Chapter 8.
Petroleum Resource Assessment of the Tlogotsho Plateau, Nahanni Karst, and Adjacent Areas Under Consideration for Expansion of Nahanni National Park Reserve, Northern Cordillera and District of Mackenzie

Kirk G. Osadetz, Zhuoheng Chen and David. W. Morrow

8.1. Abstract

The rocks that provide the spectacular scenery in eastern Nahanni National Park Reserve are also the primary reservoirs for petroleum in the Liard Fold and Thrust Belt structural gas play. Scientific and engineering study of these rocks should be permitted in a way that contributes to both efficient sustainable development of the resource outside of the Park Reserve boundaries and an improved educational experience for visitors to the Park Reserve.

Recent exploration activity and changes in development strategies have renewed interest in this play. It has a significant economic potential that represents between 181 X $10^9 m^3$ (6413 BCF) and 113 X $10^9 m^3$ (3988 BCF) of initial gas in place probably in 15 to 128 accumulations, including the seven existing discovered fields with a reserve estimated to be between 59,480 and 65,130 x $10^6 m^3$ (2105-2305 BCF), primarily in Devonian Manetoe and Carboniferous Mattson reservoirs. This resource represents between 10.5% and 6.5% of the national gas reserve and it has a probable current value of between \$40 Billion and \$25 Billion. Historically this play has one of the best success rates for exploratory wells and for the rates of addition of reserves in the Cordilleran Foreland Belt.

In general, the Nahanni National Park Reserve and its proposed extensions cover areas where the burial of the primary reservoir targets is reduced, compared to most of the prospective region. The reduced potential for an effective top seal and the decreased formation volume factor for gas, within the Park Reserve and its proposed extensions suggests that the removal of these regions from hydrocarbon development should not have a major impact on the realization of the Liard natural gas economic potential, considering the following three exceptions.

(1) The untested Twisted Mountain Anticline is located immediately adjacent to the current National Park Reserve, at its southeastern limit. (2) The Etanda Dome is located approximately mid-way at the southern margin of the proposed Tlogotsho Plateau extension. Both structures have geological characteristics that suggest they could individually contain between 2.8 and 8.5 x $10^9 m^3$ (100 and 300 BCF) of natural gas in-place and these are recommended for preservation for economic development. Between these two structures is the Mattson Anticline, which has been tested unsuccessfully by a single well. Recent developments in the Liard Field have shown that early exploration tests may not be diagnostic and that the Mattson Anticline still has potential for commercial production.

8.2. Hydrocarbon Assessment Background

The Liard Laramide Fold and Thrust Belt lies west and north of the Liard River and south of the Nahanni River and generally east of the region where structures expose Devonian and older strata west of about 125.5° W longitude (Figure 8.1; DeWit et al., 1973). The play area extends across approximately 2 million hectares in the Yukon, Northwest Territories and British Columbia. Outcrops along the South Nahanni River in the extreme southwest corner of the Northwest Territories offers some of the best exposed and most interesting Silurian-Devonian sequences that may be examined anywhere in the world. Lower Devonian shelf carbonates are particularly well developed, as are spectacular exposures of coarsely crystalline dolostones, known locally as the Manetoe dolostone. The carbonate and clastic Paleozoic rocks that crop out in the National Park Reserve give it great scenic beauty. These outcrops are the exposed equivalents of major petroleum reservoirs that have been discovered in the Liard Laramide Fold and Thrust Belt natural gas play that generally lies abutting and south of the existing Park Reserve.

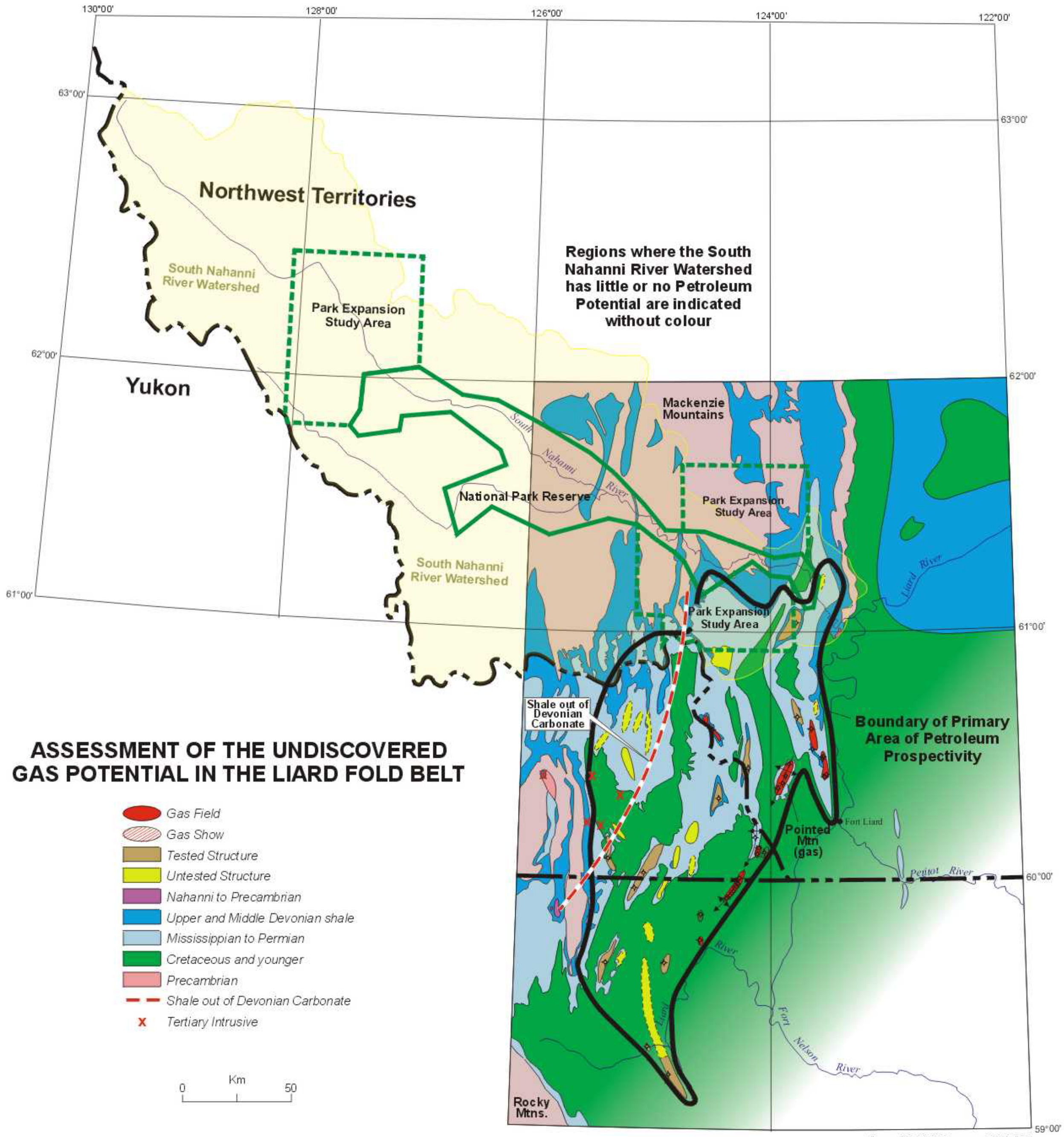

Figure 8.1. Study area and key geographic locations (From Procter and Newson, 2002). The petroleum play area is indicated by the heavy solid line that encompasses the variously coloured productive, tested, and untested structures, most of which have bedrock geological expression at map scales. See the figure legend for details.

This study reports on the history of petroleum exploration in this play. It analyses the petroleum potential, both discovered and undiscovered, and it and discusses how, with few considerations and exceptions, the proposed extensions of the Nahanni National Park in the Tlogotsho Plateau Nahanni Karst Study Areas should not have a major impact on the realization of the economic potential of the petroleum play, as long as exploration and development access to the Mattson Anticline, the Twisted Mountain Anticline and the Etanda Dome structures are preserved and permitted. All of these structures could contain between 2.8-8.5 X10^9 m^3 (100 and 300 BCF) of natural gas.

The first discoveries of petroleum in this play were made in 1958, and since 1999 there has been a renewed interest in both the exploration of new structures and the redevelopment of structures that have already been explored and in some cases developed. Because of the uncertainty in the actual size of existing discoveries, not an uncommon feature of petroleum exploration in the frontier regions, two major types of petroleum resource assessment, the sequential sampling method and the reservoir volume method, are made, each with several scenarios that attempt to capture the existing uncertainties in the description of both the discovered resource and the total potential. Most methods result in a generally similar result, but this agreement depends strongly on the number of accumulations that are expected and the magnitude of the recently revised reserve at the Liard Field.

8.3. Geology of the Liard Hydrocarbon Assessment Domain

The regional geology in the South Nahanni River area is summarized in Chapter 3 of this report. The bedrock geology of the region is mapped primarily at a reconnaissance-scale (Table 3.1; Douglas, 1970) with fewer detailed studies (Blusson, 1968; Gordey; 1981b; Morrow and Cook; 1987; Gabrielse et al. 1973). An abundance of subsurface data, both geophysical, primarily seismic, and geological, primarily wells provides a clear indication of the stratigraphic and tectonic framework (Gabrielse and Yorath, 1990), which serves as the basis for a clear understanding of the geological processes related to the function of petroleum systems and the formation of petroleum reservoirs and traps (Figure 8.2).

From the Cambrian to Late Silurian, the region subsided as part of the western miogeocline related to the formation of the Paleo-Pacific passive margin of North America. Late Silurian regression removed rocks from this region until renewed transgression in Early Devonian time, associated with the Taghanic onlap, of uncertain tectonic affinity. Subsidence and deposition continued with general continuity until late Paleozoic time. Carbonate platform deposition characterized the early stages of the Taghanic onlap succession and the deposition of the regional Nahanni-Hume lithostratigraphic unit. This was succeeded by a thick succession of basinal fine clastics and carbonates that succeeded platform deposition as base-level rise continued and the margin of the carbonate platform back-stepped to the Middle Devonian Keg River Formation Barrier Reef. During this interval there were minor epeirogenic motions on intra-basinal arches and depression such as the Beaver River, or Beavercrow, High. During the Carboniferous a shale succession, the Etanda Formation, was deposited in the western parts of the Liard Plateau as the distal equivalent of Lower Carboniferous sandstone and siltstone dominated unites of the Clausen and Yohin formations, and Upper Carboniferous carbonates of the Flett and Prophet formations. During late Carboniferous regression the deposition of Mattson Formation saw great quantities of fluvial, deltaic and near shore coarse clastics, derived from the northeast, prograde progressively across the Liard Plateau. During the Permian and Early Triassic, a shallow sea transgressed the Liard Plateau, receiving deposits of a thin, predominantly clastic, succession. During the late Triassic and Jurassic the area was emergent. With the onset of Cordilleran Foreland Basin subsidence the Liard Plateau accumulated a thick succession of westerly-derived clastics eroded from the rising and eastwardly expanding Cordillera to the west. In the Late Cretaceous, the eastwardly expanding Laramide orogenic wedge incorporated the Liard Plateau into the deformed allocthonous assemblage, giving rise to the currently observed structural geometry and forming the main petroleum prospects in the hanging wall of west dipping thrust faults. Many of the Laramide thrust faults follow Paleozoic structural elements.

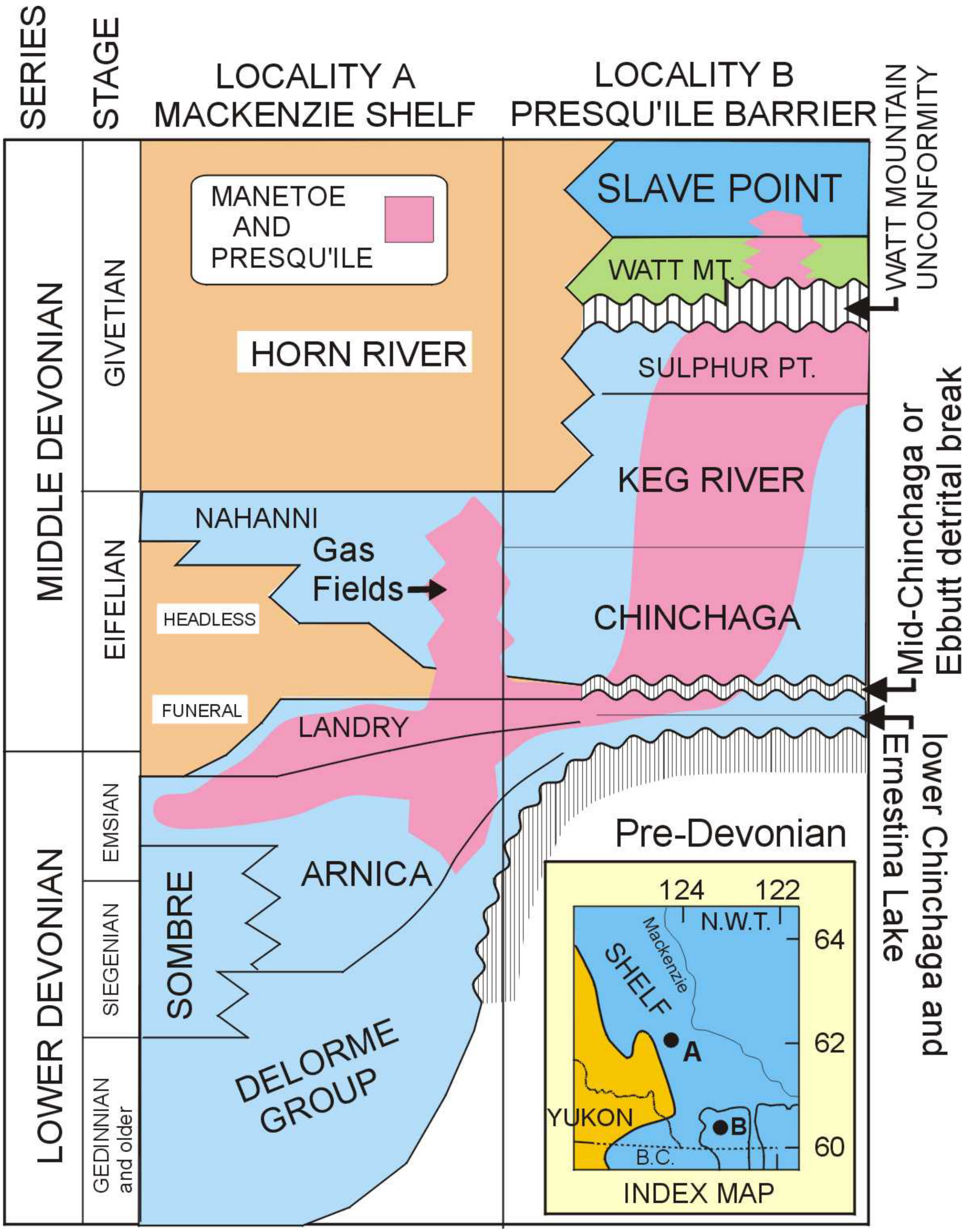

Figure 8.2: Diagram illustrating stratigraphic relationships in the main gas producing interval in the Devonian succession as discussed in the text, from Morrow (2001). See elsewhere in this report for illustrations of regional stratigraphic relationships, as discussed in the text.

Petroleum prospectivity is primarily controlled by a simple combination of stratigraphic, diagenetic and structural constraints. The two primary reservoirs are the

Devonian Manetoe Dolostone, a diagenetic alteration of the Lower and Middle Devonian Arnica to Nahanni succession, and the Carboniferous Mattson Formation predominantly sandstone. These two reservoir horizons are sealed respectively by either the fine clastics of the overlying Muskwa Member shales or by stratigraphic relationships and diagentic processes related to the unconformity between the Mattson Formation and younger overlying strata. Where such stratigraphic settings occur under antiformal closure, primarily in thrust faulted and folded Laramide structures they are prospective for petroleum accumulations. Due to the generally low matrix porosity and permeability of the two main reservoirs it is generally believed that fractures, attributed primarily to Laramide diastrophic deformation are essential to the economic recovery of petroleum from accumulations in the Liard Plateau. In detail, the local variations of stratigraphy, diagenesis and structure result in complications to this overall model, but the essential simple nature of the play and the use of seismic prospection for antiformal targets shows the general anticline nature of these accumulations.

8.3.1 Neoproterozoic successions

The oldest rocks exposed in the western Nahanni River region are Neoproterozoic basinal coarse to fine clastic strata of the Windermere Supergroup. The oldest rocks exposed in the northeastern Nahanni River region are the Mackenzie Mountains Supergroup. These rocks are not attributed any petroleum potential, but they indicate important tectonic elements that affect the overlying prospective Phanerozoic successions An east-west facies change between basinal and platformal succession first manifest during Neoproterozoic persists generally throughout the overlying Phanerozoic.

8.3.2 Cambrian, Ordovician And Silurian

Unconformably overlying the PreCambrian succession is an Upper Cambrian to Lower Ordovician succession of the Rabbit Kettle and Franklin Mountain formations. In the west Rabbit Kettle Formation, well bedded to massive silty limestone and calcareous siltstone and dark grey to black argillaceous limestone and calcareous shale is more than 1,200 m thick. The Rabbit Kettle Formation passes eastward into Franklin Mountain Formation, predominantly red-weathering dark gray, silty dolostones. The Ordovician section thickens northward and is more than 2,100 m at Virginia Falls. It thins eastward and is missing in the vicinity of Nahanni Butte. Middle Ordovician Sunblood Formation conformably overlies Rabbit Kettle and Franklin Mountain formations. Grey, finely laminated micritic, limestone the Sunblood Formation is up to 1,040 m thick. Silurian Whittaker Formation predominantly grey lime mudstone and dark grey, cherty, dolostones disconformably overlies Sunblood Formation and is over 400 m thick. To the south and east, Whittaker Formation is correlative, in part, to Lower Silurian Mount Kindle Formation. Mount Kindle Formation overlies a deeply erosional unconformity and it lies on strata as young as Sunblood Formation and as old as Proterozoic.

8.3.3 Devonian

Upper Silurian to Lower Devonian Delorme Formation, finely crystalline vuggy, silty dolostones interbedded with shale and dolomitic siltstone, up to 30 m unconformably overlies Whittaker Formation and older units. In basinal settings it is conformably overlain by Devonian Sombre Formation, which is more than 2,500 m thick, and composed of bioclastic dolostones and dolomicrites. The basinal Sombre Formation thins eastward and northward where it changes facies into Arnica Formation platformal dolostones, which are up to 625 m thick. Overlying the Arnica Formation in basinal settings is Funeral Formation -- in its lower part, calcareous shale interbedded with silty and argillaceous, limestone; overlain by thin bedded, upper argillaceous bioclastic limestone and calcareous shale -- is up to 700 m thick. Funeral Formation basinal strata pass, east of a 126° W, into platformal Lower Landry Formation, massive biostromal limestones and bioclastic dolostones up to 500 m thick, which overlie Sombre and Arnica formations. Headless Formation, up to 60 m of thin bedded argillaceous and bioclastic limestone interbedded with calcareous shale. That records a major drowning of the Landry Platform prior to offlap of the Nahanni Platform. Nahanni Formation is composed of between 10 and 137 m of platformal dolomitic limestone and crystalline limestone

The Manetoe Facies, or Manetoe Dolomite, is a generally stratiform diagenetic white, sparry dolomite, commonly 50 metres that replaces pre-existing limestones of the Landry, Headless and Nahanni formations in the area between 122^{o} to 127^{o}W longitude and 59.75^{o} to 63^{o} N latitude. Although originally mapped as Manetoe Formation, stratigraphic unit (Douglas and Norris, 1960; 1977a; 1977b; 1977c) is now interpreted as a diagenetic facies (Williams, 1981; Morrow and Cook, 1987) that is like the Presqu'ile Dolomite found at Pine Point. In some places the dolomite masses are hundreds of metres thick, where they form plumes and sinks into the Devonian stratigraphic succession (Morrow et al., 1990). Manetoe Dolomite is the primary reservoir in several gas fields the Liard Plateau (see below).

Aulstead et al. (1988) and Morrow et al. (1990) have argued for a Late Devonian-Carboniferous two-stage origin, where the diagenetic event precedes deep burial of the Landry and Nahanni carbonates. This is consistent with observations that dolomite precipitated before petroleum, as indicated by pore-lining bitumen that tends to occur in the gas fields within the upper 50 m of the Nahanni Formation. They suggest that excavation of a laterally extensive cavern system was caused by subaerial exposure and an active Watt Mountain aquifer during Early to Middle Devonian time. Subsequent hydrothermal dolomitization by superheated hypersaline Elk Point brines occurred throughout cavern system in Middle to Late Devonian time. Deep Upper Devonian to Cretaceous burial resulted in the generation and migration of petroleum in the overlying siliciclastics, possibly during Paleozoic time (Potter et al., 1993) and that this petroleum move down section the Manetoe Dolomite reservoirs. Reimer (1994) proposes that reservoir and petroleum alteration were simultaneous, with impacts on the paragenesis and absolute of the dolomitization.

Nahanni Formation is overlain by up to 36 m of bituminous shales of the Muskwa Member Horn River Formation. Conformably overlying Muskwa Member is Besa River Formation, shale up to 2,256 m thick. To the east the lower Besa River shales are correlative to Fort Simpson Formation, up to 500 m of greenish-grey calcareous, silty shales that are overlain by Tetcho and Kotcho formations, composed of 75 m of silty, fine-grained limestone and 30 m of generally greenish-grey and shaly limestone of the Kotcho Formation.

8.3.4 Carboniferous

Conformably overlying Besa River Kotcho formations are is e 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 Ekshaw, predominantly shale, and Etanda, predominantly shale, with lesser siltstones and sandstones formations, up to 425 m thick. These shales pass eastward and northward into Yohin Formation, thick silty sandstones and sandy siltstones up to 157 m thick. Yohin Formation is conformably overlain by Clausen Formation approximately 150 to 200 metres of black shale interbedded with siltstones. Conformably overlying are up to 900 m carbonates or up to 800 m thick cherts known respectively as Flett Formation and Prophet Formation. Prophet Formation cherts pass laterally into the upper Etanda Formation shales. Mattson Formation, up to 1450 m of predominantly sandstone and shales conformably overlies the Flett, Prophet and Etanda formations. Mattson Formation is composed of a lower sandstone with poor reservoir characteristics, approximately 125 m thick, and a bituminous shale, approximately 60 m thick, overlain by a middle quartzose sandstone member with good reservoir characteristics and an upper calcareous sandstone member with poor reservoir characteristics. This unit subcrops below younger units providing a major stratigraphic opportunity for petroleum entrapment (Richards, 1989; 1983).

8.3.5 Permian And Triassic

Unconformably overlying Carboniferous succession are Lower Permian Kindle Formation, interbedded calcareous silty shale, dolomitic sandy siltstone and silty limestone approximately 90 m thick. It is unconformably overlain by Upper Permian Fantasque Formation cherts, up to 55 m thick. Fantasque Formation is composed of thin laminations to thick beds of chert beds interbedded with thin shales. The formation commonly is composed of approximately 10 m of calcareous cherty sandstone at its top. Triassic Toad, Grayling and Liard formations, composed of shale, siltstone, argillaceous limestone and fine-grained argillaceous sandstone of variable thickness unconformably overlies Permian successions in the south of the Liard Plateau (Gibson and Edwards, 1990).

8.3.6 Cretaceous

Basal Cretaceous rocks are coarse cherty conglomerates to fine-grained sandstones of the Chinkeh Formation (Leckie et al, 1991), previously called the lower member of the Bucking horse Formation. Up to 32 m of thick it unconformably overlies older successions and is composed of fining upward. It is correlative to the Cadomin and Martin House formations. Garbutt Formation, silty glauconitic limestone argillaceous and concretionary siltstones and dark fissile shales between 290 m and 750 m conformably overlie it. Lower Cretaceous Scatter Formation composed of three members gradationally overlies the Garbutt Formation (Stott, 1982). These are, the basal Bullwell Member, thick resistant glauconitic sandstone; the middle Wildhorn Member, silty concretionary marine mudstone; and, the upper Tussock Member, silty glauconitic sandstone and silty mudstone. The Scatter Formation is between 60 and 375 m thick and passes into shales along the Kotaneelee River. Conformably overlying Lower Cretaceous Lepine Formation silty concretionary mudstone and black fissile marine shale contains a basal radioactive shale marker. The Lepine is up to 250 m thick, but thins to north and east. Conformably overlying the Lepine is the Lower Cretaceous Sikanni Formation, fine-grained marine sandstone and argillaceous siltstone and shale up to 250 m thick. It is conformably overlain by Lower Cretaceous Sully Formation marine, concretionary siltstone and black shale up to 300 m thick (Stott, 1960). The Lower Cretaceous succession is conformably overlain by Upper Cretaceous Dunvegan Formation, predominantly marine and non-marine sandstones with coal, that is up to 350 m thick. Upper Cretaceous Kotaneelee Formation, concretionary marine shale with rare sandstone and conglomerate up to 300 m thick conformably overlies Dunvegan sandstones. In some areas erosional remnants, up to 40 thick of friable Upper Cretaceous Wapati Formation medium- to coarse-grained sandstone and conglomerate with bentonites and coals are preserved. Near Larson Lake small alkaline stocks and dykes intrude the Cretaceous succession locally.

8.3.7 Structure

Rocky Mountain Fold and Thrust Belt structures formed within an easterly-tapering sedimentary rock wedge that is composed predominantly of a Paleozoic miogeocline and platform on the Paleo-Pacific margin of North America that was overlain by deposits of the Cordilleran Foreland Basin, which preserves the record of the closure of the Paleo-Pacific margin and the accretion of allocthonous terrains to the North American craton (Gabrielse and Yorath, 1990). Several tectono-stratigraphic packages make up this succession, with marked changes along the length of the Paleo-continental margin. The structural style is profoundly affected by variations in lithological composition of the stratigraphic succession that control the mechanical stratigraphy and the style of structure elements. Thick, competent carbonate coarse clastic successions are strong layers that favour discrete detachments and thick thrust sheets. Interlayered shales and sandstones, or thick fine-grained clastic successions favoured a more penetrative strain characterized by numerous detachments and folding. In the Liard Region and environs the essential mechanical stratigraphy is controlled by deep, thick, thrust faulted

Proterozoic to Middle Devonian Carbonate and Clastic successions, including the main reservoir horizons. These are overlain by thick, predominantly finer grained and interlayered clastic successions that characterize the post-Nahanni Formation succession, even though that succession contains major interregional unconformities, particularly between the miogeoclinal and foreland successions Folds formed above a regional detachment in a thick Upper Devonian and Carboniferous Besa River Formation shale succession. Large amplitude, folds, often with multiple hinges and straight limb segments (i.e. chevron and box folds) characterizes the Upper Paleozoic and Mesozoic strata where those strata crop out. Underlying Middle Devonian and older carbonate successions are deformed in the thick thrust sheets and associated folding that provide the primary trap.

An example of a major structural prospect is illustrated in Figure 8.3, from National Energy Board of Canada, 1995. The section runs through the Kotaneelee field and shows that the structures and structural elements of the region are not unlike those found elsewhere in the elsewhere in the Foreland Belt, considering the mechanical stratigraphy.

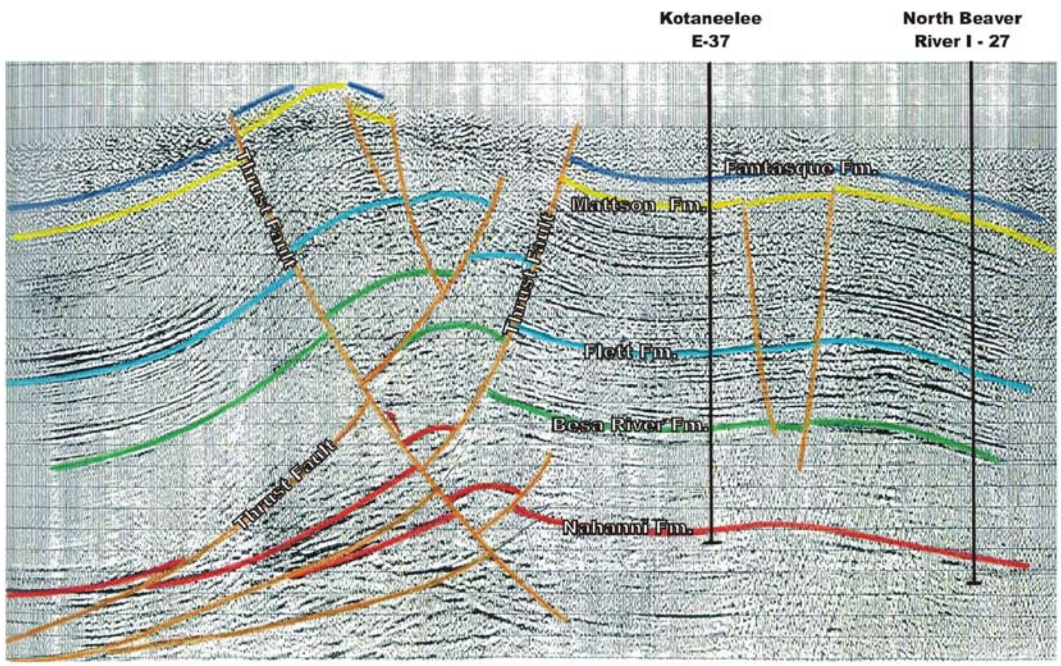

Figure 8.3: Seismic structure section from Kotaneelee Field showing the style of deformation and the compartmentalization of the reservoir by faulting (from National Energy Board of Canada, 1995). Major structures and time-stratigraphic markers, as interpreted by National Energy Board staff (ibid.) are annotated. The seismic line is Columbia oil and Gas's 1978 seismic line AAV-005.

Structures within the Liard segment of the Cordilleran Foreland are characterized by predominantly northerly and northeasterly trending elongated folds, thrust faults and associated structural elements with predominant, but not exclusive, foreland sense of vergence. Topography is closely related to structure and level of erosion. Resistant Permian and older strata form topographic highs that protrude through the Cretaceous and Triassic successions on the flanks major thrust fault anticlines as illustrated in Figure 8.1. Outcrops of younger Triassic and Cretaceous strata floor the keels of synclinoria that are also topographically low regions (Figure 8.1). Many of the largest prospects are identifiable from the bedrock geological or even topographic map. However, the structure is more complicated and even parts of regional synclinoria may be underlain by smaller structural culminations that are prospective.

8.4 Petroleum Systems

The established petroleum production and shows indicates that there is an effective petroleum system operating within the area. Potential petroleum source rocks are know or may be inferred to occur within a number of the black shale formations of the region including:

- Middle Devonian Funeral and Headless formations,
- Upper Devonian Besa River, Fort Simpson, and Kotcho formations,
- Carboniferous Ekshaw and Etanda formations,
- Triassic Toad and Grayling formations and
- Lower Cretaceous Garbutt Formation.

Potential Devonian petroleum source rocks contain total organic carbon (TOC) values between 1 to 4% and are composed of Type II marine kerogen (Potter et al, 1993). Ekshaw and Etanda potential source rocks contain 1 to 3% TOC and are composed of Type I and II kerogen mixtures. Mattson source rocks contain TOC values up to 10%, but average about 5%, and are composed primarily of Type II and III kerogen mixtures. Source rocks are also identified in the Triassic Toad-Grayling and the Lower Cretaceous Garbutt Formation (Leckie et al., 1991). Cretaceous potential source rock TOC content varies between 1.4% and 5% with Hydrogen Indices between 150 and 300, suggesting a Type III or mixed Type II and III kerogen.

Thermal maturity varies considerable throughout the succession. In general thermal maturity increases with stratigraphic age. Devonian petroleum source rocks have vitrinite reflectance values, 1.6 to 4.6%VRo, and are currently in the dry gas to overmature zone (Potter et al, 1993). Ekshaw thermal maturity varies from 1.2 to 1.5%VRo, indicating thermal maturities from the end of the oil window into the wet gas zone (Potter et al, 1993). Mattson Formation sources have thermal maturities between 0.84 and 1.0%VRo and have the potential to generate wet gas (Potter et al., 1993). Most of the study area's Cretaceous section is in the oil window. Maturation models suggest a Late Devonian heating event and the generation of liquid hydrocarbons during the Late Paleozoic to Early Mesozoic interval (Potter et al, 1993). Devonian Manetoe facies reservoirs often contain pore coating bitumen that is attributed to this early hydrocarbon generation interval. Thus, the gas in Manetoe reservoirs has been attributed to catagenesis of oil in overlying Besa River Shale, when the reservoir entered the gas window approximately 280 million years ago (Morrow et al., 1991; Potter et al., 1993).

While all of these events are well documented by authoritative study it conflicts generally with the inferred history of petroleum systems elsewhere in the Cordilleran Foreland Belt. In general, Foreland Belt Laramide structural accumulations of petroleum are inferred to have been generated syntectonically in response to tectonic burial by the stacking and thickening inherent in overthrusting and folding, often from source rocks in the footwall succession. Certainly where ever liquids are found within the southern Foreland Belt their molecular and isotopic compositions show them to be derived from footwall sources (Geological Survey of Canada, unpublished data), while the alteration of isotopic compositions in drier gas fractions by process like thermochemical sulphate reduction prevent a complete and diagnostic analysis of the source of all gases. Within the Cordilleran Foreland the syntectonic generation of reservoir charge clearly operates from Wyoming to the southern end of the play considered in this study. Therefore the early gas generation model proposed for this play is a stark, but unresolved anomaly in the Foreland Belt. Fortunately, the large discovered reserve indicates that an effective petroleum system exists, regardless of our understanding of its function and history.

8.5 Exploration History

Prior to 1950 the Geological Survey of Canada made reconnaissance geological mapping studies of the Liard area (Kindle, 1944) and the Liard and La Biche ranges (Hage, 1945). 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. These early studies indicated a northward extension of the outcrop thrust-faulted culminations in the Liard Plateau, which were the focus of early exploratory efforts in the southern foothills. During the 1950's private petroleum corporations expanded northward from the late 1940's Foothills discoveries west of Calgary (Jumping Pound Field) and east of Pincher Creek (Pincher Creek Field). Much of the industrial effort of the 1950's focused on exploration for crude oil in both the Devonian reef plays of Alberta and the Williston Basin Carboniferous subcrop play in southeastern Saskatchewan and Manitoba. Although significant field geological and geophysical surveys were made it was only at the end with the end of the 1950's that drilling occurred and discoveries were made in the Liard Plateau.

In 1951 California Standard Oil (now Chevron) conducted reconnaissance fieldwork in the Liard region (Hovdebo, 1962; Rands Exploration Co., 1954). The same company returned each year between 1955 and 1957 to conduct additional reconnaissance fieldwork in the Liard Fold and Thrust Belt (ibid.). This corporate and government fieldwork led to the recognition of the Beaver River, Pointed Mountain, Kotaneelee and La Biche antiforms as potential hydrocarbon-bearing prospects. This resulted in the issuing of Territorial Petroleum and Natural Gas Permits 1468 to 1472 to California Standard Co. in the South Beaver River Area of the Liard Basin, on which geological fieldwork was performed in 1958 and 1959 (ibid). B.C. land permits on the Beaver River Anticline were issued to Pan American (Amoco). Also in 1958 a geophysical service company, GSI conducted a 48 kilometer long, experimental, 2 man portable reflection seismic survey over Blackstone Dome for California Standard. The result of that survey was inconclusive due to equipment and technical problems. During that time the Geological Survey of Canada completed it 1:250,000 mapping of quadrangles 95B and 95C (Douglas and Norris, 1959; Douglas, 1976, 1974). At about the same time a photogeological study of the Liard Fold and Thrust Belt was conducted by Atlantic Refining Co. (now PetroCanada) (Atlantic Refining Co., 1959).

In 1957, the first well in the Liard Fold and Thrust Belt region was spudded in British Columbia on the Beaver River Anticline, a structure with a 51 km long hinge. In 1959 gas was discovered on the Beaver River Anticline in that well, the Pan American A-1 Beaver River b-63-K well (United Geophysical Co., 1962; 1961). The well was officially completed in 1961, hence the sometimes-variable discovery date. The well had blowouts of gas in the Carboniferous Prophet and Devonian Besa River formations and discovered gas in the Devonian Nahanni Formation where it is diagenetically altered to Manetoe dolostone. The gas in the Besa River was encountered at 2,549 m Kb (8,363 ft.). When gas was encountered in the Carboniferous Prophet Formation at 2,597 m Kb (8,519 ft.) the well blew out.

In 1960, British Petroleum (now Talisman) conducted a geological survey of the Nahanni region in the Northwest Territories and portions of the Yukon Territory. In 1961 California Standard acquired 48 km of reflection, and refraction seismic data over Beavercrow anticline, a prominent structure now considered to lie near the western limits of the prospective region (California Standard Company, 1963), while Amoco acquired an 85.3 km reflection seismic survey in the Kotaneelee-Liard area. Pan Am (now Amoco) spudded the Pan Am et al Kotaneelee YT P-50 well on the Kotaneelee structural culmination in the Yukon. That well flowed gas in the Nahanni at an estimated 2.41 X $10^6 m^3/d$ AOF (.085 MMcf/d) and the well was complete as a gas well. The well, was completed September 23, 1963 confirmed the extension of the Manetoe facies play into the Yukon Territory. Gas was encountered in the Nahanni Formation l. The Pan Am A-1 Mattson Creek No. 1 well in the Northwest Territories tested the Mattson Anticline. The well was positioned using both surface geology and air photo interpretation on the flat crest of a "box" fold with multiple steeply dipping limbs. It was spudded in 1961 in

Devonian Besa River Shale and penetrated the target Middle Devonian carbonate at only 507 m depth. A drill stem test of Manetoe facies dolomite recovered only gas-cut salt water, but it conceptually extended the play 120 km northeast on trend.

The Beavercrow Anticline, with a 24 km long hinge, was the next structure to be tested. In 1962 Calstan spudded the SOBC Shell Beavercrow YT K-02 well which was completed January 11, 1963, after penetrating the lower Mattson (clastics) and Ronning formations without encountering significant shows (California Standard Company, 1963; Hovdebo, 1962). In 1963 Canada Southern spudded the Canada Southern et al N. Beaver River YT I-27 well. Gas was encountered in the Nahanni Formation Manetoe dolostone and it was completed as a Nahanni gas well August 29, 1964. During this time Western Decalta Petroleum Ltd. conducted a photogeological study of the La Biche River Area in both the Yukon and Northwest territories (Lipsig, 1960) and Amoco conducted a reflection seismic study in the Mount Martin area (United Geophysical Ltd., 1964; Frontier Geophysical Ltd., 1964) and the La Biche area (Western Geophysical Ltd., 1967), as well as conducting geologic field surveys in the Beaver River area (Larsen, 1969). Canadian Homestead Oils carried out a geological study of the Beaver River area in the vicinity of the SOBC Shell Beavercrow YT well in 1967.

In 1969 Pan Am spudded the Pan Am Shell Merrill YT L-60 well. The well was completed March 6, 1969 having penetrated Devonian strata. The well flowed gas-cut brackish sulfurous water from the Manetoe facies of the Nahanni Formation without encountering significant petroleum shows. The La Biche structure that straddles the Yukon and Northwest Territories boundary lies on the northern end of the Merrill structural trend (Ponderay Exploration Ltd., 1970a; 1970b; Western Decalta Petroleum Ltd., 1963). The La Biche structure was tested by the Canadian Pacific (PanCanadian) La Biche K-08 well, which successfully tested gas from Middle Devonian dolostone reservoir.

Development drilling occurred in the Beaver River field in British Columbia and the Pointed Mountain field in the Northwest Territories between 1962 and 1968 (Tudisco, 1971; Brady, 1969; 1968; Ferguson, 1968). In 1969, Pan American (Amoco) returned to the Kotaneelee Anticline to develop the field discovered by the Beaver River G-01 drilled on the north end of the structure. The 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 Pan American (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 Pan Am 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 X $10^6 m^3$ (183 BCF) [218 X $10^6 m^3$ (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 X $10^6 m^3/d$ (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.

Texaco conducted a seismic and gravity survey (66.0 km) in 1970 over both the Beaver River and François Anticlines (Texaco Exploration Canada Ltd., 1972; 1970). June 1, 1970 Gulf completed the Gulf et al Beavercrow YT O-15 the well in the Besa River shales at 1,727.3 m, prior to reaching the Middle Devonian carbonate, because of drilling problems, without encountering significant shows. The same year Pan Am spudded the Pan Am Beaver River YT G-01 well, a step-out development well on trend of the Beaver River gas field that was discovered in 1959 in British Columbia. The YT G-01 well was completed August 20, 1970 tested Devonian age targets. In 1971 Bluemount spudded the Bluemount et al Beavercrow YT B-16 well. The well was completed May 9, 1971. It also tested Devonian targets, but without encountering significant petroleum shows.

Fort Norman Exploration Inc. and Cessland Corporation undertook and completed a geological evaluation of exploration permits in the Liard River and Mackenzie Mountains areas of the NWT and YT evaluate potential options on leases held by Augdome Corporation Limited and Resolute Petroleums. (Beaver Geophysical Services Ltd., 1974), while Mobil Oil Canada Ltd. conducted a field study of the Mattson Sandstone in the Liard Area, Yukon Territory (Van Elsberg, 1973) and Atlantic Richfield conducted a stratigraphic study of Liard Basin Lower Cretaceous Sandstones. In 1972: Beaver Geophysical Services acquired a seismic survey for Cessland Corporation Limited near Larson Lake in the Liard Basin (60° to 60°10'N; 125°22'30" to 125°15'W) and Atlantic Richfield conducted a geological field survey. At this time Texaco conducted a seismic survey over the François Anticline, in the region of 59°55' to 60°10'N; 123°45' to 124°22'30"W and Canadian Superior, Petrofina and Hudson’s Bay Oil and Gas conducted a joint seismic and gravity survey over the south La Biche anticline in the vicinity of 60°10'N 124°40'W (Canadian Superior Oil and Gas Ltd., 1972al 1972b), While Amoco and United Canso conducted seismic surveys in the La Biche area (Western Geophysical, 1972) and the Beaver River areas (Comer and Wilson Ltd., 1972), respectively.

Near Jackpine Lake in the Liard Basin Beaver Geophysical Services conducted a seismic survey for Fort Norman Explorations Inc. (Beaver Geophysical Services Ltd., 1974), in 1974, and for Pan Mackenzie Petroleums Limited near Fantasque Lake. The same year Beaver Geophysical Services also made seismic surveys for Pan Mackenzie Petroleums Limited near Gold Pay Creek and for Pan Mackenzie Petroleums Limited near Jackpine Lake. In 1977 Columbia Gas spudded the Columbia Gas et al Beavercrow YT O-15 well. The well encountered significant shows of gas in the Nahanni formation and it was completed October 21, The following year Columbia Gas spudded the Columbia Gas et al Kotaneelee YT E-37 well. The well encountered significant shows gas in the Manetoe dolostone was completed December 5, 1978. The next year Columbia Gas spudded the Columbia Gas et al Kotaneelee YT M-17 well to test the Manetoe Dolostone. The well was completed February 26, 1979 as a water disposal well in the Mattson Formation.

The Columbia Gas well Columbia et al Kotaneelee YT I-48 well was completed November 4, 1980 after encountering significant gas shows in the Arnica Formation, Manetoe dolostones. Canterra Energy conducted a seismic survey in 1983 in the Liard Area (Veezay Geodata, 1982). In 1987, Mayan Adventures Inc (the revised corporate name of Beaver River Resources Ltd.) applied for the rights to the Mattson and Nahanni zones in the abandoned Beaver River field in British Columbia. They were granted a special disposition drill within the abandoned field, and should they complete a producing gas well within three years be converted into a regular lease. In early 1989, Mayan Adventures Inc. re-entered the b-19-K/94-N-16 well that lies 5 km south of the Yukon boundary. The well was re-completed as a Nahanni gas well and it well tested gas at up to 0.34 X $10^6 m^3/d$ (12 MMcf/d) with a calculated potential of 2.23 X $10^6 m^3/d$ AOF (79 MMcf/d). In January 1990, the well was placed on production at an initial rate of 0.20 X $10^6 m^3/d$ (7 MMcf/d) with little water production, but by September 1990; gas rates had decreased to 0.01 X $10^6 m^3/d$ (0.44 MMcf/d) with 43 m3/d (270 bbl/d) of water. 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 into a Mattson Formation water disposal well. The company has since recompleted an additional Nahanni well. In the first two years after the re-completions the field has produced an additional 1,133 X $10^6 m^3$ (4 BCF) of gas. New studies suggest that an additional 113,300 to 19,830 X $10^6 m^3$ (400 to 700 BCF) may be recoverable.

The successful re-completion of abandoned structures led to the re-evaluation of other fields and new structures. This has resulted in a renewed interest in the play and the drilling of the discoveries at the P-66A, K-29 and M-25 wells, all within Manetoe dolostones, which led to a renewed exploration interest in this region. The recent discovery at the Ranger P66A well and at the Chevron K-29 and M-25 wells with their very high initial absolute open flow (AOF) rates bear strong similarities to the early discovery wells at the Beaver River, Pointed Mountain and Kotaneelee Gas Fields. Also important to the exploration history is the continued development of the Carboniferous clastic reservoirs in the Mattson and "Banff" formations. The D-073-K-094-N-16 well discovered the Beaver River Mattson "A" pool, with an initial in-place raw gas reserve of 56 million cubic metres in 1959 (officially 1961). In 1974, the C-054-K-094-N-16 discovered the Beaver River Banff "A" pool, with an initial in-place raw gas reserve of 28 million cubic metres. A recent significant discovery gas reserves was made in the Mattson Formation at the Paramount et al. Liard F-36 well. The structure at the Paramount discovery is upright subsurface folds related to the development of the Bovie Thrust Fault near Fort Liard. This new discovery strongly supports the existence of gas in Mattson deltaic and shoreface sandstones elsewhere within the Liard Plateau.

8.6 Petroleum Occurrences

8.6.1 Discovered reserves

There are seven discovered gas fields discovered in Laramide antiformal structures of the Liard Plateau. The sizes and discovery dates of these seven gas fields are listed in Table 8.1 and shown in Figure 8.3. The Canadian Gas Potential Committee did not include the Liard and Bovie Lake fields in their 2002 assessment of the play (Procter and Newson, 2002), but we are of the opinion that a consideration of the impact of the more recent activities, properly credited back to the initial discovery dates provides important constraints and insights into the potential that outweighs the uncertainties in their estimated sizes. For both of these fields the size has been estimated following the announcement of more recent discoveries. These estimates may be incorrect, but they are a reasonable consensus from some companies operating in the play. The date of the Liard Field discovery is adjusted to that of the first well that showed petroleum on the structure more recently developed and for which a revised possible reserve estimate is between 8.5-14.2 $X10^9$ m^3 (300-500 BCF). The estimated total initial in-place gas reserve is between 51.1-65.3 $X10^9$ m^3 (1805 and 2305 BCF) considering the uncertainties in the size of the Liard field. Most of the reserves occur within the Devonian Manetoe dolostones and Carboniferous Mattson Formation clastics. In general, our discovered gas reserve estimate is like that of the Canadian Gas Potential Committee, but with the addition of the Liard and Bovie Lake fields.

Table 8.1. Gas field size and discovery year (see Figure 8.4).

Disc.Date	Field Size (bcf)	Field Name
1967	640	Pointed Mountain
1961	615	Beaver River
1964	450	Kotaneelee
1986	300 to 500	Liard
1970	83	Labiche
1988	9	Crow River
1967	8	Bovie Lake

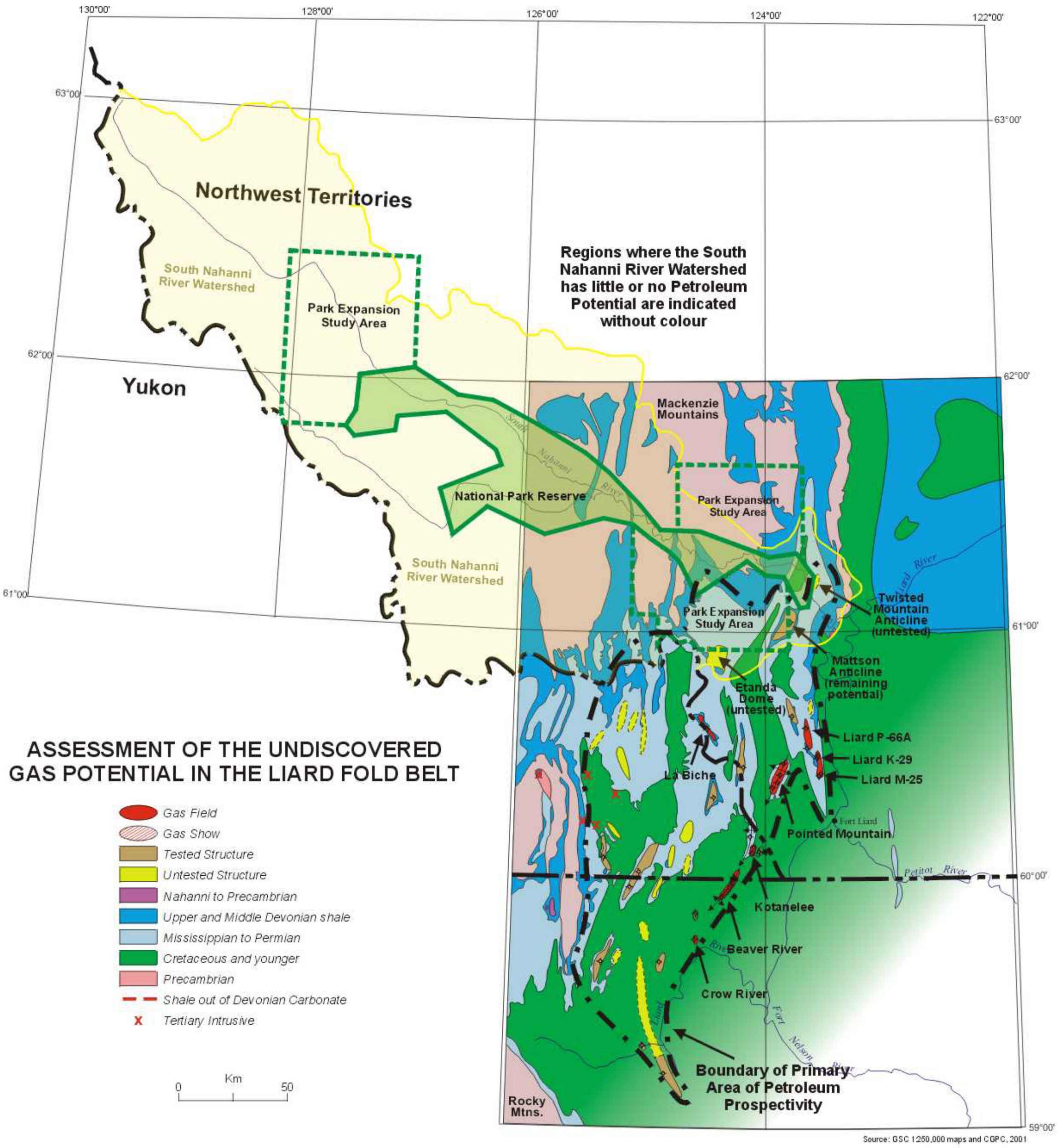

Figure 8.4: Discovered major gas fields of the Liard Plateau as described in Table 8.1 (After Procter and Newson).

8.6.2 Petroleum shows

Petroleum reserves and shows have been identified in six different stratigraphic units including:

- Gas reserves in accumulations of in Manetoe "Facies" Dolostones;
- Gas shows in fractured Devonian Besa River Formation shales (Muskwa);
- Gas shows in Carboniferous Prophet-Flett/Debolt succession carbonates;
- Gas reserves in Permo-Carboniferous Mattson Formation clastics;
- Gas shows in Permian Fantasque Formation cherts; and
- Gas and oil shows in Cretaceous Chinkeh Formation clastics.

__*Devonian Manetoe Dolostones*__

In the Beaver River, Kotaneelee, Pointed Mountain and Liard gas fields sour natural gas occurs in the Lower to Middle Devonian Arnica, Landry, Headless and Nahanni Formations where these units consist predominantly of Manetoe "facies" hydrothermal dolomite. Manetoe dolostones are the digenetic product of the hydrothermal dolomitization of limestones of the Nahanni and Headless formations in the Liard region. Accumulations occur within Laramide thrust faulted antiformal culminations. Dolomitization must have occurred for the reservoir to be productive. The diagentically altered reservoir matrix is characterized by vugs in a low porosity and permeability dolostone. Very high initial flow rates from some wells is due to a highly transmissive open fracture network that may be augment by a regional or natural fracture system that provides storage which may account for several percent of the total rock volume. Fracturing associated with the deformation increases and improves both the matrix porosity, commonly <3%, and permeability, <5 md to economically recoverable levels. The average density of unfilled or partially filled fractures is about 10 to 20 m/m2, but high fracture densities sometimes occur only over metres to tens of metres in a reservoir succession several hundred metres thick (Jamison and Graham, 2002). The same fractures that provide for the producibility of the reservoir also provide pathways for water invasion that has reduced the recovery factor in some wells. Reservoir fractures also increase the opportunity for formation damage by mud invasion during drilling. These factors impact the results of tests and recoverable reserves for petroleum in Manetoe reservoirs.

The discovery of the Beaver River Nahanni gas accumulation by the D-073-K-094-N-16 well in 1959 (official rig release 1961) established the Laramide structural play in the Liard Basin. Prior to 1992 the discovery of 10 accumulations with an initial in-place raw gas reserve of 33,820 X $10^6 m^3$, were identified. There are 12 pools in 7 fields with discovered resources exceeding the 44,080 X $10^6 m^3$ (1.56 TCF) of gas in-place (GIP) or 13,963 X $10^6 m^3$ (495 BCF) of marketable gas (IMG) reported by the National Energy Board of Canada (National Energy Board of Canada, 1993). Discovered marketable accumulation sizes range from 52 X $10^6 m^3$ (1.84 BCF) to 6,083 X $10^6 m^3$ (4,501 BCF) with a mean recoverable accumulation size of 1,163 X $10^6 m^3$ (41 BCF) (ibid.). These pools were used by the Geological Survey of Canada in its assessment of the Beaver River Devonian Play (C4729205; in Stockmal et al., 2001). Discoveries of large gas reserves in the Manetoe Dolostones within the Liard Basin in 1999 led to a renewed exploration interest in this region. The discoveries at the P-66A, K-29 and M-25 wells, all occur within Manetoe Dolostones. The recent discovery at the Ranger P66A well and at the Chevron K-29 and M-25 wells with their very high initial absolute open flow (AOF) rates bear strong similarities to the early discovery wells at the Beaver River, Pointed Mountain and Kotaneelee Gas Fields. In all these older fields high initial production rates were followed by rapid decline and water invasion of the reservoirs.

Devonian Besa River Shales

Wells in the Beaver River field tested sour gas from Besa River Formation shales at rates of up to 0.10 X $10^6 m^3/d$ (3.6 MMcf/d), without water. These flow rates declined quickly indicating a limited reservoir controlled by fracture porosity. Gas in this interval is 96 to 98% methane with 1 to 2% H2S. The Besa River Formation shales provide the top seal to Manetoe dolostone accumulations, making it common to expect natural gas in this unit where open fractures associated with the Laramide deformation provide storage. Whether commercial production could be effectively established in such accumulations remains to be shown.

Carboniferous Prophet and Flett/Debolt Formations Carbonates

Sweet dry gas occurs in the within Carboniferous shelf carbonate of the Prophet and Flett/Debolt in thrust faulted and folded Laramide structural culminations formations. Carboniferous Prophet gas was discovered with the drilling of the Beaver River Field in B.C. The Pan Am A-1 Beaver River well blew out of control in this zone at 2,597 m (8,519 ft.). This sweet gas, 98% Methane, occurred in an 18 m (60 ft.) zone and it flowed at 0.10 X $10^6 m^3/d$ (3.5 MMcf/d). Like other plays in this region fractures are important for both storage and producibility, although no reserves are currently attributed to this interval.

Permo-Carboniferous Mattson and "Banff" Formation Clastics

Sweet slightly sour gas and minor condensate occur within Permo-Carboniferous Mattson Formation clastics and adjacent stratigraphic units. Erosional truncation of the Mattson sands, which filled Liard Basin beneath Permian and Cretaceous strata, may have formed stratigraphic plays in northeast British Columbia. Upright subsurface folds related to the development of the Bovie Thrust Fault form a structural trap for the gas field at the F-36 well near Fort Liard. The D-073-K-094-N-16 well discovered the Beaver River Mattson "A" pool, with an initial in-place raw gas reserve of 56 million cubic metres in 1961. In 1974, the C-054-K-094-N-16 discovered the Beaver River Banff "A" pool, with an initial in-place raw gas reserve of 28 million cubic metres. A recent significant discovery gas reserves was made in the Mattson Formation at the Paramount et al. Liard F-36 well, which strongly supports the existence of gas in Mattson deltaic and shoreface sandstones elsewhere. The discovery of gas in the Fantasque Formation at the Tattoo Gas Field in 1973 by the Aquitaine et al Tattoo a-78-L/94-O-10 well also indicates regional potential for petroleum accumulation in the Mattson Formation even though that discovery lies outside of the Liard Plateau.

Permian Fantasque Formation Cherts

Whereas gas in the Mattson appears to occupy primary porosity, other more brittle silicified units such as the overlying Fantasque may have fracture porosity for potential gas reservoirs during burial and deformation. Minor shows of dry sweet gas have been reported from Fantasque Formation cherts in gas logs from wells in the Beaver River within the study region and from the Tatto and Maxhamish Lake areas in northern British Columbia. Like the Besa River Formation shows these indications for sweet dry gas from the Permian Fantasque chert are inferred to be stored in fractures where the chert occurs in thrust faulted Laramide antiforms. The discovery of gas in the Fantasque Formation at the Tattoo Gas Field in 1973 by the Aquitaine et al Tattoo a-78-L/94-O-10 well indicated potential in the Permian Fantasque Formation and the Carboniferous Mattson Formation although this discovery was outside of the Liard Plateau. Sources for the gas are unknown but they may occur in either the underlying organic-rich Carboniferous Etanda Formation Shale or the overlying Triassic Toad-Grayling Formation.

Cretaceous Chinkeh Formation Clastics

Lower Cretaceous strata have reservoir potential. The most prospective Cretaceous succession lies below the organic-rich Lower Cretaceous Garbutt Shale, which with the Triassic Toad-Grayling may be a source for this petroleum. Sweet gas and light to medium gravity oil occur in Lower Cretaceous Chinkeh Formation fluvial and shallow marine clastics of the Fort St. John Group. Traps and potential traps are combined structural and stratigraphic. Gas was recovered, at a rate of 1,983 m3/d, during a drill stem test of this interval in the Bovie Lake M-05, N.W.T., well lying east of the main region under consideration. The only economically significant Cretaceous field within the Liard region the Maxhamish Chinkeh Formation gas accumulation that was discovered by the Arco 94-O-14/b-21-k Maxhamish well in B.C. That field has estimated gas in place of 8.5-11.3 X10^9 m^3 (300 and 400 BCF). The well also had a show of oil, in samples from these strata. Porosities range from 5 to 18% with permeabilities between 0.5 and 30 md.

8.6.3 Previous petroleum potential assessments

Both the National Energy Board of Canada and the Geological Survey of Canada assessed the region prior to 1999. In 2002 by the Canadian Potential Gas Committee revised these studies without including estimates of the most recent potential reserve additions and revisions resulting form the "new" discoveries made in 1999. All groups used different techniques and different input data sets, largely because of changes in reserve numbers with time. In 1992 the Geological Survey of Canada made an assessment of natural gas potential in the Foreland Belt of the Eastern Cordillera (i.e. the Foothills) (Stockmal et al., 2001). That assessment considered two Liard Fold and Thrust Belt Laramide structural plays:

- a mature Beaver River Devonian gas play (C4729205) primarily occurring in Manetoe dolostone gas accumulations, and;
- an immature Beaver River Carboniferous gas play (C4719205) primarily occurring in Mattson Formation clastic reservoirs.

That study assessed the potential of structural prospects in the two primary reservoir intervals, the Manetoe Dolostone and in the Carboniferous clastics. The results of that study are shown in Table 8.2. Note that the Geological Survey of Canada 1992 estimate attributes a potential comparable to that in the Manetoe Dolostone play to the Carboniferous (Mattson) clastic play. That study also predicted very large numbers of accumulations to be discovered within the play. The results of this analysis were strongly dependent on the estimates of discovered accumulations sizes, which subsequent exploration activities have revised, as detailed below.

Table 8.2. GSC 1992 estimate of Liard Fold and Thrust Belt Undiscovered Petroleum Potential in the complete region (1992)

Play Name (GSC estimate for complete region, 1992)	Discovered 106m3 (Bcf)	Expected 106m3 (Bcf)	Total Resource 106m3 (Bcf)	Number Discovered 106m3 (Bcf)	Total # accumulations 106m3 (Bcf)	Number of undiscovered accumulations 106m3 (Bcf)
Beaver River Devonian (gas) (C4729205)	33,820	102,750	136,570	10	400	390
Beaver River Carboniferous (gas) (C4719205)	84	117,966	118,050	2	327	325
Sum	33,904	220,716	254,620	12	727	715

The National Energy Board performed two assessments of the Liard Fold and Thrust Belt plays. The first, in 1995, assessed the potential within Yukon portions of the Liard Plateau. In that study the National Energy Board of Canada identified one established and six immature gas and oil plays:

- the established Manetoe Dolomite gas play;
- the immature Devonian Besa River Shale (Muskwa) fractures shale gas play;
- the immature Carboniferous Prophet-Flett carbonate gas play;
- the immature Permo-Carboniferous Mattson clastics gas play;
- the immature Permian Fantasque chert fractured gas play;
- the immature Cretaceous Chinkeh clastics gas and oil plays.

The National Energy Board of Canada study estimated pool resources within individual stratigraphically defined plays. In that study the study considered a very large Manetoe Dolostone play area that included portions of the Yukon west of the Beavercrow Anticline, a region generally not attributed significant potential. In a subsequent study the National Energy Board of Canada revised and significantly reduced the Manetoe Dolomite gas play area (National Energy Board of Canada, 1996). Following that reduction the undiscovered natural gas potential of Manetoe Dolomite play in the Liard Fold and Thrust Belt was recalculated to have an expected volume of 38,400 X 10^6m^3 (1360 BCF) in the combined play area in the Yukon, B.C. and N.W.T. In summary, the revision of the Manetoe play by the National Energy Board of Canada, considering more conventional play boundary definitions, suggested that there was slightly less potential in the entire play region than that originally attributed to the Yukon Territory alone. In both the National Energy Board of Canada studies the method used by that study does not allow for an estimate of pool or field size characteristics of the resource, still it is useful to summarize and compare their results with those of the subsequent 1992 Geological Survey of Canada study and that of the current estimate. The results of these two studies are shown in Table 8.3. Note that the greatest reserve and potential of the National Energy Board of Canada studies occurs preponderantly in the Manetoe Dolostone structural play. This contrasts with the Geological Survey of Canada 1992 study with apportioned comparable potentials to the Manetoe and Carboniferous clastic plays.

Table 8.3. Results of previous NEB studies of Liard Fold and Thrust Belt Undiscovered Petroleum Potential in the Yukon Territory only (1995) and in the complete region (1996)

Play Name (NEB estimate for Yukon portions, 1995)	Discovered 106m3 (Bcf)	Expected 106m3 (Bcf)	Total Resource 106m3 (Bcf)	Number Discovered	Total Number accumulation s	Number of undiscovered accumulations
Manetoe Dolostone (gas)	44,080 (1,560)	43,853 (1,548)	87,933 (3,108)	12	N/A	N/A
Immature Besa River fractured shale (gas)	0	5,436 (191.9)	5,436 (191.9)	0	N/A	N/A
Immature Prophet-Flett carbonate (gas)	0	2,167 (76.5)	2,167 (76.5)	0	N/A	N/A
Immature Mattson clastics (gas)	0	4,815.8 (170.0)	4,815.8 (170.0)	0	N/A	N/A
the immature Fantasque fractured chert (gas)	0	21.5 (0.76)	21.5 (0.76)	0	N/A	N/A
Immature Chinkeh clastics (gas)	0	35.1 (1.24)	35.1 (1.24)	0	N/A	N/A
Immature Chinkeh clastics and (oil in m3 and Bcf of natural gas equivalent)	0	0.238 (.0673)	0.238 (.0673)	0	N/A	N/A
Play Name (NEB estimate for complete region, 1995)	Discovered 106m3 (Bcf)	Expected 106m3 (Bcf)	Total Resource 106m3 (Bcf)	Number Discovered 106m3 (Bcf)	Total Number of accumulation s106m3 (Bcf)	Number of undiscovered accumulations 106m3 (Bcf)
Manetoe Dolostone (gas)	44,080 (1,560)	38,400 (1,360)	82480 (2,920)	12	N/A	N/A

Canadian Gas Potential Committee 2002 Estimate

The Canadian Gas Potential Committee uses a sequential sampling, or discovery history, method based on the Geological Survey of Canada's PETRIMES computer program that is similar to that which was employed by the Geological Survey of Canada's 1992 assessment of the Cordilleran Foreland Belt. Details of their report and estimate are proprietary, but general aspects of that study have been discussed (Procter and Newson, 2002). The CPGC study used publicly available reserve estimates for seventeen accumulations in five fields. They did not include the discoveries at Laird and Bovie fields in their study. Based on a circa 2000 discovery data set from 17 pools in five fields attributed an initial gas in place reserve of 79.9 $X10^9$ m^3 (2.8 TCF) the Canadian Gas Potential Committee estimated an undiscovered potential for 30 pools with an initial gas in place resource of 78.1 $X10^9$ m^3 (2.8 TCF). They estimated that this play contained a largest undiscovered field of 30.0 $X10^9$ m^3 (1.064 TCF).

Trends in Activity and Estimation

The primary trend in the development of identified accumulations is to increase both the size of previously discovered accumulations and the recovery from those accumulations (see above). Exploration continues to add new discoveries also adding to a growth in reserves. The impact of these changes on the estimation of undiscovered potential is complicated.

The early 1990's estimate of the Geological Survey of Canada employed 12 pools in two plays with a discovered reserve of 33.9 $X10^9$ m^3 (1.20 TCF) to infer that there would be an 715 additional discoveries in Devonian dolostone and Carboniferous clastic reservoirs with an expected potential of 220.7 $X10^9$ m^3 (7.77 TCF). The large undiscovered resource estimate of this play in the 1992 Geological Survey of Canada study was a result of a large number of undiscovered pools attributed to the play. The size of the largest undiscovered accumulation in the two Liard plays was estimated to have a median potential of 5.075 $X10^9$ m^3 (179 BCF), which was comparable to size of the largest undiscovered accumulation inferred from a much more mature discovery data set in the much more intensively explored and developed Jumping Pound Rundle Play that lies in the Foothills west of Calgary (Stockmal et al., 2001). There were several reasons for the large inferred number of undiscovered fields. First the play area is very large and very sparsely explored, when compared to that of other Foreland Belt anticlinal plays. This indicated much opportunity for undiscovered potential. Second, the play was very productive. The Liard play had the highest exploratory well success rate of all plays in the Foreland Belt and the rate of reserves additions per metre of wildcat exploratory well drilled was second only to the prolific Waterton Rundle anticlinal play of the southernmost foothills and significantly higher than that of the very mature Jumping Pound Rundle Play. Such optimistic estimates were, therefore, consistent with the relative ranking of all Foreland Belt plays, especially when the comparative rates of exploratory success and geographic exhaustion of play potential were considered (e.g. Figure 8.5).

The 1995 National Energy Board of Canada estimate used a similar input data set to the Geological Survey of Canada, with a revised discovered reserve of 44,080 $X10^9$ m^3 (1,560 TCF) to predict an undiscovered potential of 38,400 $X10^9$ m^3 (1,360 TCF) in an unspecified number of undiscovered accumulations, which was a limitation of the method they employed. In 2002 the Canadian Potential Gas Committee defined 17 pools in five fields attributed an initial gas in place reserve of 79.9 $X10^9$ m^3 (2.8 TCF) to predict an undiscovered potential of 78.1 $X10^9$ m^3 (2.8 TCF) in approximately 30 undiscovered pools, using a method similar to that first employed by the Geological Survey of Canada in the 1992 estimate. The Canadian Gas Potential Committee estimated that this play contained a largest undiscovered field of 30.0 $X10^9$ m^3 (1.064 TCF), which was almost 6 times larger than the largest undiscovered potential of the largest undiscovered accumulation predicted by 1992 Geological Survey of Canada analysis, in spite of the Canadian Gas Potential Committee's much smaller total resource potential and the growth of reserves through time. The Canadian Gas Potential Committee's estimate of the largest undiscovered pool sizes can more adequately accommodate the inferred size of the most recent reserve revisions and discoveries within the play than does the 1992 Geological Survey of Canada assessment.

The result of ten years of exploration and development clearly resulted in a significant decrease in both the estimated number of undiscovered accumulations and total play potential while significantly increasing the median size of the largest undiscovered accumulation. Therefore, it is clear that the variation, through time, of specific discovery

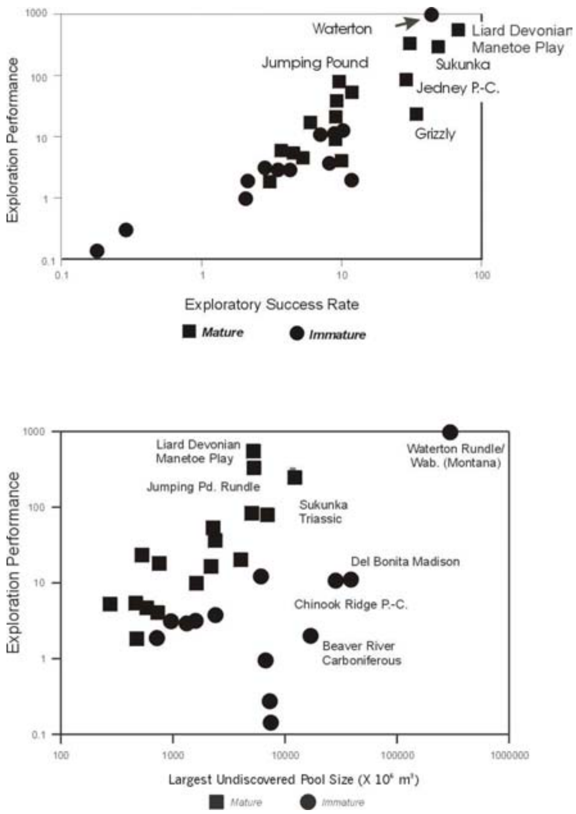

Figure 8.5: Illustration of the high rate of exploratory success and performance of the Liard Plateau gas play, compared to other gas plays in the Cordilleran Foreland Belt (from Stockmal et al., 2001). Figure 8.5A (top): A cross plot of the rate of new pool and new field wildcat success in mature and immature Cordilleran Foreland gas plays plotted against an indicator of exploration efficiency, "Exploratory Performance". This indicator is the ratio of the initial raw gas in place reserve in millions of metres, to the product of the average accumulation depth and the total number of exploration new pool and new field wildcat wells drilled to establish that reserve. The figure indicates that highest rate of exploratory success is in those plays within which the rate of reserves addition is most facile. Figure 8.5B (bottom): A cross plot of the largest remaining undiscovered accumulation size in mature and immature Foothills gas plays plotted against the same indicator of exploration efficiency, "Exploratory Performance", as defined above resulting from the earlier Geological Survey of Canada assessment (see text). Note significant potential attributed to the Liard Plateau Play.

history parameters for this play have a significant impact on the characterization of undiscovered play potential and the estimation of the size of the largest undiscovered accumulation and the number of undiscovered accumulations. In order to attempt to illustrate these uncertainties while providing the best possible constrained result this study undertakes to use an updated data set that considers accumulations not included in the Canadian Gas Potential Committee's study and by comparing the estimates of both sequential sampling and reservoir volume approaches to undiscovered petroleum assessment.

8.7 Petroleum Resource Assessment

Petroleum resource assessment predicts undiscovered petroleum accumulation characteristics using available data and knowledge. Knowledge of the mode and distribution of petroleum resources is essential for the development of public and corporate policies for the effective management, economic analysis, land-use planning and environmental impact assessment related to resource identification and development. Hence, petroleum assessment is important because decisions and action rely on sound estimates of undiscovered potential to characterize and rank exploration opportunities against the value of alternative uses. To address the demands from both government and industry, often with different goals, various petroleum assessment methods have been developed during the last thirty years. Several modern methods and models for describing the characteristics of hydrocarbon resources have been proposed.

8.7.1 Method

Assessment techniques address either "petroleum systems" or "plays". Two play-oriented methods are the "discovery process" and the "volumetric" models. The consideration of observed and inferred physical and material characteristics of undiscovered accumulations, or the volumetric approach, is used widely (White et al., 1975; Gehman et al., 1980; Lee and Wang, 1983; Baker et al, 1986; Crovelli, 1986; Brekke and Kalheim, 1996). The choice of method can depend on available geoscience data and exploration history. For example, discovery process assessments cannot predate exploration success. As a result, assessments predict undiscovered petroleum accumulations from a specific perspective.

In this study we employ and compare the predictions of two types of play-oriented petroleum assessment methods. First we employ the Geo-anchored method (Chen and Sinding-Larsen, 1999), a discovery process model based on the Successive Sampling model (Andreatta and Kaufman, 1986). Second, we conduct an independent assessment using a reservoir volume approach and the Multivariate Discovery Process model (Lee, 1999).

8.7.2 Petroleum systems analysis

Petroleum system assessments consider volumes of petroleum generated and proportions of petroleum entrapped (Dow and Magoon, 1994). The method requires either sufficient geological data or subjective inference to allow petroleum system identification and characterization, especially regarding secondary migration and entrapment efficiencies. Detailed studies of "classic" petroleum systems (Magoon and Dow, 1994; Dow, 1974) indicate significant uncertainties in petroleum systems definition and analysis (Burrus et al., 1996; Osadetz et al., 1992). Petroleum system assessments allow no inference of the size of undiscovered accumulations, precluding economic analysis of the predictions of the assessment.

8.7.3 Play-based assessments of petroleum potential

Play-based assessments are the probabilistic analysis of geological characteristics or exploration history data that allow prospects to be identified and discoveries to be made (Lee, 1999). Play-based assessment methods can provide undiscovered accumulation size information that is amenable to economic analysis (e.g. Reinson et al., 1993). There are two basic play-based approaches to petroleum assessment. If sufficient numbers of discoveries exist, then it is possible to use a sequential sampling, or discovery process, method that considers the size and sequence of discovered accumulations. The use of this method is very desirable since pools and fields are tangible assets that are among the best-described play features. Reservoir volume or "volumetric" play-oriented methods are used if there are either few or no discovered accumulations. Therefore the type of play-oriented method depends on differences in exploration history, as well as data availability. Where a lack of discoveries precludes the use of sequential sampling methods the volumetric methods can be employed regardless of whether discoveries have been made.

When discoveries exist there is a widely held, but illusory, belief that volumetric assessment is either more desirable or more reliable than discovery process assessment. This value held belief arises because the geological and geophysical observations considered by volumetric assessments are the same as those used to generate prospects and identify drilling locations. The ability to specify the variables required of a "sufficiently" precise and reliable volumetric assessment either occurs when there are sufficient discoveries to allow for a discovery process model, or when drilling results indicate prohibitively unfavourable exploratory risks. This illustrates a dilemma. Discovery process assessment is precluded until the play is established and the most critical decision, whether or not to pursue the play, has been taken. Volumetric assessment is of necessity the only play level method available to make the most critical exploration decision, that is whether to begin the play; yet, it commonly depends on extrapolation, inference and analogy, rather than observation.

Several discovery process models rely on the discovery history sequence and the characteristics of discovered accumulations. The methods differ in assumptions regarding the underlying accumulation size distribution, the bias exploration methods impart to the sampling process, and the methods employed to make statistical estimates (Lee and Gill, 1999). Many discovery process models estimate simultaneously the conditional accumulation size distribution and the number of accumulations (ibid.). The consideration of discovered accumulation characteristics and exploration history, the discovery process method, is used primarily by government agencies and academies (Kaufman et al., 1975; Lee and Wang, 1985; Lee, 1993a; Drew and Schuenemeyer, 1993; Chen, 1993; Lee, 1998). A few major oil companies also use the discovery process model (Arps and Roberts, 1958; Grace, 1988; Coustau et al., 1988; Chen et al. 1997).

A great strength of the discovery process models is the possibility of conducting historical vindication analyses on temporal subsets of the discovery history data set.

8.7.4 The Geo-anchored method

The Geo-anchored method is a discovery process model based on the Successive Sampling model of Andreatta and Kaufman (1986). The Geo-anchored method can be written in the following forms (Chen and Sinding-Larsen, 1999):

$$\hat{R} = \sum_{i=1}^{n} y_i \Bigg/ \left(1 - \exp\left\{-y_i \sum_{k=1}^{n} \frac{1}{\hat{R} - \sum_{l=0}^{k-1} y_l}\right\}\right)^{-1} \qquad y_0 = 0 \qquad (1)$$

and

$$\hat{N} = \sum_{i=1}^{n} 1 \Bigg/ \left(1 - \exp\left\{-y_i \sum_{k=1}^{n} \frac{1}{\hat{R} - \sum_{l=0}^{k-1} y_l}\right\}\right)^{-1} \qquad y_0 = 0 \qquad (2)$$

where $\hat{R}$ is the estimated play potential and $\hat{N}$ is the expected number of accumulations in the finite population. For more detailed discussion and generalization of the Geo-anchored method, refer to Chen and Sinding-Larsen (1999).

8.7.5 Historical vindication of sequential sampling assessment methods

An important feature of sequential sampling or discovery process resource assessments is their amenity to historical analysis and vindication of the prediction derived from the analysis of the total data set by a prediction made from a historical subset of the data set. The prediction derived from the use of a historically truncated data includes both the undiscovered accumulations of the total data set and the subset of discovered accumulations already discovered, but not considered in the input data set. If the truncated data set successfully predicts all of the discovered accumulations not used in the input data set then the residual unidentified resource can be confidently considered to represent the currently undiscovered potential.

Such a vindication is, where possible to calculate, an essential criterion for accepting a resource assessment. As important as it is to vindicate accumulation size and undiscovered resource potential, the use of historical vindication analysis also vindicates the estimate of the number of accumulations. **History and historical analysis shows that geoscientists habitually underestimate the number of accumulations, often significantly. That is certainly the case for the Liard Plateau.** Compare the number of accumulations estimated by the comparable pool based analysis of the Geological Survey of Canada 1992 study (727 pools) with that of the Canadian Potential Gas Committee 2002 study (30 pools). The estimate of the total number of accumulations is clearly an underlying source of the difference between these two studies. Because it is essential to this study to justify the estimated number of accumulations we present, as an example, the historical vindication of another thrust and fold belt anticlinal play to illustrated the manner in which the number of accumulations changes and how it affects the estimated resource potential as a function of play history.

Figure 8.6 illustrates an example of a well-behaved Foreland Belt play, the Jumping Pound Rundle Play, as it was analyzed in the 1992 Geological Survey of Canada Foreland Thrust and Fold Belt assessment (Lee, 1998). This play, in which the first discovery was made more than 80 years ago, should behave like the

Liard Structural Play, the latter of which has a much large play area but a higher rate of exploratory success, despite its isolated setting and difficult logistics (see above).

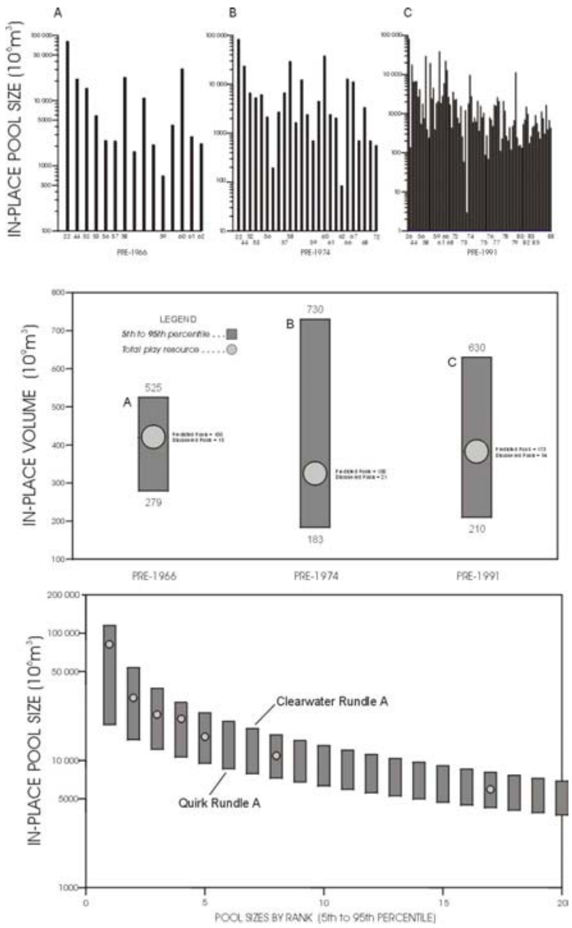

Figure 8.6: An illustration of historical analysis using the sequential sampling type of petroleum assessment model illustrated using the mature Jumping Pound Rundle Play. The 1966 data for that play is inferred to be a good analogue for the current exploratory state of the Liard Plateau. Figure 8.6A (top) shows the three different stages of the exploration history that were analyzed using a sequential sampling type of petroleum assessment. Figure 8.6B (center) indicates the resource predictions for the play potential and number of accumulations, both discovered and total for each of the three analyses. Figure 8.6C (bottom) illustrates the accumulation size by rank diagram. Discovered accumulations are predicted by the light coloured filled circles, while the size of accumulations predicted from the pre-1966 data set by the discovery process (i.e. sequential sampling) assessment are show by the dark filled boxes, which represent the 90% prediction interval for individual accumulations. The success of the earliest analysis at correctly predicting the size of large fields, Quirk Rundle A and Clearwater Rundle A, that were discovered subsequently, is discussed in the text.

The Jumping Pound Rundle Play has been analyzed at three different stages of its exploration history, 1966, 1974 and 1991 (Figure 8.6A). The three resulting petroleum resource estimates for the three discovery sequence subsets is shown in the middle diagram of Figure 8.6B) and a prediction of the range of discovered (circles) and undiscovered (boxes) accumulation sizes from the pre-1966 data set, conditioned against the discoveries at that time, is also illustrated (Figure 8.6C). This play lies immediately west of Calgary. Only 15 accumulations were discovered in this play between the first Rundle Group discovery and 1962. Still, from that data set, which is very comparable, in number of discoveries to the data set for the Liard Play, it was possible make a prediction of the total potential that was comparable to the total potential estimate in 1991 (Figure 8.6B), when 94 discoveries had been made after another three decades of exploration had elapsed in a region of easy access and logistics. More important is the observation that the pre-1966 dataset successfully predicts the Quirk Rundle A and Clearwater Rundle A pools (Figure 8.6C), the sixth and seventh largest accumulations in the play, which were not discovered until 1979 and 1974, respectively (Figure 8.6A).

The numbers of discovered accumulations and the number of predicted accumulations in each of the three calculations are, 15 and 100; 21 and 100; 94 and 173, respectively (Figure 8.6B). Through time the total number of predicted accumulations has increased through the addition of a number of accumulations of smaller size, without significant impact on the total resource potential, while the prediction of the largest accumulations has remained unchanged. Whether the Jumping Pound Rundle Play is a good analogue for the Liard Structure Play can be debated, but what cannot be debated is the efficacy of the discovery process method in predicting both play potential and number of accumulations from a small number of discoveries, early in the exploratory history of the play.

8.7.6 Reservoir volume methods

A second, independent assessment is obtained using a reservoir volumetric approach and the Multivariate Discovery Process model (Lee, 1999). If there are few or no discoveries it is necessary to assess undiscovered potential volumetrically. Where discovery process methods use discovered accumulation parameters as a biased sample of the accumulation size distribution, volumetric methods infer the accumulation size distribution using combinations of, observations, analogy and inference. Observed parameters include reservoir material and physical characteristics that incorporate well and seismic data, corrected for sampling biases, expressed as probability distributions, however, there are practical problems associated with the availability and comprehensiveness of required data. Typically the geoscience data is incomplete and observations must be augmented by extrapolations or supplemented by analogies and inferences. Geographically comprehensive seismic and well data sets, like those considered here, are not generally available. Aspects of prospect volumes, reservoir parameters and trap fill proportion must be estimated either from geographically limited data sets or appropriate analogues.

The volumetric method requires an independent estimation of the number of accumulations. This number is commonly formulated as the product of the total number of prospects, many of which must be inferred because of the geometry of the seismic grid, and the play and prospect level risks, both of which are commonly estimated subjectively in the absence of discoveries.

The Multivariate Discovery Process model also estimates simultaneously both oil and gas accumulation size distributions, but it cannot be applied to plays combining oil and associated gas accumulations with exclusively oil and gas accumulations, since the covariance between oil and gas accumulations may be diminished (Lee et al, 1999).

The volumetric method used in this study consists of a three-step procedure:

1. Estimation of the μ vector and covariance matrix of the reservoir volumetric parameters using the Multivariate Discovery Process model;
2. Estimation of oil and gas accumulation size distributions from unbiased reservoir parameters; and
3. Computation of the oil and gas potential distributions and construction of individual accumulation size by rank plots.

Using the reservoir engineering equation, the accumulation size can be expressed in the following form:

$$Z = C*A*T*\phi*S*G*HVF$$

where Z: accumulation size, A: accumulation closure area, T: net pay, ϕ: porosity, S: hydrocarbon saturation, G: trap geometric factor, HVF: reciprocal of hydrocarbon formation volume factor and C: a unit conversion factor. To incorporate the uncertainty in the accumulation size estimation, the six reservoir volumetric variables are expressed as random variables in the form of lognormal distribution. The accumulation size Z is then a lognormal random variable with a probability density function of:

$$f(z) = \frac{1}{\sqrt{2\pi}\sigma z}\exp\{-\frac{(\ln(z)-\mu)^2}{2\sigma^2}\} \qquad (4)$$

where

$$\mu = \ln(C) + \sum_{i=1}^{6}\ln(\mu_i)$$

$$\sigma^2 = \sum_{i=1}^{6}\sigma_i^2 + 2\sum_{i=1}^{6}\sum_{j=1}^{6}\sigma_{ij} \qquad i \neq j$$

and μ_i, σ_i^2, and σ_{ij} denote the mean, variance and covariance of the natural logarithms of the six volumetric variables. The play potential is the summation of all individual accumulation sizes, which can be written in the following form:

$$V = \sum_{k=1}^{N} Z_k \qquad (5)$$

where N denotes the total number of accumulations in the play.

<u>*Multivariate discovery process model:*</u> If the field size is expressed in the form of the reservoir engineering equation (eq. 3), the lognormal discovery process model becomes the Multivariate Discovery Process Model, which can be written in terms of a join density function:

(6)

$$\frac{N!}{(N-n)!}\prod_{j=1}^{n} f_{\theta}(z_j)E_{\theta}[\prod_{j=1}^{n}\frac{z_j}{b_j + z_{n+1} + \ldots + z_N}]$$

where $b_j = z_j + \ldots + z_n$; $z_{n+1}, \ldots, z_N$ (eq. 3)

denote the undiscovered accumulations, θ are the population parameters for the multivariate distribution, and N!/(N-n)! is the number of order samples of magnitude n without replacement from a population of N accumulations. $f(z_j)$ is the probability density function and can be of any probability distribution form. In this study, we use the lognormal distribution to approximate to the accumulation size distribution. Generally, each volumetric variable in eq. 3 may have an exponent to express its impact on the order of discovery. Details regarding the MDSCV model can be found in Lee (1998).

By using both and comparing these two methods we emulate a previous study in the Norwegian offshore that attempted to bridge the differences between assessment methods and to address the assessment confidence issue (Sinding-Larsen and Chen, 1996). This approach permits us to focus on the limitations of individual methods while increasing the credibility of an assessment by showing that the results of different methods are in agreement. Previous work studied the impact of correlation among reservoir parameters on the play potential and field size distribution and the need to correct sampling bias introduced by the exploration decision making process (ibid.).

This comparison of assessment techniques considers these two different approaches in an immature play. First, we assess oil and gas potential and associated petroleum accumulation size distributions using the Geo-anchored method, a specific discovery process model (Chen and Sinding-Larsen, 1999). The method calculates the total number of accumulations, the play potential and the accumulation size distribution. There are three major reasons for using the Geo-anchored method:

It is a non-parametric method independent of assumption regarding the accumulation size distribution, an unresolved topic (Schuenemeyer and Drew, 1983, Lee, 1993b).

Compared with other discovery process models (e.g. Lee and Gill, 1999), it yields reliable potential estimates and numbers of accumulations that consistently lie between results obtained using a lognormal discovery process model (Lee and Wang, 1985) and the United States Geological Survey (USGS) discovery process model (Drew and Schuenemeyer, 1993).

It estimates simultaneously both crude oil and natural gas potential and accumulation numbers. Traditionally Geological Survey of Canada (Geological Survey of Canada) assessments separate oil and gas accumulations into two independent plays.

The emulated study used combinations of exploration risk and numbers of prospects to determine numbers of accumulations. Instead, we use several estimates for the number of accumulations, 100, 50, 15, in the reservoir volume multivariate calculation. These various numbers are derived from various sources of data, including the expert opinions of industrial explorers and the number of accumulations estimated by the sequential sampling – geo-anchored analysis of the play.

8.7.7 Play definition

The Liard Fold and Thrust Belt structural gas play includes all gas fields and prospects that occur predominantly in Devonian and Carboniferous strata that are antiformally trapped in folded and faulted Laramide age diastrophic structures. This definition is essentially the same as the Canadian Potential Gas Committee's "LFP1 – Liard Fold Belt" play (Procter and Newson, 2002) and it is a field level treatment equivalent to the Geological Survey of Canada's 1992 two-pool based analyses. The play is bounded at its western limit by changes and facies and diagenesis that limit prospective reservoir development. On the north the play extends to the outcrops of Manetoe facies in the canyons of the South Nahanni River within the Nahanni National Park Reserve. On the east the play is bordered by the Kledo-Bovie Fault and to the south the Manetoe dolostones become unprospectively deep beneath a southward thickening Mesozoic succession at approximately 5910'. The play area extends across approximately 2 million hectares.

Two different major approaches have been applied to the assessment of the potential gas resource and the field size distribution. These methods include the Geo-anchored method and geologically constrained volumetric approaches, as discussed above.

8.7.8 Sequential sampling method (geo-anchored discovery history analysis)

Because the sample size is small, there are only seven fields occur in the discovery sequence, the discovery process model is sensitive to the change in sizes of individual fields. The input data for the Geo-anchored method is the discovery sequence in Table 8.1. The assessment assumes three possible sizes for the Liard gas field: 0.0 X10^9 m^3; 8.5 X10^9 m^3; 14.2 X10^9 m^3 (0, 300 and 500 BCF). Results are summarized in Table 8.4.

Table 8.4. Results from the Geo-anchored method (unit bcf). The distributions of total gas resource are conditioned on the seven discoveries.

Probability	5%	25%	50%	75%	95%	N	Mean
Liard=0	7766.5	5992.2	4752.2	3791.8	2586.4	116	5027
Liard=300	5619.3	5119.0	4819.5	4605.9	4216.9	128	5204
Liard=500	18688	17759	17084	16398	15485	885	17095

The Liard Field has reserves and is a discovery, however, the Liard Field = 0 model illustrates the results of an assessment, where the results of the initial Liard well, abandoned in 1986, would suggest a play potential like that of the Canadian Gas Potential Committee obtained, but using our method and input data set (Figures 8.7 and 8.8). If the Liard Field is not considered in the data set the Geo-anchored calculation suggests 142.4 X10^9 m^3 (5027 BCF) as the mean play potential to be discovered in 116 accumulations. Figures 8.7 and 8.8 show the complete and largest individual accumulation sizes predicted for this model. Note that the model predicts that five of the ten largest fields are not yet discovered and that all of these accumulations are expected to be larger than the La Biche Field.

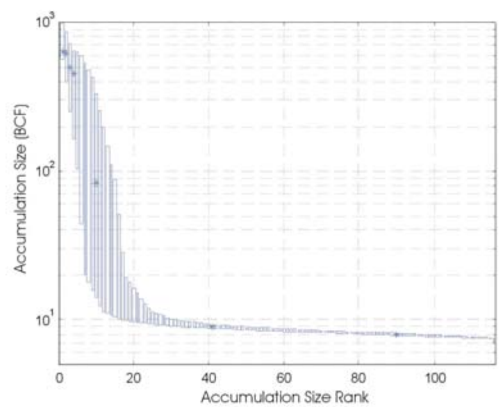

Figure 8.7: Predicted natural gas field sizes, as a function of accumulation size rank following the method of Figure 8.6C above. Predictions are made for the Geo-anchored (i.e. sequential sampling) resource assessment model that does not consider the Liard field in its input data set. This assessment prediction is effectively a field size equivalent of the assessment performed by the Canadian Gas Potential Committee (2002), using our input data set and method.

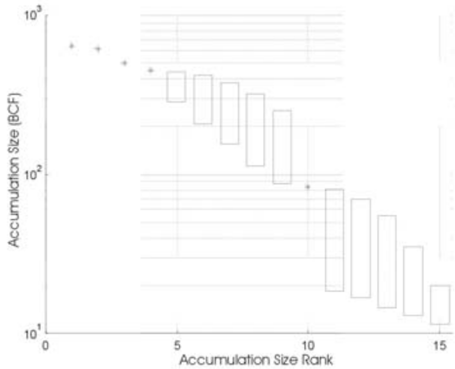

Figure 8.8: Predicted 15 largest natural gas field sizes, as a function of accumulation size rank for the a Geo-anchored resource assessment model that does not consider the Liard field in its input data set (Figure 8.7). The stars represent the size of fields that have been discovered, with the Liard Field being estimated at 14.2 $X10^9$ m^3 (500 BCF), and the open boxes representing the potential size range of undiscovered accumulations, as described in Figure 8.6C.

If Liard Field holds up to 8.5 $X10^9$ m^3 (300 BCF) gas then the expected total initial in-place gas resource is slightly more than 141.6 $X10^9$ m^3 (5 TCF) and the expected number of accumulations is between 116 and 128 (Table 8.4, Figure 8.9). The resource estimate in the case where the Liard field reserve is 8.5 $X10^9$ m^3 (300 BCF) is narrower than would have been inferred before the Liard Field was discovered (Figures 8.7 and 8.8). If the Liard Field is included in the discovery history and attributed a discovery date of 1986 and a size of 8.5 $X10^9$ m^3 (300 BCF) then the fifteen largest accumulation sizes for that model are predicted to be as shown in Figure 8.9. That model suggests that six of the ten largest accumulations are yet to be discovered and all of these are larger than the La Biche Field. It also suggests that there is probably an undiscovered accumulation that is comparable to or large than the Liard field that remains to be discovered. However, the total play potential is only marginally different from the previous case (Figure 8.7) and the results of the two predictions can be considered effectively similar, considering the uncertainty in the size of the Liard Field.

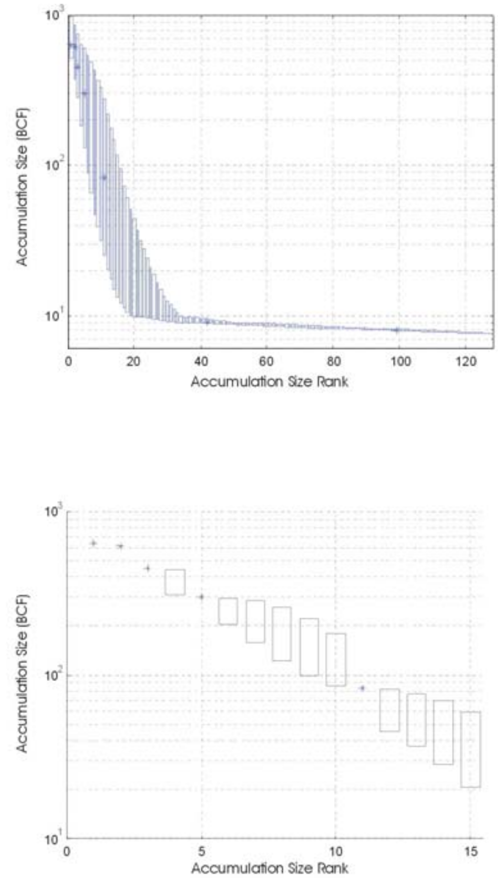

Figure 8.9: Predicted natural gas field sizes, as a function of accumulation size rank for the Geo-anchored resource assessment model that considers the Liard field in its input data set with an inferred field size of 8.5 $X10^9$ m^3 (300 BCF) and a discovery date of 1986. The prediction is not dissimilar to that made if the Liard field is not included in the data set, especially for the total resource estimated (Table 8.4). The top half of the figure shows all of the predicted accumulations, while the bottom half of the figure shows detail of the largest accumulations predicted.

If the Liard Field is 14.2 $X10^9$ m^3 (500 BCF) in size, but its discovery date is attributed to the initial well, abandoned in 1986, the mean play potential is estimated to be 484.4 $X10^9$ m^3 (17.1 TCF) initially in place, with 95% to 5% prediction interval for a play potential between

439-530 X10^{9} m^{3} (15.5 – 18.7 TCF) contained in an expected 885 accumulations. Such a projection must be compared to geologically constrained estimates of the play potential because of the very large number of accumulations that it predicts.

8.7.9 Play reservoir volume and multivariate analysis calculations

The input data used for the play and reservoir volume approaches was collected from published literature (see references) in consultation with operating companies. Table 8.5 shows both the reservoir input parameters used in for a regional geological play potential calculation and the a summary of the assessment results for accumulation numbers between 50 and 150 fields, for that calculation. The assessment result is a function of the number of accumulations.

Table 8.5. Parameters and assessment results from the regional geological approach

Volumetric parameters	Minimum	Most-likely	Maximum
Effective play area (ha)	1,700,000	2,000,000	2,100,000
Fraction of trap	0.12	0.15	0.16
Probability for gas	0.15	0.2	0.25
Average net pay (m)	45	50	55
Average porosity	0.035	0.035	0.038
Average gas saturation	0.65	0.7	0.78
Average GVF	215	217	217
Gas resource in place (bcf)	2378.5	5632.5	10493.9
Assumed number of fields N	50	100	150
Average Field Size (bcf)	47.6	56.3	69.9
Average closure area (ha)	612	600	560

The geological play constraints in Table 8.5 suggest that the original in-place gas resource may be significantly underestimated, due to the comparatively conservative estimates of accumulations size that are common in initial stages of Frontier exploration. Reserve growth through time is a well-established but poorly understood feature of petroleum field development history. The volumetric analysis suggests that the initial reserve in this play might actually be between 68 X10^{9} m^{3} (2.4 TCF), a number similar to the values used currently and employed for the discovery process analysis and as much as 297.4 X10^{9} m^{3} (10.5 TCF), with a most likely value of about 158.6 X10^{9} m^{3} (5.6 TCF). However the question of reserve growth cannot be considered in the current study, other than as a possibility.

Reservoir volumetric parameters were derived from both descriptions of the discovered gas fields in this play (Tables 8.6 and 8.7) and from an independent play analysis of the same type performed by a company exploring in the region (Table 8.8). The reservoir volumetric parameters used for the assessment consider acceptable variations in reservoir parameters and possible numbers of accumulations. The purpose of using different number of fields is to generate different scenarios that test the sensitivity of the number of fields on the size of remaining fields because recent drilling suggests that the size of even discovered fields and the numbers of prospects may not be adequately described or know with available data. If the result at the Liard Field has been revised by recent activity it is possible that other “discovered” accumulations may also need study and revision. The three estimates of number of accumulations are generally matched to, the results of the Geo-anchored Analysis (approximately 100 accumulations if Liard Field is 8.5 $X10^9$ m^3 (300 BCF)), the results of the Canadian Gas Potential Committee 2002 study (approximately 50 accumulations), and the expected number of accumulations inferred by the independent corporate analysis of the play. In all three cases, or scenarios, the variations in the reservoir parameters are characterized as probability distributions.

In the most-likely scenarios play geological constraints are combined with inferred number of fields, N, of N=100 and N=50 (scenario I and II). Scenario III is based on an independent corporate estimate of play parameters and numbers of accumulations (scenario III).

Table 8.6. Probability distribution of reservoir parameters (scenario I, number of accumulations=100 with play parameters from public sources).

Probability (%)	100	95	75	50	25	5	0
Closure Area (ha)	2	10	52	160	520	2400	10000
Net Pay (m)	3.5	7.6	16	32	56	130	500
Porosity (%)	3	3.2	3.3	3.5	3.9	4.2	10
Gas Saturation(%)	45	52	62	66	71	82	95
GVF	150	175	195	217	230	250	300
No. of field	100	100	100	100	100	100	100

Table 8.7. Probability distribution of reservoir parameters (scenario II, number of accumulations=50 with play parameters from public sources).

Probability (%)	100	95	75	50	25	5	0
Closure Area (ha)	55	170	435	840	1700	4350	11000
Net Pay (m)	3.5	7.6	16	32	56	130	500
Porosity (%)	3	3.2	3.3	3.5	3.9	4.2	10
Gas Saturation(%)	45	52	62	66	71	82	95
GVF	150	175	195	217	230	250	300
No. of field	50	50	50	50	50	50	50

Table 8.8. Probability distribution of reservoir parameters (scenario III, number of accumulations=15 with play parameters from an independent source).

Probability (%)	100	95	75	50	25	5	0
Closure Area (ha)	100	114	472	2592	5443	9036	15000
Net Pay (m)	10	13.5	40	45	45	87	150
Porosity (%)	3	3.35	3.5	3.5	3.5	4.6	6
Gas Saturation (%)	70	70	70	70	70	73	80
GVF	100	105.3	217.4	217.4	217.4	221.2	230
No. of field	15	15	15	15	15	15	15

Table 8.9. Assessment results from volumetric approach based on scenarios I, II and III.

Probability(%)	5%	25%	50%	75%	95%	Mean
(I) N=100	5362.4	4936.3	4645.7	4368.6	4046.7	4666.4
(II) N=50	9784.4	6867.6	5947.3	5360.6	4715.3	6413.1
(III) N=15	5246.5	4304.8	3856.4	3518.7	3176.1	3987.8

Table 8.9 summarizes the resource potential results for each of the three scenarios discussed above (Tables 8.6, 8.7 and 8.8). The expected value of total gas resource in place ranges from 3988 to 181.7 X10^9 m^3 (6413 BCF), with the independently estimated model (scenario III) being the most pessimistic. The mean play potential of the volumetric assessment is similar to that obtained for the Geo-anchored discovery process analysis which predicated a mean play potential of 147.4 X10^9 m^3 (5204 BCF) in approximately 128 accumulations if the Liard Field has a 8.5 X10^9 m^3 (300 BCF) initial reserve. It would appear the volumetric estimates are quite different from the Geo-anchored model that predicted 484.3 X10^9 m^3 (17,095 BCF) in 885 accumulations is the Liard Field has an initial in place reserve of 14.2 X10^9 m^3 (500 BCF). The results for the reservoir volumetric approach are also quite similar to that obtained from the regional consideration of play parameters, mentioned at the beginning of the volumetric analysis. The estimates of the volumetric analysis are independent of the estimate of the size of the initial potential reserve in the Liard because the construction of the field size distribution using this approach does not require accumulation specific information. Changes in reservoir volumetric parameters and numbers of accumulations can change the field size distribution of this calculation, as illustrated by the three scenarios.

The predicted accumulation size, as a function of accumulation size rank suggests that six of the top ten and as many as nine fields among the top fifteen fields in the play may be undiscovered. The accumulation sizes predicted for the volumetric analyses shows that the size of discovered fields does not in this case, have a serious impact on either the size by rank plots or the estimates of the undiscovered resource. Figure 8.10 shows a Liard Field of 8.5 X10^9 m^3 (300 BCF) being the fourth largest accumulation in the play. If the size of Liard field is 14.2 X10^9 m^3 (500 BCF), for the purpose of this analysis, the size rank of Liard field should be third (3) and Kotaneelee field, now third largest becomes fourth largest (4) in the size by rank plots (Figure 8.10).

If the fifteen largest accumulations of the volumetric prediction that assumes there will be 50 accumulations is inspected (Figure 8.11) it predicts that one of the two largest accumulations is yet to be found, if the Liard Field has an initial reserve of 8.5 X10^9 m^3 (300 BCF). If the Liard Field is however 8.5 X10^9 m^3 (300 BCF), then the predictions of this model are very similar to those of the volumetric model that assumes 100 accumulations and the Geo-anchored models where the size of the Liard Field does not exceed 8.5 X10^9 m^3 (300 BCF).

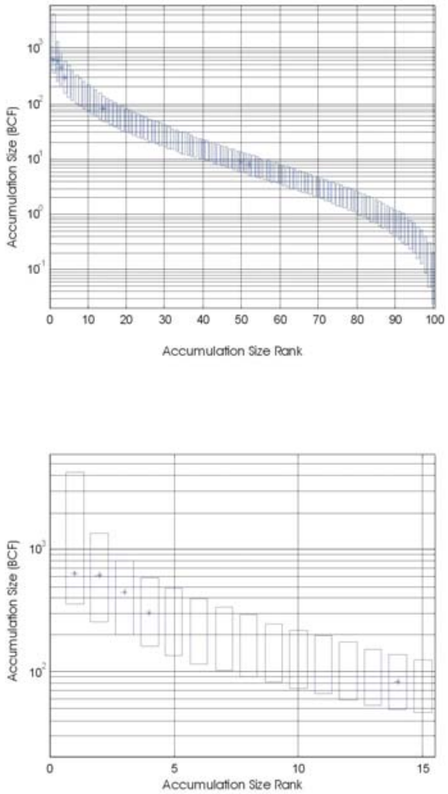

Figure 8.10: Predicted natural gas field sizes, as a function of accumulation size rank for the reservoir volume resource assessment model that assumes 100 accumulations (Tables 8.6 and 8.9). This is assessment prediction that is most closely similar to the Geo-anchored models with Liard Field reserves not exceeding 8.5 X10^9 m^3 (300 BCF) (Figures 8.7-8.9). The top half of the figure shows all of the predicted accumulations, while the bottom half of the figure shows detail of the largest accumulations predicted.

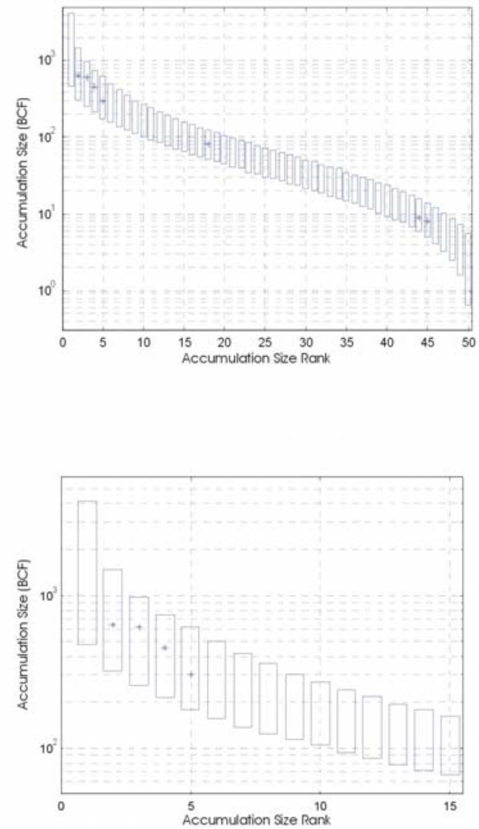

Figure 8.11: Predicted natural gas field sizes, as a function of accumulation size rank for the volumetric resource assessment model that assumes 50 accumulations (Tables 8.7 and 8.9). This assessment prediction is similar to the number of accumulations inferred analysis of the Canadian Gas Potential Committee. The match of discovered accumulations uses an estimate for the Liard Field size of 8.5 X10^9 m^3 (300 BCF). The top half of the figure shows all of the predicted accumulations, while the bottom half of the figure shows detail of the largest accumulations predicted.

8.8 Discussion

Table 8.10 summarizes the results of the Geo-anchored and Reservoir Volumetric analyses of the Liard Structure Play performed for this assessment. In general most of the analyses predict that the play potential is generally estimated to be of comparable expected size. Using both discovery process analyses and volumetric methods of assumptions and considering both the assumptions regarding the size of recent discoveries and the relatively wide range of estimates for numbers of accumulations there is a relatively small variation in the expected resource estimate, accompanied by a much larger range of potential at more marginal probabilities of the resource potential distributions. The expected total resource estimated is between 181,211 X $10^6 m^3$ (6413.1 BCF) and 112,681 X $10^6 m^3$ (3987.8 BCF) of initial gas in place expected to occur in between 15 and 128 accumulations, of which somewhere between 59,480-65,130 X $10^6 m^3$ (2105-2305 BCF) has been discovered in 7 fields. Relying on the success of the discovery process elsewhere for predicting numbers of accumulations we believe that the number of accumulations is somewhere between 100 and 128, if the Liard Field is about 8.5 X10^9 m^3 (300 BCF) in size.

Table 8.10. Summary Results of Various Calculations of Undiscovered Petroleum Potential in the Liard Fold and Thrust Belt performed for this study.

Play Name, This Study of Fields and Prospects (GSC, 2002)	Discovered	Total Resource	Number Discovered	Total Number of accumulations	Number of undiscovered accumulations
Volumetric estimate with 100 fields	59,480-65,130 (2105-2305)	131,788 (4666.4)	7	100	93
Volumetric estimate with 50 fields	59,480-65,130 (2105-2305)	181,211 (6413.1)	7	50	43
Volumetric estimate with 15 fields	59,480-65,130 (2105-2305)	112,681 (3987.8)	7	15	8
Sequential sampling without Liard Field	52,274 (1805)	142,044 (5027)	6	116	110
Sequential sampling with 300 Bcf Liard Field	59,480 (2105)	147,046 (5204)	7	128	121
Sequential sampling with 500 Bcf Liard Field	65,130 (2305)	483,043 (17095)	7	885	878

If the size of the Liard Field has been significantly underestimated and it has an initial reserve of 14.2 X10^9 m^3 (500 BCF) or more, then the number of accumulations in the play could significantly exceed 100 and the resource potential could be much higher than that suggested by all of the other analyses performed here or by other groups and agencies. However, experience shows that industry, even with the most comprehensive data sets, tends to significantly underestimate the number of accumulations, often by a factor of ten. Therefore the comparison of the industrially formulated volumetric scenario III with the estimates from the geo-anchored analysis and the Canadian Gas Potential Committees estimate of number of accumulations suggests that a value for the number of accumulations of approximately 100 is probably appropriate for the current understanding of this play. The reservoir volume method prediction for only 15 accumulations (Figure 8.12) is also shown. It predicts that the largest accumulation in the play has not been discovered, which is an improbable conclusion, as is the inference that only 15 accumulations occur within the play.

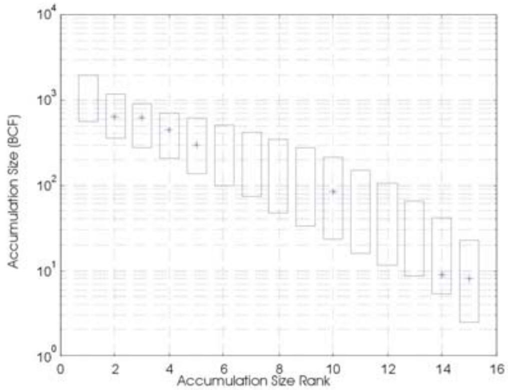

Figure 8.12: Predicted natural gas field sizes, as a function of accumulation size rank for the volumetric resource assessment model that assumes 15 accumulations (Tables 8.7 and 8.9). The model uses what is widely agreed to be too small a number of accumulations and it predicts that the largest accumulation is yet to be discovered. This result is considered to be improbable.

In general most models predict that approximately 5 or 6 of the top ten accumulations remain to be discovered. All of these accumulations are larger than the economically viable La Biche Field. Therefore it is reasonable to assume that there are at least 5 or 6 undiscovered accumulations that are between about 2.8-8.5 X10^9 m^3 (100 and 300 BCF) remain to be discovered in this play. If the criteria for economic viability is closer to that of the recent 2.27 X10^9 m^3 (80 BCF) Bovie Lake discovery then there are probably between 20 and 30 accumulations that remain to be discovered (Figures 8.7-8.12). Two important potential untested prospects, with bedrock geological expression, are the Etanda Dome and Twisted Mountain Anticline, which occur adjacent to the current park reserve, at its southeaster limit and the southern proposed extension, the Tlogotsho Plateau Study Area, at its southern boundary, respectively. Both of these structures have geological characteristics that suggest they could individually contain initial natural gas resources of between 2.8-8.5 X10^9 m^3 (100 and 300 BCF). It appears that both structures can be accessed and exploited without significant adjustment to the boundaries of either the park reserve or its proposed extensions. Between these two structures is the Mattson Anticline, which has been tested by a single well, the Pan Am A-1 Mattson Creek No. 1 that was spudded in 1961 in Devonian Besa River Shale and penetrated the target Middle Devonian carbonate at only 507 m depth. A drill stem test of Manetoe facies dolomite in that well recovered only gas-cut salt water, but it is possible that the complicated faulting of these structures has provided isolated reservoir compartments which have retained their seal, especially considering the large size of the structure. Recent developments in the Liard Field have shown that early exploration tests may not be diagnostic of the entire structure, and that the Mattson Anticline may still contain potential for commercial production.

Because the resources provided for this study did not permit the detailed or extensive evaluation of all the discovered accumulation sizes or the remaining identifiable prospects we employed different scenarios and methods to test the sensitivity of predicted undiscovered field sizes and resource potentials in this play. In spite of the general agreement of most of the calculations there are significant differences, especially in the estimate of the size of the largest undiscovered accumulation. Much more work could be done to resolve some of these remaining uncertainties. Foremost of among the uncertainties that remain are uncertainties in discovered accumulation sizes, as illustrated by the history of the Liard structure between 1986 and 1999. Also unresolved is the significant difference in the number of untested prospects, which ranges between 8 and 121, but which might be as high as 878. However, the general agreement among a number of the methods and with the predictions of other groups suggests that sufficient precision exists to make policy decisions regarding land use.

All assessments point to a very significant economic potential that could have considerable impact on the economies of, and workforce employment in northernmost British Columbia, the Yukon Territory and the Northwest Territories. The results of this resource assessment should be subject to a microeconomic analysis if the true economic potential of this study is to be determined.

Petroleum is Canada's primary source of energy and a great source of employment and national wealth, domestically and for export. Canada is the third largest natural gas producer, the eleventh largest oil producer and the eleventh largest coal producer worldwide. There are great future opportunities for the development of both new geographic regions and new source and types of petroleum in all portions of the country. One of the most prospective regions for the development of additional gas resources is the Liard Plateau, as confirmed by recent new industrial activity and this assessment. This study estimates that the initial gas resource in the Liard Plateau is between 181,211 X $10^6 m^3$ (6413.1 BCF) and 112,681 X 10 $^6 m^3$ (3987.8 BCF) of initial gas in place expected to occur in between 15 and 128 accumulations, of which somewhere between 59,480-65,130 X $10^6 m^3$ (2105-2305 BCF) has been discovered in 7 fields. In comparison the national remaining established reserve of natural gas is approximately 1720 X10^9 m^3 (60.7 TCF), so that the gas resources of the Liard Plateau represent approximately 10.5% to 6.5% of that value. Canada exported about 108 X10^9 m^3 (3.8 TCF) of natural gas to the United States for a value of $25.6 Billion in 2001 (NRCan/MMS, 2003). Petroleum industry jobs are particularly well paid, averaging more than twice the national average industrial wage. The undiscovered resources of the Liard Plateau are an important potential contribution to this very important economic activity, especially as it might contribute to employment and economic activity in the NWT and Yukon.

8.9 Implications and Recommendations for NNPR and Proposed Extensions

Specific Areas Outside and On the Margins of the Proposed Park Reserve Extensions To Preserve for Economic Development

Two important potential untested prospects, with bedrock geological expression, are the Etanda Dome and Twisted Mountain Anticline (Figure 8.13), which occur adjacent to the southern proposed extension, the Tlogotsho Plateau Study Area, at its southern boundary, and the current park reserve, at its southeastern limit, respectively. Both of these structures have geological characteristics that suggest they could individually contain initial natural gas resources of between 2.8-8.5 X10^9 m^3 (100 and 300 BCF). However, it appears that both structures can be accessed and exploited without significant adjustment to the boundaries of either the park reserve or its proposed extensions. Access to and development of these prospects should be preserved in any extension of the national park reserve or subsequent land use planning activities. An important aspect for the preservation of exploration and development potential is access and transportation access for exploration, development and production from these two structures should be preserved.

Access to other structures (Figure 8.13), even if they have been tested and those wells abandoned should be preserved, as the recent exploratory experience at the Liard Field indicates that earlier tests may not have been diagnostic, for various reasons.

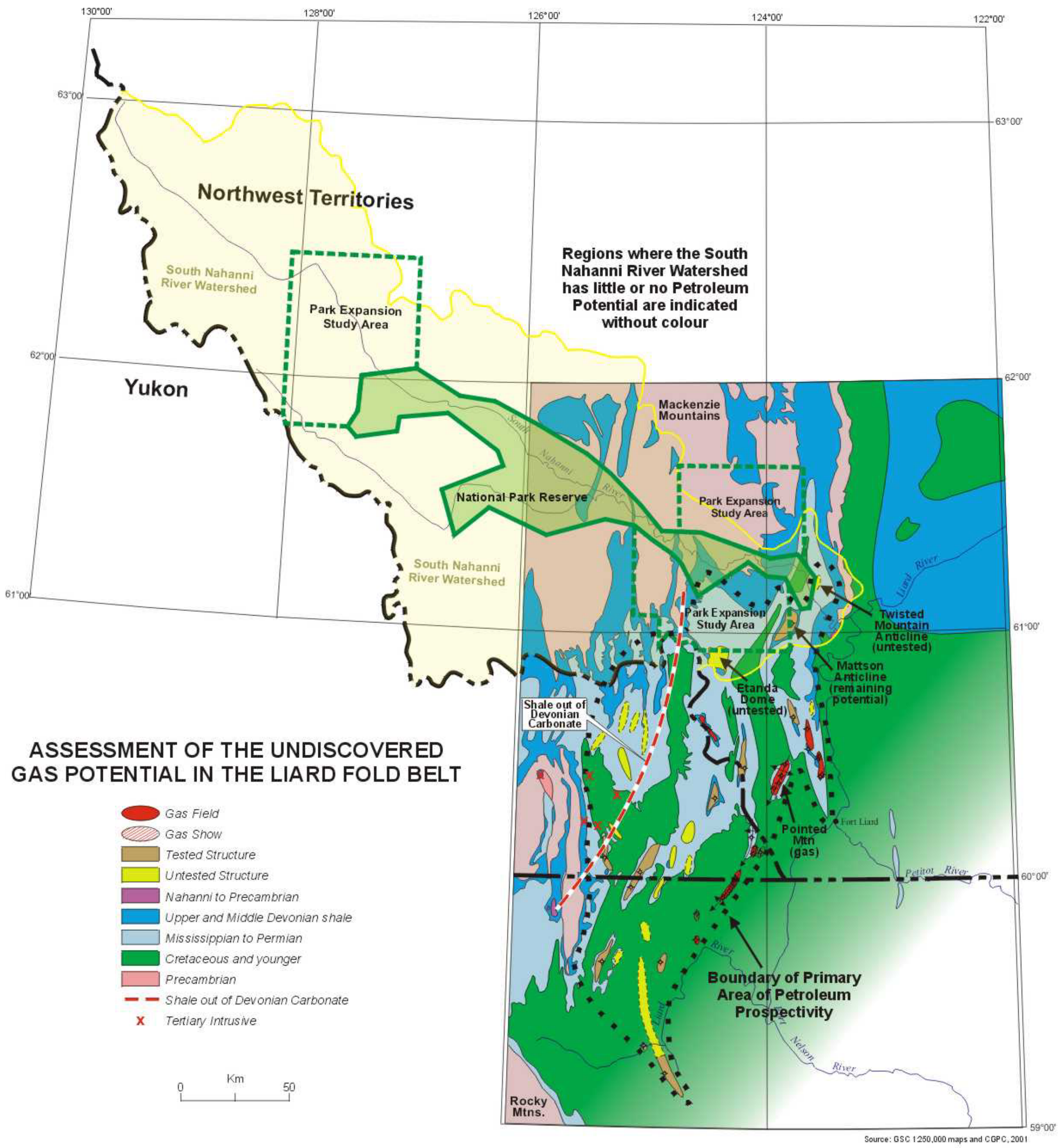

Figure 8.13: Play area map showing the location of the three structures, Etanda Dome, Twisted Mountain Anticline and Mattson Anticline that should be preserved for future economic development (Following Procter and Newson, 2002).

8.9.1 Factors favourable for the sterilization of the proposed park reserve extensions

Otherwise several geological features suggest that the current park reserve and its two proposed extensions will probably have a minimal impact on the development of this play if they are removed from exploration and exploitation, considering the two conditions made above. First, the outcrops of Devonian carbonates that provide the spectacular scenery in the Park Reserve indicate the breeching of the reservoir top seal and the removal of all potential from the deeper of the primary prospective reservoirs. The regional structure that exposes the Devonian carbonates is a broad feature that results from the regional uplift of the Mackenzie Mountains and associated ranges that expose Devonian and older rocks on both sides of the Nahanni River. There are additional reasons why this reduces the conflict between the Park Reserve and the economic petroleum potential. This region is almost exclusively prospective for natural gas. Natural gas trapping and reservoir volume factor (the compression of the gas in the reservoir, compared to its volume at surface) are all significantly reduced as an inverse function of depth. Therefore shallower targets can be expected to be less effectively sealed and to contain less natural gas per volume of porous reservoir than would deeper prospects. Finally, most of the identified untested and prospective large targets, with the three exceptions mentioned above occur in regions where the primary target reservoir strata are more deeply buried, more effectively sealed. As a result, acknowledging the three exceptions described above, the lands identified for removal from exploration by the expansion of the national park reserve are among the less prospective portions of the Liard Plateau petroleum play and their sterilization should not have major adverse impacts on the realization of the potential economic benefits from the exploration and development of the petroleum potential in the Liard Plateau.

8.9.2 Access for scientific and engineering studies in the park reserve

Efficient and responsible scientific and engineering exploration and development of the Liard Plateau petroleum potential will be greatly aided by the provision of reasonable access to study the primary reservoirs as they outcrop within the Park Reserve. Therefore, it would be desirable to make scientific and engineering field trips to examine and sample outcrops with the park reserve a permitted use. This could be done in such a manner that it enhanced the understanding of Canadians regarding the natural history, heritage and benefits between the rocks that provide spectacular scenery and their subsurface counter-parts that are a primary contributor to the Canadian economy.

8.10 Conclusions

The Petroleum Potential of the Liard Plateau structure play is between 181,211 X $10^6 m^3$ (6413.1 BCF) and 112,681 X 10 $^6 m^3$ (3987.8 BCF) of initial gas in place expected to occur in between 15 and 128 accumulations, of which somewhere between 59,480-65,130 X $10^6 m^3$ (2105-2305 BCF) has been discovered in 7 fields.

Recent petroleum exploration activity and changes in development strategies have resulted in a renewed interest in this play and the identification of a significant economic potential that represents, in place, approximately 10.5% to 6.5% of the national reserve of gas and which has a probable value between $40 Billion and $25 Billion.

Three large structures including the untested Twisted Mountain Anticline and Etanda Dome (Figure 8.13) occur adjacent to the current park reserve, at its southeastern limit and the southern proposed extension, in the Tlogotsho Plateau Study Area, at its southern boundary, respectively. Both of the untested structures have geological characteristics that suggest they could indivi dually contain initial natural gas resources of between 2.8-8.5 X10^9 m^3 (100 and 300 BCF) and they should be preserved for development. Between these two structures is the Mattson Anticline, which has been tested by a single well. Recent developments in the Liard Field have shown that early exploration tests may not be diagnostic and that the Mattson Anticline may still contain potential for commercial production.

In general the Park Reserve and its Proposed extensions cover areas where the burial of the primary reservoir targets is reduced, compared to most of the prospective region. The reduced potential for an effective top seal on the reservoir and the decreased formation volume factor for gas suggests that the sterilization of these regions should not have a major impact on the realization of the economic potential of the region, if these lands are removed from exploration and development, considering the exceptions in point 3 above.

The same rocks that provide them most spectacular scenery in the Nahanni Park Reserve are the primary reservoirs for petroleum in the subsurface. Scientific and engineering study of these rocks should be permitted in a way the contributes to both efficient sustainable development of the resource outside of the Park Reserve boundaries and an improved educational experience for visitors to the Park Reserve.