Tantalus Structural Oil Play.

The Whitehorse Takwahoni Structural Oil Play incorporates clastic rocks of the Laberge Group that represent a proximal facies of sediments that are derived from the Coast Belt and Stikinia to the west and southwest. This proximal facies consisting of conglomerates and sandstones is known as the Takwahoni Formation. The mean play potential is $1.30 \times 10^7 \text{ m}^3$ or 83 million barrels of in-place oil.

The stratigraphic oil play in the Takwahoni Formation with small-scale hydrocarbon traps adjacent to the Llewellyn Fault System is classified as a speculative play. Insufficient reservoir information was available in order to properly assess the play. Similarly, information was limited on the reefal carbonates constituting the Whitehorse Lewes River Stratigraphic Gas Play.

Total resource potential for the three conceptual plays analyzed above is $1.36 \times 10^9 \text{ m}^3$ (48 BCF) of gas and $1.48 \times 10^7 \text{ m}^3$ or 94 million barrels.

The total gas resource in the Yukon in the Whitehorse Trough is $1.53 \times 10^{11} \text{ m}^3$ or 5.4 TCF. Similarly, the total oil resource in the Yukon portion of the Whitehorse Trough is $1.48 \times 10^7 \text{ m}^3$ or 94 million barrels.

The Whitehorse Takwahoni Structural Oil Play is classified as an area of good potential in the assessment. The Whitehorse Tantalus Structural Oil and Gas Plays are categorized as having poor potential due to the limited play areas involved.

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

APPENDIX 2: STATISTICAL OUTPUT

FIGURE CAPTIONS

Map 1: Bowser/Whitehorse Oil & Gas Assessment - Cretaceous/Paleogene Gas Plays (Bowser Skeena Structural, Sustut Upper Cretaceous Structural, Whitehorse Tantalus Structural, Northern Rocky Mountain Trench Sifton Structural)

Map 2: Bowser/Whitehorse Oil & Gas Assessment - Cretaceous Oil Plays (Bowser Skeena Structural, Sustut Upper Cretaceous Structural, Whitehorse Tantalus Structural)

Map 3: Bowser/Whitehorse Oil & Gas Assessment - Jurassic Plays (Bowser Mid-Jurassic-Lower Cretaceous Structural (Gas), Whitehorse Takwahoni Structural & Stratigraphic (Oil & Gas), Whitehorse Inklin Structural (Gas))

Map 4: Bowser/Whitehorse Oil & Gas Assessment - Permian & Triassic Plays (Whitehorse Lewes River Structural & Stratigraphic (Gas), Whitehorse Taku Fractured Carbonate (Gas))

Map 5: Bowser/Whitehorse Oil & Gas Assessment - Cenozoic Plays (Whitehorse Cenozoic Stratigraphic Gas)

Map 6: Bowser/Whitehorse Oil & Gas Assessment - Hydrocarbon Potential Map

Figure 1: Field size by rank diagram of Bowser Skeena Structural Gas Play=

Figure 2: Field size by rank diagram of Bowser Skeena Structural Oil Play

Figure 3: Field size by rank diagram of Bowser Mid-Jurassic-Lower Cretaceous Structural Gas Play

Figure 4: Field size by rank diagram of Sustut Upper Cretaceous Structural Gas Play

Figure 5: Field size by rank diagram of Sustut Upper Cretaceous Structural Oil Play

Figure 6: Field size by rank diagram of Northern Rocky Mountain Trench Sifton Structural Gas Play

Figure 7: Field size by rank diagram of Whitehorse Takwahoni Structural Gas Play

Figure 8: Field size by rank diagram of Whitehorse Inklin Structural Gas Play

Figure 9: Field size by rank diagram of Whitehorse Lewes River Structural Gas Play

Figure 10: Field size by rank diagram of Whitehorse Tantalus Structural Gas Play

Figure 11: Field size by rank diagram of Whitehorse Tantalus Structural Oil Play

Figure 12: Field size by rank diagram of Whitehorse Takwahoni Structural Oil Play