# PETROLEUM RESOURCE ASSESSMENT OF THE LIARD PLATEAU, YUKON TERRITORY, CANADA

**National Energy Board**
**for Energy Resources Branch**

**November 1994**
**Whitehorse, Yukon**

Yukon
Economic Development

Box 2703
Whitehorse, Yukon Y1A 2C6
phone: 867-667-8525
fax: 867-393-6262
email: David.Downing@gov.yk.ca

ISBN 1-55018-801-1

# FOREWORD

The Government of Canada and the Government of Yukon have reached an agreement to transfer to Yukon the administrative legislative powers and responsibilities of managing onshore oil and gas resources. In the interim, officials of Canada involved in the administration of federal oil and gas legislation are cooperating and consulting with Yukon to facilitate implementing the Accord.

A study of the petroleum resources of the Yukon part of the Liard Plateau was undertaken by the National Energy Board (NEB) in response to a request from the Yukon Territorial Government. Assessment of petroleum resource potential is important for forming regulatory policies for these resources and for providing a basis for planning and issuing exploration rights.

# EXECUTIVE SUMMARY

The Liard Plateau is an immaturely explored area with proven Middle Devonian gas measures. The potential exists for further discoveries in Devonian, Carboniferous, Permian and Lower Cretaceous parts of the basin.

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|---|---|
| **Basin Age** | Early Paleozoic to Cretaceous; Quaternary cover. |
| **Basin Area in Yukon** | 8,553 km2 (3,302 mi2). |
| **Depth to Target Zones** | Middle Devonian targets: 3,500 to 5,000 m (11,500 to 16,400 ft).;<br>Carboniferous targets 2,250 to 3,000 m (7,380 to 9,840 ft.);<br>Lower Cretaceous targets: 600 to 800 m (1,960 to 2,625 ft.). |
| **Maximum Basin Thickness** | Over 6,000 m; up to 3,600 m of Mesozoic rocks. |
| **Hydrocarbon Shows** | Surface: none.<br>Subsurface: Gas: Carboniferous Prophet Formation, Devonian Besa River, Nahanni and Arnica formations.<br>Oil: none. |
| **First Discovery** | Canadian Southern et al North Beaver River YT I-27 (R.R. 12-Apr-64;<br>Manetoe facies – Nahanni Formation; sour, acid gas). |
| **Discovered Resources** | Gas (Initial Gas In-place): 12,030 106m3 (437 Bcf).<br>Gas (Rec. Resources; median value): 5,297 106m3 (192 Bcf).<br>Oil: none. |
| **Production** | Gas (to 06/30/93): 1,256 106m3 (46 Bcf).<br>Oil: none. |
| **Potential Resources** | Gas: mean = 56,298 106m3 (1.99 Tcf) @ 38.6% Probability.<br>Oil: mean = 0.002 106m3 (0.015 MMBbls) @ 41.7% Probability. |
| **Basin Type** | Paleozoic: epiric sea on a stable platform; Mesozoic to Recent: foreland basin. |
| **Depositional Setting** | Paleozoic: carbonate shelf, bank and slope; Mesozoic: fluvial, deltaic and shallow shelf clastics. |
| **Potential Reservoirs** | Gas: Cretaceous Fort St. John Group clastics, Permian fractured chert, Carboniferous Mattson clastics and Prophet Formation chert, Devonian Besa River fractured shale, Middle Devonian Nahanni, Landry and Arnica formations (Manetoe facies dolomite).<br>Oil: basal Cretaceous clastics. |
| **Regional Structure** | Northwesterly, northerly and northeasterly trending Laramide folded anticlines, high angle reverse faults and thrust faults; northeasterly Laramide and post-Laramide normal faults formed along pre-existing structural zones of Paleozoic age. |
| **Seals** | Cretaceous Targets: shale of the Buckinghorse, Lepine, Sully and Garbutt Formations<br>Permian Targets: Triassic and Cretaceous shale.<br>Carboniferous Targets: Carboniferous Etanda shale, Triassic and Cretaceous shale.<br>Manetoe Facies Targets: Devonian shales and tight limestone. |
| **Source Rocks** | Cretaceous shale; Triassic shale; Middle Devonian Besa River shale. |
| **Depth to Oil/ Gas Window** | Top: surface to 1,200 mKb (3,936 ft.) (Cretaceous to Mattson strata).<br>Base: 500 to 2,500 mKb (1,640 ft. – 8,200 ft.) (in the Golata shale). |
| **Wells in Study Area** | 11 (2 gas wells, 4 abandoned gas wells, 4 dry, 1 injection) |
| **Released Seismic Coverage** | 2D: more than 850 line kilometres (525 miles), 6% post 1975.<br>3D: 0 line kilometres, 0% post 1975. |
| **Pipelines** | West Coast Pipeline – Kotaneelee/Pointed Mountain [10 inch line; maximum capacity 300 $10^6m^3$/day (11 Bcf/day); percentage utilization 20% (July/94)]; Gas processed at Fort Nelson B.C. Plant [about 100 $10^6m^3$/day (3.5 Bcf/day) in spare capacity at the plant (July/94)]. |

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# INTRODUCTION

The objective of the study was to investigate the petroleum resource potential and endowment of the Liard Plateau area in the Yukon. The study area is located in the southeastern part of the Yukon Territory, between the Yukon-Northwest Territories (NWT) border to longitude 126°W and latitudes 60° to 61°N (Figure 1). This region lies within the Canadian Cordillera west of the northern portion of the Western Canadian Interior Plains and is bordered by the Rocky Mountains to the south and the Mackenzie and Franklin mountains to the north. The area is marked by a complex landscape of rugged anticlinal mountains and plateaus with elevations up to 1,500 m. The terrain is deeply dissected by more or less parallel northerly trending wide intermontane valleys with elevations ranging from 450 to 600 m.

## ACKNOWLEDGEMENTS

The NEB would like to acknowledge the previous work and effort of the staff of the Geological Survey of Canada's (GSC) Institute of Sedimentary and Petroleum Geology in Calgary. Their work laid the foundation for the concepts derived in this study. In particular the work of Drs. D. Morrow, B. Richards and D. Leckie were heavily drawn upon; thanks is also expressed to T. Bird, P. Hannigan, K. Ozadetz and Drs. P.J. Lee, L. Snowdon, and J. Wendte for discussion and suggestions which led to improving the original manuscript.

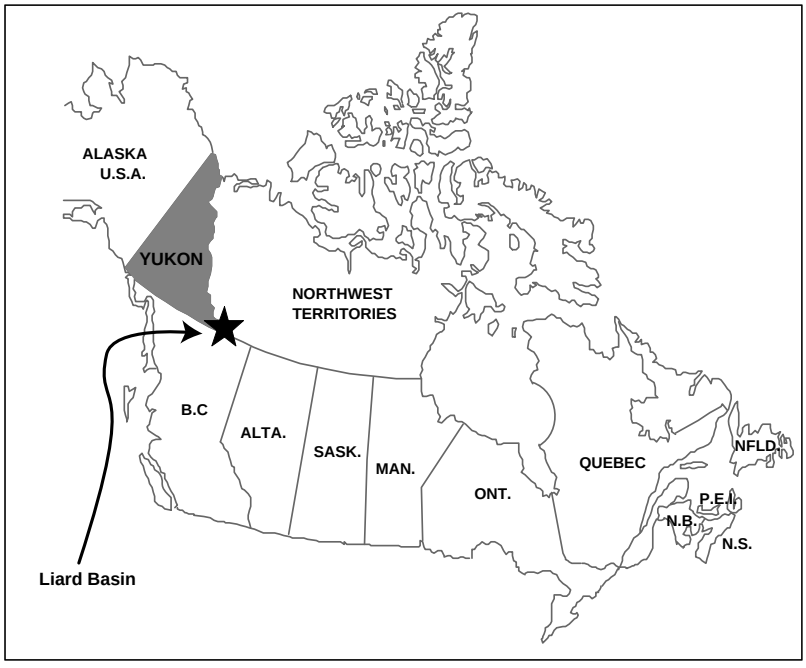
## METHODOLOGY

The analysis of the hydrocarbon endowment of the Liard study area began with the documentation and synthesis of the regional geological setting as it relates to the basin evolution, geometry, sedimentation history, geochemistry, structural history and hydrocarbon occurrence (shows and discoveries) within the study area. Current publications relating to the geology and discovered resources of the study area are listed in the references.

The initial phase of the study was supplemented with a comparative study of the geology and the discoveries in adjacent areas of the Northwest Territories and British Columbia. The results of these studies were synthesized into a series of geologic illustrations and maps that show: 1) the geologic settings of the discoveries and the parameters that control discovered resources; 2) a series of schematic cross-sections that describe the parameters controlling the play and; 3) a series of play maps that show the potential for discoveries similar to those already made and for conceptual discoveries that should be present based on sound geological analysis.

Within this framework, models for hydrocarbon entrapment in the study area were developed.

***Figure 1.*** *Liard Basin location map.*



Quantification of the discovered hydrocarbon resources was undertaken utilizing the methodology outlined in the Fall 1993 Board *Release of Discovered Resources of the Mainland Territories*. This methodology utilizes the probabilistic pool reserve calculations developed by the Geological Survey of Canada as outlined in GSC Open Files Nos. 2374 and 2703.

The above geoscientific analysis was followed by the systematic statistical analysis of the undiscovered resource base utilizing a resource assessment methodology developed by the NEB. This methodology uses a series of developed in-house templates, created in the spreadsheet software package "Excel 4.0®" by Microsoft Corporation combined with Pallisade Corporation's "@RISK®" add-in set of programs. @RISK links directly to Excel and adds risk analysis and modelling capabilities to the Excel spreadsheet models.

The probabilistic methodology utilized in the templates was adapted from Roadifier (1979) and was developed by NEB staff. A probabilistic estimate of the petroleum resources is achieved by multiplying independently randomly selected values from input distributions for hydrocarbon volume, hydrocarbon yield and risk using the following model:

Hydrocarbon Volume x Yield x Risk = Undiscovered Resources

A full description of this methodology was included in the NEB's *Natural Gas Resource Assessment, Northeast British Columbia,* released as a NEB working paper in January 1994.

## UNITS/ABBREVIATIONS

$10^6m^3$ - million cubic meters
ac-ft - acre feet
AOF - absolute open flow
Bbls - barrels
Bcf - billion cubic feet
BOE - barrels of oil equivalent
d - day
ft - feet
ft kb - feet below Kelly (the floor of the drill platform)
GIP - gas in place
GOR - gas/oil ratio
Ha - hectares
IMG - marketable gas
km - kilometres
m - metres
md - millidarcies
mi - miles
mKb - metres below Kelly (the floor of the drill platform)
MMbbls - million barrels
MMcf - million cubic feet
psi - pounds per square inch
Tcf - trillion cubic feet

# REGIONAL GEOLOGICAL SETTING

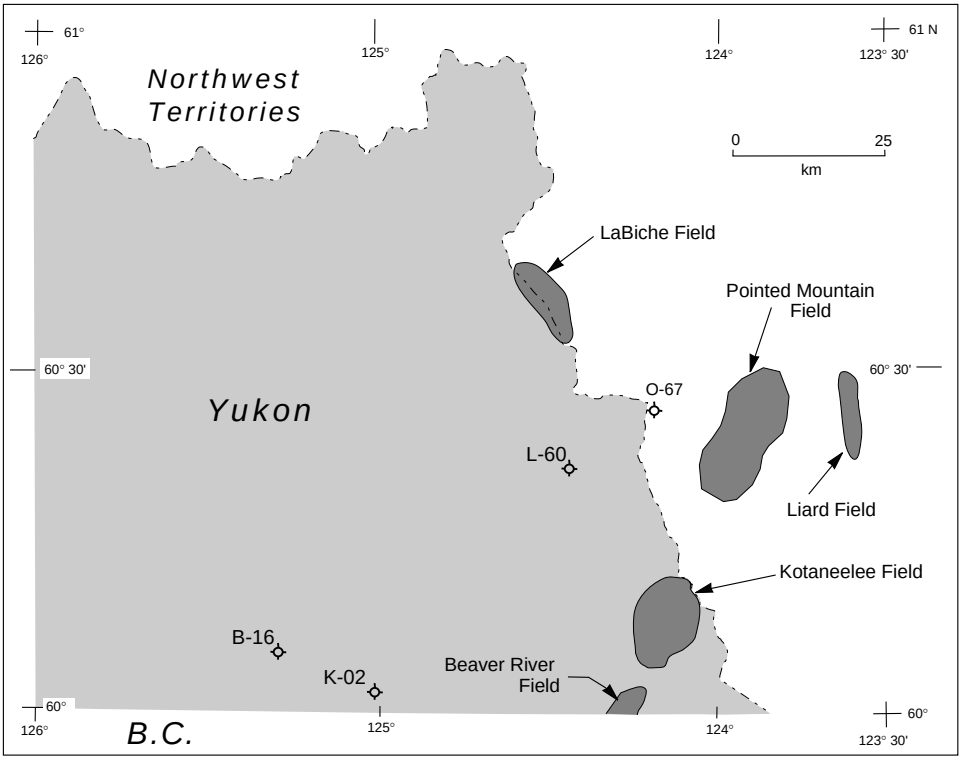
The study area occupies an area of 8,553 km² (3,302 mi²) and is situated in the vicinity of the boundaries of the province of British Columbia, and the Yukon and Northwest Territories. It is bounded to the north and east by the Yukon–NWT border, to the south by the British Columbia–Yukon border and to the west by longitude 126 (the approximate eastern margin of the Hyland Plateau) (Figure 2). The study area includes the following present-day physiographic elements: the Liard Plateau and portions of the southern Mackenzie and Franklin Mountains.

The Liard Plateau lies between the Rocky Mountains to the south and the Mackenzie and Franklin mountains to the north and includes the Tlogotsho Plateau in the Northwest Territories. To the east of the Liard Plateau lies a vast area of low relief called the Great Slave Plain (an extension of the Interior Plains of North America), largely underlain by Cretaceous to Paleozoic strata and generally below 300 m in elevation. To the west of the Liard Plateau lies a well timbered low relief area called the Hyland Plateau.

In the eastern part of the study area lie the Liard and Nahanni ranges, while to the west the more rugged Sunblood, Sombre, Arnica, Manetoe and Funeral Ranges. Overall the study area is rugged and mountainous with local elevations above 1,500 m. The plateau is deeply dissected by resistant anticlinal ridges with Paleozoic cores trending northerly. These are separated by wide synclinal valleys with Mesozoic cores, at elevations of 450 to 600 m, partially covered by alluvium. Two major rivers dissect the plateau and drain eastward into the Liard River: the Beaver River and the Nahanni River.

The central portion of the study area is composed of the fairly flat-topped Nahanni and Tlogostsho plateaus which are dissected by the canyon of the Nahanni River. To the southwest lies the more gentle rolling heavily timbered country around the Beaver River Anticline which includes Spruce Lake, Fantasque Lake and Larsen Lake.

***Figure 2.*** *Liard Plateau study area.*




Underlying the sedimentary cover of the study area and forming the effective basement is a melange of meta-sedimentary, metamorphic and igneous rocks of Precambrian age. These rocks are generally overlain by miogeoclinal Paleozoic strata characterized by marine carbonate and shale. Mesozoic strata are predominantly fine- and medium-grained clastics derived from the erosion of the emerging Cordillera in the west, and to a minor extent, from the Canadian Shield to the east.

Surface exposures of Devonian and older rocks are confined

mainly to the northwest half of the study area, while Carboniferous and Cretaceous rocks are exposed in the southeast. Cretaceous rocks lie directly upon rocks of Permian age. No Upper Carboniferous or Jurassic strata are present in the study area.

Access to the area is via the Alaska Highway (approximately 30 to 100 km to the south), by boat or barge on the Liard River to the east and on the Nahanni River downstream from Virginia Falls; by float plane on Larsen Lake, Spruce Lake and Fantasque Lake; or by fixed-wing plane from the airstrips at Fort Liard or Nahanni Butte, Northwest Territories. The presence of muskeg in the low-lying valleys, windfall, and burnt dead-fall makes surface summer travel away from the main river courses extremely difficult in the summer.

## STRATIGRAPHY AND DEPOSITIONAL SETTING

From the Cambrian to Late Silurian, the study area underwent continuous subsidence and deposition as part of the western miogeocline. In Late Silurian time, there is some evidence that the seas withdrew briefly, possibly in response to the Caledonian Orogeny. By Early Devonian time the seas had returned and continued their transgression (onlap) to the east without a major break in carbonate/shale deposition through to the late Devonian. Near the end of the late Devonian, uplift occurred to the south in the Toad River area of British Columbia and may have extended northward into an area on the southwestern margin of the study area (in an area sometimes referred to as the Beaver River or Beavercrow High). This Late Devonian uplift to the south and west enhanced the miogeocline, causing a thickened Upper Devonian succession in the central and eastern parts of the study area.

In the Carboniferous, a thick succession of shale (the Etanda Formation) was deposited in the central and western parts of the study area. This shale is associated with sandstone and siltstone of Banffian age (the Clausen and Yohin formations), and carbonates of Late Carboniferous age (Flett and Prophet formations). The Flett and Prophet carbonates were laid down in the central and eastern margins of the study area while laterally equivalent shale was laid deposited south and west. During the latest Carboniferous, great quantities of fluvial, deltaic and near shore sands sourced from the northeast were deposited over the study area (Mattson Formation).

During the Permian and Early Triassic, the study area was transgressed by a shallow sea within which a thin clastic succession was deposited. During the late Triassic and Jurassic the area became emergent as indicated by no strata of this time interval being discernable. The study area was again inundated during the Cretaceous and a thick succession of clastics deposited. Near the end of Late Cretaceous, orogenic activity in the area uplifted the strata and produced most of the west dipping faults seen at surface in the eastern portion of the study area. These faults appear to have developed along previous Early Paleozoic hinges. In the central part of the study area, the strata are more gently folded into antiforms with a minimum of faulting, while on the western margin, east dipping faults appear to dominate the structural grain.

The Liard Plateau offers a setting of stratigraphic conditions suitable for the sourcing, migration and entrapment of hydrocarbons. For these reasons, a thorough understanding of the stratigraphy and depositional setting is important, for the analysis of discovered hydrocarbon accumulations, and for the predicting possible conceptual accumulations. The age, name and gross lithology of potential reservoir and source rock horizons found in the study area are outlined in Figure 3 and in the following written summary.

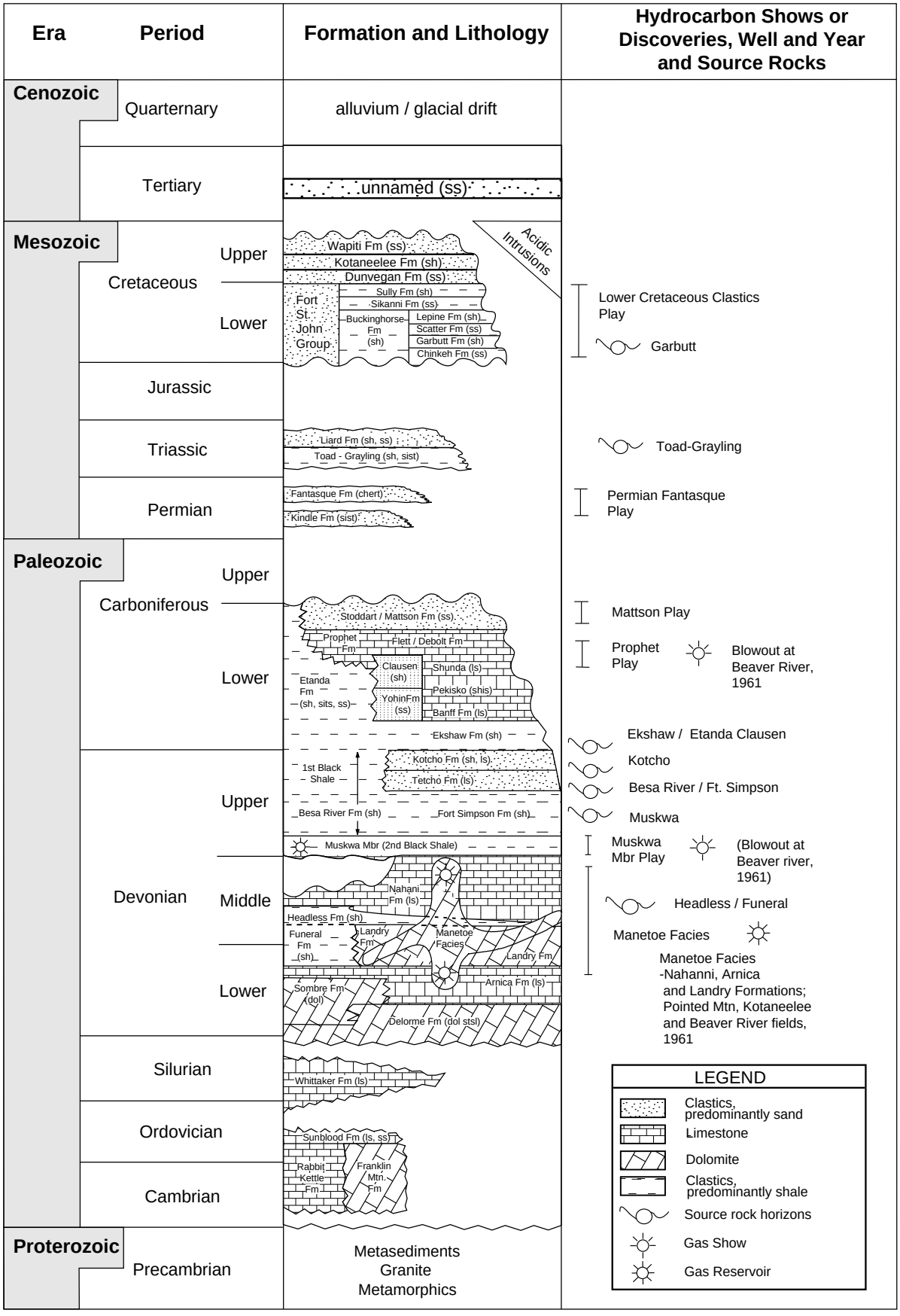
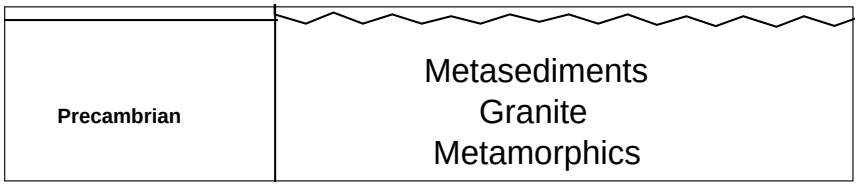



***Figure 3.*** *Stratigraphic column for the Liard Plateau study area.*

### PRECAMBRIAN

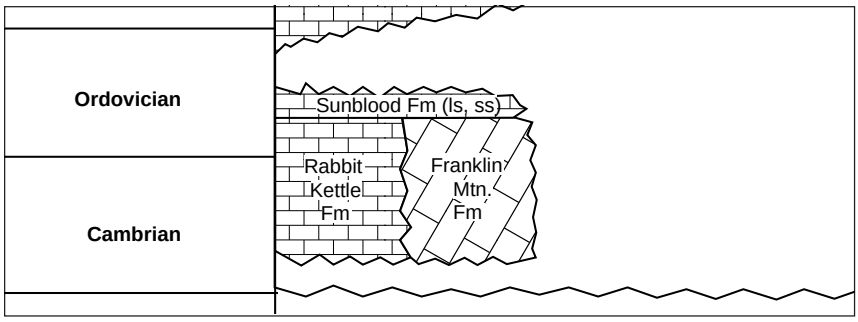
Underlying the Phanerozoic cover of the study area and forming the effective economic basement is a melange of meta-sedimentary (argillite), metamorphic and igneous rocks of Precambrian (mostly Helikian) age. No wells in the study area have been drilled into the Precambrian. However a few wells have penetrated the Precambrian in areas adjacent to the study area. An outcrop of Helikian laminated siliceous-green to grey-green platy argillite is identified on the GSC 'A series' surface geology map 1380A on the western boundary of the study area and commented on in the NEB Report No. 045-01-01-0024.




### CAMBRO-ORDOVICIAN

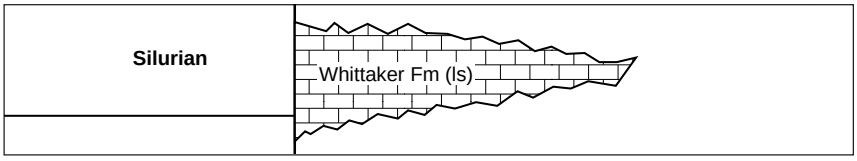
Unconformably overlying the Precambrian strata are Upper Cambrian (Franconian) to Lower Ordovician (Upper Canadian) rocks of the Rabbitkettle and Franklin Mountain formations. The Rabbitkettle Formation, in the western portion of the study area, consists of well bedded to massive silty limestone and calcareous siltstone characterized by wavy bedding and by finely laminated dark grey to black argillaceous limestone and calcareous shale with thicknesses greater than 1,200 m. The Rabbitkettle Formation undergoes a lateral facies change eastward and becomes the Franklin Mountain Formation in the eastern and central portion of the study area. The Franklin Mountain Formation consists of red-weathering dark grey, anhydritic, silty dolomite. These carbonates are exposed in the Funeral, Caribou and Sunblood ranges and at the Beaver River high. They generally comprise recessive weathering Upper Ordovician limestone and recessive weathering Middle Ordovician limestone and dolomite. The Ordovician section thickens rapidly northward to Virginia Falls (north of the study area in Nahanni National Park) where it reaches over 2,100 m thick. It then thins rapidly eastward and is missing in the vicinity of Nahanni Butte, Northwest Territories (NEB Report No. 045-01-01-0024). Neither the Rabbitkettle nor the Franklin Mountain are considered prospective hydrocarbon exploration targets due to their extreme depth and lack of potential source and reservoir rock horizons.

The Middle Ordovician Sunblood Formation conformably overlies the Rabbitkettle and Franklin Mountain formations and is composed of grey, micritic, finely laminated limestone in which mudcracks are common. The Sunblood reaches a maximum thickness of 1,040 m in measured sections just north of the study area. No porosity of economic potential has been observed in the Sunblood, however some fracture porosity may exist. Lack of source rocks to charge this zone is considered as the other main deterrent for considering this horizon as a viable petroleum exploration target.



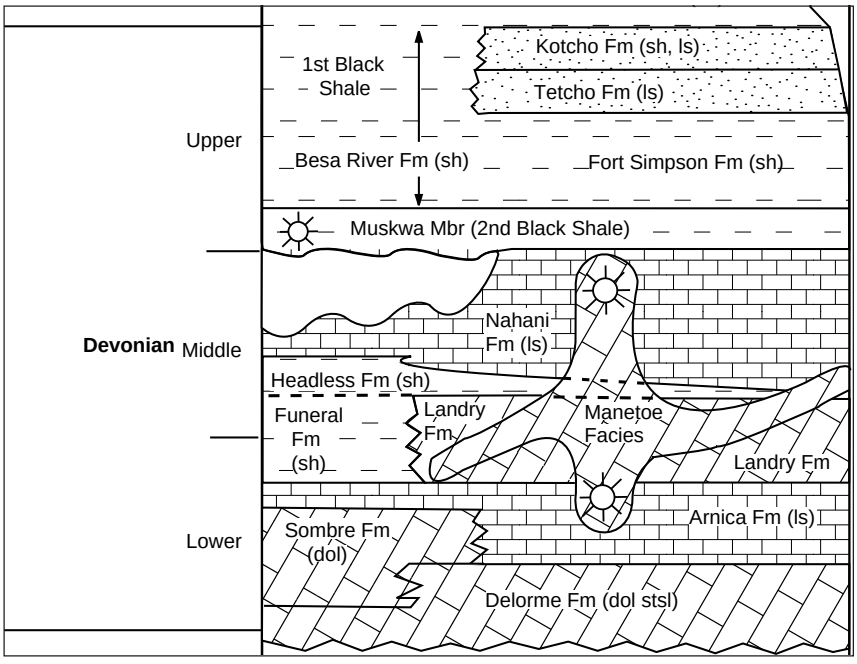
## SILURIAN

Silurian strata in the study area are represented by the Whittaker Formation which disconformably to unconformably overlies the Sunblood Formation and is composed of over 400 m of grey thinly bedded grey to olive-grey, microcrystalline limestone, dark grey, cherty, fossiliferous dolomite with secondary anhydrite fracture and vug fill (in the SOBC Shell Beavercrow YT K-02 well). NEB Report No. 045-01-01-0024 incorrectly identifies this zone as the Ronning Formation in the SOBC Shell Beavercrow YT K-02 well (see Appendix B). In the south and eastern part of the study area, the Whittaker Formation is partly equivalent to the Lower Silurian light grey, argillaceous, fossiliferous medium crystalline dolomite and dark grey, fissile graptolytic shale of the Mount Kindle Formation. In the facies transition zone, the lithology varies from dolomite and sandy dolomite to siltstone and interbedded shale. The Mount Kindle unconformably overlies the Sunblood, Franklin Mountain and Helikien strata. The total thickness of the Silurian unit varies from 500 to 900 m. No porosity of economic potential has been observed in the Whittaker or Mount Kindle, however some fracture porosity may exist (NEB Report Nos. 045-01-01-0024 and 045-01-01-00027). These formations are referred to as the Ronning Dolomite in NEB Report No. 045-01-01-00027. As with the Sunblood Formation, the lack of source rocks for charging the potential Silurian reservoirs decreases their hydrocarbon potential.




## DEVONIAN

The Devonian strata in this area are characterized by complex facies and thickness changes. The succession from oldest to youngest is as follows. Up to 30 m of light grey, finely crystalline vuggy, silty dolomite interbedded with dark grey shale and dolomitic siltstone called the Delorme Formation (Upper Silurian to Lower Devonian) rests unconformably on Whittacker to Precambrian strata. The Delorme is called the "Buff Group" in outcrop in northeast B.C. (NEB Report No. 045-01-01-0024) and was penetrated in the SOBC Shell Beavercrow YT K-02 well. In the south and western part of the study area, the Delorme Formation is conformably overlain at an abrupt contact by over 2,500 m of grey to black fossiliferous dolomites and dolomicrites of the Sombre Formation (Lower to Middle Devonian). The Sombre thins eastward and northward and forms a gradational facies change into the Arnica Formation composed of up to 625 m of dark grey to brownish-grey, medium crystalline dolomite (cherty at top) with poorly preserved fossils.




Conformably overlying the Sombre and Arnica formations in the eastern and central parts of the study area are up to 500 m of grey weathering, massive cryptocrystalline reefal limestones and locally mottled

medium- to dark-grey dolomite with abundant brachiopod fauna of the Landry Formation (Lower to Middle Devonian). Locally the dolomite is brecciated, fractured and is referred to as the Lone Mountain Formation in NEB Reports Nos. 045-01-01-0024 and 045-01-01-00027. The term Lone Mountain is, however, no longer used. The section is now subdivided into Arnica, Landry, and Nahanni formations and the Manetoe facies. West of a line trending around 126° W, the Landry passes through a facies transition into the shale of the Funeral and Headless formations.

The Funeral Formation [Middle Devonian (Eifelian)] is composed of two parts: a lower part of dark grey to black, platy, calcareous shale and mudstone interbedded with black, silty to argillaceous, pale buff weathering, recessive limestone; and an upper part composed of thin bedded bioclastic argillaceous limestone and black calcareous shale. This section is up to 700 m thick.

The Headless Formation [Middle Devonian (Early Givetian)] conformably overlies the Landry and Funeral formations and is composed of up to 60 m of argillaceous, thin-bedded, cryptocrystalline to fine-grained fossiliferous limestone interbedded with calcareous shale. In NEB Report No. 045-01-01-0024, these shales are termed Wrigley Creek shales. Conformably overlying the Headless Formation shales (transgressively) are 10 to 137 m dark-grey, bedded, dolomitic limestone and light grey weathering, dense, finely crystalline limestone of the Nahanni Formation [Middle Devonian (Givetian)]. The succession provides ample source and reservoir possibilities, which makes these Middle Devonian carbonates a highly prospective interval.

Within the Arnica, Landry and Nahanni formations is a light grey weathering, mottled white and black, coarsely crystalline, diagenetic, hydrothermal dolomite, of Late Devonian age called the Manetoe facies dolomite. In places the dolomite is up to 150 m thick. It has cavernous porosity and some “karstic” caverns filled with carbonate sand, and silt with quartz. This diagentic facies was previously misinterpreted and given formational status. The Manetoe is the principal reservoir and target for gas in the study area.

The following reservoir development model for the Manetoe is adapted from Morrow et al. (1990). The Manetoe facies dolomite reservoirs resulted from a two stage process. The first stage was the excavation of a laterally extensive cavern system during the Early to Middle Devonian in more soluble limestone strata of the Landry, Arnica, Headless and Nahanni formations. This was caused by subaerial exposure and an actively moving Watt Mountain aquifer. In the Middle to Late Devonian, this was followed by precipitation of hydrothermal dolomite from superheated hypersaline Elk Point brines that circulated through the Manetoe cavern system. During the Late Paleozoic to Early Mesozoic, deep burial by an organic rich, predominantly fine-grained siliciclastic sequence (Upper Devonian to Cretaceous) resulted in the maturation and expulsion of hydrocarbons from the siliciclastics. These hydrocarbons migrated downward and laterally into the enhanced permeable zones of the Manetoe facies, where it was developed to the top of the Nahanni Formation or interfingered with diagentic dolomite on the western margin. Intense deformation during the Tertiary Laramide Orogeny resulted in further permeability enhancement (fractures) within the reservoir. This same structuring created anticlinal folding and thrust faulting, which thickened the reservoir net pay section. Middle Devonian carbonates that are not of Manetoe facies have insufficient porosities (less than 3%), and permeabilities (less than 5 md), to be considered producible economic reservoirs.

Reimer (1994) poses an alternate explanation for the development of the Manetoe Dolomite. In his model "an aggressive hydrothermal reaction was initiated by thermochemical sulphate reduction (TSR), involving the oxidation of pre-existing oil pools (within the Middle Devonian limestones). This reaction caused the dissolution of the limestone host rock, followed by the precipitation of dolomite, concurrent with pyrobitumen and sulphite mineral formation. Methane and carbon dioxide evolved as principal by-products of this reaction." The true history of the reservoir is probably a combination of the two models. Both models lead to the same conclusions for the play area and prospectivity.

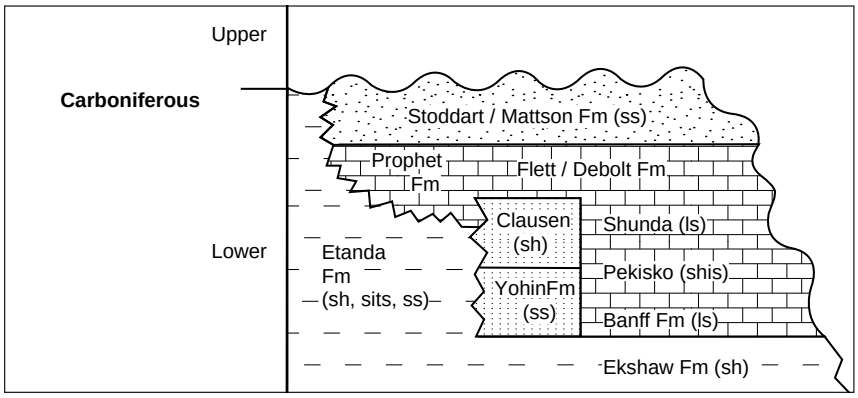
Unconformably (in the south and west) to conformably (north and east) overlying the Nahanni Formation and the Manetoe facies dolomites are the up to 36 m of fissile, grey to black, bituminous, highly radioactive micaceous, siliceous and pyritic shales of the Horn River Formation (Muskwa Member) (Middle to Upper Devonian). The Muskwa Member is referred to as the Second Black Shale marker in the Beaver River, Kotaneelee, and Pointed Mountain fields and to the lowermost part of the Fort Creek (abandoned nomenclature) in NEB Reports Nos. 045-01-01-0024 and 045-01-01-00027. This shale is the source rock horizon for the Manetoe facies dolomite reservoirs and a potential reservoir itself when fractured.

Conformably overlying the Muskwa Member are the up to 2,256 m of dark grey to black, thinly bedded, fissile, calcareous, pyritic and cherty shale of the Besa River Formation [Devonian to Carboniferous (Givetian to Chesterian)]. The Besa River Shale is attributed to be the zone of décollement in northeast British Columbia and has been identified as a source rock zone and a potential fractured reservoir. In the Beaver River, Kotaneelee, and Pointed Mountain fields, the First Black Shale marker is contained within the Besa River Formation. The Besa River Formation equates to the "upper part of the Fort Creek" (abandoned nomenclature; now subdivided into Hare Indian, Canol and Imperial) in NEB Reports Nos. 045-01-01-0024 and 045-01-01-00027.

In the extreme eastern portion of the study area, the Besa River is characterized by a facies transition into up to 500 m of greenish-grey calcareous, silty shales and mudstones called the Fort Simpson Formation. Conformably overlying the Fort Simpson Formation are 75 m of light-coloured silty, fine-grained limestone of the Tetcho Formation (Famennian). Generally, porosity and permeability within the Tetcho are insufficient for it to be considered as having potential reservoirs, although there may be some possibility that fracture-enhanced porosity could produce potential reservoir-quality sections. Conformably overlying the Tetcho are less than 30 m of greenish-grey locally bituminous shales and shaly limestone of the Kotcho Formation (mid Famennian). The Kotcho represents an additional potential source rock. Westward, both the Tetcho and Kotcho grade into shales of the Besa River equivalent to the First Black Shale.

### CARBONIFEROUS

Conformably overlying the Devonian Besa River Shale in most of the study area and the Kotcho in the extreme east are up to 425 m of Carboniferous medium grey to black, non-calcareous, bituminous and micaceous, fissile basinal shale interbedded with medium grey, fine- to very fine-grained quartzose, cherty, tight siltstone, sandstone and limestone of the Etanada and Ekshaw formations [Carboniferous (Osage to Meramec)]. Chevron, in Report No. 045-01-01-00027 called the Etanada-Ekshaw section the Beavercrow Shale (a term that was never recognized). This shale represents the basinal equivalent of the Carboniferous clastics and carbonates. The organic richness of the




shale makes it an excellent source rock candidate for hydrocarbons trapped in the Carboniferous clastic and carbonate reservoirs.

The Carboniferous basinal shale changes laterally eastward and northward into the 157 m thick calcareous, siliceous, silty sandstone and sandy siltstone platform edge turbidites of the Yohin Formation [Lower Carboniferous (Tournasian)]. Conformably overlying the Yohin are 150 to 190 m of Lower Carboniferous (Kinderhookean) thinly laminated, variably calcareous, black shale with interbedded resistant black siltstone and mudstone, called the Clausen Formation. Eastward the Yohin and Clausen strata grade into the carbonate bank strata of the Banff, Pekisko and Shunda Formations.

Conformably overlying the Lower to Middle Carboniferous platform to basin sequence is up to 900 m of skeletal lime packstone and grainstone, shale and marlstone, with chert nodules of presumed turbidite origin representing the Flett Formation [Lower to Upper Carboniferous (Upper Tournaisian to Upper Viséan)]. The Flett changes westward and northward into the Prophet Formation, an up to 800 m thick horizon of cherty, spicularite, skeletal to ooid limestone with shale, marlstone and minor dolostone. Further westward and northward the Prophet Formation grades into the basinal Etanda Formation shale. Fractured carbonates in the Flett-Prophet section present possible secondary targets for gas sourced in the Besa River and Etanda, and to a minor extent, Clausen, formations.

Conformably overlying the Flett Formation in the north and east and Etanda Formation shale in south and west are up to 1450 m of fine- to medium-grained chert and sub-chert arenite and quartzitic sandstone with thin intervals of shale, limestone, dolomite and coal representing the Mattson Formation [Upper Carboniferous (Upper Viséan to Lower Namurian)]. The Mattson Formation is subdivided into three informal members: 1) a 125 m thick, lower, siliceous, argillaceous, light grey, well sorted, quartzose, dense sandstone with poor porosity and permeability and a 60 m thick bituminous shale (Calstan Report No. 045-01-01-00027); 2) a middle, friable, quartzose sandstone with good porosity and permeabilty; and, 3) an upper calcareous sandstone with poor porosity and permeability. These Mattson strata indicate both excellent reservoir and source potential and are considered excellent secondary targets.

### PERMIAN

Unconformably overlying the Carboniferous strata are Lower Permian Kindle Formation strata composed of a rhythmically interbedded sequence, greater than 90 m of calcareous silty shale, dolomitic sandy siltstone and silty brachiopod-rich limestone. Unconformably overlying the Kindle Formation is the Upper Permian Fantasque Formation (total thickness 55 m) comprised chert beds 0.3 to 3 m thick separated by thin shale and capped by a 9 m calcareous cherty sandstone.

### TRIASSIC

Unconformably overlying the Permian strata in the extreme south of the study area are shale, siltstone, argillaceous limestone and fine-grained argillaceous sandstone of the Toad, Grayling and Liard formations.

## JURASSIC

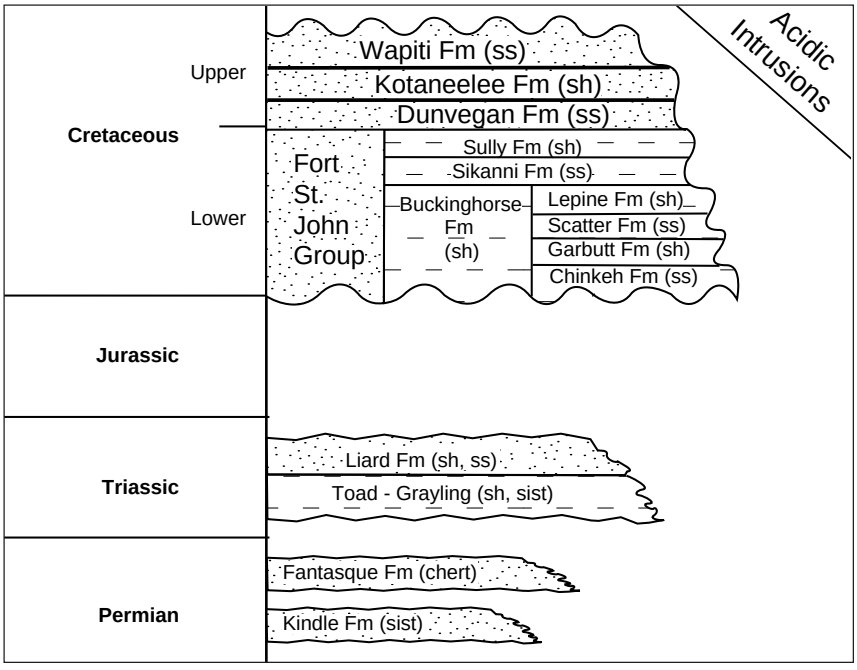
No Jurassic strata are preserved in the study area.

## CRETACEOUS

Generally confined to synclines and unconformably overlying Triassic strata in the southern and western parts of the study area, and Carboniferous to Devonian strata in the northern and eastern parts, are clastic rocks of Cretaceous age. This recycled sediment was dominantly sourced from the east with minor western influence. The oldest formation is the Chinkeh Formation (Leckie et al, 1991), an up to 32 m thick fining upward, coarse cherty conglomerate to a fine-grained sandstone that is probably equivalent to the Cadomin to the south and the Mount Goodenough, Martin House and San Sault formations to the north. The Chinkeh was previously called the lower member of the Buckinghorse Formation, the basal Garbutt Formation, or the basal Cretaceous sandstone. This unit represents a succession from non-marine valley fill on the Paleozoic unconformity, through to progradational marine near-shore sandstone of shoal and barrier origin.

Conformably overlying the Chinkeh are strata belonging to the Garbutt Formation [Fort St. John Group; Lower Cretaceous (Lower Aptian)]. The Garbutt consists of up to 290 m of silty glauconitic limestone and an argillaceous siltstone with sideritic concretions and bentonite seams followed by rubbly sideritic mudstone, argillaceous siltstone and finely laminated sandstone, in the north of the study area, and up to 750 m of dark, fissile shale in the centre and east, which grade southward along the B.C. border into interbeds of very fine-grained sandstone and siltstone. The Garbutt grades upward into the Scatter Formation [Lower Cretaceous (Lower to Middle Albian)]. The Scatter consists of three members: 1) basal Bullwell Member a thick resistant glauconitic sandstone; 2) the middle Wildhorn Member, a silty concretionary marine mudstone; and, 3) the Tussock Member, which comprises alternating units of silty glauconitic sandstone and silty mudstone. Total thickness for the Scatter ranges from 60 to 375 m with the unit generally thinning to the south. The Scatter shales out along the Kotaneelee River.

Conformably overlying the Scatter is the Lepine Formation [Lower Cretaceous (Middle to Upper Albian)], which consists of a lower unit of fossiliferous (ammonites and graptolites), silty concretionary marine mudstone and an upper unit of black flaky to fissile, marine shale. A radioactive shale occurs at the base of the Lepine and provides an excellent marker for stratigraphic correlation. The unit in the study area is up to 250 m thick and thins to north and east. It generally underlies tree-covered topographic lows.




Conformably overlying the Lepine is the Sikanni Formation [Lower Cretaceous (Upper Albian)], a fine-grained glauconitic, calcareous, finely cross-bedded sandstone and argillaceous siltstone and shale up to 250 m thick. Conformably overlying the

Sikanni Formation is the Sully Formation (Lower Cretaceous), a predominantly marine, muddy siltstone with sideritic concretions, and a flaky black shale up to 300 m thick with a yellow efflourescence. Conformably overlying the Sully is the Dunvegan Formation [Upper Cretaceous (Cenomanian)], a succession of marine, deltaic and non-marine sandstones with thin beds of shale, shaly limestone and coal up to 350 m thick. Conformably overlying the Dunvegan is the Kotaneelee Formation (Late Cretaceous), a concretionary marine shale with rare sandstone and conglomerate up to 300 m thick. Conformably overlying the Kotaneelee are erosional remnants up to 40 m thick comprising the Wapati Formation (Upper Cretaceous), composed of medium- to coarse-grained, friable, feldspathic, calcareous sandstone, pebble conglomerate, sandy shale, bentonite and coals.

#### *Acidic Intrusions*

On the western margin of the study area (in the vicinity of Larson Lake), several small bodies of porphyritic horneblende-biotite trachytes intrude strata of the Fort St. John Group, and the Dunvegan, Kotaneelee and Wapiti formations. These have been mapped by the Geological Survey of Canada. Mapping suggests that these bodies are late Cretaceous to Tertiary in age and associated with orogenic activity.

### TERTIARY TO RECENT

Glacial drift extends over much of the area and is preserved mainly in the valley floors of the synclines. In the central and eastern parts of the study area, the thickness varies from less than a metre to greater than 100 m. The thickest deposits are often found in the main river valleys and may reflect, to some extent, pre-glacial and post-glacial drainage effects. Glaciation has also left a pronounced lineation pattern on the landscape, observable from the air. There are east-northeast trending drumlins and drumlinoids and southeast trending moraines.

## STRUCTURAL GEOLOGY

The Liard Plateau study area is situated in the Cordilleran Structural Province, where there is a marked change in structural style and trend. This is a result of the area being in a transitional zone between two areas of differential shortening: the Rocky Mountains to the south and the Mackenzie Mountains to the north. Deformation in the Rocky Mountain disturbed belt is generally thought to result from décollement above crystalline basement, without the basement having been disturbed. Studies in the Mackenzie Mountains indicate that the faulting is high angle (often reverse) with dips either east or west, and the result of near vertical movement of basement fault blocks. The resulting convergence and competition of these structural styles has produced diverse structural features and trends.

At about latitude 60° north, the general northwesterly trend of the Rocky Mountains in British Columbia is deflected to the northeast, and results in an east-west right-hand, en echelon offsetting of mountain blocks. Structures within the Liard Plateau are characterized by northwesterly, northerly and northeasterly trending elongated folds, high angle reverse faults and thrust faults, which dip both easterly and westerly. These are predominantly Laramide and are often offset by northeasterly trending normal faults of Laramide to post-Laramide age that formed along pre-existing structural zones of Paleozoic age.

Main structural features have sinuous axial traces that mostly trend north-south to northeast-southwest. Topography and structural style, and the degree of structural deformation and lithology, are closely related within the study area. Resistant Permo-Carboniferous rocks form topographic highs and protrude through the Cretaceous and Triassic cover, which forms the flanks of structurally high anticlines such as Beavercrow, LaBiche, Beaver River, Pointed Mountain, Liard and Mattson. Topographic lows are cored by synclines of Quaternary, Cretaceous and Triassic strata. The overall intensity of the deformation varies with the composition of the geologic section. Structural complexity increases in the western part of the study area, where most of the resistant Middle Devonian to Ordovician carbonates have shaled out. Intensity of structural deformation generally increases from south to north, where dips on eastern limbs of the assymetric folds steepen, and the structures are dissected by cross-cutting faults. Faulting appears to be confined to areas where rock units have undergone facies changes to shale. High-angle faults, however, cut across lithologic boundaries, and all faulting seems to be the result of basement movements.

Many of the above structural features are shown on the seismic section (Figure 4) found at the end of the report. The section runs through the Kotaneelee field and shows the complexity of structural geometry.

## REGIONAL GEOCHEMISTRY

An examination of the stratigraphy of the study area suggests the following source rock horizons: Middle Devonian Funeral and Headless formations, the Upper Devonian Besa River, Fort Simpson, and Kotcho formations, the Carboniferous Ekshaw and Etanda formations, the Triassic Toad and Grayling formations and the Lower Cretaceous Garbutt Formation. Maturation data indicate that the top of the present oil window is at 700 m (within the Permian Fantasque to the Carboniferous Mattson) with the base of the oil window at about 1350 m (within strata of Middle to Lower Carboniferous age). The principal source of the hydrocarbons and bitumen is unstructured liptinite.

Devonian source rocks (Funeral, Headless and Besa River formations), contain type II amorphous kerogen of marine origin with vitrinite reflectance values from 1.6 to 4.6%$VR_o$, Total Organic Carbon (TOC) values of 1 to 4% and low hydrogen indices (Potter et al, 1993). Maturation models suggest a Late Devonian heating event with generation and migration of liquid hydrocarbons probably occurring in the Late Paleozoic to Early Mesozoic. Devonian Manetoe facies reservoirs often contain pore-coating bitumen which must have been formed by the Late Devonian and may indicate a late Devonian gas catagenesis event. Manetoe reservoir gas is most likely due to catagenesis of oil from the overlying Besa River Shale, which occurred when the reservoir entered the gas window approximately 280 mya (Morrow et al., 1991; Potter et al., 1993).

Ekshaw and Etanda source rocks, and their equivalent shelf deposits the Yohin, Clausen and Prophet, contain mixed kerogen (types I and II) with TOC values of 1 to 3% and calculated vitrinite reflectance values from 1.2 to 1.5%$VR_o$, indicating they are in the catagenic gas stage (Potter et al, 1993).

The source rocks of the Mattson Formation and their Etanda equivalents contain mixed type II and III kerogen with TOC values up to 10% (average around 5%) and vitrinite reflectances at 0.84 to 1.0%$VR_{o,}$ and high hydrogen indices (over 100). These strata are

mature for oil and gas having entered the oil window some 230 mya. The lower Mattson could have potential to generate condensate and wet gas (Potter et al., 1993).

Source rocks within the Triassic Toad and Grayling formations and the Lower Cretaceous Garbut Formation have been identified by Leckie et al., 1991. TOC content within the Cretaceous section varies between 1.36% and 5% and hydrogen indices vary between 150 and 300. Most of the study area's Cretaceous section is in the oil window, and therefore has good hydrocarbon potential.

# PETROLEUM GEOLOGY

## EXPLORATION HISTORY

E.D. Kindle of the Geological Survey of Canada was the first geologist to publish the results of a detailed examination of the geology of the study area (Kindle 1944). Kindle's work outlined the prominent structures in the area and was followed up by Hage (1945) and Douglas and Norris (1959), who further outlined the stratigraphy and structural geology. The first recorded evidence of active petroleum exploratory effort in the area began in 1955 with reconnaissance field work performed by California Standard (Chevron). Further work led to the recognition of the Beaver River, Pointed Mountain, Kotaneelee and LaBiche antiforms as potential hydrocarbon-bearing prospects, and lead to Territorial P and NG permits 1468 to 1472 being issued to California Standard (Chevron) and partners, and B.C. land permits on the Beaver River Anticline being issued to Pan American (Amoco). The following year four permits were issued to companies in the Northwest Territories.

In 1957, the first well in the Liard Plateau region was spudded just south of the study area in British Columbia on the Beaver River Anticline, and completed in 1959 [Pan American (AMOCO) A-1 Beaver River B-63-K]. The well tested gas in the Carboniferous Prophet-Flett Formation (blowout), in the Devonian Besa River Formation (blowout) and in the Manetoe facies of the Devonian Nahanni Formation 0.1 $10^6 m^3/d$ (3.6 MMcf/d). The gas in the Besa River was encountered as the well was being drilled through fractured shales and siltstones at 2,549 mKb (8,363 ft.). The well was brought under control using a mud weight of 9.3 lbs/gal. The Mississippian Prophet Formation gas encountered at 2,597 mKb (8,519 ft.) set the rig on fire and killed 2 lease hands. The flow rate during this blowout was measured at over 0.1 $10^6 m^3/d$ (3.5 MMcf/d).

In 1962, a follow-up well (Pan Am et al. Kotaneelee YT P-50) on the Kotaneelee antiform structural trend further north in the Yukon, tested gas in the Nahanni at an absolute open flow (AOF) of 2.41 $10^6 m^3/d$ (.085 MMcf/d) and confirmed the extension of the Manetoe facies play onto lands under the jurisdiction of the Yukon Territory. This well, drilled by Pan American (Amoco) on farmed-in Home Oil acreage, was not ideally located but did prove educational. It highlights some of the problems in drilling for and locating wells to test Middle Devonian carbonate targets. The main problems were: 1) nonsymmetrical surface and deep subsurface features, so careful planning and evaluation of seismic is necessary; 2) the complexity of faulting; and, 3) large lateral variation and thickening in the overlying Besa River section.

The Mattson Anticline was the next structure tested, with the drilling of the PanAm A-1 Mattson Creek No. 1 well in the Northwest Territories in 1961. The well was spotted on the basis of surface geology and air photo interpretation, and located on the flat crest of a tight box fold with steeply dipping limbs. It was spudded in Devonian Besa River Shale and penetrated Middle Devonian carbonate after 507 m. A drillstem test carried out in Manetoe facies dolomite recovered gas-cut salt water and extended the play on a trend 120 km to the northeast.

The Beavercrow Anticline was the next anticline to be tested. In 1962, California Standard (Chevron) drilled the SOBC Shell Beavercrow YT K-02 well at a position located seismically on the 24 km long structure. The Mattson Sandstone, Arnica,

Delorme and Whittacker carbonates were tested, resulting in a good recovery of fresh water filtrate.

From 1962 to 1968, development drilling continued on the Beaver River field in B.C. and the Pointed Mountain field in the NWT. In 1969, Pan American (Amoco) returned to the Kotaneelee Anticline and continued to prove out its original discovery along this 51 km structure and drilled the Beaver River G-01 well in the Yukon at the north end of the Beaver River structure. The Merrill structure to the northwest was also drilled in 1969 by the PanAm Shell Merrill YT L-60 well where the well flowed gas-cut brackish sulfurous water from the Manetoe facies of the Nahanni Formation.

Gas was recovered in sufficient quantities during the drilling of the Pan American (Amoco) wells in 1959 and 1962. However, due to the remote location of this discovery, the field was not further developed until 1967, when a gas development contract was signed between PanAmerican (Amoco) and Westcoast Gas Transmission Company. In 1969, Pan American (Amoco) proved the extension of the Beaver River Field northward into the Yukon with the drilling of the PanAm C-1 Beaver River YT G-01 well, approximately 0.75 km north of the B.C.—Yukon border. The Beaver River field produced a total of 5,040 $10^6 m^3$ (183 Bcf) [218 $10^6 m^3$ (7.9 Bcf) from the G-01 well in the Yukon] before being shut-in in 1978 due to water influx problems caused by gas production rates exceeding 6.5 $10^6 m^3/d$ (230 MMcf/d). Pan American (Amoco) finally abandoned the field in 1983, with all the B.C. and NWT leases reverting to the crown.

These original gas discoveries spurred other companies into action, and land permits were rapidly assigned in the two territories. Active exploration continued throughout the 1960s by California Standard (Chevron), PanAmerican (Amoco), Canada Southern, Canadian Homestead, Banff Oil, and Shell. This resulted in the shooting of more than 150 line kilometres of 2-D seismic, along with magnetic and gravity imaging programs. These surveys helped to identify additional drilling prospects with sufficient closure on several antiforms, and led to the drilling of 4 wells in the Yukon Territory and other wells in the Northwest Territories.

During the 1970s, Gulf spudded the Gulf et al. West Beavercrow YT O-15 well. However, the well was abandoned early in the Besa River shales at 1,727.3 m, prior to reaching the Middle Devonian carbonate, because of hole problems. Canadian Pacific (PanCanadian) also spudded the LaBiche K-08 well in the Northwest Territories to test the LaBiche structure that straddles the Yukon and Northwest Territories border. It is on the northern part of the Merrill structural trend. The well successfully tested Middle Devonian gas and further proved up the Manetoe facies play.

In 1973, the Tattoo Gas Field in British Columbia (NTS Map Sheet 94-O-10) was discovered with the drilling of the Aquitaine et al Tattoo a-78-L/94-O-10 well. The gas-bearing formations in this area are the Permian Fantasque Formation (Belloy equivalent) (400 to 1,500 mKb) and the Carboniferous Mattson Formation (Kiskatinaw equivalent) (500 to 1,650 mKb). Potential also was indicated in the Lower Cretaceous Scatter Formation at 300 to 1,100 mKb. This discovery proved the potential of this portion of the section in the basin.

During the 1970s and 1980s, over 700 line kilometres of 2-D seismic was shot and 7 wells were drilled. Companies active in the area at this time include: Gulf, PanAmerican (Amoco), Bluemont, Fort Norman Exploration, Cessland Corporation, Mobil, Texaco, Canadian Superior, Atlantic Richfield, Beaver Geophysical, and Columbia Gas.

In 1987, Beaver River Resources Ltd. (now known as Mayan Adventures Inc.) applied for the rights to the Mattson and Nahanni zones in the 4,373 Ha (10,800 acres) that

comprise the former Beaver River field in British Columbia. Mayan Adventures Inc. was granted a special disposition by the Government of British Columbia by way of an Order-In-Council for a maximum 3 year period. This stated that, if a well was completed as a gas producer within the term, then the disposition would be converted into a regular lease under the British Columbia Petroleum and Natural Gas Act. In early 1989, Mayan Adventures Inc. re-entered the b-19-K/94-N-16 well (approximately 5 km south of the 60°N latitude Yukon border), and re-completed it as a Nahanni gas well. Upon completion, the b-19-K/94-N-16 well tested gas at rates up to 0.34 $10^6m^3/d$ (12 MMcf/d) with an AOF potential of 2.23 $10^6m^3/d$ (79 MMcf/d). In January 1990, the well was placed on production at an initial rate of 0.20 $10^6m^3/d$ (7 MMcf/d) with little water production, but by September 1990, gas rates had decreased to 0.01 $10^6m^3/d$ (0.44 MMcf/d) with water production of 43 $m^3/d$ (270 bbl/d). In order to handle anticipated water production from the well, Mayan Adventures Inc. applied for and received approval to convert the well d-64-K/94-N-16 (approximately 3 km south of the Yukon border) into a Mattson Formation water disposal well. The company has since re-completed an additional Nahanni well.

In the two years since the completions were attempted, the field has produced an additional 1,133 $10^6m^3$ (4 Bcf) of gas. New pool studies have led the current operator to conclude that the pool is a closed aquifer system, and that 113,300 to 19,830 $10^6m^3$ (400 to 700 Bcf) of additional gas reserves are available for capture from the field. The current operator's theory is that because the field is a closed system, if one pumps water out of the water leg at high rates then the water level in the field will drop. This will allow for the production of gas at higher rates with much lower water cuts. The field is currently shut-in to prepare for further well re-completions and program planning. Future plans for the field include further well completions and possible horizontal wells to extract gas left behind by older wells. A more detailed chronology of previous exploratory efforts is given in Appendix A.

A total of 6 petroleum exploration plays have been identified in the study area. One play, the Manetoe facies dolomite play, can be considered established (it is a play with discoveries and production). The five other plays are based on drill stem test (DST) shows and on analogies with established plays either in northeastern British Columbia or the adjacent Northwest Territories, and are immature.

***Table 1.*** *In 1993, the NEB released the resource estimates for the 5 discovered pools within the study area. Below are the estimated volumes.*

| Field | Pool | Discovery Date (yy-mm-dd) | Gas In Place (GIP) ($10^6m^3$) | Recoverable Gas ($10^6m^3$) | Comments |
|---|---|---|---|---|---|
| **Beaver River** | Nahanni "C" (B.C. and Yukon); Manetoe dolomite | 69-08-20 | 891.59 | 284.59 | 218.22 x $10^6m^3$ recoverable gas in Yukon |
| Field Total (B.C. and Yukon) | Nahanni "A" (B.C.), "B" (B.C.) and "C" (B.C. and Yukon) pools; all Manetoe dolomite | **** | 7,287.1 | 2,597.91 | Total gas produced to 1978 = 5044 $10^6m^3$ (178 Bcf); total to 1991 = 5156 $10^6m^3$ (182 Bcf) |
| **Kotaneelee** | Nahanni E-37 area; Manetoe dolomite | 78-12-05 | 1,610.53 | 724.74 | *** |
| | Nahanni I-27 area; Manetoe dolomite | 64-09-29 | 7,863.16 | 3,538.42 | *** |
| | Arnica I-48; Manetoe dolomite | 80-04-11 | 1,664.87 | 749.19 | *** |
| Field Total | **** | ***** | 11,138.56 | 5,012.35 | *** |
| **LaBiche F-08** | Nahanni; Dolomitic siltstone | 71-03-13 | 2,342.7 | 1,770.7 | Mostly in NWT |

# POTENTIAL RESOURCES

## PETROLEUM PLAYS

The following definitions were modified from Reinson et al. (1993). For the purposes of this study a **play** is defined as a family of pools and/or prospects that share a common history of hydrocarbon generation, migration, reservoir development and trap configuration (Energy, Mines and Resources Canada, 1977). A **prospect** is defined as an untested exploration target within a single stratigraphic interval; it may or may not contain hydrocarbons; it is not synonymous with an undiscovered pool. An **established** play is one which is demonstrated to exist by virtue of discovered pools with established reserves. An **immature** play is one which, by geological analysis and hydrocarbon shows, has been proven to exist, but for which there are no commercial discoveries.

Six petroleum plays were identified within the study area (five gas, and one gas with potential oil). One play can be considered established (Manetoe facies dolomite play) as it has proven discoveries and gas production; the other five are considered significant hydrocarbon shows from analogues within adjacent areas, and are also considered immature. The plays in the study area are outlined in Table 2.

***Table 2.*** *Established and immature plays in the Liard Area.*

| Play | Resource |
|---|---|
| *Established Plays* | |
| Middle Devonian Manetoe Facies Dolomite Play . . . . . | sour gas |
| *Immature Plays* | |
| Lower Cretaceous Clastics Play ..... | sweet gas & oil shows (NWT) |
| Permian Fantasque Fractured Chert Play ..... | sweet gas show (B.C.) |
| Permo-Carboniferous Mattson Clastics Gas Play ..... | sweet gas show (B.C.) |
| Carboniferous Prophet/Flett Carbonate Play ..... | sour(?) gas show (B.C.) |
| Middle Devonian Besa River (Muska) Fractured Shale Play . | sour(?) gas show (B.C.) |

## PLAY SHEETS

As part of the potential resources a play sheet was prepared for each play. Each play sheet provides a description of the geology, a discussion of the discovered resources in that play and a discussion of the area potential. Included on the play sheet is a map showing the discovery or show locations and the area of potential, and a schematic cross-section showing the key elements of the play. On the page following the play sheet is the @RISK data input sheet and a results sheet.

| Marketable Product Volume | Value at a probability of 95% | Value at a probability of 50% | Value at a probability of 5% | Value at the mean | Probability of mean |
|---|---|---|---|---|---|
| Lower Cretaceous Gas $10^6m^3$ (Bcf) | 13.0 (.46) | 32.0 (1.13) | 69.6 (2.46) | 35.1 (1.24) | 41.7 |
| Lower Cretaceous Oil m3 (MMBbl) | 793.7 (0.005) | 2,063.5 (0.013) | 4,920.6 (0.031) | 2,381.0 (0.015) | 41.7 |
| Permian Fantasque Gas $10^6m^3$ (Bcf) | 4.2 (0.15) | 16.7 (0.59) | 51.8 (1.83) | 21.5 (0.76) | (39.8) |
| Mattson Gas $10^6m^3$ (Bcf) | 1,305.9 (46.10) | 4,196.3 (148.13) | 10,185.2 (359.54) | 4,815.8 (170.0) | 41.9 |
| Prophet/Flett Gas $10^6m^3$ (Bcf) | 793.2 (28.0) | 1,898.0 (67.0) | 4,334.2 (153.0) | 2,167.1 (76.5) | 41.7 |
| Muskwa/Besa River Gas $10^6m^3$ (Bcf) | 1,019.8 (36) | 4,220.9 (149) | 13,371.1 (472) | 5,436.2 (191.9) | 36.4 |
| Manetoe Gas $10^6m^3$ (Bcf) | 8,356.9 (295) | 34,022.6 (1,201) | 108,498.6 (3,830) | 43,852.6 (1,548) | 36.9 |
| Total Gas Immature Plays $10^6m^3$ (Bcf) | 3,136.1 (110.71) | 10,363.9 (365.85) | 28,011.9 (989) | 12,475.9 (440.4) | 38.4 |
| Total Oil Immature Play $m^3$ (MMBbl) | 793.7 (0.005) | 2,063.5 (0.013) | 4,920.6 (0.031) | 2,381.0 (0.015) | 41.7 |
| Total Gas Mature Play $10^6m^3$ (Bcf) | 8,356.9 (295) | 34,022.6 (1,201) | 108,498.6 (3,830) | 43,852.6 (1,548) | 36.9 |
| Total Oil Mature Plays $m^3$ (MMBbl) | 0 | 0 | 0 | 0 | 0 |
| Total Gas $10^6m^3$ (Bcf) | 11,493 (406) | 44,837 (1,567) | 136,510.4 (4,818) | 56,298.3 (1,988) | 38.6 |
| Total Oil $m^3$ (MMBbl) | 793.7 (0.005) | 2,063.5 (0.013) | 4,920.6 (0.031) | 2,381.0 (0.015) | 41.7 |

***Table 3.*** *Potential marketable resources within the Liard Plateau study area.*

Devon

# MANETOE FACIES DOLOMITE

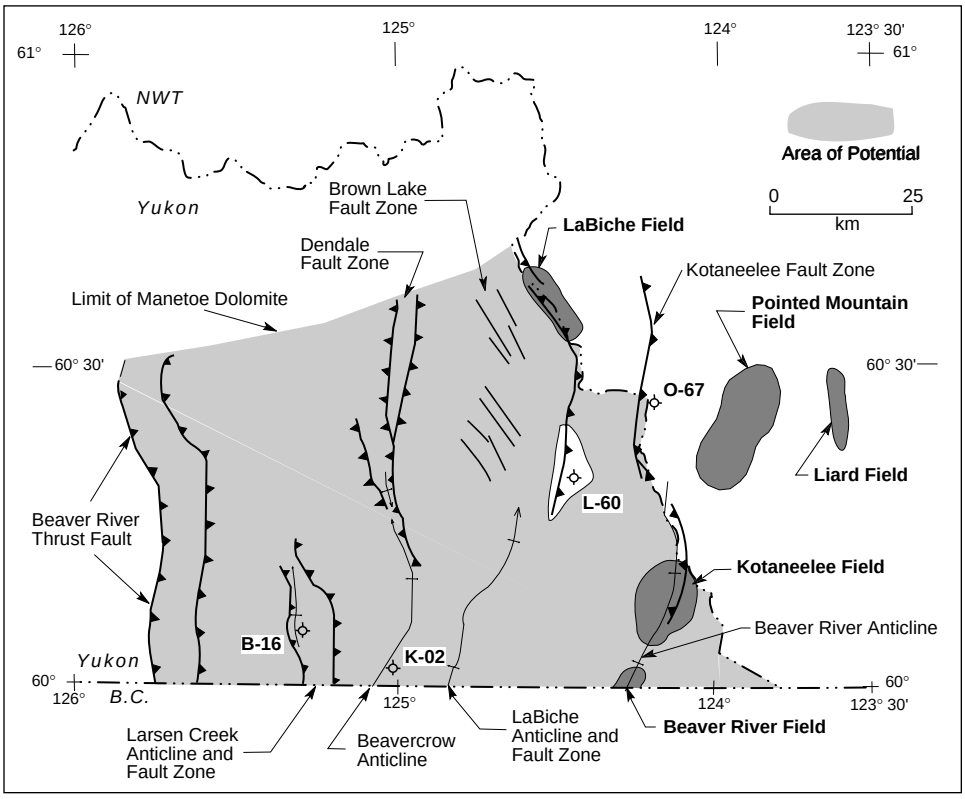
## ESTABLISHED GAS PLAY

### *Reservoir description*

The Manetoe facies dolomite play is a sour, acid, dry gas play. It is defined to include all pools and prospects hosted in fractured diagentic hydrothermal dolomites of the Manetoe facies within carbonates of the Middle Devonian Arnica, Landry and Nahanni formations that are structurally trapped in closures formed by antiforms, normal, reverse and/or thrust faults. The play area is delineated on the west by the Laramide affected Hyland Plateau, on the north by the mapped limit of the Manetoe Dolomite and on the east and south by the study area boundary (border with B.C. and the NWT).

### *Hydrocarbon occurrence model*

Laramide antiforms structurally complicated by normal, reserve and thrust faults form the trap for this play. The seal for the reservoir, and the source of the gas, is provided by the organic rich Besa River Shale that overlie and interfingers with the Middle Devonian carbonate. An alternate or additional source of the gas could be the Middle Devonian carbonate, the gas having been generated during the formation of the hydrothermal dolomite. The reservoir consists of Manetoe facies hydrothermal dolomite within the Middle Devonian carbonate (Arnica, Landry and Nahanni formations). Dolomitization must have occurred for the reservoir to be productive. Fracturing associated with the structural axes of the antiforms has increased the background porosity (less than 3%)



and permeability (less than 5 md) to levels sufficient for economic recovery of the entrapped hydrocarbons.

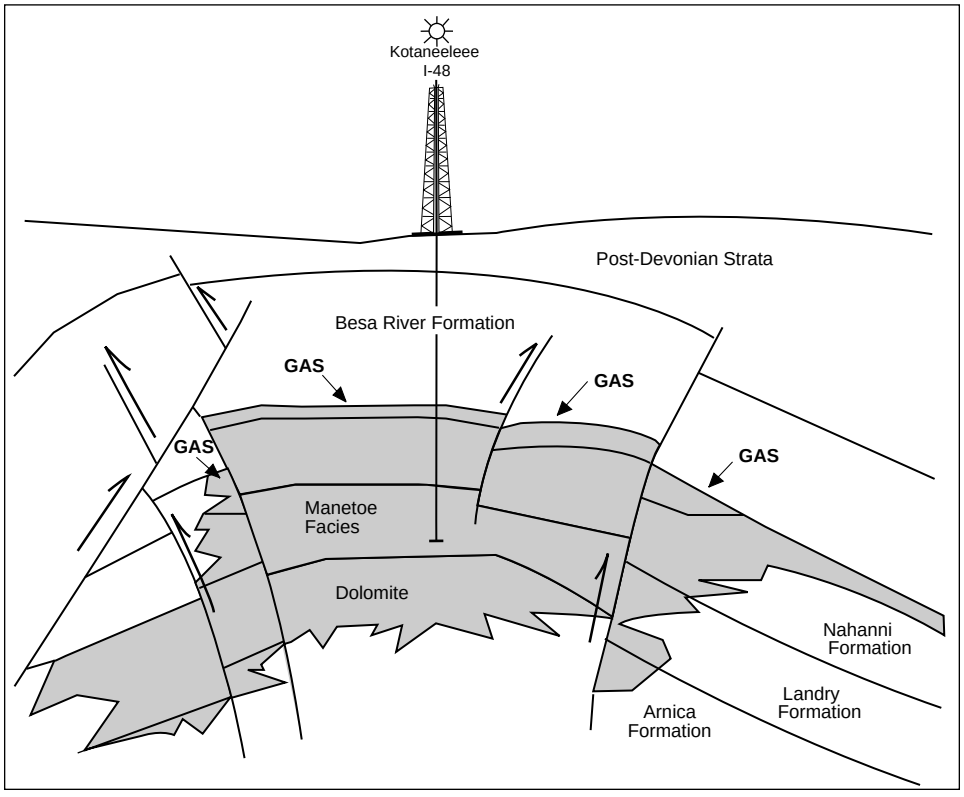
The Beaver River, Kotaneelee, Pointed Mountain, LaBiche and Liard fields in the Yukon and Northwest Territories are representative of this play where gas is trapped on top of water. The fracturing in the reservoir has two important implications. First is the increased risk of water coneing up the fracture system if production rates are set too high; the second is formation damage by mud invasion while drilling the well. Heavily over-balanced muds tend to leak back into the fracture system and plug up the product intervals. These intervals do not tend to clean up on flow testing. Operator diligence is therefore important during drilling, completion and production in order to maximize gas recovery.

### *Discovered resources*

To date, the only published estimate of the discovered Manetoe facies gas resources is the 1993 NEB *Discovered Resource Estimates of the Mainland Territories*. Discovered resources in this play, including areas outside of the study area, total 44,080 $10^6m^3$ (1.56 Tcf) of gas in-place (GIP) or 13,963 $10^6m^3$ (495 Bcf) of marketable gas (IMG) in 12 pools (assuming a marketable gas fraction of 0.74). Total discovered resources for this play within the Yukon total 14,165 $10^6m^3$ (503 Bcf) GIP and 5,181 $10^6m^3$ (184 Bcf) IMG or 37%. Discovered marketable pool sizes range from 52 $10^6m^3$ (1.84 Bcf) to 6,083 $10^6m^3$ (4,501 Bcf) with a mean recoverable pool size of 1,163 $10^6m^3$ (41 Bcf).

### *Potential resources*

A search of current literature found no previously published estimates of the gas resources for this play. This work indicates that, within a 90% probability range, there is a marketable gas potential of 8,356 $10^6m^3$ (295 Bcf) to 108,498 $10^6m^3$ (3,830 Bcf) with a mean of 43,852 $10^6m^3$ (1,548 Bcf).



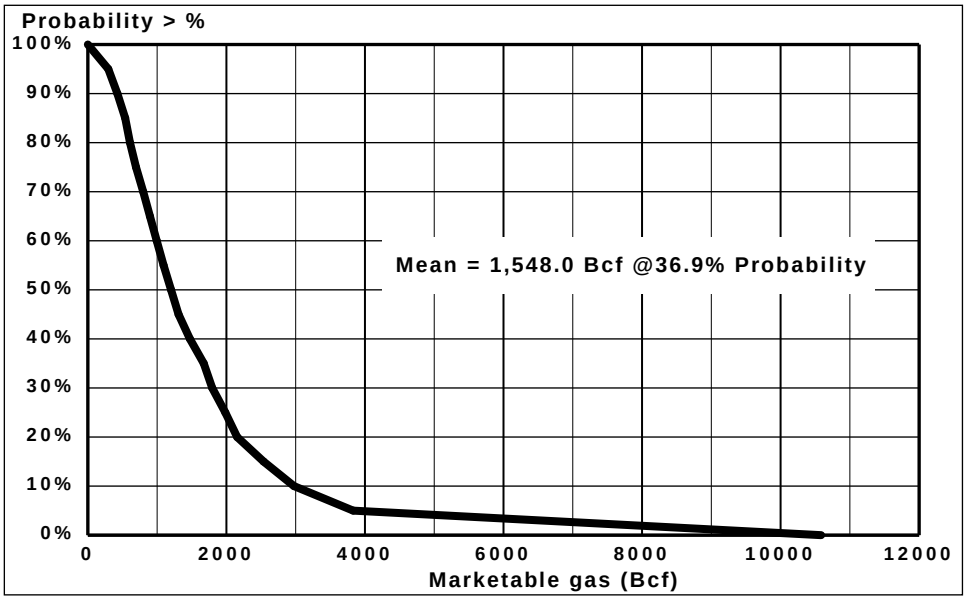
*Estimate of potential petroleum resources*

| | Minimum | Most likely | Maximum | Mean |
|---|---|---|---|---|
| Total play area (MM acres) | 0.3111 | 0.8584 | 1.4109 | 0.860 |
| Tested play area (MM acres) | 0.280 | 0.300 | 0.350 | 0.310 |
| Untested play area (MM acres) | 0.031 | 0.558 | 1.061 | 0.550 |
| Fraction of total play area in trap | 0.100 | 0.150 | 0.300 | 0.183 |
| Fraction of untested play area filled (areally) | 0.750 | 0.800 | 0.900 | 0.817 |
| Potential hydrocarbon area (MM acres) | | | | 0.082 |
| Porosity | 0.030 | 0.060 | 0.120 | 0.070 |
| Hydrocarbon saturation | 0.700 | 0.770 | 0.800 | 0.757 |
| Oil recovery factor | 0.000 | 0.000 | 0.000 | 0.000 |
| Gas recovery factor | 0.500 | 0.600 | 0.750 | 0.617 |
| Average net pay (ft.) | 100.0 | 150.0 | 500.0 | 250.0 |
| Probability of hydrocarbons | 0.050 | 0.200 | 0.400 | 0.217 |
| Fraction of pore volume oil bearing | 0.000 | 0.000 | 0.000 | 0.000 |
| Potential oil area (MM acres) | | | | 0.000 |
| Potential gas area (MM acres) | | | | 0.018 |
| Gas oil ratio (GOR) (MMcf/bbls) | 1.406 | 1.480 | 1.554 | 1.480 |
| Formation volume factor (FVF) | 1.801 | 1.844 | 1.886 | 1.844 |
| Gas compressibility factor 'Z' | 0.992 | 1.013 | 1.033 | 1.013 |
| Gas volume factor (GVF) | | | | 0.332 |
| Oil in place (bbls/acre-foot) | | | | 222.9 |
| Oil recovery (bbls/acre-foot) | | | | 0.0 |
| Gas in place (MMcf/acre-foot) | | | | 766.6 |
| Raw gas recovery (MMcf/acre-foot) | | | | 472.7 |
| Marketable gas recovery (MMcf/acre-foot) | | | | 349.8 |
| Liquid yield (bbls/MMcf) | 0.0 | 0.0 | 0.0 | 0.0 |
| $H_2S$ content | 0.005 | 0.025 | 0.030 | 0.020 |
| $CO_2$ content | 0.010 | 0.065 | 0.100 | 0.058 |
| Gas to BOE conversion factor (MMcf/BOE) | | 6.000 | | |
| Surface loss (fuel gas, etc.) | | 0.170 | | |
| Marketable gas (fraction of raw) | | 0.740 | | |

*Total for play*

| | Oil (MMb) | Solution gas (Bcf) | Non associated gas (Bcf) | Total gas (BcF) | Liquids (MMb) | Barrels of oil equivalent (MMBOE) | Marketable gas (Bcf) |
|---|---|---|---|---|---|---|---|
| **In place** | 0.00 | | 3,420.17 | 3,420.17 | | 570.03 | |
| **Recoverable** | 0.00 | 0.00 | 2,109.11 | 2,109.11 | 0.00 | 351.52 | 1,560.74 |
| **Sulphur (MMlt)** | | 1.57 | | | | | |

Oil depth: 14,800 ft.; gas depth: 14,800 ft.; gas pressure: 7,511 psi; gas reservoir temperature: 332.48°F




***Percentile values***

| | |
|---|---|
| 100% | 0 |
| 95% | 295 |
| 90% | 426 |
| 85% | 539 |
| 80% | 608 |
| 75% | 695 |
| 70% | 799 |
| 65% | 896 |
| 60% | 994 |
| 55% | 1,093 |
| 50% | 1,201 |
| 45% | 1,309 |
| 40% | 1,473 |
| 35% | 1,673 |
| 30% | 1,795 |
| 25% | 1,984 |
| 20% | 2,155 |
| 15% | 2,537 |
| 10% | 2,976 |
| 5% | 3,830 |
| 0% | 10,585 |

Cretaceous

# CHINKEH CLASTICS

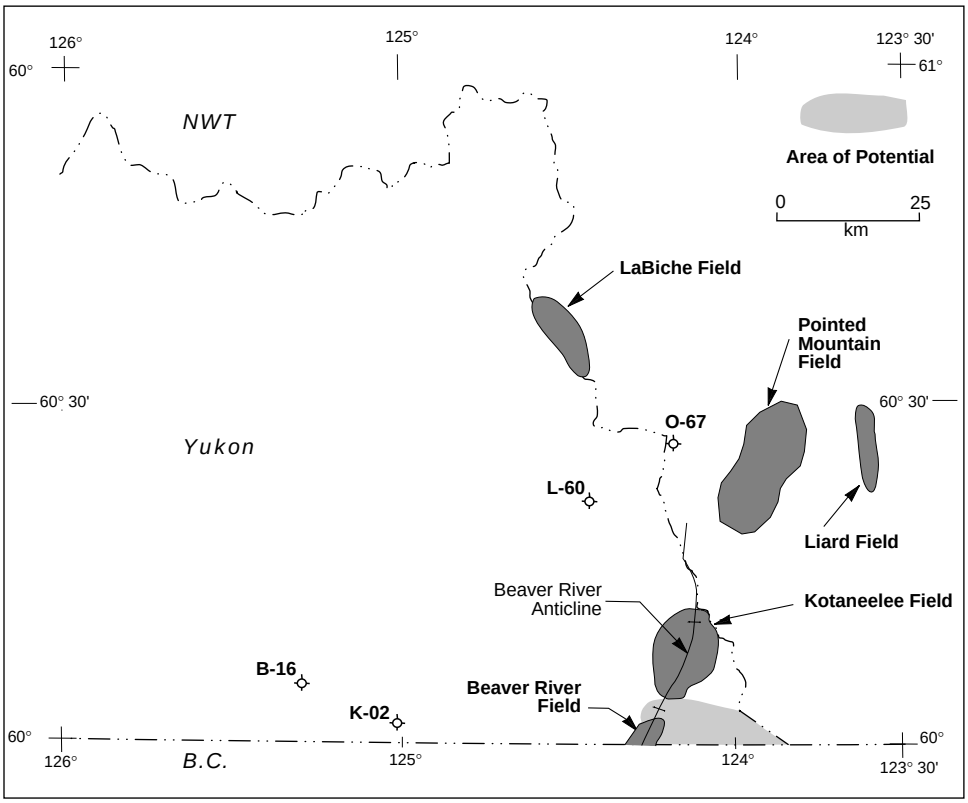
## IMMATURE GAS AND OIL PLAY

### *Reservoir description*

The Lower Cretacous Chinkeh clastics play is a sweet gas and light to medium gravity oil play. It is defined to include all pools and prospects within the Lower Cretaceous fluvial and shallow marine clastics of the Chinkeh Formation of the Fort St. John Group (valley fill, channel sands and shelf sands). The play area is delineated on the west and east by basinal shales, and on the south and north by the study area boundary (border with B.C. and the NWT).

### *Hydrocarbon occurrence model*

The trap is stratigraphic in nature and is resulting from valley fill, channel fill and near-shore sands that accumulated on the pre-Cretaceous unconformity. Laramide antiforms and normal, reserve and thrust faults complicate the trap configuration for this play and increase the risk of the trap being breached. Seal for the reservoir, and the source of the gas, is provided by the organic-rich Lower Cretaceous Garbutt Shale that overlies and interfingers with the reservoir. A possible secondary source would be the Triassic Toad-Grayling. Observed zone porosities range from 5 to 18%, permeabilities from 0.5 to 30 md and $S_w$ from 20 to 30%.

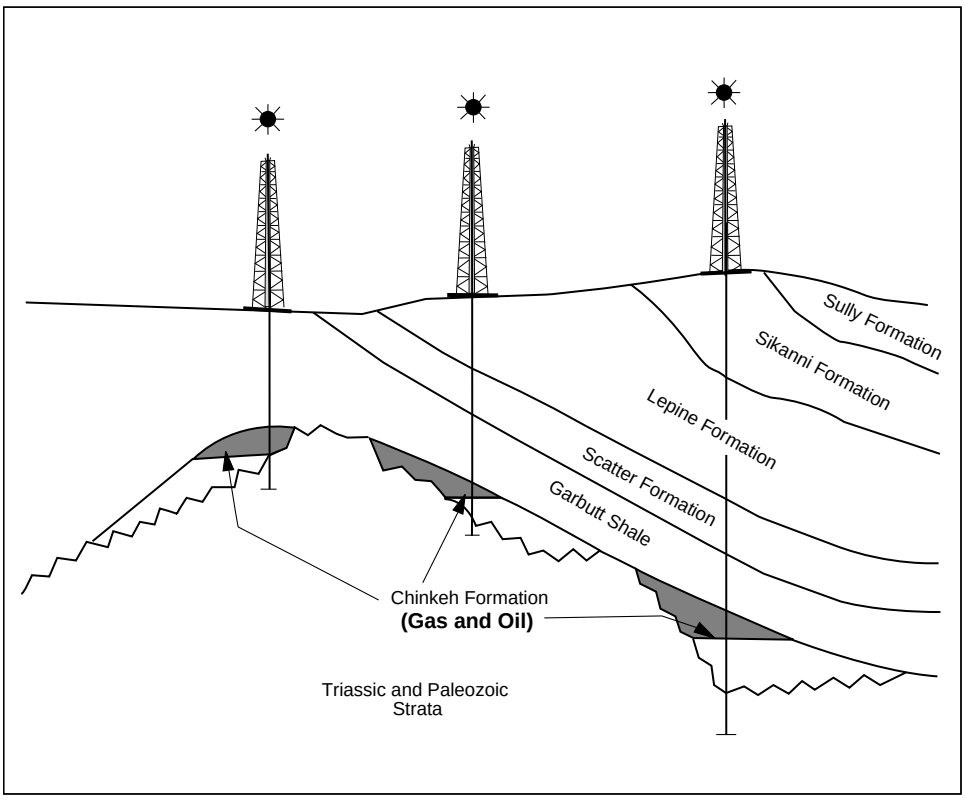


### *Discovered resources*

To date there are no documented discovered Chinkeh Formation gas resources in the study area. However, gas was recovered on a DST test in this zone from the Bovie Lake M-05 well to the east of the study area in the Northwest Territories. The gas flowed at a rate of 1,983 $m^3$/d. In addition the Arco 94-O-14/b-21-k Maxhamish well to the southeast in B.C. had an oil show in samples from this zone. Most of this play's expected potential lies to the south and east of the study area.

### *Potential resources*

A search of current literature found no previously published estimates of gas or oil resources of this play. This work indicates that, within a 90% probability range, there is a marketable gas potential of 13.0 $10^6m^3$ (0.46 Bcf) to 69.9 $10^6m^3$ (2.46 Bcf) with a mean of 35.1 $10^6m^3$ (1.24 Bcf) and an recoverable oil potential of 793 $m^3$ (5,000 Bbl) to 4,920 $m^3$ (31,000 Bbl) with a mean of 2,381 $m^3$ (15,000 Bbl).



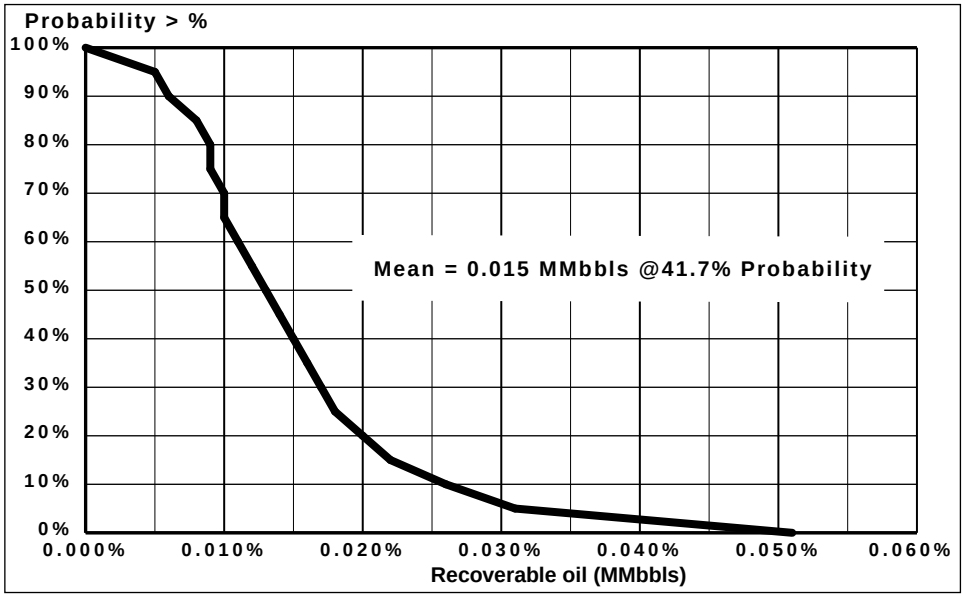
*Estimate of potential petroleum resources*

| Minimum | Most likely | Maximum | Mean | |
|---|---|---|---|---|
| Total play area (MM acres) | 0.0040 | 0.0045 | 0.0055 | 0.005 |
| Tested play area (MM acres) | 0.000 | 0.000 | 0.000 | 0.000 |
| Untested play area (MM acres) | 0.004 | 0.005 | 0.006 | 0.005 |
| Fraction of total play area in trap | 0.200 | 0.300 | 0.700 | 0.400 |
| Fraction of untested play area filled (areally) | 0.800 | 0.850 | 0.900 | 0.850 |
| Potential hydrocarbon area (MM acres) | | | | 0.002 |
| Porosity | 0.150 | 0.180 | 0.210 | 0.180 |
| Hydrocarbon saturation | 0.590 | 0.640 | 0.750 | 0.660 |
| Oil recovery factor | 0.150 | 0.200 | 0.250 | 0.200 |
| Gas recovery factor | 0.700 | 0.800 | 0.900 | 0.800 |
| Average net pay (ft.) | 6.0 | 15.0 | 36.0 | 19.0 |
| Probability of hydrocarbons | 0.100 | 0.150 | 0.200 | 0.150 |
| Fraction of pore volume oil bearing | 0.010 | 0.020 | 0.030 | 0.020 |
| Potential oil area (MM acres) | | | | 0.000 |
| Potential gas area (MM acres) | | | | 0.000 |
| Gas oil ratio (GOR) (MMcf/bbls) | 0.219 | 0.230 | 0.242 | 0.230 |
| Formation volume factor (FVF) | 1.125 | 1.131 | 1.138 | 1.131 |
| Gas compressibility factor 'Z' | 0.872 | 0.890 | 0.908 | 0.890 |
| Gas volume factor (GVF) | | | | 0.071 |
| Oil in place (bbls/acre-foot) | | | | 814.8 |
| Oil recovery (bbls/acre-foot) | | | | 163.0 |
| Gas in place (MMcf/acre-foot) | | | | 369.6 |
| Raw gas recovery (MMcf/acre-foot) | | | | 295.7 |
| Marketable gas recovery (MMcf/acre-foot) | | | | 280.6 |
| Liquid yield (bbls/MMcf) | 0.1 | 0.2 | 0.5 | 0.3 |
| $H_2S$ content | 0.000 | 0.001 | 0.002 | 0.001 |
| $CO_2$ content | 0.000 | 0.000 | 0.000 | 0.000 |
| Gas to BOE conversion factor (MMcf/BOE) | | 6.000 | | |
| Surface loss (fuel gas, etc.) | | 0.050 | | |
| Marketable gas (fraction of raw) | | 0.949 | | |

*Total for play*

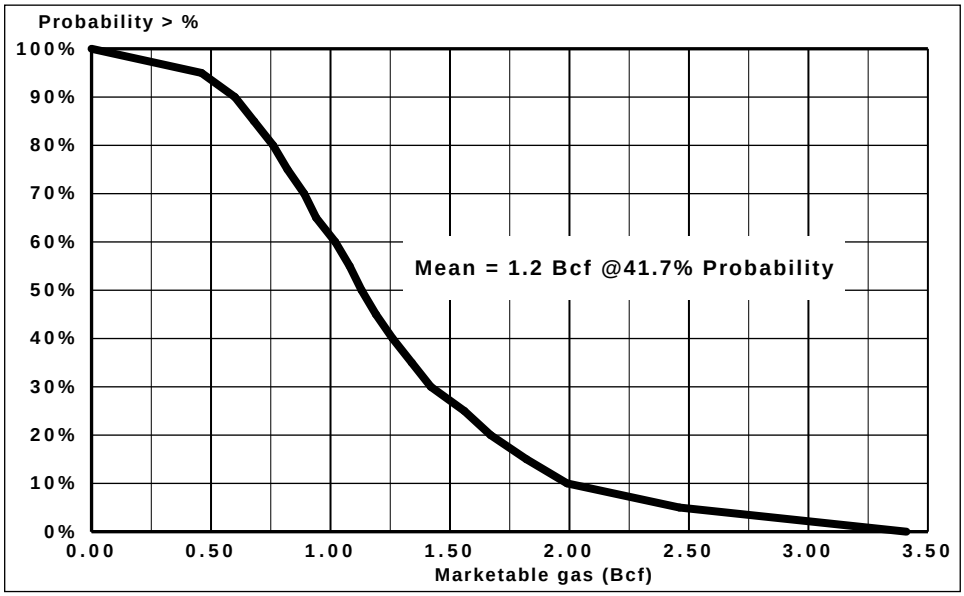
| | Oil (MMb) | Solution gas (Bcf) | Non associated gas (Bcf) | Total gas (BcF) | Liquids (MMb) | Barrels of oil equivalent (MMBOE) | Marketable gas (Bcf) |
|---|---|---|---|---|---|---|---|
| **In place** | 0.07 | | 1.64 | 1.64 | | 0.35 | |
| **Recoverable** | 0.01 | 0.00 | 1.31 | 1.31 | 0.00 | 0.23 | 1.25 |
| **Sulphur (MMlt)** | | 0.00 | | | | | |

Oil depth: 2,300 ft.; gas depth: 2,300 ft.; gas pressure: 958 psi; gas reservoir temperature: 74.79°F




*Percentile values*

| | | |
|---|---|---|
| 100% | ..... | 0.000 |
| 95% | ..... | 0.005 |
| 90% | ..... | 0.006 |
| 85% | ..... | 0.008 |
| 80% | ..... | 0.009 |
| 75% | ..... | 0.009 |
| 70% | ..... | 0.010 |
| 65% | ..... | 0.010 |
| 60% | ..... | 0.011 |
| 55% | ..... | 0.012 |
| 50% | ..... | 0.013 |
| 45% | ..... | 0.014 |
| 40% | ..... | 0.015 |
| 35% | ..... | 0.016 |
| 30% | ..... | 0.017 |
| 25% | ..... | 0.018 |
| 20% | ..... | 0.020 |
| 15% | ..... | 0.022 |
| 10% | ..... | 0.026 |
| 5% | ..... | 0.031 |
| 0% | ..... | 0.051 |




*Percentile values*

| | | |
|---|---|---|
| 100% | ..... | 0.00 |
| 95% | ..... | 0.46 |
| 90% | ..... | 0.60 |
| 85% | ..... | 0.68 |
| 80% | ..... | 0.76 |
| 75% | ..... | 0.82 |
| 70% | ..... | 0.89 |
| 65% | ..... | 0.94 |
| 60% | ..... | 1.02 |
| 55% | ..... | 1.08 |
| 50% | ..... | 1.13 |
| 45% | ..... | 1.19 |
| 40% | ..... | 1.26 |
| 35% | ..... | 1.34 |
| 30% | ..... | 1.42 |
| 25% | ..... | 1.56 |
| 20% | ..... | 1.67 |
| 15% | ..... | 1.82 |
| 10% | ..... | 1.99 |
| 5% | ..... | 2.46 |
| 0% | ..... | 3.41 |

Permian

# FANTASQUE FRACTURED CHERT

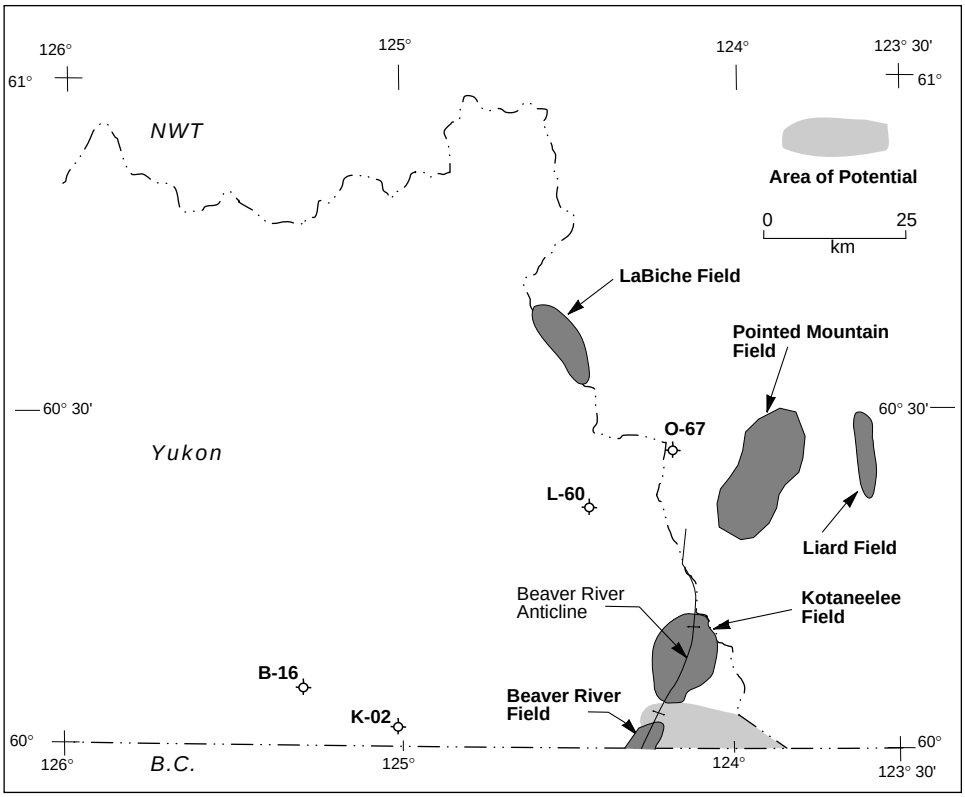
## IMMATURE GAS PLAY

### *Reservoir description*

The Permian Fantasque fractured chert play is a sweet, dry gas play. It is defined to include all pools and prospects hosted within Permian chert in fractured structural traps formed along the crests of antiforms or thrust faults. The play is limited to the west and north by surface outcrop traces and to the east and south by the Yukon border.

### *Hydrocarbon occurrence model*

Laramide antiforms structurally complicated by normal, reserve and thrust faults form the trap for this play. The seal for the reservoir, and the source of the gas, is provided by the organic-rich Carboniferous Etanda Formation Shale that underlie the reservoir. The Triassic Toad-Grayling may also be a source for this gas. Fracturing associated with the axial traces of the antiforms is absolutely necessary for this reservoir, as the background porosity is less than 3% and the permeability less than 10 md. Expected reservoir parameters are listed on the input data sheet for this play.

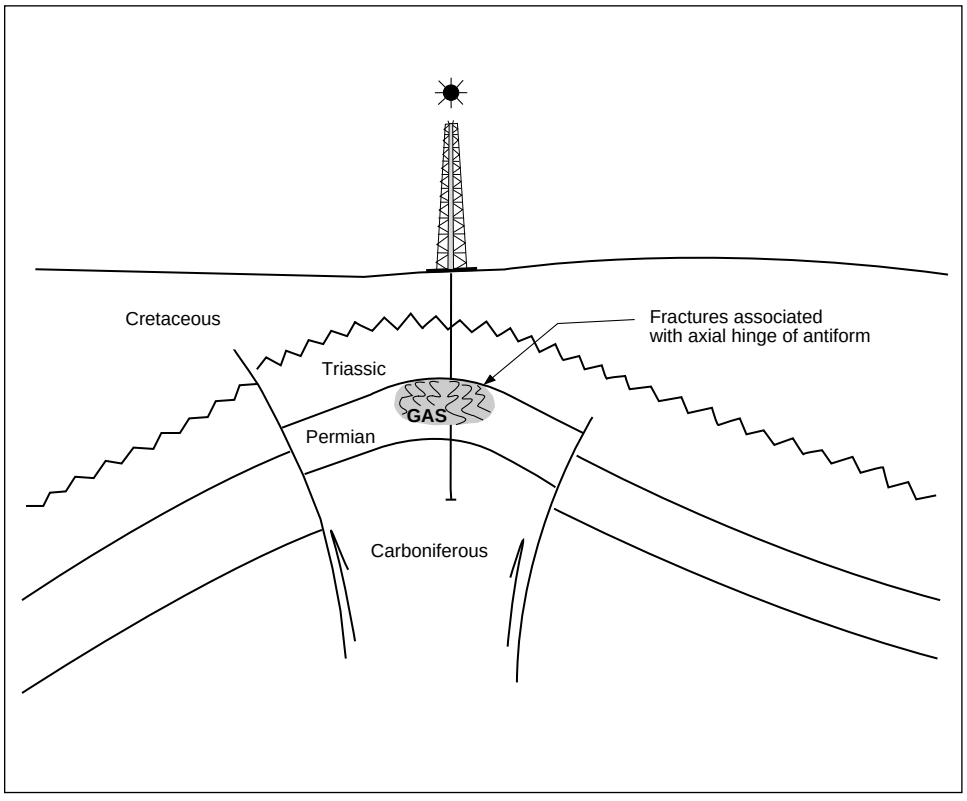


### *Discovered resources*

To date there are no discovered Fantasque Formation gas resources documented for the study area. However, minor shows of Fantasque gas were reported from the gas logs of wells drilled in the Beaver River, Tatto and Maxhamish Lake areas just south of the border in B.C. The majority of this play's expected potential lies to the south and east of the study area.

### *Potential resources*

A search of current literature found no previously published estimates of the gas resources for this play. This work indicates that, within a 90% probability range, there is a marketable gas potential of 4.2 $10^6 m^3$ (0.15 Bcf) to 51.8 $10^6 m^3$ (1.83 Bcf), with a mean of 21.5 $10^6 m^3$ (0.76 Bcf).



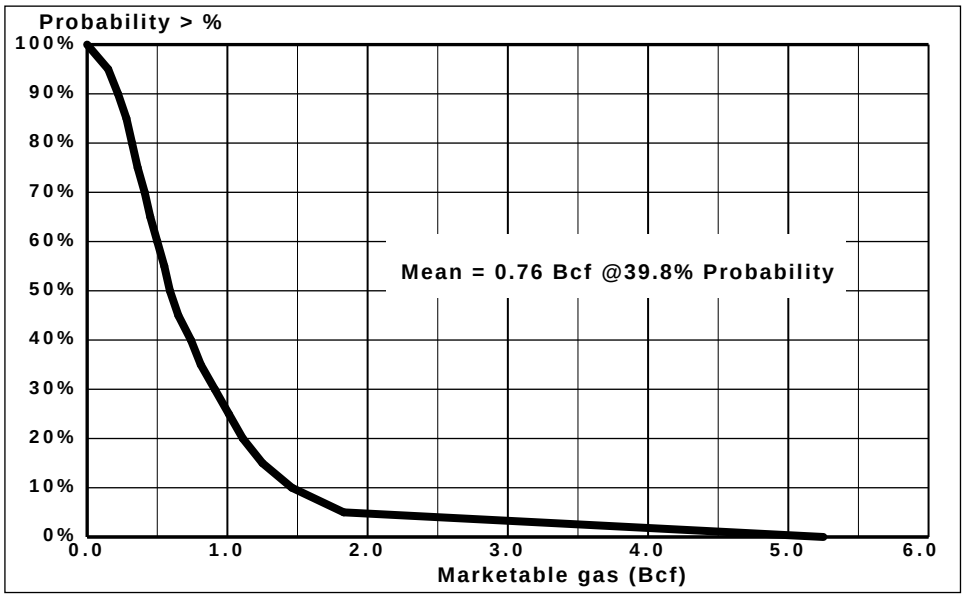
*Estimate of potential petroleum resources*

| | Minimum | Most likely | Maximum | Mean |
|---|---|---|---|---|
| Total play area (MM acres) | 0.0038 | 0.0500 | 0.0625 | 0.039 |
| Tested play area (MM acres) | 0.000 | 0.001 | 0.001 | 0.001 |
| Untested play area (MM acres) | 0.003 | 0.049 | 0.061 | 0.038 |
| Fraction of total play area in trap | 0.050 | 0.150 | 0.250 | 0.150 |
| Fraction of untested play area filled (areally) | 0.300 | 0.450 | 0.600 | 0.450 |
| Potential hydrocarbon area (MM acres) | | | | 0.003 |
| Porosity | 0.030 | 0.050 | 0.075 | 0.052 |
| Hydrocarbon saturation | 0.550 | 0.600 | 0.750 | 0.633 |
| Oil recovery factor | 0.000 | 0.000 | 0.000 | 0.000 |
| Gas recovery factor | 0.300 | 0.450 | 0.550 | 0.433 |
| Average net pay (ft.) | 10.0 | 40.0 | 90.0 | 46.7 |
| Probability of hydrocarbons | 0.050 | 0.150 | 0.250 | 0.150 |
| Fraction of pore volume oil bearing | 0.000 | 0.000 | 0.000 | 0.000 |
| Potential oil area (MM acres) | | | | 0.000 |
| Potential gas area (MM acres) | | | | 0.000 |
| Gas oil ratio (GOR) (MMcf/bbls) | 0.181 | 0.190 | 0.200 | 0.190 |
| Formation volume factor (FVF) | 1.103 | 1.108 | 1.114 | 1.108 |
| Gas compressibility factor 'Z' | 0.882 | 0.900 | 0.918 | 0.900 |
| Gas volume factor (GVF) | | | | 0.072 |
| Oil in place (bbls/acre-foot) | | | | 229.1 |
| Oil recovery (bbls/acre-foot) | | | | 0.0 |
| Gas in place (MMcf/acre-foot) | | | | 103.0 |
| Raw gas recovery (MMcf/acre-foot) | | | | 44.6 |
| Marketable gas recovery (MMcf/acre-foot) | | | | 42.4 |
| Liquid yield (bbls/MMcf) | 0.0 | 0.0 | 0.0 | 0.0 |
| $H_2S$ content | 0.000 | 0.000 | 0.000 | 0.000 |
| $CO_2$ content | 0.000 | 0.000 | 0.000 | 0.000 |
| Gas to BOE conversion factor (MMcf/BOE) | | 6.000 | | |
| Surface loss (fuel gas, etc.) | | 0.050 | | |
| Marketable gas (fraction of raw) | | 0.950 | | |

*Total for play*

| | Oil (MMb) | Solution gas (Bcf) | Non associated gas (Bcf) | Total gas (BcF) | Liquids (MMb) | Barrels of oil equivalent (MMBOE) | Marketable gas (Bcf) |
|---|---|---|---|---|---|---|---|
| **In place** | 0.00 | | 1.84 | 1.84 | | 0.31 | |
| **Recoverable** | 0.00 | 0.00 | 0.80 | 0.80 | 0.00 | 0.13 | 0.76 |
| **Sulphur (MMlt)** | | 0.00 | | | | | |

Oil depth: 1,900 ft.; gas depth: 1,900 ft.; gas pressure: 977 psi; gas reservoir temperature: 73.19°F




**Percentile values**

| | | |
|---|---|---|
| 100% | ..... | 0.00 |
| 95% | ..... | 0.15 |
| 90% | ..... | 0.22 |
| 85% | ..... | 0.28 |
| 80% | ..... | 0.32 |
| 75% | ..... | 0.36 |
| 70% | ..... | 0.41 |
| 65% | ..... | 0.45 |
| 60% | ..... | 0.50 |
| 55% | ..... | 0.55 |
| 50% | ..... | 0.59 |
| 45% | ..... | 0.65 |
| 40% | ..... | 0.74 |
| 35% | ..... | 0.81 |
| 30% | ..... | 0.91 |
| 25% | ..... | 1.01 |
| 20% | ..... | 1.11 |
| 15% | ..... | 1.25 |
| 10% | ..... | 1.46 |
| 5% | ..... | 1.83 |
| 0% | ..... | 5.25 |

## Permo-Carboniferous

# MATTSON CLASTICS

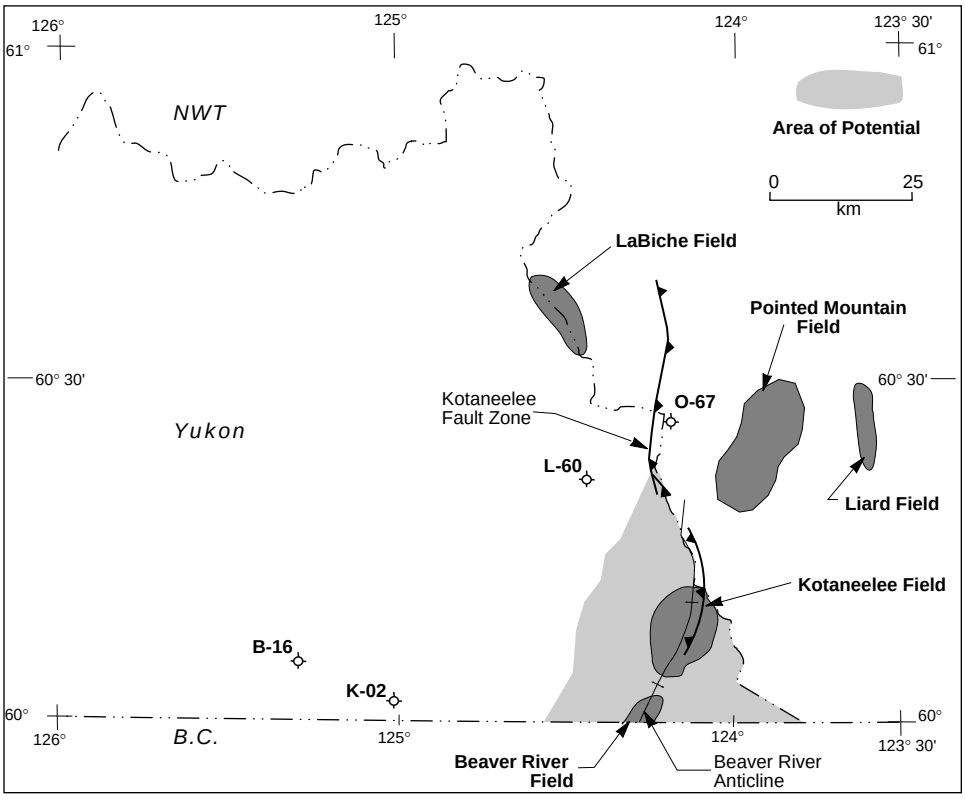
## IMMATURE GAS PLAY

### *Reservoir description*

The Permo-Carboniferous Mattson clastics gas play is a sweet, slightly acidic gas play with a possibility of minor condensate or wet gas. It was defined to include all pools and prospects of fluvio-deltaic sandstone reservoirs in structural and structural-stratigraphic traps formed by anticlines, normal and/or thrust faults. The play area for the study is bordered on the west by the easternmost limit of the Mattson outcrop and the approximate seaward edger of the Mattson deltaic complex, by the outcrop along the Kotaneelee Anticline and on the east, south and north by the study area boundary (border with B.C. and the NWT).

### *Hydrocarbon occurrence model*

Pools of this type would have resulted from a combination of stratigraphic traps and structural enhancements. The stratigraphic traps were caused by facies changes within the fluvial deltaic deposits due to the interplay of the marine and fluvial processes. Fracturing caused by Larimide folding and faulting (normal, reserve and thrust) produced fault-bounded traps. Stratigraphic prospects can be seismically defined and



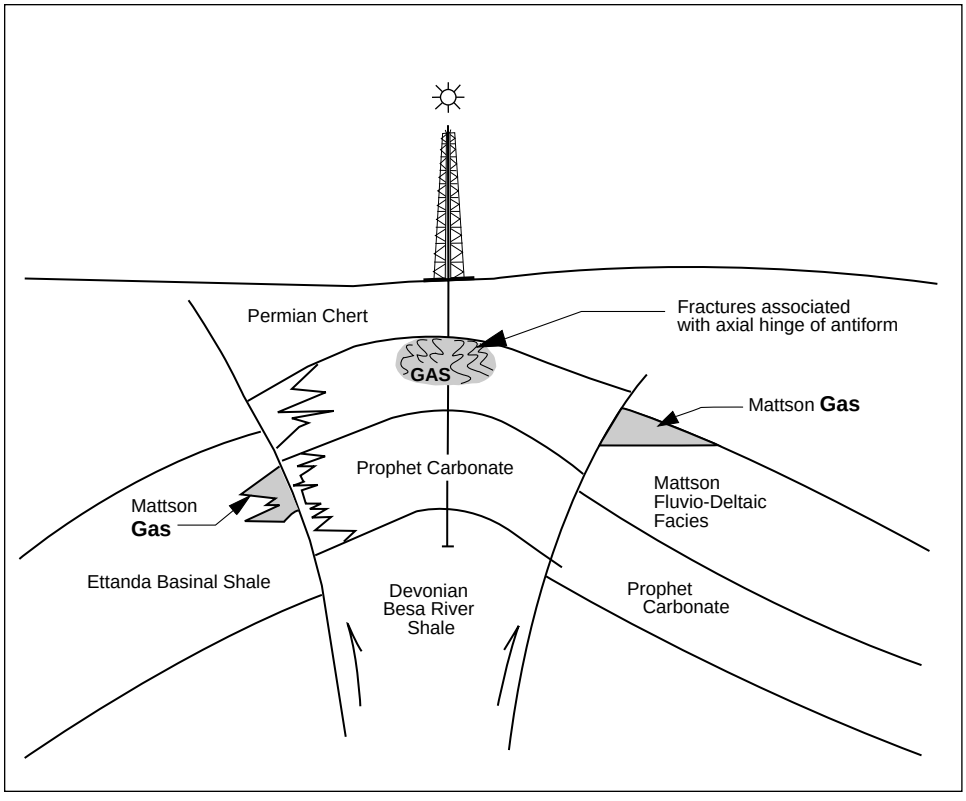
range from 200 to 600 Ha. Tight Permian Fantasque chert provides the top seal for the reservoir, and tighter Mattson facies and basinal Etanda shale provides the lateral seal. The organic-rich Etanda shale that overlies and interfingers with the reservoir is the source of the gas. DST tests in adjacent areas gave the following results: gas composition is mainly methane with a trace of $CO_2$; no $H_2S$ is evident in the gas stream; expected AOF values should range between 0.01 $10^6m^3/d$ (0.5 MMcf/d) and 0.08 $10^6m^3/d$ (3.0 MMcf/d). The majority of this play's expected potential lies to the south and east of the study area.

### *Discovered resources*

To date, there are no discovered Mattson Formation gas resources documented for the study area.

### *Potential resources*

A search of currently published literature found no previously published estimates of the gas resources of this play. This work indicates that, within a 90% probability range, there is a marketable gas potential of 1,306 $10^6m^3$ (46 Bcf) to 10,185 $10^6m^3$ (360 Bcf), with a mean of 4,815 $10^6m^3$ (170 Bcf).



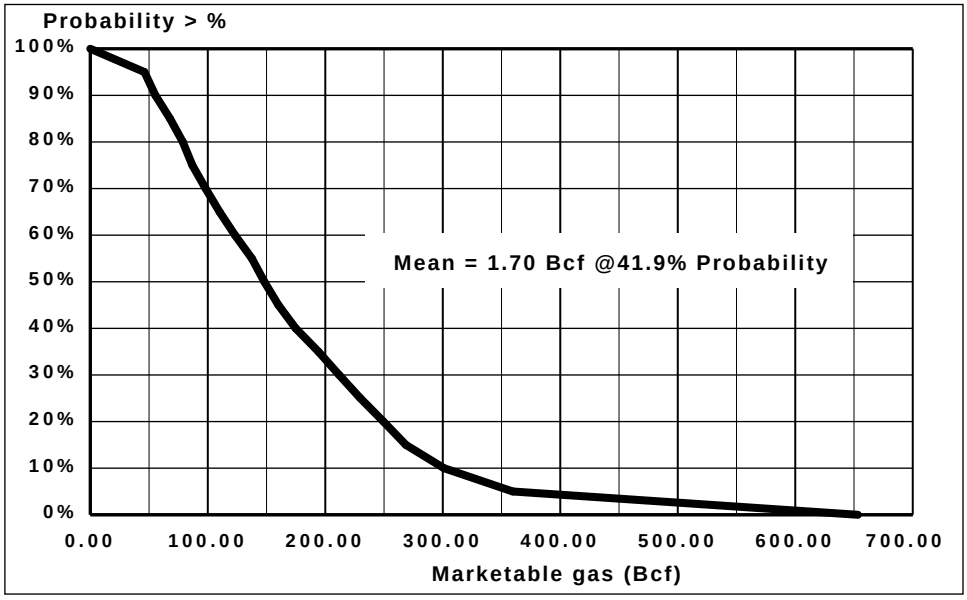
*Estimate of potential petroleum resources*

| | Minimum | Most likely | Maximum | Mean |
|---|---|---|---|---|
| Total play area (MM acres) | 0.1200 | 0.1490 | 0.1800 | 0.150 |
| Tested play area (MM acres) | 0.027 | 0.030 | 0.033 | 0.030 |
| Untested play area (MM acres) | 0.093 | 0.119 | 0.147 | 0.120 |
| Fraction of total play area in trap | 0.150 | 0.300 | 0.550 | 0.333 |
| Fraction of untested play area filled (areally) | 0.400 | 0.500 | 0.900 | 0.600 |
| Potential hydrocarbon area (MM acres) | | | | 0.024 |
| Porosity | 0.080 | 0.120 | 0.175 | 0.125 |
| Hydrocarbon saturation | 0.550 | 0.600 | 0.750 | 0.633 |
| Oil recovery factor | 0.000 | 0.000 | 0.000 | 0.000 |
| Gas recovery factor | 0.450 | 0.500 | 0.550 | 0.500 |
| Average net pay (ft.) | 50.0 | 125.0 | 350.0 | 175.0 |
| Probability of hydrocarbons | 0.050 | 0.100 | 0.250 | 0.133 |
| Fraction of pore volume oil bearing | 0.000 | 0.000 | 0.000 | 0.000 |
| Potential oil area (MM acres) | | | | 0.000 |
| Potential gas area (MM acres) | | | | 0.003 |
| Gas oil ratio (GOR) (MMcf/bbls) | 0.532 | 0.560 | 0.588 | 0.560 |
| Formation volume factor (FVF) | 1.303 | 1.319 | 1.335 | 1.319 |
| Gas compressibility factor 'Z' | 0.882 | 0.900 | 0.918 | 0.900 |
| Gas volume factor (GVF) | | | | 0.185 |
| Oil in place (bbls/acre-foot) | | | | 465.6 |
| Oil recovery (bbls/acre-foot) | | | | 0.0 |
| Gas in place (MMcf/acre-foot) | | | | 638.2 |
| Raw gas recovery (MMcf/acre-foot) | | | | 319.1 |
| Marketable gas recovery (MMcf/acre-foot) | | | | 303.2 |
| Liquid yield (bbls/MMcf) | 0.0 | 0.0 | 0.0 | 0.0 |
| $H_2S$ content | 0.000 | 0.000 | 0.001 | 0.000 |
| $CO_2$ content | 0.000 | 0.000 | 0.000 | 0.000 |
| Gas to BOE conversion factor (MMcf/BOE) | | 6.000 | | |
| Surface loss (fuel gas, etc.) | | 0.050 | | |
| Marketable gas (fraction of raw) | | 0.950 | | |

*Total for play*

| | Oil (MMb) | Solution gas (Bcf) | Non associated gas (Bcf) | Total gas (BcF) | Liquids (MMb) | Barrels of oil equivalent (MMBOE) | Marketable gas (Bcf) |
|---|---|---|---|---|---|---|---|
| **In place** | 0.00 | | 356.41 | 356.41 | | 59.40 | |
| **Recoverable** | 0.00 | 0.00 | 178.20 | 178.20 | 0.00 | 29.70 | 169.29 |
| **Sulphur (MMlt)** | | 0.00 | | | | | |

Oil depth: 5,600 ft.; gas depth: 5,600 ft.; gas pressure: 2,851 psi; gas reservoir temperature: 147.56°F




**Percentile values**

| | | |
|---|---|---|
| 100% | ..... | 0.00 |
| 95% | ..... | 46.10 |
| 90% | ..... | 55.41 |
| 85% | ..... | 67.87 |
| 80% | ..... | 78.72 |
| 75% | ..... | 86.85 |
| 70% | ..... | 98.15 |
| 65% | ..... | 110.02 |
| 60% | ..... | 123.15 |
| 55% | ..... | 137.51 |
| 50% | ..... | 148.13 |
| 45% | ..... | 160.10 |
| 40% | ..... | 174.85 |
| 35% | ..... | 194.19 |
| 30% | ..... | 211.82 |
| 25% | ..... | 229.88 |
| 20% | ..... | 249.54 |
| 15% | ..... | 268.59 |
| 10% | ..... | 301.03 |
| 5% | ..... | 359.54 |
| 0% | ..... | 653.32 |

Carboniferous

# PROPHET-FLETT CARBONATE

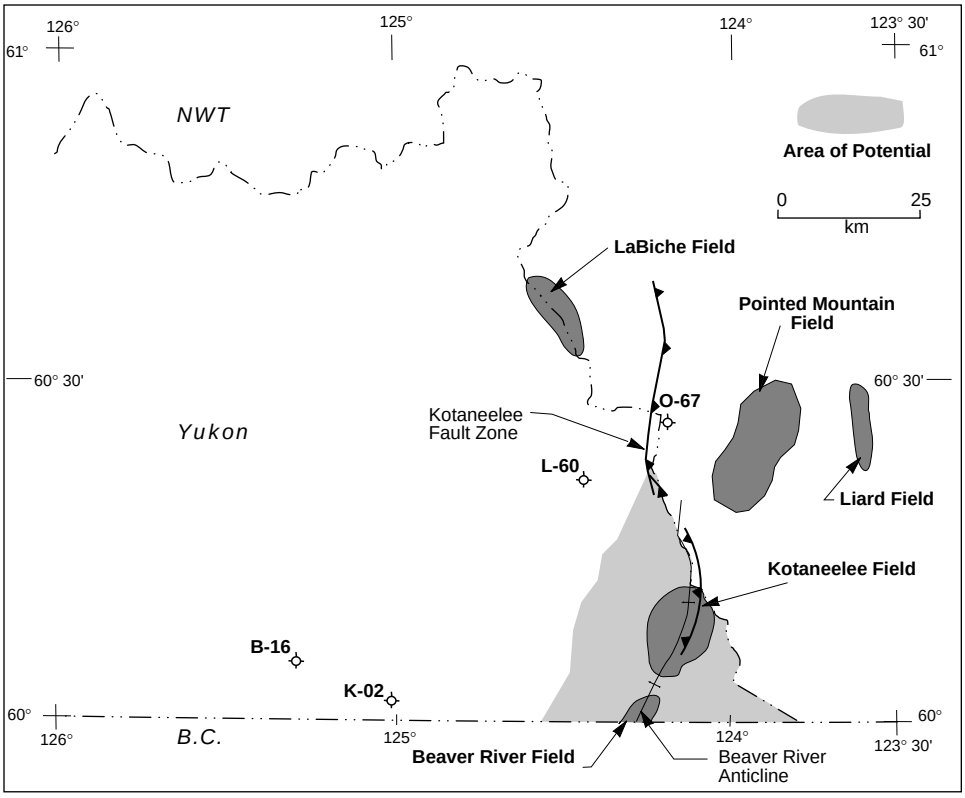
## IMMATURE GAS PLAY

### *Reservoir description*

The Carboniferous Prophet-Flett carbonate play is a sour(?), dry gas play. It is defined to include all pools and prospects in Laramide antiformal structural traps (thrusts, folds and faults) and in structurally enhanced stratigraphic traps (fracture-enhanced matrix porosity) within shelf carbonate of the Prophet and Debolt formations. The play area limit to the west is the carbonate bank edge, and to the east, south and north, the study area boundary (B.C. and NWT borders).

### *Hydrocarbon occurrence model*

Laramide antiforms structurally complicated by normal, reserve and thrust faults form the trap for this play. Seal for the reservoir, and the source of the gas, is provided by the organic-rich Etanda Shale that interfingers with the reservoir carbonate. Fracturing associated with the axial traces of the antiforms is essential to this play, as background matrix porosity is marginal and permeability is negligible.

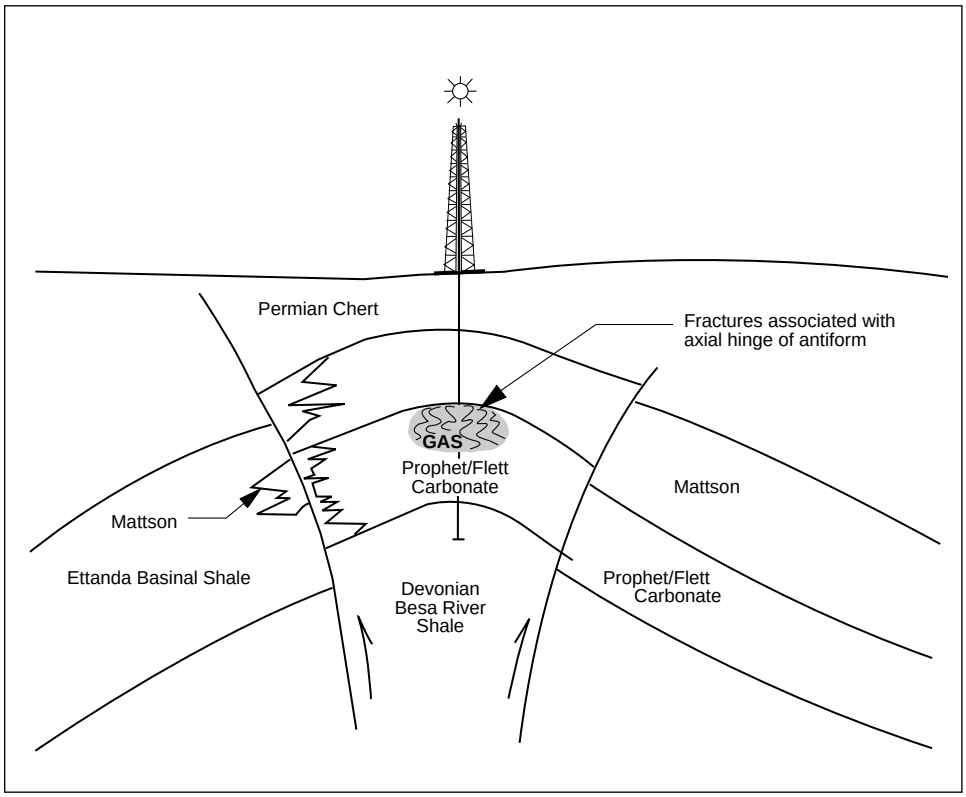


### *Discovered resources*

To date, there are no discovered Prophet Formation gas resources documented for the study area. Carboniferous Prophet gas was originally discovered in B.C. with the drilling of the Beaver River Field. The Pan Am A-1 Beaver River well blew out of control in this zone at 2,597 m (8,519 ft.), setting the rig on fire and killing two people. The gas was recovered from a 18 m (60 ft.) zone and was 98% Methane (with no $H_2S$ evident). The flow rate was measured at 0.10 $10^6m^3/d$ (3.5 MMcf/d). Most of this play's expected potential lies to the south and east of the study area.

### *Potential resources*

A search of current literature found no previously published estimates of the gas resources for this play. This work indicates that, within a 90% probability range, there is a marketable gas potential of 793 $10^6m^3$ (28 Bcf) to 4,334 $10^6m^3$ (153 Bcf), with a mean of 2,167 $10^6m^3$ (77 Bcf).



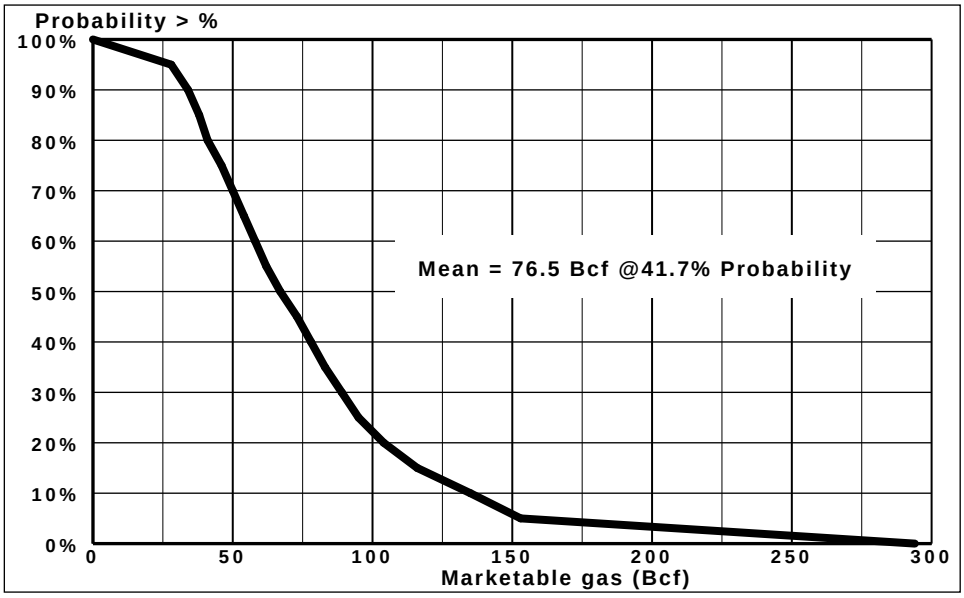
*Estimate of potential petroleum resources*

| | Minimum | Most likely | Maximum | Mean |
|---|---|---|---|---|
| Total play area (MM acres) | 0.1440 | 0.1600 | 0.1760 | 0.160 |
| Tested play area (MM acres) | 0.027 | 0.030 | 0.033 | 0.030 |
| Untested play area (MM acres) | 0.117 | 0.130 | 0.143 | 0.130 |
| Fraction of total play area in trap | 0.150 | 0.250 | 0.450 | 0.283 |
| Fraction of untested play area filled (areally) | 0.400 | 0.500 | 0.900 | 0.600 |
| Potential hydrocarbon area (MM acres) | | | | 0.022 |
| Porosity | 0.030 | 0.035 | 0.060 | 0.042 |
| Hydrocarbon saturation | 0.650 | 0.750 | 0.800 | 0.733 |
| Oil recovery factor | 0.000 | 0.000 | 0.000 | 0.000 |
| Gas recovery factor | 0.400 | 0.450 | 0.500 | 0.450 |
| Average net pay (ft.) | 75.0 | 150.0 | 300.0 | 175.0 |
| Probability of hydrocarbons | 0.050 | 0.200 | 0.350 | 0.200 |
| Fraction of pore volume oil bearing | 0.000 | 0.000 | 0.000 | 0.000 |
| Potential oil area (MM acres) | | | | 0.000 |
| Potential gas area (MM acres) | | | | 0.004 |
| Gas oil ratio (GOR) (MMcf/bbls) | 0.532 | 0.560 | 0.588 | 0.560 |
| Formation volume factor (FVF) | 1.303 | 1.319 | 1.335 | 1.319 |
| Gas compressibility factor 'Z' | 0.882 | 0.900 | 0.918 | 0.900 |
| Gas volume factor (GVF) | | | | 0.185 |
| Oil in place (bbls/acre-foot) | | | | 179.7 |
| Oil recovery (bbls/acre-foot) | | | | 0.0 |
| Gas in place (MMcf/acre-foot) | | | | 246.3 |
| Raw gas recovery (MMcf/acre-foot) | | | | 110.8 |
| Marketable gas recovery (MMcf/acre-foot) | | | | 99.8 |
| Liquid yield (bbls/MMcf) | 0.0 | 0.0 | 0.0 | 0.0 |
| $H_2S$ content | 0.000 | 0.000 | 0.001 | 0.000 |
| $CO_2$ content | 0.000 | 0.050 | 0.100 | 0.050 |
| Gas to BOE conversion factor (MMcf/BOE) | | 6.000 | | |
| Surface loss (fuel gas, etc.) | | 0.050 | | |
| Marketable gas (fraction of raw) | | 0.900 | | |

*Total for play*

| | Oil (MMb) | Solution gas (Bcf) | Non associated gas (Bcf) | Total gas (BcF) | Liquids (MMb) | Barrels of oil equivalent (MMBOE) | Marketable gas (Bcf) |
|---|---|---|---|---|---|---|---|
| **In place** | 0.00 | | 190.54 | 190.54 | | 31.76 | |
| **Recoverable** | 0.00 | 0.00 | 85.74 | 85.74 | 0.00 | 14.29 | 77.17 |
| **Sulphur (MMlt)** | | 0.00 | | | | | |

Oil depth: 5,600 ft.; gas depth: 5,600 ft.; gas pressure: 2,851 psi; gas reservoir temperature: 147.56°F




**Percentile values**

| | | |
|---|---|---|
| 100% | ..... | 0 |
| 95% | ..... | 28 |
| 90% | ..... | 34 |
| 85% | ..... | 38 |
| 80% | ..... | 41 |
| 75% | ..... | 46 |
| 70% | ..... | 50 |
| 65% | ..... | 54 |
| 60% | ..... | 58 |
| 55% | ..... | 62 |
| 50% | ..... | 67 |
| 45% | ..... | 73 |
| 40% | ..... | 78 |
| 35% | ..... | 83 |
| 30% | ..... | 89 |
| 25% | ..... | 95 |
| 20% | ..... | 104 |
| 15% | ..... | 116 |
| 10% | ..... | 135 |
| 5% | ..... | 153 |
| 0% | ..... | 294 |

Devonian

# BESA RIVER (MUSKWA) FRACTURED SHALE

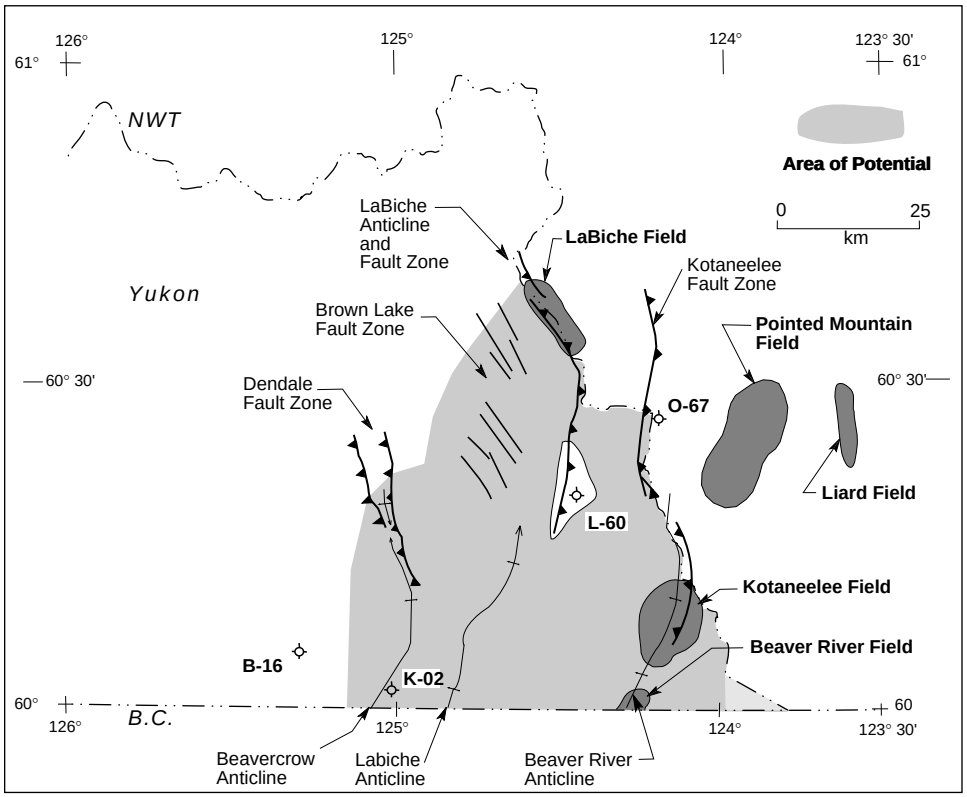
## IMMATURE GAS PLAY

### *Reservoir description*

The Middle Devonian Besa River (Muskwa ) fractured shale play is a sour(?) dry gas play. It is defined to include all pools and prospects in Laramide antiformal structural traps (thrusts, folds and faults) with fracture-enhanced porosity and permeability within basinal shale of the Besa River Formation. The play area for the study is limited on the west by shale affected by the Laramide Orogeny, and on the east, south and north by the study area boundary (B.C. and NWT borders).

### *Hydrocarbon occurrence model*

Laramide antiforms structurally complicated by normal, reserve and thrust faults form the trap for this play. The organic-rich Besa River (Muskwa) shale provides the seal for the reservoir and is the source of gas. The reservoir unit is composed of fractured shale. Fracturing associated with the axial traces of the antiforms is absolutely necessary for the existence of this play.

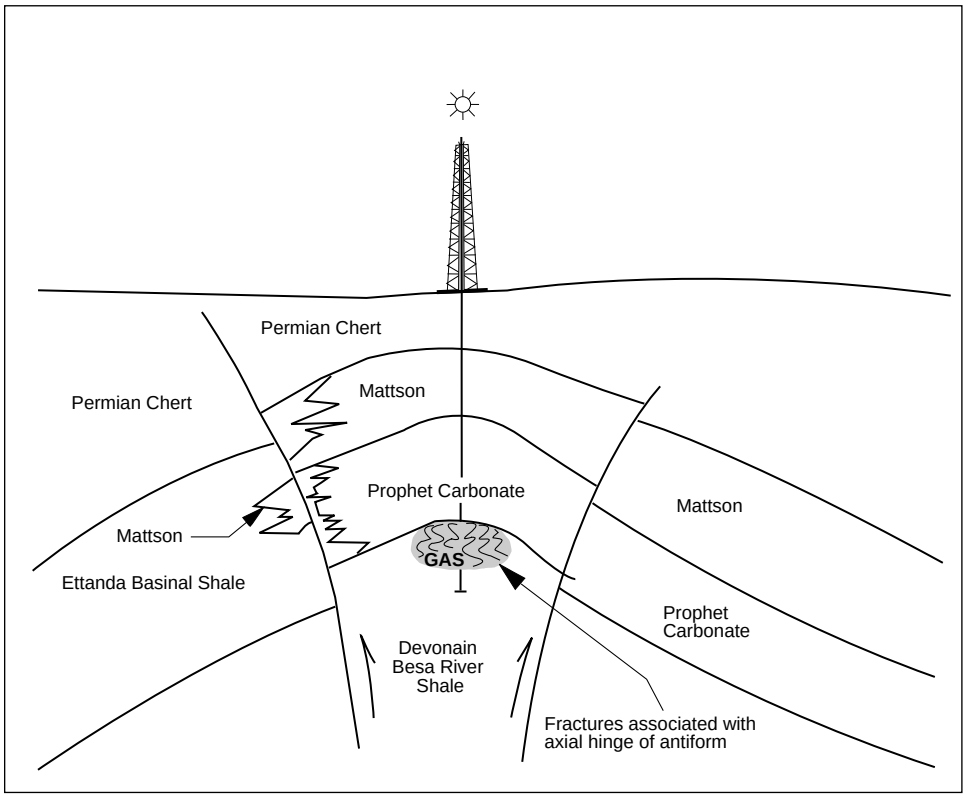


### *Discovered resources*

To date, there are no discovered Besa River (Muskwa) gas resources documented for the study area. The wells in the Beaver River field tested slightly sour gas from this zone at initial rates up to 0.10 $10^6m^3$/d (3.6 MMcf/d), with no water. The gas rates declined quickly indicating limited reservoir extent. The gas is generally 96 to 98% methane with 1 to 2% $H_2S$. Further expected play potential lies to the south and east of the study area.

### *Potential resources*

A search of current literature found no previously published estimates of the gas resources for this play. This study indicates that, within a 90% probability range, there is a marketable gas potential of 1,019 $10^6m^3$ (36 Bcf) to 13,371 $10^6m^3$ (472 Bcf), with a mean of 5,436 $10^6m^3$ (192 Bcf).



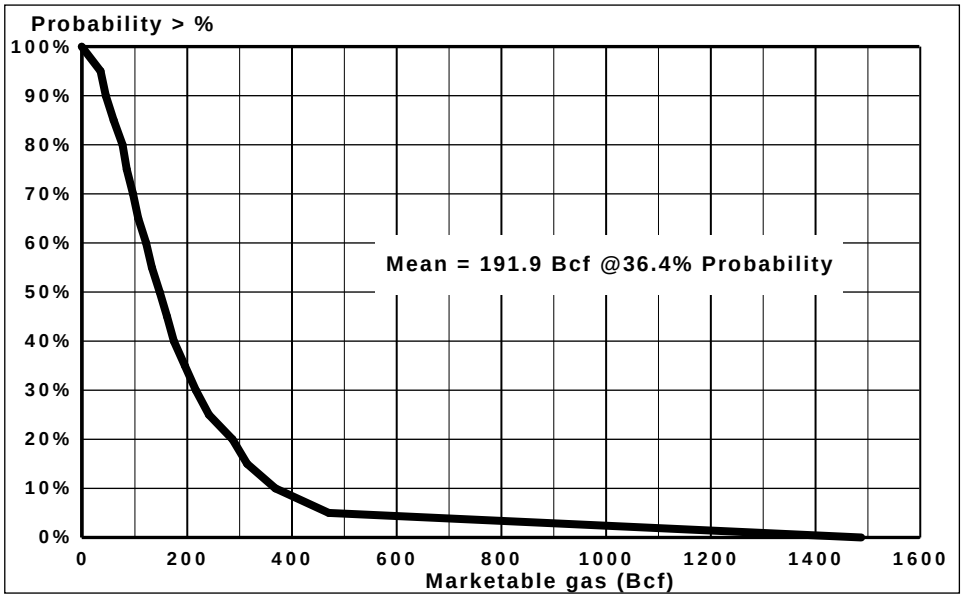
*Estimate of potential petroleum resources*

| | Minimum | Most likely | Maximum | Mean |
|---|---|---|---|---|
| Total play area (MM acres) | 0.3111 | 0.4500 | 0.8600 | 0.540 |
| Tested play area (MM acres) | 0.280 | 0.300 | 0.350 | 0.310 |
| Untested play area (MM acres) | 0.031 | 0.150 | 0.510 | 0.230 |
| Fraction of total play area in trap | 0.100 | 0.150 | 0.300 | 0.183 |
| Fraction of untested play area filled (areally) | 0.750 | 0.850 | 0.900 | 0.833 |
| Potential hydrocarbon area (MM acres) | | | | 0.035 |
| Porosity | 0.030 | 0.040 | 0.060 | 0.043 |
| Hydrocarbon saturation | 0.700 | 0.770 | 0.850 | 0.773 |
| Oil recovery factor | 0.000 | 0.000 | 0.000 | 0.000 |
| Gas recovery factor | 0.350 | 0.400 | 0.450 | 0.400 |
| Average net pay (ft.) | 60.0 | 90.0 | 300.0 | 150.0 |
| Probability of hydrocarbons | 0.050 | 0.200 | 0.400 | 0.217 |
| Fraction of pore volume oil bearing | 0.000 | 0.000 | 0.000 | 0.000 |
| Potential oil area (MM acres) | | | | 0.000 |
| Potential gas area (MM acres) | | | | 0.008 |
| Gas oil ratio (GOR) (MMcf/bbls) | 1.036 | 1.090 | 1.145 | 1.090 |
| Formation volume factor (FVF) | 1.590 | 1.621 | 1.652 | 1.621 |
| Gas compressibility factor 'Z' | 0.882 | 0.900 | 0.918 | 0.900 |
| Gas volume factor (GVF) | | | | 0.306 |
| Oil in place (bbls/acre-foot) | | | | 160.4 |
| Oil recovery (bbls/acre-foot) | | | | 0.0 |
| Gas in place (MMcf/acre-foot) | | | | 446.3 |
| Raw gas recovery (MMcf/acre-foot) | | | | 178.5 |
| Marketable gas recovery (MMcf/acre-foot) | | | | 164.1 |
| Liquid yield (bbls/MMcf) | 0.0 | 0.0 | 0.0 | 0.0 |
| $H_2S$ content | 0.000 | 0.000 | 0.001 | 0.000 |
| $CO_2$ content | 0.010 | 0.030 | 0.050 | 0.030 |
| Gas to BOE conversion factor (MMcf/BOE) | | 6.000 | | |
| Surface loss (fuel gas, etc.) | | 0.050 | | |
| Marketable gas (fraction of raw) | | 0.920 | | |

*Total for play*

| | Oil (MMb) | Solution gas (Bcf) | Non associated gas (Bcf) | Total gas (BcF) | Liquids (MMb) | Barrels of oil equivalent (MMBOE) | Marketable gas (Bcf) |
|---|---|---|---|---|---|---|---|
| **In place** | 0.00 | | 510.47 | 510.47 | | 85.08 | |
| **Recoverable** | 0.00 | 0.00 | 204.19 | 204.19 | 0.00 | 34.03 | 187.75 |
| **Sulphur (MMlt)** | | 0.00 | | | | | |

Oil depth: 10,900 ft.; gas depth: 10,900 ft.; gas pressure: 5,536 psi; gas reservoir temperature: 254.09°F




**Percentile values**

| | | |
|---|---|---|
| 100% | ..... | 0 |
| 95% | ..... | 36 |
| 90% | ..... | 46 |
| 85% | ..... | 61 |
| 80% | ..... | 78 |
| 75% | ..... | 86 |
| 70% | ..... | 98 |
| 65% | ..... | 108 |
| 60% | ..... | 123 |
| 55% | ..... | 134 |
| 50% | ..... | 149 |
| 45% | ..... | 163 |
| 40% | ..... | 176 |
| 35% | ..... | 197 |
| 30% | ..... | 218 |
| 25% | ..... | 243 |
| 20% | ..... | 288 |
| 15% | ..... | 316 |
| 10% | ..... | 370 |
| 5% | ..... | 472 |
| 0% | ..... | 1,489 |

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# APPENDIX A: Chronology of previous exploratory efforts in the study area

### PRE-1950

1944: GSC reconnaissance mapping of Liard area (Kindle).

1945: GSC mapping of Liard and LaBiche ranges (Hage).

### 1950 TO 1960

1951: California Standard Oil (CalStan; now Chevron) reconnaissance field work in Liard (Report 045-01-01-0020 and 0021).

1955: CalStan reconnaissance field work in Liard (Unpublished Report 045-01-01-0020 and 0021).

1956: CalStan reconnaissance field work in Liard (Unpublished Report 045-01-01-0020 and 0021).

1957: CalStan reconnaissance field work in Liard (Unpublished Report 045-01-01-0020 and 0021).

Issuance of Territorial P and NG permits 1468 to 1472 to California Standard Co. in the Liard Basin (South Beaver River Area).

1958: CalStan geological field work on South Beaver River Permits (Unpublished Report 045-01-01-0020 and 0021).

1959: CalStan geological field work on the Beaver River and South Beaver River Permits (Report 045-01-01-0020 and 045-01-01-0021).

GSI experimental 2 man portable reflection seismic survey shot in Blacstone Dome area for Calstan (48 km); inconclusive results due to equipment and hole problems (Unpublished Report 045-01-01-0021).

GSC completes “A series” mapping of quadrangles 95B and 95C (Douglas).

Gas was discovered in the British Columbia portion of the Liard Plateau region with the drilling of the **Pan American A-1 Beaver River b-63-K** well on the Beaver River Anticline (Carboniferous-aged Prophet and Devonian Besa River formations - blow outs; gas in the Manetoe facies of the Devonian Nahanni Formation).

Atlantic Refining Co. (now PetroCanada) carried out a photogeologic study of the Liard Plateau (Unpublished Report 246-02-01-0001) {an excellent report}.

### 1960 TO 1970

1960: British Petroleum (now Talisman) carried out a geological survey of the Nahanni area NWT (includes portions of the YT) (Unpublished Report 039-01-01-0004).

1961: CalStan shot 48 km of reflection seismic and some refraction seismic over Beavercrow anticline with the objective of delineating the structure of the Middle Devonian Carbonate section (Unpublished Report 045-06-01-0027).

Amoco shot 85.3 km of reflection seismic in the Kotaneelee- Liard area (Unpublished Report 060-06-01-0033).

1962: Calstan spudded the **SOBC Shell Beavercrow YT K-02** well. The well was completed January 11, 1963 and drilled through rocks of the lower Mattson (clastics) to dolomite of the Ronning without encountering significant shows of hydrocarbons (Unpublished Reports 045-01-01-0024 and 0027).

Pan Am (now Amoco) spudded the **Pan Am et al Kotaneelee YT P-50** well. The well was completed September 23, 1963 and drilled through rock of Triassic age (clastics) to carbonate of the Middle Devonian aged Nahanni formation. Gas was encountered in the Nahanni and the well was complete as a Nahanni gas well.

1963: Canada Southern spudded the **Canada Southern et al N. Beaver River YT I-27** well. The well was completed August 29, 1964 and tested Cretaceous clastics of the Scatter Formation to Middle Devonian Nahanni carbonate. Gas was encountered in the Nahanni (Manetoe facies) and the well was complete as a Nahanni gas well.

Western Decalta Petroleum Ltd. carried out a photogeologic study of the LaBiche River Area, YT and NWT (Permit 3232) (Unpublished Report 019-02-01-00014).

1964: Amoco shot an unknown amount of reflection seismic in the Mount Martin area (Unpublished Report 060-06-04-0050).

Amoco shot an unknown amount of reflection seismic in the Mount Merrill area (Unpublished Report 060-06-04-0051).

1967: Canadian Homestead Oils carried out a geological study of the Beaver River area in the vicinity of the SOBC Shell Beavercrow YT well; (Unpublished Report 059-01-01-00003).

Amoco shot an unknown amount of reflection seismic in the LaBiche area (Unpublished Report 060-06-04-0059).

1968: Banff Oil carried out a stratigraphic reconnaissance of the Liard River Basin (Unpublished Report 216-01-01-00020) (A good report).

Amoco carried out a geologic field study of the Beaver River area (Unpublished Report 060-01-01-00076).

1969: Pan Am spudded the **Pan Am Shell Merrill YT L-60** well. The well was completed March 6, 1969 and tested rocks of Devonian age without encountering significant shows of hydrocarbons.

## 1970 TO 1980

1970: Texaco conducted a geophysical survey (seismic and gravity) (66.0 km) over the Beaver River and François Anticlines (59°47'30" to 60°10'N; 123°45' to 124°22'30"W) (Unpublished Report 017-06-01-00051).

Gulf spudded the **Gulf et al Beavercrow YT O-15** well. The well was completed June 1, 1970 and tested rocks of Lower Mattson to Devonian age without encountering significant shows of hydrocarbons.

Pan Am spudded the **Pan Am Beaver River YT G-01** well. The well was completed August 20, 1970 and tested rocks of Triassic to Devonian age. This well was a step-out development well on trend of the Beaver River gas field that was discovered in 1959 in British Columbia (Nahanni Formation - Manetoe facies).

1971: Bluemount spudded the **Bluemount et al Beavercrow YT B-16** well. The well was completed May 9, 1971 and tested rocks of Lower Mattson to Devonian age without encountering significant shows of hydrocarbons.

Fort Norman Exploration Inc. and Cessland Corporation undertook and completed a geological evaluation of P and NG permits in the Liard River and Mackenzie Mountains areas of the NWT and YT for the purposes of evaluating the Farm-in potential of leases held by Augdome Corporation Limited and Resolute Petroleums. (Unpublished Report 827-01-04-001).

Mobil Oil Canada Ltd. conducted a field study of the Mattson Sandstone in the Liard Area, Yukon Territory (Unpublished Report 057-01-01-076) (A good report).

Atlantic Richfield carried out a paleogeographic study of the Lower Cretaceous Sandstones in the Liard Basin, Yukon and Northwest Territories (Unpublished Report 246-01-01-032).

1972: Beaver Geophysical Services shot 45.6 km of seismic for Cessland Corporation Limited near Larson Lake in the Liard Basin (60° to 60°10'N; 125°22'30" to 125°15'W) (Unpublished Report 827-06-01-002).

Atlantic Richfield carried out a geological field study of the Liard Basin, Yukon and Northwest Territories (Unpublished Report 246-01-01-043).

Texaco carried a seismic survey (66.0 km) over the François Anticline (59°55' to 60°10'N; 123°45' to 124°22'30"W); (Unpublished Report 017-06-01-00051).

Canadian Superior, Petrofina and Hudson's Bay Oil and Gas conducted a joint seismic/gravity survey (seismic: 25.8 km; gravity/magnetics: 59.6 km) over the south LaBiche anticline (60°10'N 124°40'W); (Unpublished Reports 25-06-01-024 and 025-07 (08)-01-026).

Amoco shot 37 km of reflection seismic in the LaBiche area (Unpublished Report 060-06-01-00126).

United Canso shot 20.9 km of seismic in the Beaver River area (Unpublished Report 352-06-01-00041).

1973: Discovery of the Tattoo Gas Field in British Columbia (Map Sheet 94-O-10) with the drilling of the **Aquitaine et al Tattoo a-78-L/94-O-10** well. The gas bearing formations in this area are the Permian-aged Fantasque Formation (Belloy equivalent) (400 to 1,500 mKb) and the Upper Carboniferous-aged Mattson Formation (Kiskatinaw equivalent) (500 to 1,650 mKb). Potential also exists for Lower Cretaceous (Scatter Formation ?) clastic plays at depths of 300 to 1,100 mKb.

Beaver Geophysical Services shot 32.5 km of seismic for Fort Norman Explorations Inc. (Cessland Corporation Limited) near Jackpine Lake in the Liard Basin (Unpublished Report 827-06-01-003).

1974: Beaver Geophysical Services shot 32.5 km of seismic for Pan Mackenzie Petroleums Limited near Arrow Mountain (Fantasque Lake) in the Liard Basin (Unpublished Report 827-06-01-004).

Beaver Geophysical Services shot 31.9 km of seismic for Pan Mackenzie Petroleums Limited near Gold Pay Creek in the Liard Basin (Unpublished Report 827-06-01-005).

Beaver Geophysical Services shot 37.8 km of seismic for Pan Mackenzie Petroleums Limited near Jackpine Lake in the Liard Basin (Unpublished Report 827-06-01-006; note may be listed as 627-06-01-001).

1977: Columbia Gas spudded the **Columbia Gas et al Beavercrow YT O-15** well. The well was completed October 21, 1977 and tested rocks of Cretaceous to Middle Devonian Nahanni age and encountered significant shows of hydrocarbons (gas) in the Nahanni.

1978: Columbia Gas spudded the **Columbia Gas et al Kotaneelee YT E-37** well. The well was completed December 5, 1978 and tested rocks of Lower Mattson to Middle Devonian Nahanni age and encountered significant shows of hydrocarbons (gas) in the Nahanni (Manetoe facies).

1979: Columbia Gas spudded the **Columbia Gas et al Kotaneelee YT M-17** well. The well was completed February 26, 1979 and tested rocks of Cretaceous Spirit River Group to those of Lower Mattson age. The well was drilled and completed as a water disposal well in the Mattson (disposal of production waters from Nahanni gas wells).

## 1980 TO 1994

1980: Columbia Gas spudded the **Columbia et al Kotaneelee YT I-48** well. The well was completed November 4, 1980 and tested rocks of Triassic to Middle Devonian Arnica age and encountered significant shows of hydrocarbons (gas) in the Arnica (Manetoe facies).

1983: Canterra Energy shot 47 kilometres of 2D seismic in the Liard Area (Unpublished Report 9129-C55-1E).

# APPENDIX B: Wells in the study area

## BLUEMOUNT ET AL BEAVERCROW YT B-16

**Drilling Authority Number**: 0502

**Latitude**: 60.08425 **Longitude**: 125.30131

**Spud Date**: 71-02-04 **Rig Released**: 71-05-09

**Status**: Dry and Abandoned

**K.B. (m)**: 1,152.9 **T.D. (m)**: 2,288.4

**Logs available**: IES, BHC-SGR-C, MLC, DIL, FDC, SNP, CDM, SRS

**Sample Intervals (mKb)**: 216.4 to 2,288.4

**Cored Intervals**

| *Interval no.* | *mKb* | *Interval no.* | *mKb* |
|---|---|---|---|
| 1 | 1,740.4 to 1,741.9 | 12 | 1,921.5 to 1,922.1 |
| 2 | 1,754.4 to 1,755.6 | 13 | 1,939.7 to 1,940.4 |
| 3 | 1,769.4 to 1,770.6 | 14 | 1,954.4 to 1,955.0 |
| 4 | 1,784.6 to 1,785.8 | 15 | 1,958.0 to 1,959.3 |
| 5 | 1,799.2 to 1,799.8 | 16 | 1,998.0 to 2,000.1 |
| 6 | 1,813.3 to 1,813.9 | 17 | 2,067.5 to 2,068.1 |
| 7 | 1,829.1 to 1,830.6 | 18 | 2,153.4 to 2,154.9 |
| 8 | 1,843.4 to 1,845.0 | 19 | 2,240.0 to 2,241.5 |
| 9 | 1,860.8 to 1,862.3 | 20 | 2,284.0 to 2,286.0 |
| 10 | 1,885.2 to 1,886.7 | 21 | 2,286.0 to 2,288.1 |
| 11 | 1,906.8 to 1,907.4 | | |

**DST/RFT/EFT Tests**

| *Test #* | *mKb* | *Results* |
|---|---|---|
| 1 | 1,754.4 to 1783.1 | 1,268.0 m fr. wtr. |
| 2 | 2,276.6 to 2288.4 | 7,52.9 m fr. wtr. |
| 3 | 2,185.1 to 2270.8 | 1,426.5 m fr. wtr |

**Completed Intervals**: NIL

**Geologic Tops**

| *Formation* | *mKb* |
|---|---|
| Mattson | 0 |
| Etanda | 1,232 |
| Besa River (1st Black Sh mmbr) | 1,475.8 |
| Muskwa | 1,572.8 |
| Nahanni | 1,722.1 |
| Arnica | 1,889.8 |
| TD. | 2,288.4 |

## SOBC SHELL BEAVERCROW YT K-02

**Drilling Authority Number**: 0113

**Latitude**: 60.02889 **Longitude**: 125.02000

**Spud Date**: 62-03-20 **Rig Released**: 63-01-11

**Status**: Dry and Abandoned

**K.B. (m)**: 1133.9 **T.D. (m)**: 3976.1

**Logs available**: IES, GRS, ML, LL, CAL, DIP, CANSTRAT

**Sample Intervals (mKb)**: 3.0 to 3976.1

**Cored Intervals**

| *Interval no.* | *mKb* | *Lithology* |
|---|---|---|
| 1 | 1,405.4 to 1,406.3 | Limestone: tight, cryptocrystalline with annealed fractures |
| 2 | 1,458.8 to 1,465.5 | Dolomite: fine crystalline, fossiliferous, bituminous, dense and tight |
| 3 | 2,325.6 to 2,327.1 | Dolomite: microcrystalline, argillaceous, vuggy, open fractures. |
| 4 | 3,242.2 to 3,255.6 | Anhydrite and tight silty dolomite |
| 5 | 3,503.7 to 3,509.5 | Dolomite: tight, microcrystalline, pyritic, anhydritic, silty |
| 6 | 3,510.1 to 3,520.1 | Dolomite: tight, cryptocrystalline, anhydritic |

**DST/RFT/EFT Tests**

| *Test no.* | *mKb* | *Results* |
|---|---|---|
| 1 | 451.1 to 479.5 | Good air blow; Rec. 176.8 m. muddy wtr (filtrate); ISIP = 2,344.3 kPa; FSIP = 2,344.3 kPa. |
| 2 | 1,403.0 to 1,429.5 | Strong air blow dec. to nil; Rec. 143.3 m. mud and 914.4 m fr.wtr. (filtrate); ISIP = 10,604.5 kPa; FSIP = 10,666.6 kPa. |
| 3 | 1,458.2 to 1,464.9 | Good air blow: Rec. 929.6 m. fr. wtr. (filtrate); ISIP = 11,169.9 kPa; FSIP = 10,859.6 kPa. |
| 4 | 2,320.1 to 2,327.1 | Very weak air blow; Rec. 411.5 m. fr. wtr. (filtrate); ISIP = 19,499.1 kPa; FSIP = 19,561.1 kPa. |
| 5 | 3,478.4 to 3,509.5 | misrun; Rec. 265.2 m. wtr. cshn |
| 6 | 3,453.4 to 3,540.6 | Very weak air blow; Rec. 914.4 m. wtr; 853.4 m. wtr. cshn; ISIP = 19,705.9 kPa; FSIP = 18,113.2 kPa. |
| 7 | 3,917.6 to 3,976.1 | misrun; no rec. |
| 8 | 3,910.6 to 3,976.1 | Weak air blow (dead in 10 min.); 853.4 m. wtr. cshn; 152.4 m. mud; ISIP = nil kPa; FSIP = 24,918.5 kPa. |

**Completed Intervals**: Nil

**Geologic Tops**

| *Formation* | *mKb* |
|---|---|
| Surface (Mattson) | 4.3 |
| L. Mattson Ss. | 425.0 |
| Etanda | 611.4 |
| Exshaw | 984.5 |
| Sombre/Arnica | 1,404.5 |
| Manetoe facies | 2,993.2 |
| Delorme | 3,458.0 |
| Whittaker | 3,886.2 |
| T.D. | 3,976.1 |

## PAN AM ET AL A-1 KOTANEELEE YT P-50

### (in Kotaneelee Field)

**Drilling Authority Number**: 0110

**Latitude**: 60.16301 **Longitude**: 124.13165

**Spud Date**: 62-04-10 **Rig Released**: 63-09-23

**Status**: Suspended Gas well

**K.B. (m)**: 451.4 **T.D. (m)**: 4,410.5 **P.B.T.D. (m)**: 3,596.3

**Logs available**: GRN, IES, MLC, GRS, VL, DIP, CAL

**Sample Intervals (mKb)**: 3.0 - 4410.5 (Note: no sample from bottom 82.3 m of hole; picks may be questionable for this portion of the section)

**Cored Intervals**

| *Interval no.* | *mKb* |
|---|---|
| 1 | 3,018.4 to 3,031.8 |
| 2 | 3,376.3 to 3,377.5 |

**DST/RFT/EFT Tests**

| *Test no.* | *mKb* | *Results* |
|---|---|---|
| 1 | 3,444.1 to 4,410.5 | GTS in 40 min @ TSTM; Rec. 457.2 m gas-cut mud |

**Geologic Tops**

| *Formation* | *mKb* |
|---|---|
| Recent | 0 |
| Triassic (Chert,sh) | 350.4 |
| Fault?? | 960.1 |
| Triassic Chert,Sh (repeated) | 1,021.1 |
| Mississippian (Flett) | 1,674.3 |
| 1st Black shale (Dev.) | 2,993.9 |
| 2nd Black shale (Dev.) | 4,047.7 |
| Nahanni | 4,391.3 |
| T.D. | 4,410.5 |

## CANADA SOUTHERN ET AL N. BEAVER RIVER YT I-27

### (in Kotaneelee Field)

**Drilling Authority Number**: 0117

**Latitude**: 60.11155 **Longitude**: 124.06462

**Spud Date**: 630324 **Rig Released**: 640829

**Status**: Suspended gas Well

**K.B. (m)**: 435.6 **T.D. (m)**: 4418.1 **P.B.T.D. (m)**: 3,719.8

**Logs available**: IES, GRN, MC, GRS, CAL, LL, DIP, DIR and CB

**Sample Intervals (mKb)**: 0 to 4,418.1

**Cored Intervals**

| *Interval no.* | *mKb* |
|---|---|
| 1 | 3,837.7 to 3,846.3 |

**DST/RFT/EFT Tests**

| *Test no.* | *mKb* | *Results* |
|---|---|---|
| 1 | 1,358.8 to 1,407 | misrun; Rec. 274 m. Drlg fl. and mud |
| 2 | 1,367.3 to 1,407 | Rec. 152.4 m mud |
| 3 | 3,616.5 to 3,726.5 | misrun; tool plugged |
| 4 | 3,703.3 to 3,811.8 | Gas TSTM; Rec. 1066.8 m muddy fresh water; 1,067 gassy fresh water |
| 5 | 3,849.6 to 3,942.6 | misrun; packer seat failure; rec. 1,527.0 m mud |
| 6 | 3,857.5 to 3,988.0 | misrun; tool failed to open |
| 7 | 3,867.6 to 4,006.0 | Gas TSTM; Rec. 1,524.4 m gas cut mud |
| 8 | 4,209.9 to 4,284.9 | misrun; packer seat failure |

**Geological Tops**

| *Formation* | *mKb* |
|---|---|
| Recent (Drift) | 5.2 |
| Scatter Marker | 36.6 |
| Triassic | 359.6 |
| Fantasque | 707.1 |
| Mattson | 883 |
| Mississippian (Flett) | 1,674.3 |
| Etanda | 1,825.8 |
| Flett | 2,033 |
| Besa River | 2,923.9 |
| Nahanni | 3,892.9 |
| Arnica | 4,114 |
| TD | 4,418.1 |
| PBTD | 3,719.8 |

## PAN AM SHELL MERRILL YT L-60

**Drilling Authority Number**: 0348

**Latitude**: 60.32500 **Longitude**: 124.43333

**Spud Date**: 69-01-24 **Rig Released**: 69-03-06

**Status**: Dry and Abandoned

**K.B. (m)**: 594.4 **T.D. (m)**: 1,634.3

**Logs available**: SNP, FDC, CDM, LITH, DIL, BHCS

**Sample Intervals (mKb)**: 0–1,634.3

**Cored Intervals**

| *Interval no.* | *mKb* |
|---|---|
| 1 | 1,597.2 to 1,603.6 |
| 2 | 1,603.6 to 1,613.9 |
| 3 | 1,613.9 to 1,623.4 |
| 4 | 1,623.4 to 1,634.3 |

**DST/RFT/EFT Tests**

| *Test no.* | *mKb* | *Results* |
|---|---|---|
| 1 | 1,520.6 to 1,634.3 | Rec. 1,475.2 m brksh sulf wtr; v. sm. amt gcmd; 36.6 m mud |

**Geologic Tops**

| *Formation* | *mKb* |
|---|---|
| Mattson | 0 |
| Etanda | 152.4 |
| Exshaw | 1,077.4 |
| 1st Black Shale | 1,082.0 |
| Muskwa (2nd Black shale) | 1,378.9 |
| Nahanni | 1,522.2 |
| Manetoe Dolomite | 1,554.7 |
| T.D. | 1,634.3 |

## GULF ET AL WEST BEAVERCROW YT O-15

### (in Kotaneelee Field)

**Drilling Authority Number**: 0402

**Latitude**: 60.08303 **Longitude**: 125.29552

**Spud Date**: 70-02-03 **Rig Released**: 70-01-06

**Status**: Dry and Abandoned

**K.B. (m)**: 1147.9 **T.D. (m)**: 1727.3

**Logs available**: IES, BHCS, GR-C

**Sample Intervals (mKb)**: 0 to 1727.3

**Cored Intervals (mKb)**: Nil

**DST/RFT/EFT Tests:** Nil

**Completed Intervals**: Nil

**Geologic Tops**

| *Formation* | *mKb* | *m Subsea* |
|---|---|---|
| Mattson | 3 | |
| Besa River/Etanda | 562.4 | |
| T.D. | 1,727.3 | |

## PAN AM BEAVER RIVER YT G-01

### (in Beaver River Field)

**Drilling Authority Number**: 0325

**Latitude**: 60.00694 **Longitude**: 124.26333

**Spud Date**: 69-12-06 **Rig Released**: 70-08-20

**Status**: Abandoned Gas Well (78-08-31)

**K.B. (m)**: 797.7 **T.D. (m)**: 4499.5 **P.B.T.D. (m)**: 4411.1

**Logs available**: DIL, S, CDM, BHCS, CR, SNP, FDC

**Sample Intervals (mKb)**: 0 to 4,465.9

**Cored Intervals**

| *Interval no.* | *mKb* | *Interval no.* | *mKb* |
|---|---|---|---|
| 1 | 2,182.4 to 2,183.0 | 11 | 3,116.0 to 3,126.3 |
| 2 | 2,183.0 to 2,183.3 | 12 | 4,123.9 to 4,135.5 |
| 3 | 2,671.3 to 2,684.7 | 13 | 4,135.5 to 4,142.5 |
| 4 | 3,061.7 to 3,072.4 | 14 | 4,164.5 to 4,182.8 |
| 5 | 3,076.3 to 3,091.6 | 15 | 4,183.1 to 4,195.3 |
| 6 | 3,093.7 to 3,102.3 | 16 | 4,224.9 to 4,256.2 |
| 7 | 3,102.3 to 3,105.0 | 17 | 4,256.2 to 4,258.1 |
| 8 | 3,105.0 to 3,108.0 | 18 | 4,258.1 to 4,259.0 |
| 9 | 3,108.0 to 3,115.1 | 19 | 4,320.5 to 4,330.6 |
| 10 | 3,115.1 to 3,116.0 | 20 | 4,392.2 to 4,399.8 |

**DST/RFT/EFT Tests**

| *Test no.* | *mKb* | *Results* |
|---|---|---|
| 1 | 2,186.3 to 2,200.7 | strong blow; GTS @ 35 MMcf/d; no fluid rec. |
| 2 | 2,670.0 to 2,703.0 | misrun; plugged recorder; packers leaked; rec. 411.5 m wtr cut mud |
| 3 | 3,099.8 to 3,115.1 | Gts TSTM; Rec. 570.0 m mud; 609.6 m wcmud |
| 4 | 4,442.5 to 4,499.5 | misrun |
| 5 | 4,442.5 to 4,499.5 | GTS (no recorded rate); Rec. 2,222.0 m drilling fluids and mud; 914.4 m wtr cshn; 1,307.6 m fm wtr |

**Geologic Tops**

| *Formation* | *mKb* |
|---|---|
| Garbutt | 5.2 |
| Triassic | 121.9 |
| Fantasque | 434.0 |
| Mattson | 637.0 |
| Besa River | 2,192.1 |
| Dev Ls. | 3,041.3 |
| 1st Black Shale | 3,541.2 |
| 2nd Black Shale | 3,947.8 |
| Nahanni (dol) | 4,111.8 |
| T.D. | 4,499.5 |

## COLUMBIA GAS ET AL KOTANEELEE YT H-38 (B-38)

### (in Kotaneelee Field)

**Drilling Authority Number**: 0878

**Latitude**: 60.12111 **Longitude**: 124.10083

**Spud Date**: 77-04-06 **Rig Released**: 77-10-21

**Status**: Gas Well

**K.B. (m)**: 693.4 **T.D. (m)**: 3898.1

**Logs available**: DILL, CN, BHCS, YD, WF, LITH

**Sample Intervals (mKb)**: 304.8 to 3873.4

**Cored Intervals**

| *Interval no.* | *mKb* |
|---|---|
| 1 | 2,479.2 to 2,489.9 |
| 2 | 3,563.1 to 3,581.4 |
| 3 | 3,660.8 to 3,677.1 |
| 4 | 3,736.8 to 3,755.1 |
| 5 | 3,794.8 to 3,813.0 |
| 6 | 3,873.4 to 3,887.7 |
| 7 | 3,887.7 to 3,898.1 |

**DST/RFT/EFT Tests**

| *Test no.* | *Formation/mKb* | *Results* |
|---|---|---|
| 1 | 2,354.6 to 2,414.3 | GTS @ 37.7 $10^3$ $m^3$/d; Rec. 411.48 m gc mud |
| 2 | 3,544.8 to 3,563.1 | GTS @ 50.7 $10^3$ $m^3$/d; Rec. 228.6 m gc wtr cshn |
| 3 | 3,560.1 to 3,624.1 | misrun |
| 4 | 3,564.6 to 3,624.1 | misrun |
| 5 | 3,564.6 to 3,624.1 | GTS (no rate); rec. 243.9 m muddy wtr cshn |

**Geologic Tops**

| *Formation* | *mKb* |
|---|---|
| Cretaceous | surface |
| Triassic | ? |
| Fantasque | 335.3 |
| Mattson | 505.4 |
| Etanda | 1,709.9 |
| Exshaw | 3,102.9 |
| Muskwa | 3,456.4 |
| Nahanni | 3,546.3 |
| T.D. | 3,898.1 |

## COLUMBIA GAS ET AL KOTANEELEE YT E-37
### (in Kotaneelee Field)

**Drilling Authority Number**: 0898

**Latitude**: 60.10750 **Longitude**: 124.12111

**Spud Date**: 78-01-21 **Rig Released**: 78-12-05

**Status**: Gas Well

**K.B. (m)**: 621.2 **T.D. (m)**: 4191.0

**Logs available**: DIP, BHCS, CN, DIR, DILL

**Sample Intervals (mKb)**: 0 to 4191.0

**Cored Intervals**

| *Interval no.* | *mKb* |
|---|---|
| 1 | 3,878.9 to 3,881.0 |
| 2 | 3,881.0 to 3,883.5 |
| 3 | 3,901.1 to 3,919.4 |
| 4 | 3,919.4 to 3,937.7 |
| 5 | 3,937.7 to 3,953.0 |
| 6 | 4,002.6 to 4,020.9 |

**DST/RFT/EFT Tests:** Nil

**Geologic Tops**

| *Formation* | *mKb* |
|---|---|
| Mattson | 818.4 |
| Flett | 2,033.0 |
| Etanda | 2,923.9 |
| 1st Black Shale | 3,388.2 |
| Muskwa (2nd Black Shale) | 3,780.7 |
| Nahanni | 3,892.9 |
| T.D. | 4,191.0 |

## COLUMBIA ET AL KOTANEELEE YT M-17

### (in Kotaneelee Field)

**Drilling Authority Number**: 0918

**Latitude**: 60.1125 **Longitude**: 124.05833

**Status**: Water Disposal Well

**Spud Date**: 790101 **Rig Released**: 790226

**K.B. (m)**: 419.1 **T.D. (m)**: 1332

**Logs available**: DIL,BHCS,CN,LFDC

**Sample Intervals (mKb)**: 300.0 to 1332.0

**Cored Intervals**: Nil

**DST/RFT/EFT Tests:** Nil

**Geologic Tops**

| *Formation* | *mKb* |
|---|---|
| Spirit River | 7.6 |
| Toad Grayling | 405 |
| Fantasque | 755 |
| Mattson | 948 |
| TD | 1,332 |

## COLUMBIA ET AL KOTANEELEE I-48 (in Kotaneelee Field)

**Drilling Authority Number**: 0929

**Latitude**: 60.1266389 **Longitude**: 124.1268056

**Spud Date**: 79-04-18 **Rig Released**: 80-11-04

**Status**: Gas Well

**K.B. (m)**: 835 **T.D. (m)**: 4430

**Logs available**:

**Sample Intervals (mKb)**: 300 - 4,429.4

**Cored Intervals**

| *Interval no.* | *mKb* | *Interval no.* | *mKb* |
|---|---|---|---|
| 1 | 3,660.0 to 3,665.7 | 9 | 3,910.4 to 3,912.6 |
| 2 | 3,665.7 to 3,668.8 | 10 | 3,912.6 to 3,916.0 |
| 3 | 3,668.8 to 3,672.1 | 11 | 3,949.2 to 3,956.8 |
| 4 | 3,723.0 to 3,741.0 | 12 | 4,035.0 to 4,036.6 |
| 5 | 3,741.0 to 3,759.2 | 13 | 4,036.6 to 4,043.6 |
| 6 | 3,759.2 to 3,771.6 | 14 | 4,043.6 to 4,046.0 |
| 7 | 3,771.6 to 3,774.2 | 15 | 4,158.2 to 4,165.2 |
| 8 | 3,774.2 to 3,782.4 | 16 | 4,424.4 to 4,429.4 |

**DST/RFT/EFT Tests**

| *Test no.* | *mKb* | *results* |
|---|---|---|
| 1 | 4,266 to 4,274 | misrun; tubing string problems |
| 2 | 4,266 to 4,274 | plugged tool; GTS (est. @ 0.1 MMcf/d with 12.6 mm choke) |
| 3 | 4,266 to 4,274 | GTS in 50 min @ est. @ 2 MMcf/d; rec. wtr cshn. |
| 4 | 4,362 to 4,415 | misrun; tool plugged |
| 5 | 4,390 to 4,402 | GTS in 60 min @ 192.56 x $10^3 m^3/d$; rec. 28 m mud and 28 m fr. wtr. |
| 6 | 4,226 to 4,274 | misrun; tool plugged; GTS in 65 min @ 33.98 x $10^3 m^3/d$; rec. 627 m wtr. |
| 7 | 4,266 to 4,274 | GTS in 15 min @ 1,78.4 x $10^3 m^3/d$; rec. 28.5 m wtr.; 114 m mud |
| 8 | 4,050 to 4,073 | GTS Tstm; Rec. 466 m wtr.; 56 m gel mud |

**Geological Tops**

| *Formation* | *mKb* |
|---|---|
| Triassic | 7.6 |
| Fantasque | 75 |
| Mattson | 256.6 |
| Flett | 1,712.6 |
| Besa River | 2,490.8 |
| Nahanni | 3,616 |
| Headless | 3,805.5 |
| Arnica | 3,989.9 |
| T.D. | 4,429.4 |