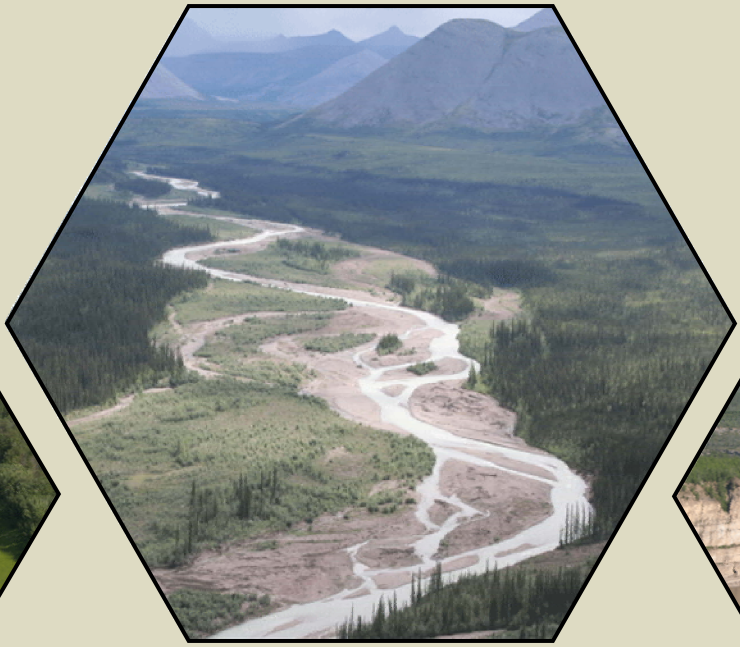

NWT Open File 2007-01

Ts' ude niline Tu' eyeta (Ramparts River and Wetlands) Candidate Protected Area Phase I Non-renewable Resource Assessment - Petroleum

Northwest Territories, Canada

NTS 106G, H, I, J

L.P. Gal

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>>> NORTHWEST TERRITORIES GEOSCIENCE OFFICE

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EXECUTIVE SUMMARY

The Northwest Territories Geoscience Office (NTGO) has completed a Phase I Non-renewable Resource Assessment (NRA) for Petroleum of the Ts' ude niline Tu' eyeta Candidate Protected Area (Ts' ude niline Tu' eyeta), which is being advanced under the Northwest Territories Protected Area Strategy (PAS). The NRA has generally been carried out as part of Step 5 of the PAS process, which also includes ecological and cultural evaluations of the Candidate Protected Area (Northwest Territories Protected Areas Strategy Advisory Committee, 1999). The PAS calls for a phased approach to NRAs, and this report summarizes Phase I work which consisted of selecting study areas, data compilation, gap analysis, and evaluation of all available geoscience information relative to petroleum geology. The NRA is undertaken in support of the Government of Canada's Minerals and Metals Policy (1996), and informed land use decision-making.

Ts' ude niline Tu' eyeta covers 15,063 km^2, or approximately 1.5 million hectares, stretching from the Mackenzie River to the border of the Gwich'in Settlement Area. The settlement of Fort Good Hope is located adjacent to the proposed eastern boundary of Ts' ude niline Tu' eyeta. The study area that is the subject of this report is bounded by 65°N and 67°N latitude and 128°W and 132°W longitude, and is covered by National Topographic System 1:250,000 scale map sheets: 106G, H, I, and J.

The northern and central parts of the study area (Peel Plain) are predominantly flat-lying, with an average elevation of about 100 m above sea level. Peel Plain is covered with unconsolidated glacial deposits up to 70 m thick, which almost completely obscure bedrock. The southern part of the study area lies in the Mackenzie Mountains. More bedrock is exposed in this upland region, with elevations locally greater than 1500 m above sea level.

Most of Ts' ude niline Tu' eyeta lies within the Interior Platform geological province, an area of generally undeformed Phanerozoic aged sedimentary rock, comprising Cambrian to Cretaceous sandstone, shale, limestone, and dolostone. The bedrock directly underlying Ts' ude niline Tu' eyeta is dominantly Cretaceous shale and sandstone. The Mackenzie Mountains lie in the southern portion of Ts' ude niline Tu' eyeta, and large structures bring rocks as old as Proterozoic to surface.

The petroleum resource assessment covers conventional oil and natural gas. Twenty-one oil exploration wells were drilled between 1945 and 1991 within proposed boundaries of Ts' ude niline Tu' eyeta, and 44 within the entire study area. Drilling activity was concentrated in the 1960s and 70s, and in the southeast quadrant of the study area. One well is classed as a suspended gas well, the others as drilled and abandoned. Middle Devonian reefal carbonates were the primary exploration target, but many of the most recent wells (early 1990s) tested the Cretaceous section. Oil and gas shows and indications have been found through a range of strata from Ordovician to Cretaceous rocks.

Seven conceptual hydrocarbon plays have been delineated within the study area. Those judged to have the greatest exploration potential are: Kee Scarp (Middle Devonian reef), basal Cretaceous siliciclastics, Arnica/Landry platform (Lower Devonian carbonate), and Upper Devonian siliciclastics. These are associated with: significant occurrences, and/or known or suspected petroleum systems with rich source rocks, and/or good trapping and preservation probabilities within the study area. Cambro-Ordovician platform play probably has less potential, partly because of a lack of source rocks. Basal Cambrian clastic play is poorly understood due to a lack of information and few well intersections, and supposed restricted reservoir opportunities. Tuttle play (Devono-Mississippian siliciclastics) is restricted in its distribution within the study area, based on geological mapping.

Consideration of all the plays together indicate the highest potential for oil and gas in a southeast to west, westward-expanding arc across the study area, encompassing Mackenzie Plain, Peel Plain, and Peel Plateau. The Mackenzie Mountains in the south part of the study area have the lowest potential.

POTENTIAL Ranking	CONFIDENCE Ranking			
	Rank 1: Abundant reliable information	Rank 2: Moderate amount of information	Rank 3: Some information	Rank 4: Very little and/or unreliable information
Rank A: Very High:			X	X
Rank B: High:		NE Mackenzie Plain, SE corner of study area.	Peel Plain and Plateau, Central Grandview Hills, west-central part of study area; lowlands between Chick Lake and Mackenzie River.	X
Rank C: Moderate to High:			NE margin Peel Plain and western Grandview Hills; area south of Ft. Good Hope and lower Mountain River area.	
Rank D: Moderate:			Mackenzie River and to the NE, north of Ft. Good Hope; East side of Beavertail, East Mtn., Imperial anticline structures; Carcajou anticline; Imperial syncline; front margin of Mackenzie Mtns.	
Rank E: Low to Moderate:			West side of Beavertail, East Mtn., and Imperial anticline structures; SE quadrant of study area	
Rank F: Low:				Mackenzie Mountains main ranges; southern margin of study area
Rank G: Very Low:				
Rank H: Not Assessed:	X	X		

Table 1. *Petroleum potential summary*

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INTRODUCTION

Background

In early 2000, the Sahtu Heritage Places and Sites Joint Working Group identified locations on the lower Ramparts River and surrounding wetlands (Tuyat'ah), and the bluffs along the Mackenzie River upstream from Fort Good Hope (Fee Yee) as important heritage sites (Sahtu Heritage Places and Sites Joint Working Group, 2000). In August 2001 the NWT Protected Areas Strategy (PAS) Secretariat attended an information workshop in Fort Good Hope to introduce the PAS, and discuss important areas for conservation in the Fort Good Hope area.

A protected area initiative report for Ducks Unlimited Canada (Hunter et al., 2002) focused on an expanded study area of about 4,448 km^2 that included the above mentioned heritage areas. This area became the focus of a second community workshop in June 2002, the purpose of which was to facilitate the community's entry into the PAS process. A request for information (including non-renewable resources) was received by the PAS Secretariat from the Fort Good Hope Renewable Resources Council in October 2002. This request for information was partly addressed in a brief report in November 2002 (Gal and Lariviere, 2002a).

In May 2003, a third community workshop was held with an objective to define boundaries of the area of interest to focus further study. A fourth community workshop in April 2004 re-examined the previously defined boundaries and expanded them by a factor of three to the current state. The community passed a resolution defining the interim boundary, and accepted the Canadian Wildlife Service as the sponsoring agency. A new request for information was received by the PAS Secretariat in August 2004. This second request for information was addressed in October, 2004 with an updated Preliminary Economic Information Request on Minerals, Oil & Gas (Gal and Lariviere, 2004a).

In the preliminary Draft of the Sahtu Land Use Plan (Sahtu Land Use Planning Board, 2003) Ts' ude niline Tu' eyeta was identified as a Conservation Area, with similar boundaries to the current proposed protected area. In the most recent draft of the Sahtu Land Use Plan (Sahtu Land Use Planning Board, 2005) Ts' ude niline Tu' eyeta is identified as a Special Management Area, surrounding a core Conservation Zone that is similar in shape and size to the original lower Ramparts River and surrounding wetlands (Tuyat'ah) area identified in 2000.

In November 2005, the Yamoga Land Corporation submitted a proposal for the advancement of Ts' ude niline Tu' eyeta through the NWT PAS, and a Notice of Applications (for Land Withdrawal) was filed. The Yamoga Land Corporation and Fort Good Hope Renewable Resources Council are now working on a proposal for interim land withdrawal (Northwest Territories Protected Areas Strategy, 2005).

At time of writing, no land withdrawal of Ts' ude niline Tu' eyeta candidate protected area had yet taken place. However, the area has been provisionally excluded from recent Calls for Nomination for Petroleum Exploration Licenses issued by Indian and Northern Affairs Canada. Upon withdrawal of the lands, typically for a five-year period, no issuance of mineral claims, prospecting permits, or Petroleum Exploration Licenses can take place. It is during this withdrawal phase that various assessments of the candidate protected area (required under step 5 of PAS process) typically take place (Northwest Territories Protected Areas Strategy, 2001).

Terms of Reference

The Northwest Territories Geoscience Office (NTGO) has completed a Phase I Non-renewable Resource Assessment (NRA) of Ts' ude niline Tu' eyeta, a candidate protected area being advanced under the Northwest Territories Protected Area Strategy (PAS). The NRA has generally been initiated at Step 5 of the eight-step PAS process, and includes ecological and cultural evaluations of the Candidate Protected Area (NWT Protected Areas Strategy Advisory Committee, 1999). The NRA is undertaken in support of the Government of Canada's Minerals and Metals Policy (1996), which states that the mineral potential of an area should be fully taken into account before a decision to create a protected area on federal lands is taken. More generally the NRA supports informed land use decision-making.

The PAS calls for a phased approach to NRAs, and this report constitutes the Phase I NRA. The work included selection of a study area, data compilation, gap analysis, and evaluation of the collected information. A study area (Figure 1) larger than the proposed boundaries of Ts' ude niline Tu' eyeta Candidate Protected Area was selected in order to have a broad enough base to collect and assess information, and allow for extrapolations and later boundary modifications.

This assessment is an informed evaluation of what lies at or below the surface of the earth. It uses geological knowledge, informed opinion, and modeling applied to the known information available, and considers the potential of certain land areas to hold petroleum resources, ranking the areas accordingly in a qualitative sense. An absolute measure of the non-renewable mineral resource potential of an area cannot be provided. Various probabilistic methods exist for quantitatively estimating hydrocarbon resources, but such statistical methods are beyond the scope of this report.

Resource assessments are based on the best geoscientific information available *at the time of the study*. Assessments must be revised and updated as the state of knowledge of mineral and hydrocarbon deposits evolve, as new information becomes available, and as socio-economic conditions change with respect to factors such as commodity prices and existing infrastructure. Thus the concept of potential is considered to be dynamic, and in using the NRA as a planning tool, its limitations must be recognized. This resource assessment represents a best estimate of potential, and the conclusions are dependent on the information available currently.

Petroleum Potential Evaluation Ranking System

Definitions

The concept of a petroleum **play** is central to this assessment of petroleum potential. The definitions of play and other terms below are taken from Reinson et al. (1993). A play is defined as a family of pools and/or prospects (definitions below) that share common geological characteristics and history of hydrocarbon generation, migration, reservoir development, and trap configuration.

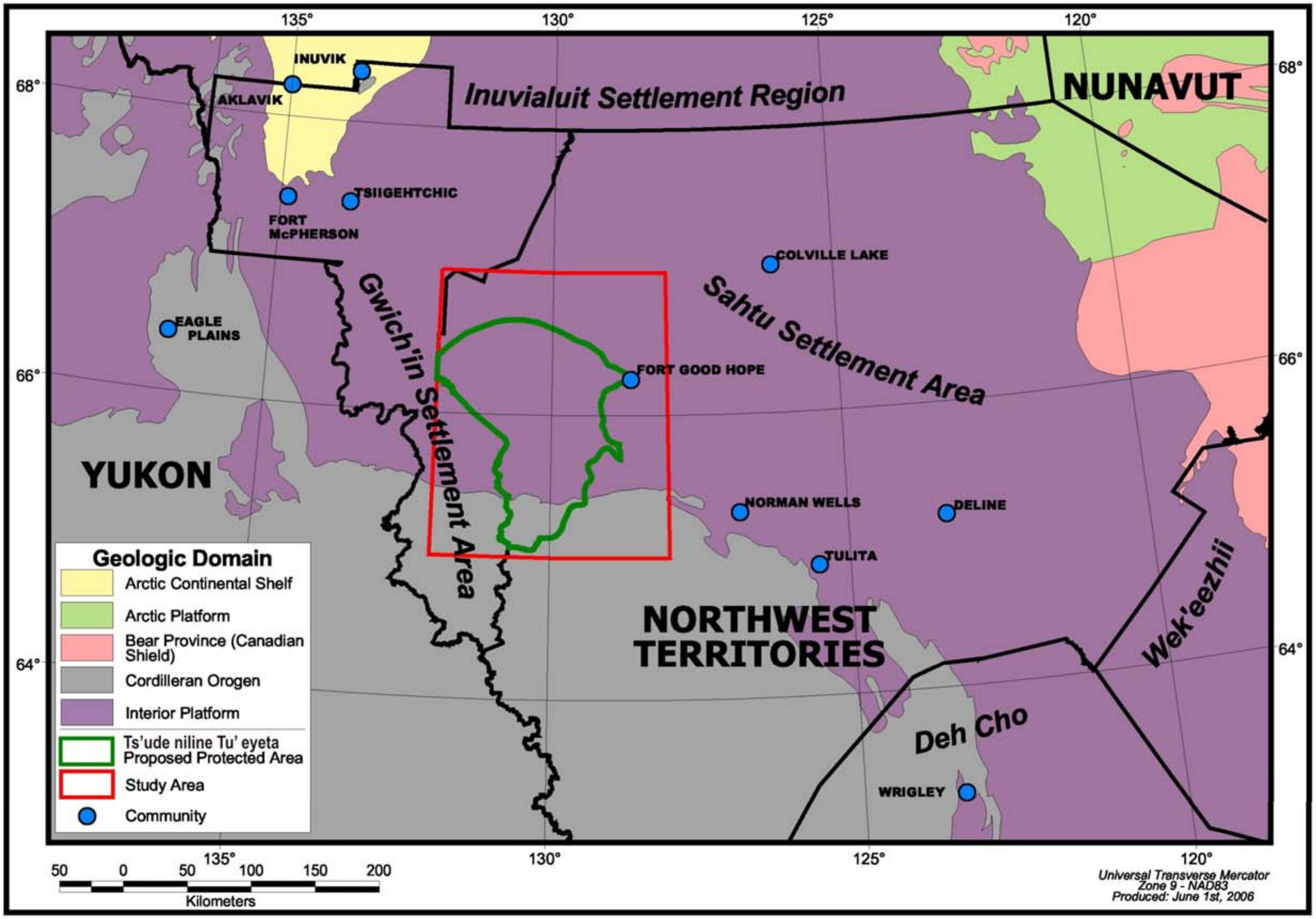

***Figure 1**. Geological domains and location of Ts 'ude niline-Tu' eyeta candidate protected area and study area*

A **prospect** is defined as an untested exploration target within a single stratigraphic interval; it may or may not contain hydrocarbons.

A **pool** is a discovered accumulation of hydrocarbons, typically within a single stratigraphic interval, that is hydrodynamically separate from other hydrocarbon accumulations.

Plays can be further described as **established** or **conceptual**. Established plays are demonstrated to exist by virtue of discovered pools with established reserves. Conceptual plays do not yet have any associated discoveries, but geological analyses indicate the possibility of their existence.

Assessment Criteria

Table 2 outlines the evaluation ranking criteria for oil and gas potential. The criteria partly follow those of the Mineral and Energy Resource Assessment (MERA) process used by the GSC (Scoates et al., 1986; Jones et al., 1992). These criteria are based on the overall geological favourability for oil and/or natural gas; and the occurrence and number of known established and conceptual hydrocarbon plays, indications of hydrocarbons (shows), and known accumulations. The presence of mapped structural features, or the probability of these features, is accounted for. Based on these criteria, an assignment of very high potential (Rank A) to very low (Rank G) is given.

In addition to a ranking of potential, a second ranking is assigned, based on a confidence factor (Gal and Lariviere, 2002b). This factor is a function of the amount and quality of information used in the first ranking. It is a qualitative judgment ranging from abundant reliable information (Rank 1) to very little and/or unreliable information (Rank 4). This confidence level is also influenced by the establishment of known occurrences. This is because exploration drilling, testing, and ultimately production, are all accompanied by an increase in the amount of information and therefore confidence concerning a given pool or field, and by extension, a play.

The assessment results are represented by placement in a matrix (Table 2). Certain ranking codes are unlikely to be used, for example, a very high potential ranking (Rank A) with a low confidence ranking (Rank 4). An area of known significant accumulation would, almost certainly, have more than a little information available, even if resource estimates and individual well data were still confidential. Certain areas that cannot be assessed for various reasons may be given a special ranking (Rank H).

POTENTIAL RANKING	**CONFIDENCE RANKING –** from data quality and availability			
	Rank 1: Abundant reliable information	**Rank 2:** Moderate amount of information	**Rank 3:** Some information	**Rank 4:** Very little and/or unreliable information
Rank A: Very High: Geological environment is favourable for oil and/or gas. Multiple plays, at least one is established. Closures identified and mapped. Significant accumulations are known in the study area.			X	X
Rank B: High: Geological environment is favourable for oil and/or gas. Multiple plays. Closures identified and mapped. Known hydrocarbon occurrences in the study area.				X
Rank C: Moderate to High: Geological environment is favourable for oil and/or gas. One or two plays. Closures identified and mapped for at least one play.				
Rank D: Moderate: Geological environment is favourable for oil and/or gas. One or two plays. High probability of blind structural/stratigraphic closures.				
Rank E: Low to Moderate: Geological environment is mainly favourable for oil and/or gas. At least one conceptual play. High probability of blind structural/stratigraphic closures.				
Rank F: Low: Some aspects of geological environment are favourable for oil and/or gas. Significant probability of blind structural/stratigraphic closures.				
Rank G: Very Low: Unfavourable geological environment.				
Rank H: Not Assessed: Deposit types unknown, overlooked, beyond the scope of the assessment, or not worth mentioning at the time the assessment was done (could be a higher rating in the future).	X	X		
Notes: An evaluated deposit type would be assigned an alphanumeric ranking (e.g. C3, D4, etc.) based on its placement within the matrix defined by geologic potential and confidence. The crossed-out fields (X's) are unlikely to be used. The criteria for assessing hydrocarbon potential partly follows the Geological Survey of Canada's Mineral and Energy Resource assessment rating scale (Scoates et al., 1986; Jones et al., 1992); and Gal and Lariviere (2004b).				

***Table 2**. Petroleum potential evaluation system*

Location, Area and Access

Proposed boundaries of the Ts' ude niline Tu' eyeta Candidate Protected Area lie between 65°03'05" N and 66°40'05" N latitude and 128°41'55" W and 132°00'00" W longitude and cover an area of 15,063 km^2 (1.5 million hectares). The candidate protected area is covered by 1:250,000 scale National Topographic System map sheets 106G, 106H, 106I, and 106J. These four map sheets constitute the study area that is the focus of this report, bounded by 65° and 67°N latitude, and 128° and 132°W longitude (Figure 1).

Ts' ude niline Tu' eyeta lies west of Mackenzie River, and includes parts of the watersheds of the Ramparts, Hume, and Ontaratue rivers (Figure 2). The Mackenzie River itself is a major transportation corridor. Traditional trails are concentrated along the lower Ramparts and Hume rivers (Hunter et al., 2002). Recent trails tend to follow seismic survey cut lines.

Physiography, Climate and Vegetation

The study area lies mainly within Great Slave Plain, a physiographic region of generally low relief (average elevation of less than 350 m above sea level). Mackenzie Mountains in the southern part of the study area are rugged upland ranges, with elevations up to 1990 m.

The study area lies within the Taiga Plains and Taiga Cordillera ecozones (Environment Canada, 2005; Figure 2). The portion of the study area within Taiga Plains ecozone includes several ecoregions: Fort McPherson Plain, Mackenzie River Plain, and Peel River Plateau. The climate of these regions is marked by short cool summers and long cold winters, and classified as high subarctic, ranging to subhumid boreal along Mackenzie River. Mean annual summer temperatures range from 9.5 to 11.5°C; winter temperatures range from –22.5 to –25°C (Environment Canada, 2005). Mean annual temperatures in the Mackenzie Mountains are similar, if somewhat cooler in summer, and with more precipitation (up to 500 mm).

Vegetation in the region (Environment Canada, 2005) is dominated by open, stunted stands of black spruce and tamarack, with secondary white spruce and ground cover of willow, birch, shrubs, cotton grass, lichen, and moss. Wetlands make up a significant portion of the study area (Figure 3), and these areas support sedge, cotton grass, and moss. Along Mackenzie River, taller stands of black spruce with jack pine dominate, with a lower cover of shrubs, moss, and lichen. Higher elevations in Mackenzie Mountains are dominantly alpine tundra vegetation (lichen, dwarf shrubs, sedge), with bare rock and talus. Lower elevations in the mountains feature white spruce, willow, and birch.

Previous Work

Regional Government Surveys

The geology of the study area is covered by Geological Survey of Canada (GSC) 1:250,000 scale maps for NTS sheets 106G and H (Aitken et al., 1982), 106J (Cook and Aitken, 1975), and 106I (Aitken et al., 1969). This mapping was carried out during the GSC's Operation Norman in the late 1960s and early 1970s. Smaller scale compilation maps covering the area include works by Yorath and Cook (1981) and more recently Journeay and Williams (1995), and Wheeler et al. (1996).

Figure 2. *Ecozones, topography, and geographic names and locations mentioned in the text*

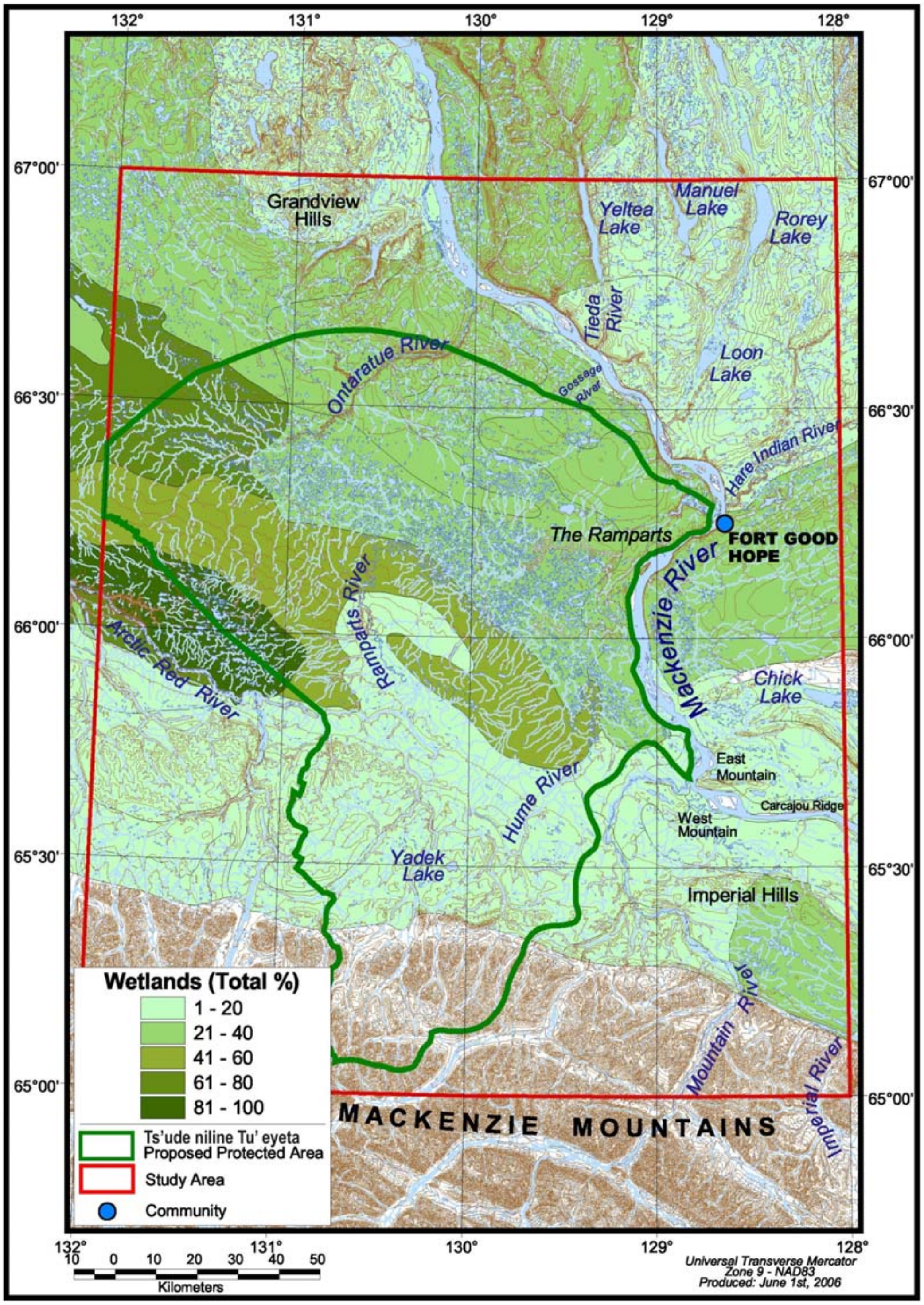

Figure 3. *Percentage of study area covered by wetlands (bogs, marshes, fens, and swamps)*

GSC surficial geology maps are published at 1:250,000 scale (or larger) for the north part of the study area (Rampton and Fulton, 1970; Duk-Rodkin and Hughes, 1992a, b) and the southern half (Hughes, 1970; Hanley et al., 1973; Monroe, 1973; Duk-Rodkin and Hughes, 1993a, b).

The GSC has published gravity anomaly maps at 1:1,000,000 scale covering the study area (Seemann et al., 1988). Aeromagnetic total field maps at 1:100,000 scale are available for NTS map sheet 106H (Dumont, 2000a-d), part of 106G (Dumont et al., 2000), 106I (Dumont et al., 2001a, b), and 106J (Dumont et al., 2001c, d). Older vintage aeromagnetic surveys (GSC G-series maps at 1:250,000 scale) cover the balance of the study area.

No known government geochemical surveys have been carried out in the area.

Oil and Gas Exploration History

Aboriginal peoples made use of oil seeps in the Mackenzie Valley well before the first commercial discovery of oil in 1920 at Norman Wells, about 140 km southeast of Fort Good Hope (NWT Department of Industry, Tourism and Investment, 2006). Exploration and development associated with the Norman Wells oilfield (the 1942-44 Canol Project) spurred geological investigations throughout the Mackenzie Valley. The first exploration well drilled within the study area was the Imperial Oil Company Sans Sault #1 (H-24) in 1944 (Figure 4).

The busiest period in exploration across the study area was in the 1960s and 1970s, when about 70% of the 44 wells drilled in the study area were completed (Figure 5). Drilling was preceded and accompanied by a considerable amount of seismic surveys (Figure 6), geological field studies, and mapping projects. Gravity surveys and other geophysical techniques were also employed. Most of the study area was covered by petroleum exploration permits for at least part of the 1960s and 1970s. Some of the major explorers included predecessors of Petro-Canada, Amoco, and Gulf. In the 1980s drilling tailed off, with five wells drilled in the area between Mountain and Mackenzie rivers. The most recent exploration has been by Chevron Canada Resources Ltd. in the early 1990’s, with five wells drilled between Ramparts and Mountain rivers. A fair number of seismic surveys were also carried out in this area in the late 1980s-early 1990s, including a small 3-D survey (Langton, 1989).

Within the proposed boundaries of the Ts’ ude niline Tu’ eyeta candidate protected area, 20 wells have been drilled between 1944 and 1991 (Figures 4, 5).

Currently there are two active Exploration Licenses (EL) within the study area (Figure 7). These are EL 415 (in the west-northwest; issued 2001, expires 2009) held by Hunt Oil Co. of Canada, and EL 401 (in the southeast; issued 2000, expires 2008) held by EOG Resources Canada. The Northern Oil and Gas Directorate of Indian and Northern Affairs Canada maintains up-to-date maps for location and status of existing Exploration Licenses, Significant Discovery Licenses, and Production Licenses (website address: http://www.ainc-inac.gc.ca/oil/index_e.html).

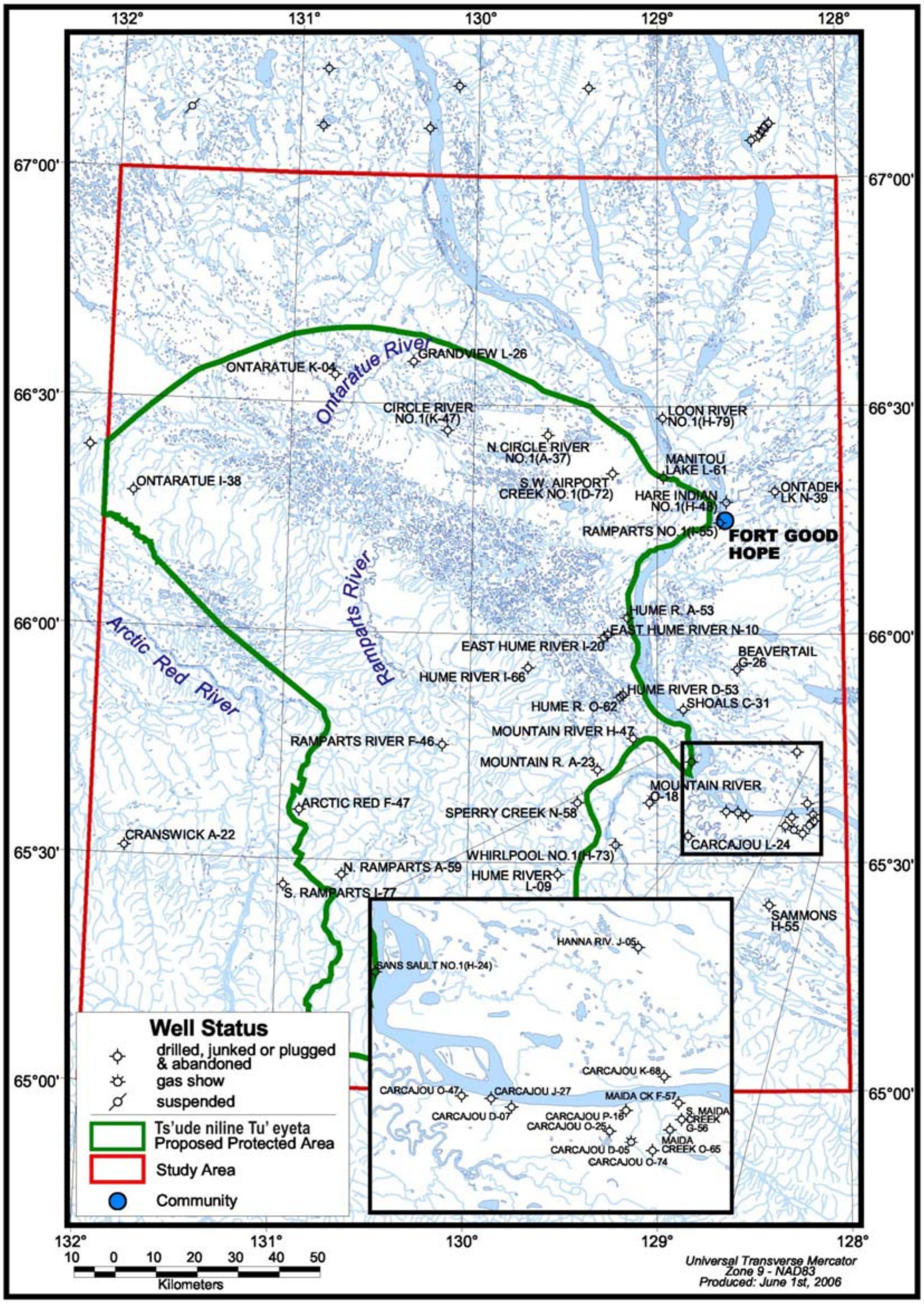

Figure 4. *Well index map*

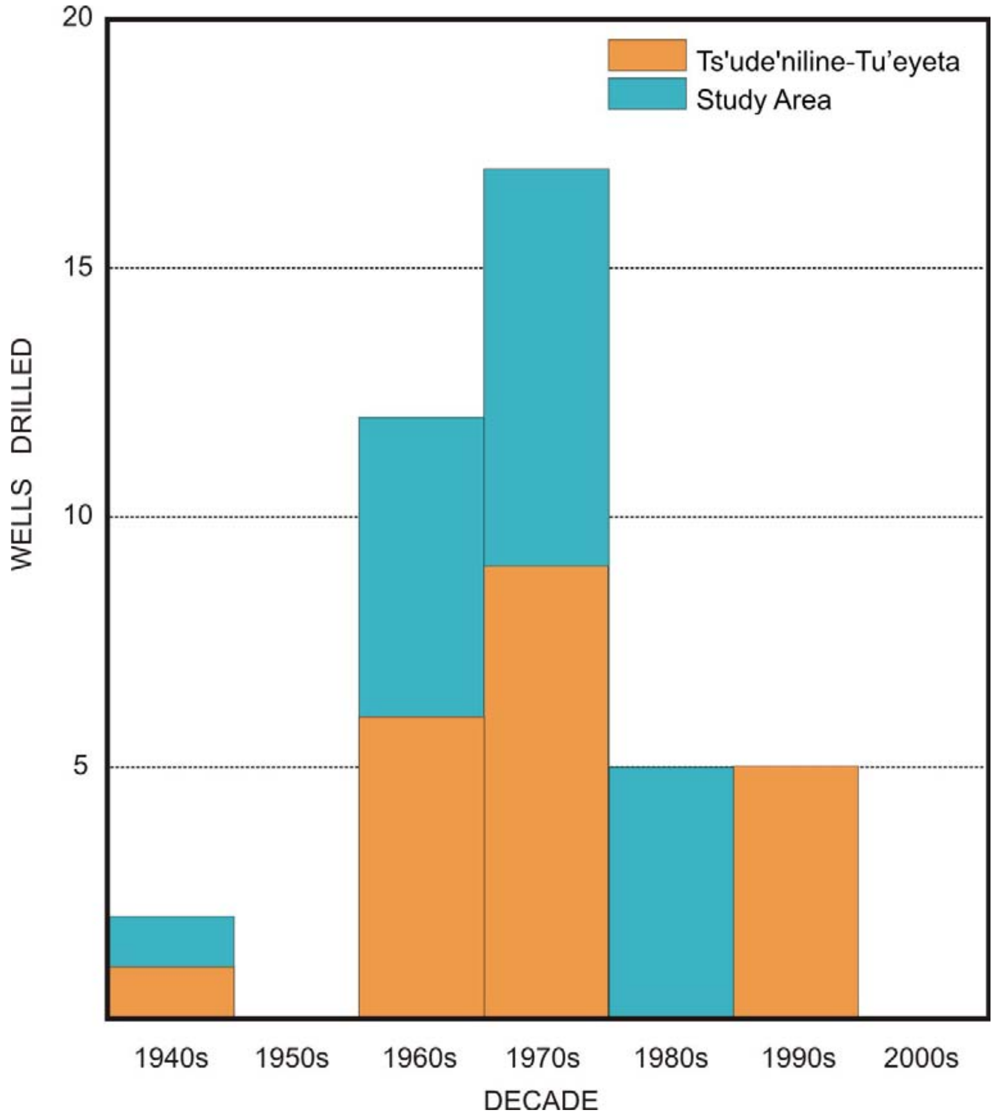

Figure 5. *Number of wells drilled by decade, within Ts 'ude niline-Tu' eyeta candidate protected area and balance of study area*

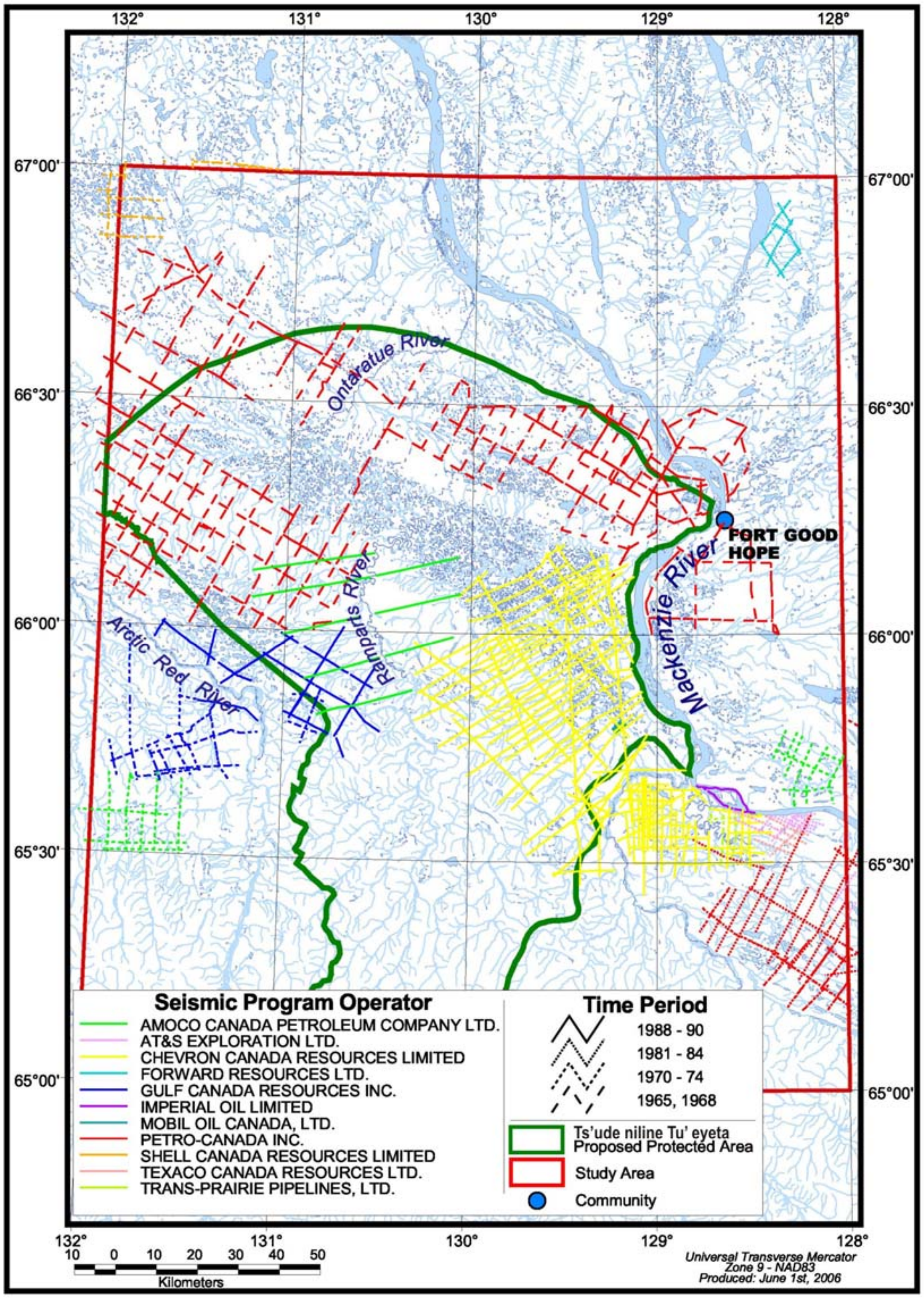

Figure 6. *Seismic survey lines by operator and year of program*

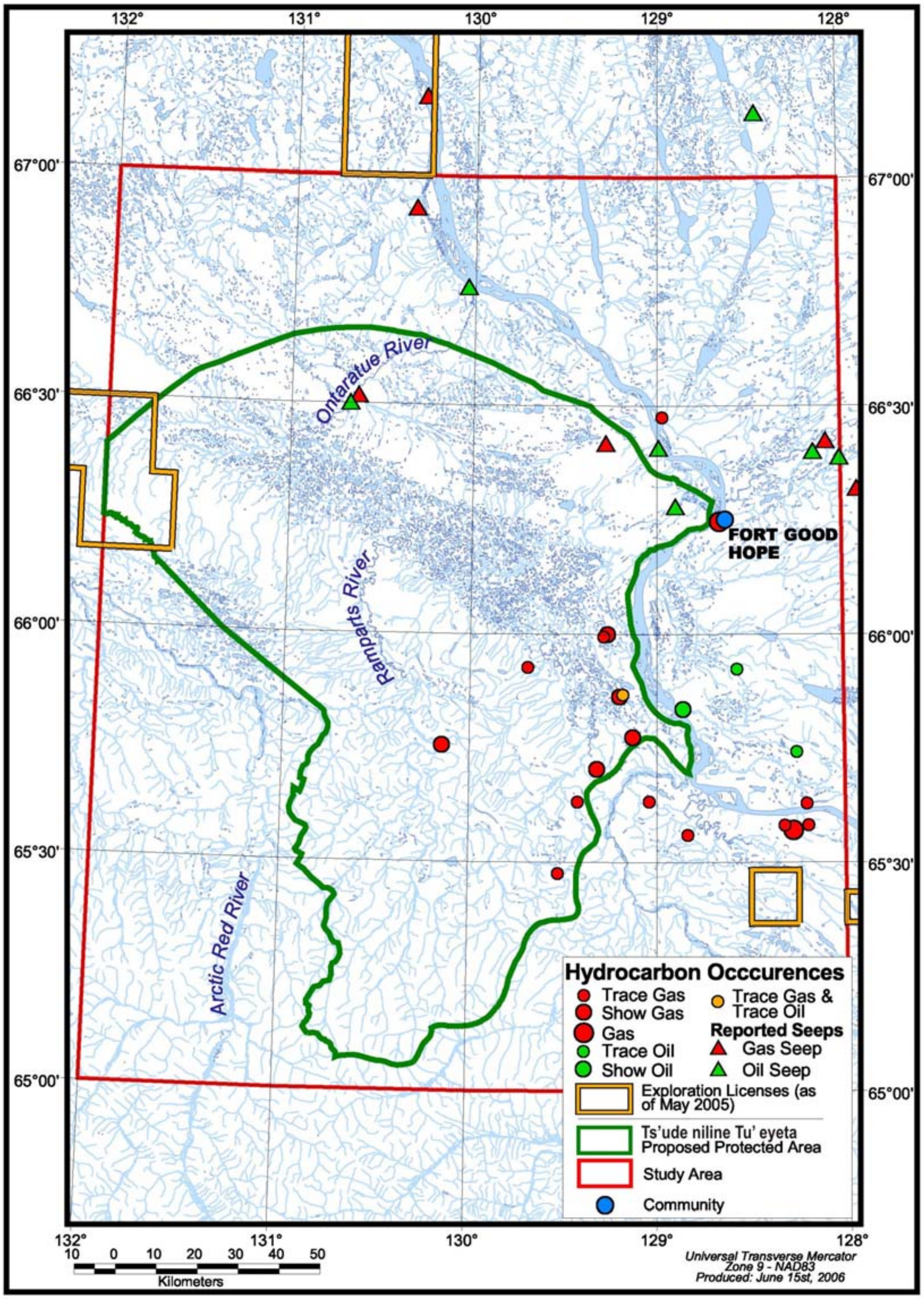

***Figure 7.** Hydrocarbon occurrences in the study area and exploration licenses*

REGIONAL GEOLOGY

General Tectonic and Geological History of the Study Area

Pyle et al. (2006) present a good review of the geology of Peel Plateau and Plain, which includes much of the current study area.

Ts' ude niline Tu' eyeta lies mainly within the Interior Platform geological province, a vast basin of Phanerozoic sedimentary rocks lying between the Canadian Shield to the east and the Cordillera to the west and south (Figure 1). Sedimentary rocks of Interior Platform are generally shallowly dipping, and form a west-southwestward thickening wedge (Figure 8). These lie upon a "basement" of Proterozoic rocks, which are also largely sedimentary.

In the southern part of Ts' ude niline Tu' eyeta are the Mackenzie Mountains, a belt of uplifted and deformed rocks that include the same Phanerozoic rocks as in the Interior Platform, and the older Proterozoic rocks. In Mackenzie Mountains, these rocks are uplifted, and exposed in folds and faulted slices.

Proterozoic sediments were deposited in an ocean basin at the edge of the ancestral North American continent, with early rifting followed by later quiescent platform conditions. Several kilometres of dominantly siliciclastic and carbonate sedimentary rocks were deposited. Periodic episodes of uplift, tilting, deformation, and erosion affected these rocks. Ancient glaciation is also indicated by the Proterozoic lithologies (e.g., Aitken, 1993).

The Phanerozoic saw continued marine deposition of sedimentary rocks. Through much of the Cambrian to Middle Devonian periods, the continental margin was a relatively tectonically quiet passive margin setting that saw the deposition of voluminous Mackenzie Platform carbonate rocks (Aitken, 1993).

The Ellesmerian orogeny began in Late Devonian time and resulted in siliciclastic sediments being shed into the study area from a landmass to the north and west (Moore, 1993). Siliciclastic deposition continued into the Carboniferous (Richards et al., 1993). A long period of non-deposition and erosion followed, through to the Jurassic (Poulton et al., 1993).

The Columbian and Laramide orogenies occurred during the Cretaceous, and formed the modern Mackenzie Mountains. Uplifted lands to the west and south shed sediments into a Cretaceous sea (Stott et al., 1993; Dixon, 1999). Upon withdrawal of the sea in the Late Cretaceous, continental alluvial and fluvial sediments were deposited.

Subsequent erosion and Pleistocene glaciation events modified the landscape and left a veneer of glacio-fluvial unconsolidated sediments over much of the study area. Fluvial erosion continues today, particularly in the upland areas, and the Mackenzie River and its tributaries carry a large volume of sediment.

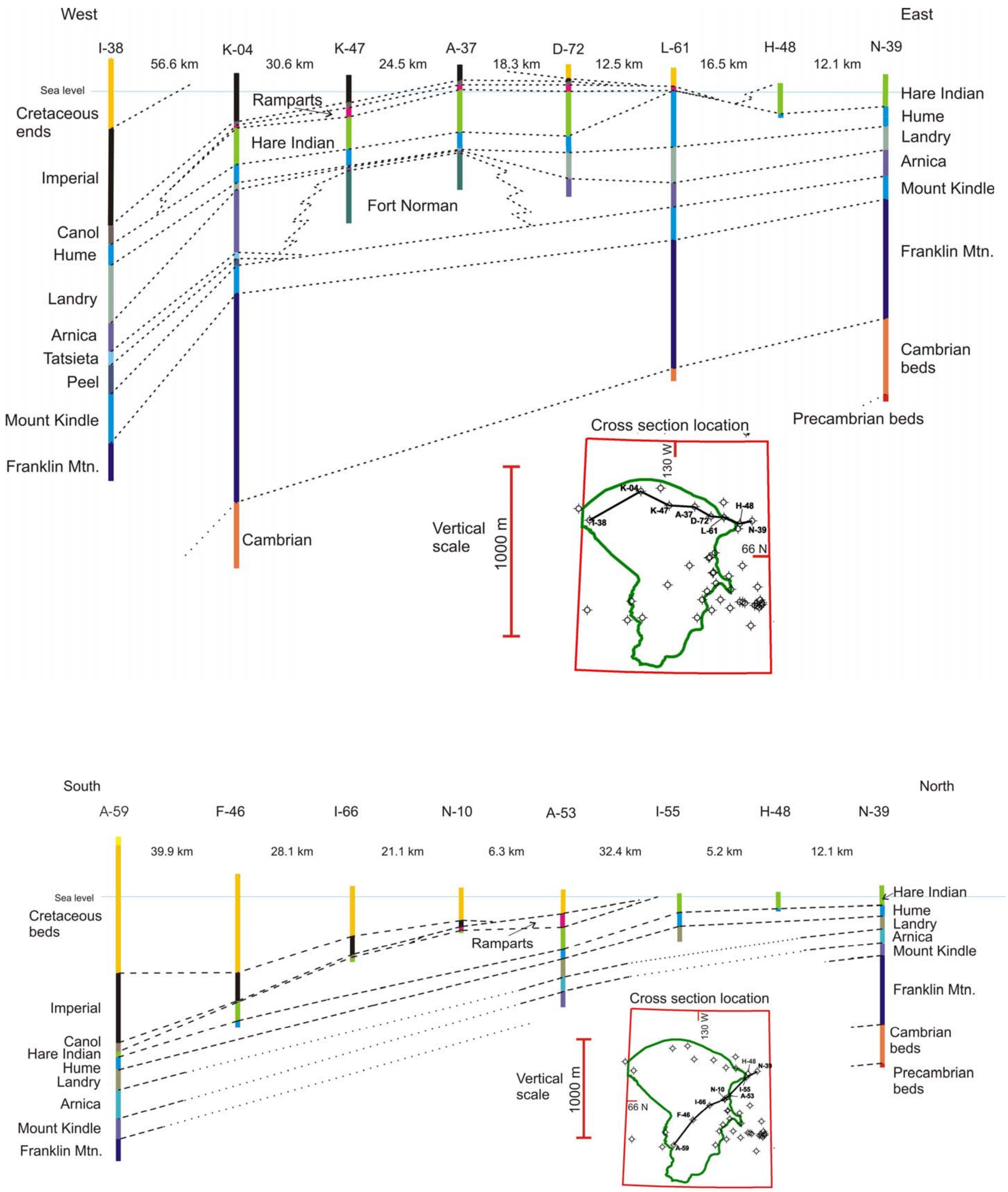

***Figure 8**. West-east and north-south cross sections from well data across Ts' ude niline Tu' eyeta. Vertical bars represent wells (indicated on index map inset) and colours represent formations. Distance between wells (in km) and vertical scale bar are indicated; horizontal and vertical scales are not equal*

Proterozoic Geology

A basement of Proterozoic rocks underlies the Phanerozoic succession throughout the study area. Proterozoic rocks are known from outcrops in Mackenzie Mountains, and from wells within the study area that penetrated the basement. Morphology of the basement surface can be inferred from seismic surveys. In the north half of the study area, the surface dips gently west-southwest, while in the south, the dip is relatively steep and south trending (Figure 9). Gentle warps and flexures were also identified on basement surface (MacLean, 1999), which could be tectonic and/or erosional features.

Lithology of basement rocks in the Interior Platform has been inferred from geophysical surveys (magnetics, gravity) and from rare borehole intersections. Four assemblages of Middle and Late Proterozoic unmetamorphosed sedimentary rocks have been identified, including two that are exposed in Mackenzie Mountains (Figure 10). These four assemblages were deposited over a time period of more than 1 billion years, and they overlie still older metamorphic, igneous, and volcanic rocks. Brief lithological descriptions below are taken primarily from Aitken (1993).

Hornby Bay assemblage

Hornby Bay assemblage rocks comprise feldspathic sandstones, conglomerates, and mudrocks, with a significant amount of carbonate beds in the upper part of the section. The assemblage is up to three km thick. MacLean (1999) interpreted Hornby Bay rocks to be distributed through the central and western parts of the study area (Figure 10). However, Aitken (1993) shows most of the study area being underlain by Mackenzie Mountains supergroup (see below).

Dismal Lakes assemblage

Dismal Lakes assemblage overlies Hornby Bay assemblage. Lithologies include mainly siliciclastic rocks in the lower third of the unit, and carbonate rocks in the upper part. Hornby Bay and Dismal Lakes assemblages together were deposited from about 1660 to 1210 million years ago (Ma; Cook and MacLean, 2004). Dismal Lakes assemblage underlies the northeast part of the study area (Figure 10).

Mackenzie Mountains supergroup

Mackenzie Mountains supergroup, in the lower part of the section, is composed of sandstones, shales, and siltstones overlain by grey cherty dolostone. These units are overlain by mudstones with subordinate sandstone and carbonate of Tsezotene Formation. Above this lies quartz sandstone, minor shale, and carbonate rock of Katherine Group. The supergroup is capped by Little Dal Formation; a lithologically varied package of limestone, dolostone, anhydrite, gypsum, mudstone, and sandstone. Flows of basaltic lava are locally preserved at the top of Little Dal Formation. Mackenzie Mountains supergroup is up to four km thick, and deposited from about 1,000 to 780 Ma (Pyle et al., 2006).

Mackenzie Mountains supergroup outcrops in Mackenzie Mountains in the southern part of the study area, and correlates with Shaler Assemblage (Shaler Group of some workers) inferred to underlie the east-central part of the study area (MacLean, 1999). Figure 11 schematically illustrates the stratigraphic relationships of Mackenzie Mountains supergroup in the study area.

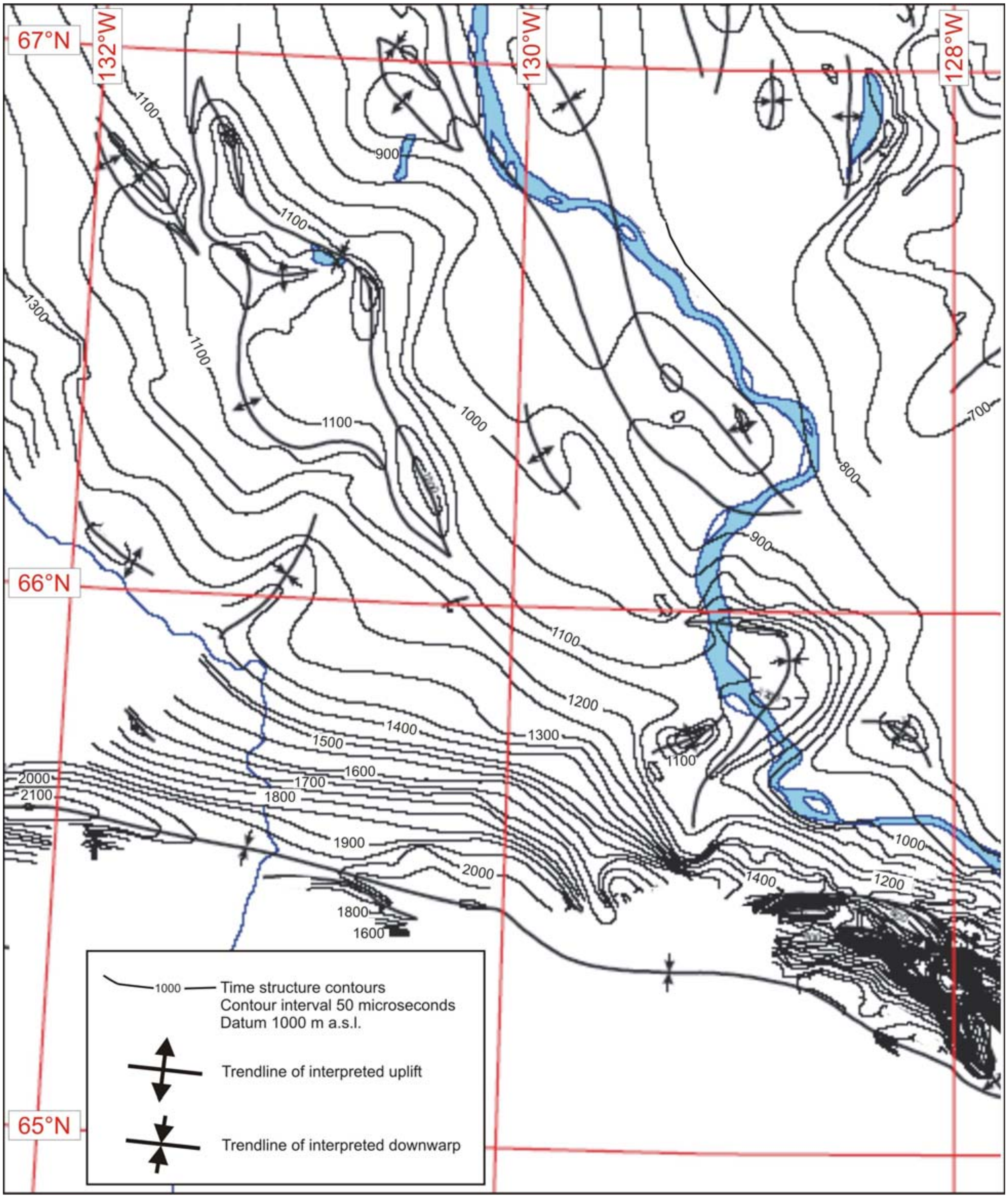

Figure 9. *Structure contours on basement (Proterozoic) surface, interpreted from seismic survey data (after MacLean, 1999)*

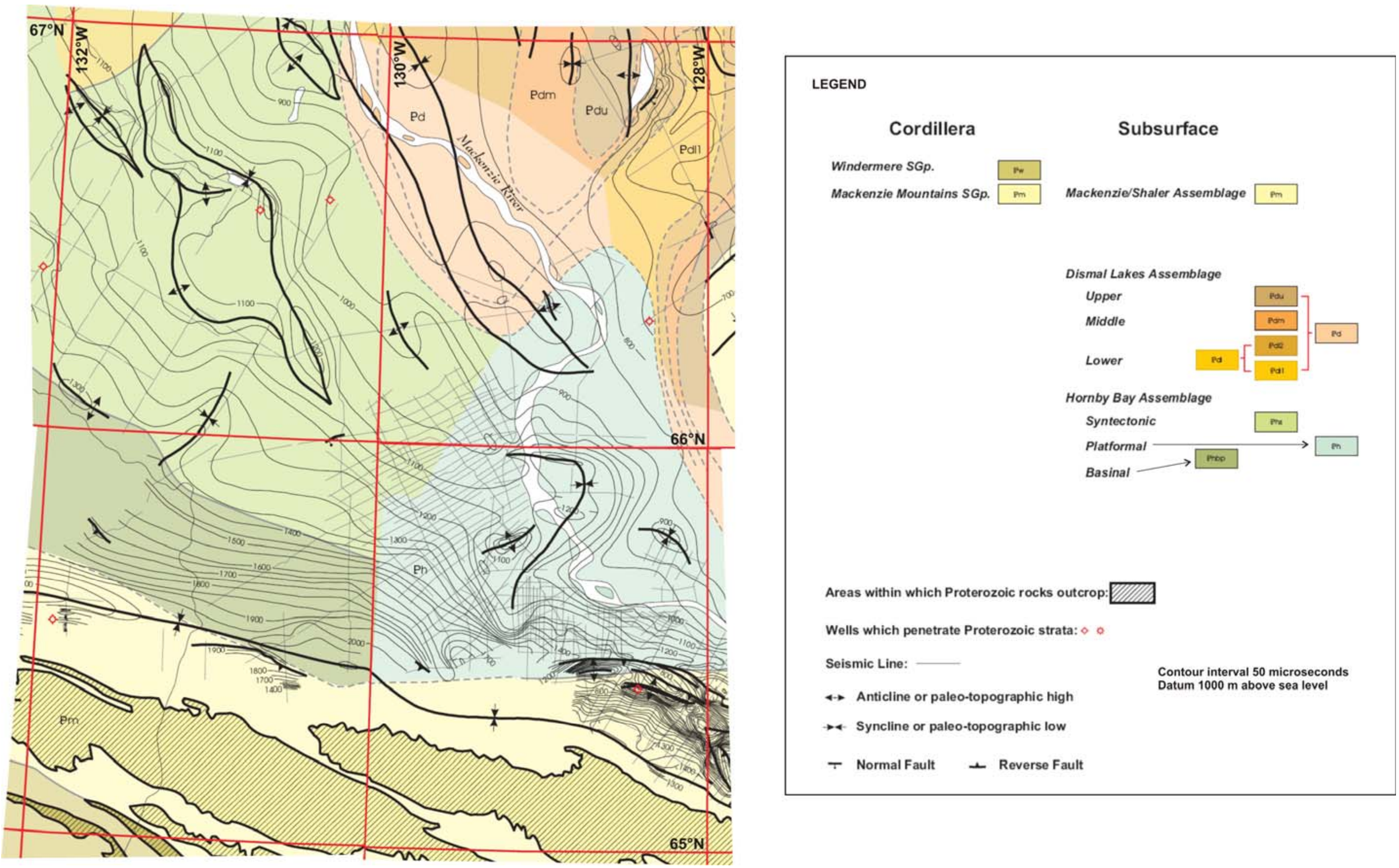

Figure 10. *Interpreted basement (Precambrian) geology, after MacLean (1999)*

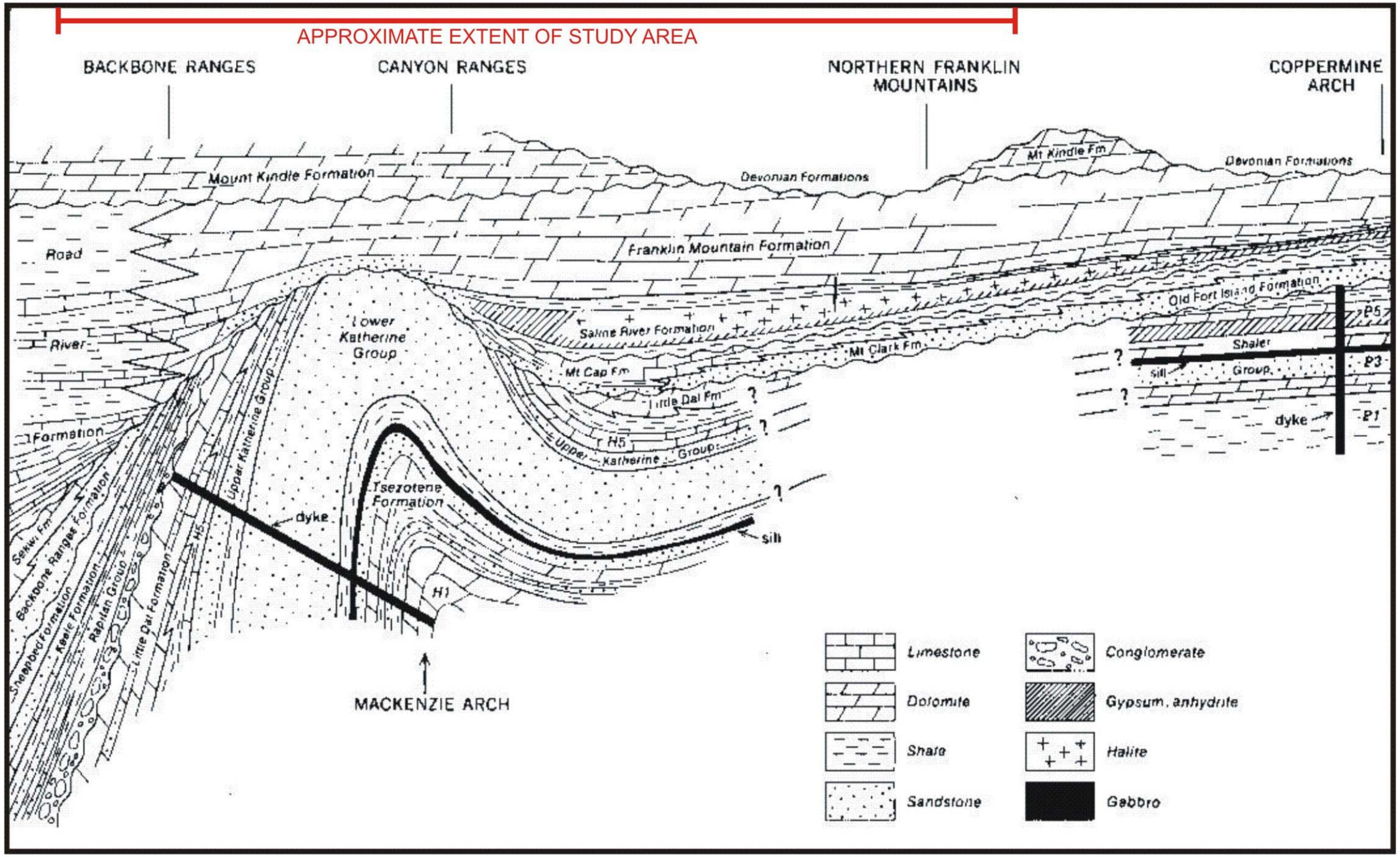

Figure 11. *Diagrammatic restored regional stratigraphic (sub-Devonian) cross section, Mackenzie Mountains and eastward. Approximate location of study area indicated by red line. From Aitken et al. (1973)*

Windermere supergroup

Latest Proterozoic Windermere supergroup strata outcrop in the interior ranges of Mackenzie Mountains, in the extreme southwest corner of the study area. The basal Thundercloud Formation includes volcanic-derived sandstone and conglomerate, limy mudstone, dolostone, minor evaporates, and cyclically interbedded sandstone and shale. It is gradationally overlain by Redstone River Formation fanglomerates, redbeds, and anhydrite. Coppercap Formation carbonate rocks gradationally succeed Redstone River Formation. Sayunei Formation locally overlies Coppercap Formation conformably, but commonly is unconformable, and in many places is the oldest Windermere supergroup unit present. It consists of varicoloured siltstone, argillite, sandstone, conglomerate, and diamictite. Iron formation occurs widely near the top of the unit. Shezal Formation overlies Sayunei or older formations. It consists mainly of very thick-bedded greenish or reddish diamictite, with minor interbeds of sandstone and mudstone.

Shezal Formation is overlain by six formations, which comprise three shale-carbonate cycles. These are: Twitya Formation (mudstones and distal turbidites) and Keele Formation (dolostone, limestone, with a middle shaly member); Sheepbed Formation (mudstone and minor coarse sandstones) and Gametrail Formation (carbonate); and Blueflower Formation (mudstone, turbiditic sandstone, and limestone) and Risky Formation (carbonate). These shale-carbonate couplets top the Proterozoic section.

Middle to Late Proterozoic Tectonic and Depositional History

The summary below is taken from Aitken (1993) and illustrated in Figure 12. Sedimentation associated with the Hornby Bay/Dismal Lakes assemblages began before 1660 Ma and ended before eruption of Coppermine basalts (1270-1210 Ma), northeast of the study area. Hornby Bay assemblage was deposited in an extensional basin, with minor associated volcanism. Faults were periodically reactivated. Dismal Lakes assemblage was deposited in a trangressive regime ranging from earlier fluvial clastic environments to later marine carbonate shelf carbonate rocks. The continental margin faced north and west.

Locally significant unconformities between Hornby Bay and Dismal Lakes assemblages indicate an intervening period of uplift and erosion. Both assemblages, as well as overlying Coppermine basalts were subsequently deformed during the Racklan Orogeny.

Uplift and erosion preceded deposition of the Mackenzie Mountains supergroup. A maximum age for these deposits may be 1000 Ma (Rainbird et al., 1996), and they are cut by basic intrusions dated 780 Ma (Harlan et al., 2003). The sedimentary environment was a continental platform margin. Individual units thicken basinward, toward the southwest. Some workers suggest that Mackenzie Mountains supergroup was deposited in a “two-sided basin”, i.e., with continental margins to northeast and south or west (Aitken, 1993).

Uplift, tilting, and erosion followed deposition of Mackenzie Mountains supergroup, as indicated by regional unconformities. Rifting was initiated, accompanied by local volcanism. Diamictite deposits indicate glacio-marine sedimentation.

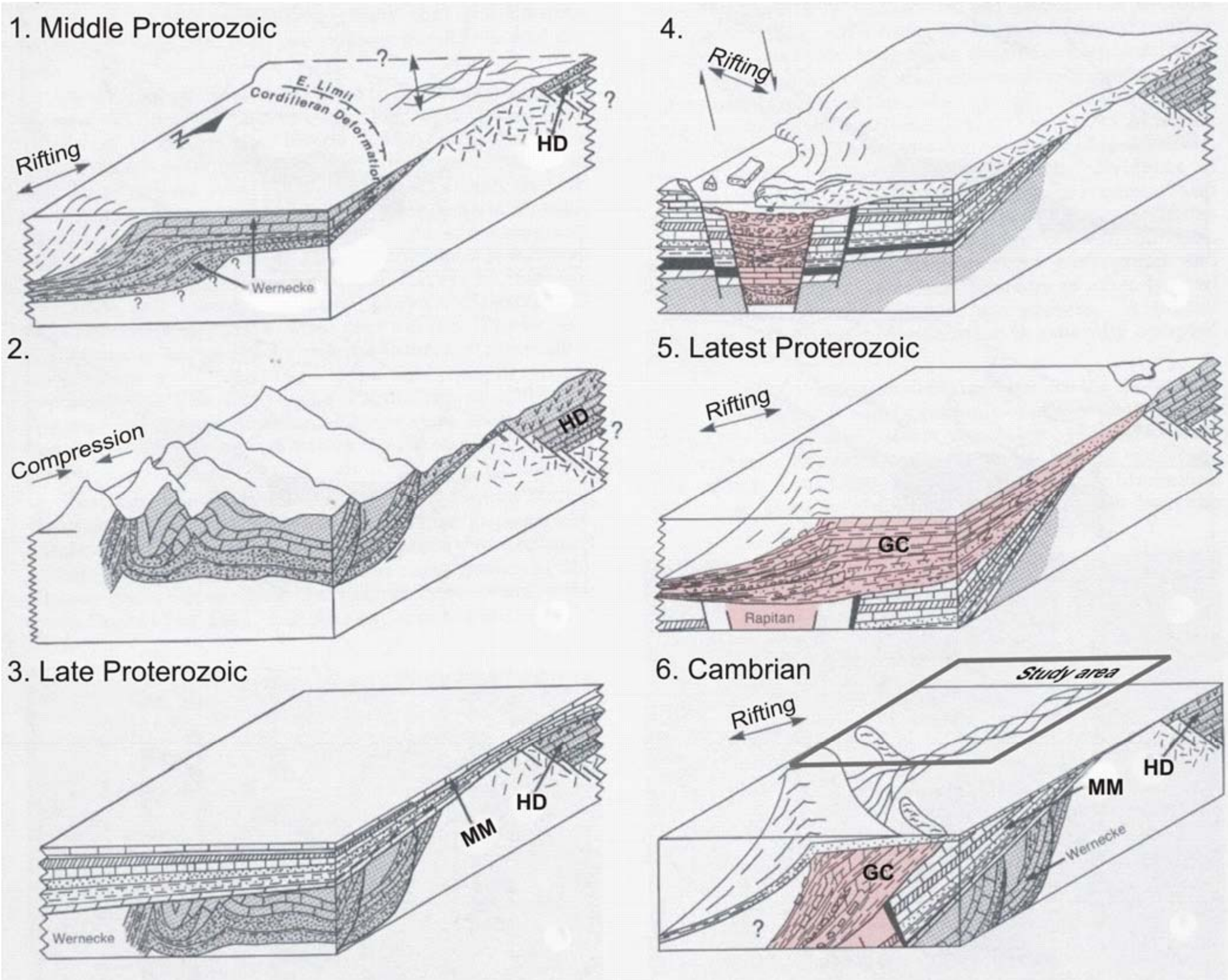

Figure 12. *Middle Proterozoic to Cambrian depositional and tectonic history of the study area and region: 1. Deposition of Wernecke Supergroup on cratonic margin and epicratonic Hornby Bay – Dismal Lakes assemblages (HD) 2. Eruption of Coppermine basalts above HD, and Racklan orogeny (deformation of Wernecke supergroup) 3. Erosion, and deposition of Mackenzie Mountains supergroup (MM; Tsezotene to Little Dal formations) 4. localized rifting, volcanic intrusions, deposition of Rapitan Group and Windermere supergroup (Thundercloud to Shezal formations) 5. Subsidence, deposition of Windermere supergroup carbonate-shale cycles (GC; Twitya to Sheepbed formations) 6. tilting, erosion, deposition of the first Cambrian beds. The grey polygon represents the approximate study area. After Aitken (1993)*

By the latest Proterozoic, rifting had subsided and there was widespread subsidence along a passive continental margin hinge. A series of shale-carbonate cycles were deposited as sea levels rose and fell in a marine platform to basin environment.

These latest Proterozoic marine deposits were followed by another phase of uplift and local erosion, and then finally by marine transgression, and deposition of the basal Cambrian beds.

Phanerozoic Geology

Throughout the study area, the total thickness of Phanerozoic rocks increases from northeast to southwest, from less than 2,100 m in the northeast to over 4,000 m in the southwest (Morrell, 1995). Cambrian through Cretaceous rocks are present. Unconsolidated Quaternary deposits of varying thickness cover much of the study area, effectively obscuring bedrock, except in the mountain regions and the larger stream valleys. Table 3 summarizes the Phanerozoic stratigraphic units of the study area. Distribution of Phanerozoic formations in the study area subsurface is presented schematically in Figure 13. Figure 14 is a bedrock geology map. The lithology, nature of contacts, distribution, and thickness of the formations, ordered from oldest to youngest, are described below. These are followed by brief summaries of the tectonic and depositional history of the rock units.

Phanerozoic Stratigraphy-Cambrian to Silurian

Mount Clark Formation

Early Cambrian Mount Clark Formation lies unconformably above Proterozoic basement. Mount Clark Formation is quartzose sandstone, fine-grained to predominantly medium to coarse-grained, with lesser conglomerate and siltstone-shale beds. There may be silica cement and/or degrees of silicification (e.g., Rose, 1984). Mount Cap Formation generally overlies Mount Clark Formation disconformably. Mount Clark Formation is restricted to the eastern edge of the study area (Hamblin, 1990; Pugh, 1993; Dixon, 1997), although there may be outliers further west (Pugh, 1983; and see below). Distribution of the unit is quite irregular, as it fills paleo-depressions and topographical irregularities on the Proterozoic basement surface. The unit is over 50 m thick east of the study area (Pugh, 1993).

Within the study area, subsurface occurrences are not certain, although five wells likely penetrated the basement, and hence would have intersected Mount Clark Formation if present. In Ontaratue K-04, up to75 m of reddish-brown and greenish grey quartzite and black argillite occurs in the bottom of the hole, at least part of which may correlate with Mount Clark Formation. The well sample logs for Cranswick A-22 (Cannon, 1972a) reported 6 m of fine-grained white to light grey fine-grained quartzite at the base of the hole, called Cambrian by the operator, but it may in fact be Proterozoic. Differentiation of the Cambrian from underlying Proterozoic Katherine Group quartz sandstones may be through grain size (as reported by Pugh, 1983): Mount Clark Formation should include some medium-grained or coarser sand, while underlying Katherine Group sandstones are dominated by the very fine fraction, with almost nothing coarser.

In the extreme southwest corner of the study area, age-equivalent strata comprising quartz sandstones, quartzites, dolostone, and shale of Backbone Ranges Formation crop out at the head of Arctic Red River.

PERIOD (EPOCH)			FORMATION (OR GROUP/ASSEMBLAGE)		MAJOR LITHOLOGIES
			West part of study area	East part of study area	
Quaternary	Pleistocene		Laurentide till, glaciofluvial deposits	Laurentide till, glaciofluvial deposits; Columbian till	sand, gravel, till,
unconformity					
Cretaceous	Late (?)		Slater River	--	shale
			Trevor	--	sandstone
	unconformity				
	Early-Middle		Trevor	--	shale, sandstone (?)
			Arctic Red	Arctic Red	shale, siltstone, sandstone
			Martin House	Martin House	sandstone, siltstone, shale
unconformity					
Carbon-iferous	Early		Tuttle	--	sandstone, conglomerate, siltstone
unconformity					
Devonian	Late		Imperial	Imperial	siltstone, shale, sandstone
			Canol	Canol	shale
	unconformity				
	Middle		--	Ramparts	limestone, siltstone, shale
			Hare Indian	Hare Indian	shale, siltstone
			Hume	Hume	limestone, shale
	Early		Landry	Landry (Bear Rock at surface)	limestone, dolostone, carbonate breccia
			Arnica	Arnica (Bear Rock at surface)	dolostone, limestone, carbonate breccia
				Fort Norman	anhydrite, dolostone
			Tatsieta	--	limestone, dolostone, shale,
			Peel	--	dolostone, limestone
unconformity					
Ordovician–Silurian			Mount Kindle	Mount Kindle	dolostone
unconformity					
Cambrian–Ordovician			Franklin Mountain	Franklin Mountain	dolostone
Cambrian (Early-Middle)			Saline River	Saline River	shale, dolostone, evaporites
			unconformity (?)		
			Mount Cap	Mount Cap	dolostone, shale, quartzose sandstone
			Mount Clark (?)	Mount Clark	quartzose sandstone
unconformity					
Proterozoic	Late Proterozoic	Windermere supergroup	Risky	--	carbonate
		Windermere supergroup	Blueflower	--	mudstone, sandstone, limestone
		Windermere supergroup	Gametrail	--	carbonate
		Windermere supergroup	Sheepbed	--	mudstone, sandstone
		Windermere supergroup	Keele	--	dolostone, limestone, shale
		Windermere supergroup	Twitya	--	mudstone, turbidite
		Windermere supergroup	Shezal	--	diamictite, sandstone, mudstone
		Windermere supergroup	Sayunei	--	siltstone, argillite, sandstone, conglomerate, diamictite, iron formation
		Windermere supergroup	unconformity		
		Windermere supergroup	Coppercap	--	carbonate
		Windermere supergroup	Redstone River	--	fanglomerate, redbeds, anhydrite
		Windermere supergroup	Thundercloud	--	sandstone, conglomerate, mudstone, dolostone, shale
		Mackenzie Mountains supergroup	Little Dal	Little Dal	limestone, dolostone, evaporates, mudstone, sandstone, gabbro
		Mackenzie Mountains supergroup	Katherine Group	Katherine Group	quartz sandstone, carbonate, shale
		Mackenzie Mountains supergroup	Tsezotene	Tsezotene	mudstone, sandstone, carbonate
		Mackenzie Mountains supergroup	unnamed	unnamed	sandstone, shale, siltstone, dolostone
	unconformity				
	Early-Middle Proterozoic		--	Dismal Lakes assemblage	siliciclastic and carbonate
			unconformity		
			Hornby Bay assemblage	Hornby Bay assemblage	sandstone, conglomerate, mudstone, carbonate

***Table 3**. Table of formations*

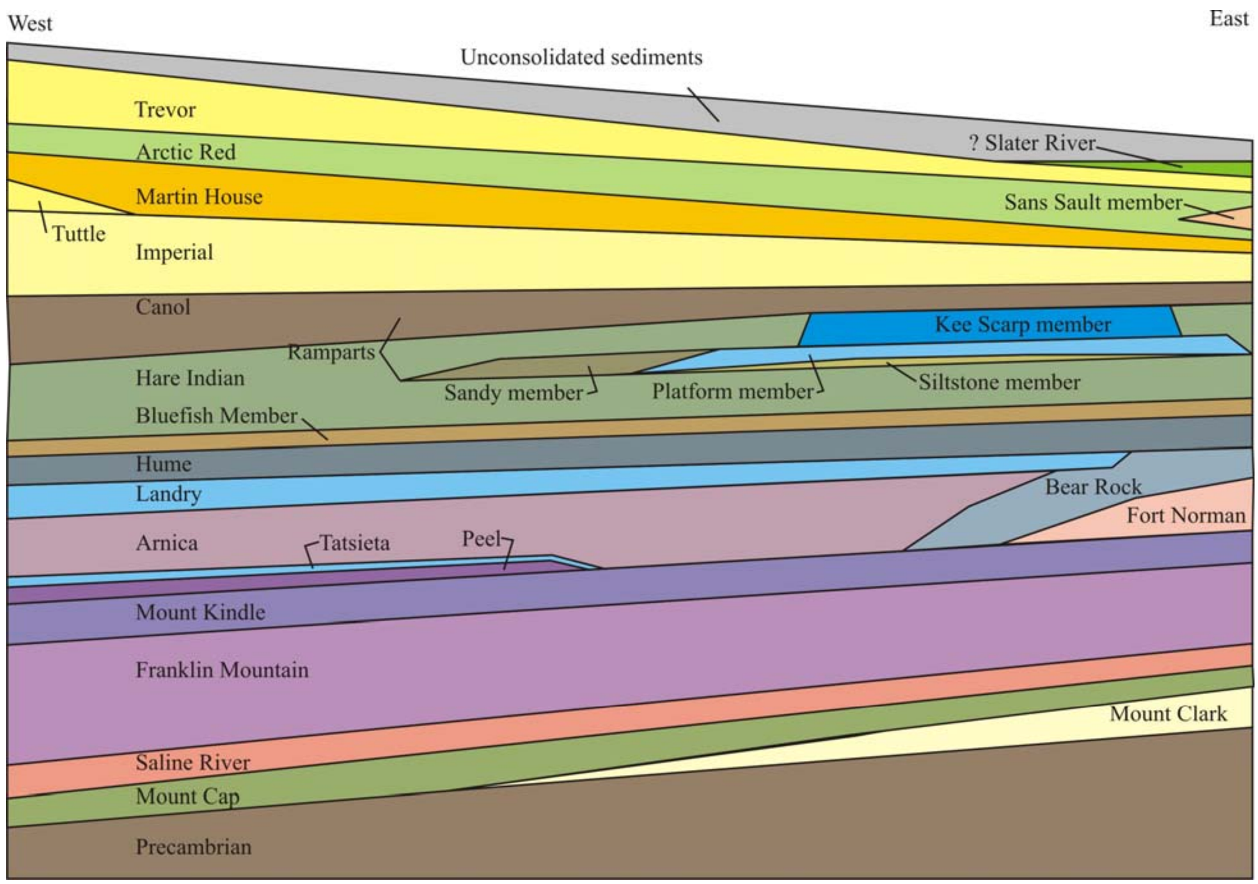

Figure 13. *Schematic stratigraphic relationships between Phanerozoic formations in a west to east section of subsurface of study area*

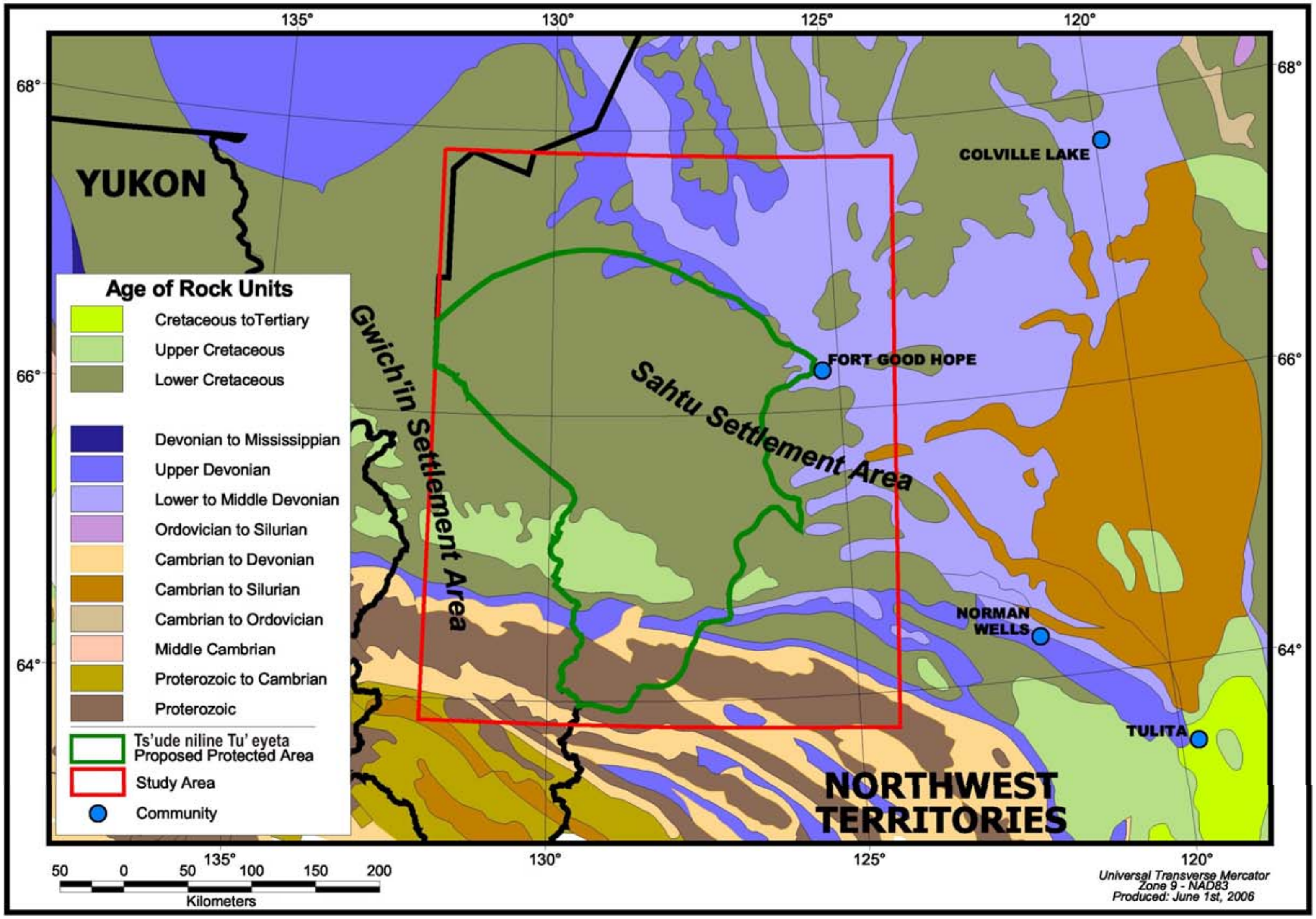

Figure 14. *Bedrock geology map of the study area (from Wheeler et al., 1996)*

Mount Cap Formation

Early to Middle Cambrian Mount Cap Formation comprises varicoloured shale, siltstone, dolostone, and lesser chert, oolite, sandstone, and siltstone in the eastern part of the study area (Pugh, 1983). The sediments are characteristically glauconitic. The lower contact with Mount Clark Formation is abrupt. The upper contact with Saline River Formation is likely a minor depositional hiatus (Pugh, 1993).

Mount Cap Formation is distributed widely throughout the study area, although it is locally absent. More than 150 m of strata is present in the northeast corner of the study area around Manuel Lake (Pugh, 1993). In the southeast corner of the study area, Mount Cap Formation outcrops in Imperial River canyon.

Saline River Formation

Middle Cambrian Saline River Formation comprises: a lower clastic member of dominantly greenish and more rarely maroon shale, argillaceous dolostone and associated anhydrite; a middle member of salt, anhydrite, dolostone, and varicoloured shale; and an upper member of maroon and greenish, dolomitic, or silty shale with interbedded dolostone and anhydrite (Dixon and Stasiuk, 1998). Salt is restricted in distribution to the east side of the study area (Pugh, 1983). Saline River Formation is gradationally and conformably overlain by Franklin Mountain Formation.

Saline River Formation is widely distributed through the study area, thinning to the southwest and west toward a depositional edge near 133°W (Pugh, 1983). Over 300 m of Saline River strata occurs in the central eastern part of the study area, just northwest of Fort Good Hope. In Ontadek N-39, 265 m of salt occurs, but this is likely due to some tectonic thickening. Saline River Formation outcrops in places at the front of Mackenzie Mountains in the southeastern corner of the study area.

Franklin Mountain Formation

Upper Cambrian to Ordovician Franklin Mountain Formation is dominated by gray, fine-grained dolostone and is divided into four (some workers identify three) informal members (Pugh, 1983). The lowermost cyclic member consists of argillaceous brown and grey dolostone with interbedded shale, which decreases upward in the section. The rhythmic member comprises very fine to medium-grained, pale grey and buff dolostone. The overlying cherty unit comprises fine to coarse-crystalline, pale grey to white dolostone with pale to multi-coloured chert abundant near the top of the unit, and silicified oolites and clear quartz grains. The uppermost dolostone member, locally absent due to erosion comprises pale, medium to coarse-crystalline dolostone.

Franklin Mountain Formation is a regionally distributed, widespread unit. It overlies Saline River Formation gradationally and is overlain unconformably by Mount Kindle Formation. Thickness increases from southeast to northwest across the study area, from 500 m to about 1,000 m (northwest of Ontaratue K-04). Franklin Mountain Formation outcrops widely in Mackenzie and Franklin mountains (Norman Range) within the study area.

Mount Kindle Formation

Late Ordovician to Silurian Mount Kindle Formation is composed mainly of medium to dark greyish-brownish fine-grained crystalline dolostone, with some chert and silicified fossils. It is undivided through much of the study area, although Pugh (1993) recognized three informal members in the southeastern corner of the study area.

Mount Kindle Formation unconformably overlies Franklin Mountain Formation, and is unconformably overlain by Peel Formation or younger beds. Mount Kindle Formation occurs throughout the subsurface in the study area, increasing in thickness from approximately 100 m in the east to 300 m in the west.

Cambrian to Silurian Tectonic and Depositional History

The following section is summarized from Pugh (1983). Lower Paleozoic sediments in the study area were deposited in a marine platform environment (the Mackenzie Platform) under mainly quiescent conditions, established after continental separation and rifting in earliest Cambrian time. The continental shoreline lay to the east, and to the west, the broad upwarp of the Mackenzie Arch limited the deposition of sediments (Figures 11, 15). There were scattered offshore highlands underlain by more resistant Proterozoic lithologies. Further to the west, beyond the study area, lay the deep basin of the Richardson Trough.

Basal Cambrian quartz sandstones (Mount Clark Formation) were deposited in paleotopographic depressions on the Precambrian surface, during marine transgression. Sediment sources might have been the Precambrian Shield, and/or Proterozoic quartz sedimentary rocks exposed on Mackenzie Arch (Pugh, 1983). Continued sea level rise and encroachment accompanied sedimentation of Mount Cap Formation shales and oolitic dolostones. The Mackenzie Arch likely continued to act as a barrier separating the relatively shallower Mackenzie platform sea from the deeper basin to the west and south. Further uplift on the Mackenzie Arch during the end of Mount Cap deposition resulted in some erosion of these beds, and gave rise to shallow restricted marine basins that hosted evaporite deposition (salt, anhydrite) of middle Saline River Formation.

Following the restricted marine conditions, there was slow subsidence of the entire marine shelf, creating open marine conditions and deposition of progressively less shale (upper part of Saline River, lower Franklin Mountain formations), and then a thick carbonate sequence (Franklin Mountain, Mount Kindle, Peel formations). From latest Cambrian to Silurian time, the cratonic shelf was generally tectonically stable, with periods of uplift and erosion. The Keele Arch, southeast of the study area, may have been a topographically positive feature as early as Middle Cambrian, limiting the deposition of sediments (Yorath and Cook, 1981).

Phanerozoic Stratigraphy-Devonian to Mississippian

Peel Formation

Upper Silurian (?) to Lower Devonian Peel Formation is present in the western half of the study area, but removed by erosion in the east (Pugh, 1983). Peel Formation is composed mainly of pale grey and buff, fine-grained to micro-sucrosic dolostone. Some medium-crystalline, darker

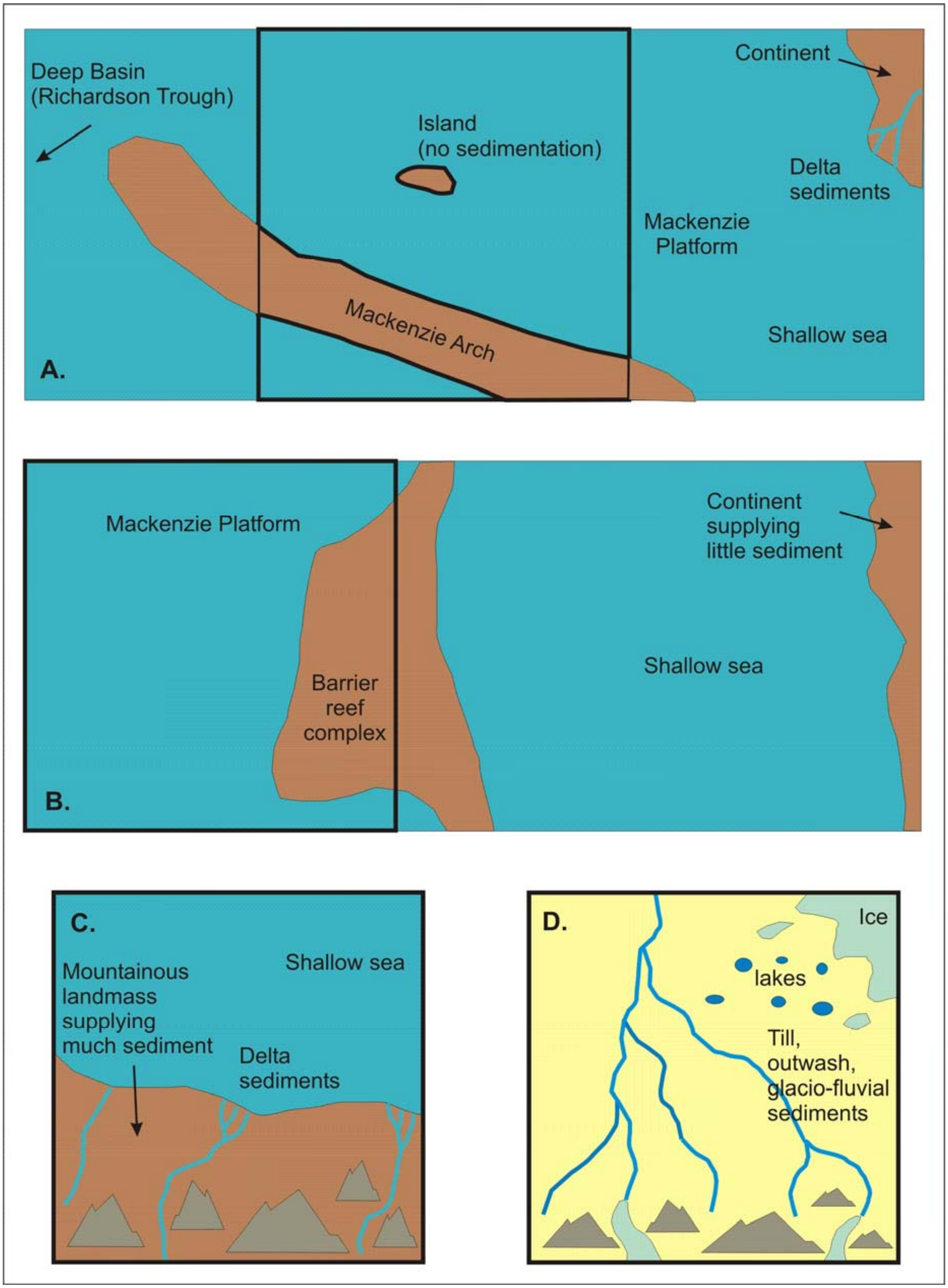

Figure 15. *Schematic paleogeographic maps of the study area (bold outlined box) in A: lower Cambrian time, B: Middle Devonian time, C: Late Cretaceous time, and D: Pleistocene time (about 13,000 years ago)*

argillaceous dolostone may be present in the lower part, and dark grey shale occurs in the upper part of the unit. The lower contact with Mount Kindle Formation is unconformable, and may represent the region-wide sub-Devonian unconformity, while the upper contact is gradational. Peel Formation increases in thickness westward from a zero edge to about 200 m.

Tatsieta Formation

Lower Devonian Tatsieta Formation comprises pale buff very fine-grained limestone and pale green shale, with some dolostone. It is present in the western part of the study area, with an erosional zero edge at about 130°W (Pugh, 1993). Tatsieta Formation lies conformably (and gradationally?) above Peel Formation (Morrow, 1999), although Pugh (1983) presented a different interpretation. The upper contact with Arnica Formation is conformable. Tatsieta Formation is up to approximately 100 m thick in the northwest corner of the study area.

Tatsieta and Peel formations outcrop in the southwestern corner of the study area, in the upper Arctic Red River drainage. Aitken et al. (1982) mapped the units as unnamed Upper Silurian and Lower Devonian beds, together which are called Delorme group by many workers.

Fort Norman Formation

Lower Devonian Fort Norman Formation is dominantly anhydrite with dolostone. It is restricted to the southeastern corner of the study area, and is in part, equivalent to Arnica and Landry formations (see below). Fort Norman Formation unconformably overlies Mount Kindle Formation, and is gradationally overlain and interfingered with Arnica and Landry formations. Over 200 m of strata lie in the extreme southeastern corner of the study area, although there may be some structural thickening in this area (Pugh, 1983).

Equivalent strata mapped in the Mackenzie and Franklin mountains (Aitken and Cook, 1974) are termed Bear Rock Formation and include gypsum, dolostone, and carbonate solution-breccias.

Arnica Formation

Lower Devonian Arnica Formation consists of medium to dark grey-brown and buff very finely crystalline dolostone (with local minor limestone, particularly in the west). It is a widely distributed unit throughout the study area (as is overlying Landry Formation), with conformable and somewhat gradational contacts. The thickness increases from 50 m in the southeast, northwestward to about 200 m.

Surface exposures in Franklin Mountains, and eastern part of Mackenzie Mountains in the study area were assigned to Bear Rock Formation (Aitken and Cook, 1974).

Landry Formation

Lower Devonian Landry Formation comprises lower pale buff and upper, brown, fine-grained, and variably argillaceous and/or pelletal limestone with shale interbeds.

Landry Formation conformably overlies Arnica Formation, and is unconformably overlain by Hume Formation. Landry Formation is up to approximately 250 m thick and thins eastward to an erosional edge.

Landry Formation outcrops in the southwestern part of the study area. Toward the east, it is undifferentiated in outcrop from Arnica Formation, and together they are mapped as Bear Rock Formation (Aitken and Cook, 1974).

Hume Formation

Middle Devonian Hume Formation is composed of bioclastic, fossiliferous, and argillaceous limestone interbedded with greenish or grey calcareous shale. Many workers call the shaly lower part Headless Formation, which is the correlative unit found south and west of the study area. Pugh (1993) proposed it be called Headless member, comprising grey microcrystalline and argillaceous limestone, and much grey to black shale. This lower member is overlain by a middle member of bioclastic, fossiliferous limestone with varying amounts of argillaceous limestone and calcareous shale. The uppermost member is characterized by light grey to buff and brown bioclastic, fossiliferous, microcrystalline limestone.

The lower contact with Landry Formation is abrupt and unconformable. The upper contact with overlying Hare Indian Formation is likewise abrupt, but there is no evidence of erosion.

Hume Formation is distributed throughout the subsurface, and outcrops in the Franklin and Mackenzie mountains. Thickness ranges from 70 m in the northeast to 200 m in the southwest.

Hare Indian Formation

Middle Devonian Hare Indian Formation is dominantly shale and is divided into three members (Pugh, 1993). The basal Bluefish Member is dark brown to black, bituminous, siliceous shale, locally calcareous at the base. The overlying Grey Shale member varies gradationally from dark brown-grey upward through to green grey and pale grey shale. The shale is also variably micaceous and calcareous, and tends to coarsen up section slightly to include silty beds. Grey Shale member is discernible only as far west as 131°W (Pugh, 1993). The uppermost Black Shale member is a western facies equivalent to the Grey Shale member, consisting of black, bituminous, variably siliceous, pyritic, and locally calcareous shale.

The basal contact with Hume Formation is apparently conformable, although there could be localized erosion surfaces (e.g., at the top of Hume bioherms; Pugh, 1993). The upper contact is conformable. Where intervening Ramparts Formation is missing (see below), the Black Shale member is difficult to distinguish from overlying Canol Formation shale, and the two units are mapped together.

Hare Indian Formation is widely distributed through the study area. The formation thins gradually to the west, from a thickness of approximately 100 m in the southeastern part of the study area.

Ramparts Formation

Late Middle Devonian Ramparts Formation is dominantly limestone, including a basal bedded platform member and overlying massive reef member (Kee Scarp Member). Pugh (1983) additionally recognized a basal siltstone member and an uppermost sandy member. The siltstone member consists of generally pale-coloured calcareous siltstone grading to silty and argillaceous limestone. The siltstone unit is rather widely though unevenly distributed. The platform member comprises brown to white and grey limestone, with varying amounts of lime mud and biosiliciclastic material. The siltstone and platform members are intergradational. The Kee Scarp member consists of massive light-coloured limestone characterized by tabulate corals and stromatoporoids. The sandy member (Charrue sandstone of Mackenzie et al., 1975) is a facies equivalent of the other members. It consists of variably calcareous and micaceous quartz siltstone to very fine-grained sandstone, with silty shale, and discontinuous lenses of silty bioclastic limestone.

The lower contact with Hare Indian Formation is conformable; the contact with overlying Canol Formation is disconformable.

Ramparts Formation is restricted to east of approximately 131°W. Ramparts Formation is over 300 m thick in the extreme southeastern corner of the study area, thinning to the north and west. The silty and sandy members lie to the northwest, the reefal Kee Scarp member to the east and south. Ramparts Formation outcrops in Franklin Mountains, and in Mackenzie Mountains about as far west as Gayna River.

Canol Formation

Late Devonian Canol Formation consists of black, bituminous, siliceous, pyritic, and non-calcareous shales. Locally at the base, allochthonous limestone debris beds shed from contemporaneous Ramparts Formation reefs are present, and thin carbonate beds occur at the top of the unit.

Contacts with underlying Ramparts or Hare Indian formations and overlying Imperial Formation are conformable and abrupt.

Canol Formation is distributed throughout the study area, except in the northeast where it thins to an erosional edge. The thickness increases up to 90 m toward the western part of the study area, although this may include some underlying Black Shale member of Hare Indian Formation. Canol Formation outcrops at Carcajou Ridge and Imperial Hills, and in Mackenzie Mountains, although in places it is undifferentiated from, and grouped with Hare Indian Formation (Aitken et al., 1982).

Imperial Formation

Late Devonian Imperial Formation consists of interbedded shale, siltstone, sandstone, and rare limestone. Sandstone is more common in the upper part of the section, but overall the relative proportions of grain sizes are variable throughout the formation's area of distribution.

The contact with underlying Canol Formation is conformable and non-gradational. Where overlain by Mississippian Tuttle Formation, the contact is conformable. Imperial Formation is distributed throughout the study area, except in the northeast corner where it is removed by erosion. It outcrops in Mackenzie and Franklin mountains.

Imperial Formation increases in thickness westward from an eroded zero edge to over 700 m in the northwest part of the study area (Pugh, 1983).

Tuttle Formation

Mississippian Tuttle Formation consists of quartz and chert conglomerate, variably micaceous, non-calcareous, poorly-sorted sandstone, siltstone, and grey-brown shale. The sandstone is often kaolinitic although clean quartz sandstones occur at the top of the section. Within the study area the finer grain sizes dominate, although regionally grain size increases to the north and west.

The contact with underlying Imperial Formation is conformable and gradational. Tuttle Formation is unconformably overlain by Cretaceous sediments.

Tuttle Formation is restricted to the extreme southwest corner of the study area, with a maximum thickness of approximately 100 m.

Devonian to Permian Tectonic and Depositional History

The following summary is condensed mainly from Pugh (1983). Tectonically stable marine shelf conditions continued in the Devonian Period, following a period of post Mount Kindle Formation uplift and erosion. Platform carbonate deposition continued with Peel Formation. Slightly different depositional conditions are suggested by argillaceous limestone and shale of Tatsieta Formation. The sea was shallow and restricted in the southeast, where Fort Norman Formation anhydrite and dolostone were deposited.

Pugh’s (1983) interpretation that Tatsieta Formation was deposited on the regional sub-Devonian unconformity, is contrary to other workers (e.g., Morrow, 1999) who place the unconformity at the top Mount Kindle Formation.

Gradual subsidence of the platform led to deposition of Arnica Formation dolostone. Depositional boundaries between Arnica and Fort Norman formations, and Arnica and Landry formations, fluctuated but stepped gradually eastward over time, such that Landry Formation limestone eventually covered the entire platform.

A widespread, uniform series of shale and bioclastic limestone was then deposited throughout Mackenzie Platform (Hume Formation). This possibly indicates increased subsidence and deeper water deposition. Small bioherms are known in Hume Formation, in the eastern part of the study area.

Between Middle and Upper Devonian time, little sediment was deposited on Mackenzie Platform. Deposition re-commenced with organic-rich Bluefish Member muds settling out into a sediment-starved basin. At the same time, an offshore reef complex (Ramparts Formation) began to develop in the eastern parts of the study area (Figure 15). Detrital material was introduced from the continental shore to the east, which became part of the siliciclastic members of Ramparts Formation, and further basinward, the grey shales of middle Hare Indian Formation. Reef growth then diminished, and a quiescent time followed. Organic rich muds (Canol Formation) settled into the basin that received little other sediment. Carbonate debris was locally shed from the Ramparts reef margins, and incorporated into basal Canol Formation.

Late Devonian time heralded the Ellesmerian orogeny, which uplifted a landmass in the area of the present Arctic Islands. Sediments shed in a clastic wedge from this mountainous land were transported southward (Imperial Formation). Initial sediments were marine and fine-grained. Deltaic systems and marine fans then transgressed southward, carrying coarser sediments. Clastic wedge deposition continued into the Early Mississippian with coarse sediments shed from an area to the northeast (Tuttle Formation).

The advancing shorelines produced by these prograding clastic wedges were steadied, or began retreating, by post-Tuttle, Early Carboniferous time. A marine clastic wedge, comprising shoreward conglomerate, and basinward cherty carbonate and shale was developed. Increased subsidence of the basin resulted in black organic-rich shale deposition. These rocks are preserved only west of the study area.

The platform was uplifted in latest Carboniferous–Early Permian time, resulting in widespread erosion. Any sediments of this age deposited in the study area have been removed by pre-Cretaceous erosion. Later Permian marine platform sediments were likely deposited in the western part of the study area, but have since been removed by erosion.

Triassic to Jurassic Tectonic and Depositional History

Triassic deposits may have been deposited in the study area, but are not preserved. In Jurassic to earliest Cretaceous time the study area was probably emergent with no deposition, and may have supplied sediment to Brooks-Mackenzie basin to the west-northwest (Poulton et al., 1993; Dixon, 2004). In Middle Jurassic time, there is evidence of some tectonism and differential uplift, preserved in rocks that are exposed west of the study area. Far to the south, Late Jurassic rocks record the onset of mountain uplift (Columbian orogeny) through the deposition of a thick series of clastic sediments in a series of foredeep basins. The Columbian orogeny marked an end to passive margin tectonics that had generally persisted throughout early Paleozoic time.

Phanerozoic Stratigraphy-Cretaceous

Martin House Formation

Early Cretaceous (Aptian/Albian) Martin House Formation consists of brownish-grey interbedded shale, siltstone, and commonly glauconitic sandstone. Coaly beds are locally present in the northeastern part of the study area.

A basal interval of medium to thick-bedded fine to medium-grained sandstone, with local thin beds of pebble sandstone, is generally present. The basal sandstone is 14 m thick in the Ontaratue-Circle rivers area (Campbell, 1960).

Martin House Formation unconformably overlies Mississippian or Devonian rocks, and is conformably but sharply overlain by Arctic Red Formation. The unit ranges from about 50 m to 75 m thick throughout the study area, and is thicker to the south and west (Dixon, 1999).

Arctic Red Formation

Early Cretaceous (Albian) Arctic Red Formation is dominated by dark grey, silty to sandy shale, with concretions and bentonite beds. Overall the formation coarsens upward. In the eastern part of the study area, a local succession of interbedded sandstone and shale (San Sault member) occurs low in the section (Dixon, 1999).

The lower contact of Arctic Red Formation is conformable; the upper contact is conformable and somewhat gradational. Thickness of the unit increases toward the southwest throughout the study area, from less than 100 m in the northeast to over 1,000 m in the southwest (Dixon, 1999). Arctic Red Formation subcrops widely throughout the area, lying beneath unconsolidated till, and is locally exposed in stream valleys.

Trevor Formation

Early to Late Cretaceous (Albian/Cenomanian) Trevor Formation consists of fine to coarse-grained, locally conglomeratic sandstone inter-bedded with shale. A predominant shale interval within Trevor Formation likely marks an Early/Late Cretaceous unconformity (Yorath and Cook, 1981; Dixon, 1999)

Trevor Formation gradationally and conformably overlies Arctic Red Formation. The unit is distributed through the southern part of the study area, from the Hume River westward. Distribution and thickness are not well documented, but thickness seems to increase toward the east (up to 1,100 m in the Hume River area; Yorath and Cook, 1981).

Slater River Formation

Late Cretaceous Slater River Formation consists of soft black shale with abundant thin bentonite interbeds and concretions. Within the study area, Dixon (1999) indicated a restricted area of deposition (and/or preservation?) around Yadek Lake in the core of the Lichen Syncline. The contact with underlying Trevor Formation is likely conformable and probably gradational. A measured section along Hume River (Yorath and Cook, 1981) records about 225 m of shale sitting above Trevor Formation sandstones, which likely correlates with Slater River Formation. Yorath and Cook (1981), however, interpreted Slater River Formation as a facies equivalent to Trevor Formation.

Net thickness of Cretaceous to Tertiary strata increases from northeast to southwest across the study area, from less than 250 m around Fort Good Hope, to over 2,000 m east of the Arctic Red River at the Mackenzie Mountain front (Dixon, 2004).

Cretaceous and Tertiary Tectonic and Depositional History

The following is taken mostly from Dixon (1999; 2004). During the Cretaceous period, sea level rise and orogenesis affected the region, uplifting Mackenzie Mountains to the south and west of the study area, and creating a partly enclosed marine basin between the mountains and cratonic continent to the east (Figure 15). The Peel Trough foreland basin began to receive sediment by Late Aptian time. Some earlier Cretaceous non-marine sediment has been identified, but the environment of deposition was dominantly marine.

In addition, in Early Cretaceous, Canada Basin was opening northwest of the study area, as northern Alaska and Yukon rotated relatively counter-clockwise, away from the present Arctic Islands. Rifting along Aklavik Arch resulted in subsidence and increased sedimentation to the northwest of the study area.

The earliest marine transgressive deposits are represented by glauconitic Martin House Formation sandstone. In Late Aptian, most of the study area was a marine shoreline to inner shelf environment, while the northeast corner was a more proximal fluvial to coastal plain environment (Dixon, 1999). Deposition of coarser sand bodies was localized around shallows and local uplifts (e.g., Sans Sault member of Arctic Red Formation around Keele Arch), while platformal muds were deposited elsewhere during Early Albian. From Middle to Late Albian, the northern part of the study area was an interior shelf receiving mud and silt (Arctic Red Formation), with a nearshore environment in the south (Dixon, 2004). By late Middle Albian time, an episode of orogenic uplift gave rise to coarser sediments (Trevor Formation). Middle to late Albian regression may have resulted in some exposure and erosion (within Trevor Formation), although Yorath and Cook (1981) suggested continuous deposition over this interval. By late Albian time, Keele Arch had been drowned and the study area and Great Bear basin to the southeast were in communication.

The Albian-Cenomanian boundary is a major unconformity and marks a change in the style of deposition. Cenomanian strata in the study area are organic rich, indicating deposition in low oxygen conditions (Dixon, 2004), and rather quiet tectonic time with little siliciclastics shed from mountains (Slater River Formation). During Cenomanian to Turonian time, the south part of study area was an inner shelf to shoreline environment (Dixon, 2004).

Since the start of Late Cretaceous time, the ancestral Mackenzie and Franklin mountains provided sediment. Through Late Cretaceous, nearshore and non-marine sediments were deposited, but are not preserved in the study area. In the latest Cretaceous (Maastrichtian) only the northeast corner of the study area was within the Cretaceous seaway, and a succeeding veneer of continental sediments blanketed much of the study area. The balance of the study area was uplifted accompanying Laramide orogeny (Stott and Aitken, 1993). Laramide tectonism is indicated in the study area by broad folds associated with the northern Franklin Mountains and Mackenzie Mountains. Cretaceous strata are involved in deformation at the edge of the Cordilleran foldbelt, in a narrow band in the southeast part of the study area (Dixon, 2004).

Tertiary sediments were deposited in the Mackenzie Delta to the northwest, and Mackenzie Plain to the southeast. The study area at this time lay across the boundary of a major watershed. In the west, sediments were transported northeastward to the Arctic Ocean. In the east half of the study area, sediments were transported eastward toward Hudson Bay (Duk-Rodkin and Hughes, 1994, 1995; Dixon, 1999). Any Tertiary sediment deposited has since been eroded from the study area (Dixon, 1999).

Phanerozoic Stratigraphy-Quaternary

Descriptions of Quaternary deposits in the study area are taken from Duk-Rodkin and Hughes (1995) and surficial geology maps (Duk-Rodkin and Hughes, 1992 a, 1992b, 1993a, 1993b). Quaternary deposits are dominantly glacial moraine plain through the northern, northeastern, and eastern parts of the study area. The northern half of the study area is underlain by 80% till, 10% glaciolacustrine, 4% glaciofluvial, and 5% organic deposits. Hummocky, ridged, and rolling moraine deposits are up to 60 m thick. The Ramparts I-77 well history report cites 70 m of unconsolidated deposits (Haddow, 1973a).

Major glaciolacustrine deposits lay along the lower Ramparts and Hume rivers as far northwest as Ontaratue River, and also along the lower Hare Indian River. A large area of glaciofluvial deposits lies along the lower Mountain River in the southeast part of the study area.

Quaternary deposits in mountainous regions are dominantly colluvial and sheetwash deposits that form thin veneers over bedrock. Large tracts of dominantly organic deposits trend west-northwest across the middle part of the study area, from Mackenzie River to the western boundary of the map area.

The maximum extent of Laurentide glaciation (about 30,000 years before present) reached all but the extreme southwest and southern margins of the study area. Ice pushed up the Gayna, Mountain, and Arctic Red valleys. River drainages during this time were to the east and north. Montane glacial deposits formed north and northeast trending lobes off the main body of Mackenzie Mountains, along major valleys, and just reached onto the southern part of the study area (Figure 15). Following the Laurentide maximum, there were two major re-advances: the Katherine Lake (about 22,000 years before present) and Tutsieta Lake (about 13,000 years before present) phases, which again covered much of the study area.

Drumlinoid ridges and indications of Laurentide ice flow direction are most common in the northern and eastern parts of the study area. Along the northern margin of the study area, these are oriented mostly north-northeast, with mostly northerly ice flow directions. In the eastern parts of the study area, drumlinoid ridges are oriented northwest to southwest, with westerly flow directions indicated.

Large eskers are not very common, and are mainly in the northern half of the study area, trending west to northwest. There are a few long eskers (10 km plus) in Ontaratue River area.

Dunes are present west of Ontadek Lake and across Mackenzie River from the mouth of Tieda River. Other dune fields were noted near Mackenzie River, from Carcajou River to Donnelly River. These dunes are mainly glaciofluvial deposits reworked by modern winds.

TS' UDE NILINE TU' EYETA STUDY AREA GEOLOGY

Bedrock Lithologies

Stratigraphic units discussed above occur in the subsurface of all or parts of the study area. This section focuses on the lithological character and structure of bedrock exposed within the study area. Particular attention is paid to the Interior Platform part of the study area, where bedrock outcrops are rare and widely spaced.

Interior Platform

Throughout the study area, the sub-Cretaceous unconformity has cut progressively downward through Devonian units from southwest to northeast. This, coupled with the regional southwest dip, has resulted in the oldest rocks being exposed in the northeast corner of the study area. However, outcrops are relatively rare on the Interior Platform due to topography, flat lying nature of the bedrock, predominance of soft shales, and overlying veneer of Quaternary deposits.

Hume Formation outcrops in a few places south of Hare Indian River on the east boundary of the study area. Exposed rock consists of dense, brown, thin to medium-bedded, fossiliferous limestone (Aitken et al., 1969). An east-northeast trending, down to the northwest normal fault marks the contact with Hare Indian Formation at this location.

Hare Indian Formation is very rarely exposed within the study area, due to the recessive nature of the shale. One outcrop was mapped by Aitken et al. (1969) on the Bluefish River, another section was measured on lower Gossage River (Cook and Aitken, 1975), and outcrops occur along Mackenzie River at the Ramparts and just downstream from Tieda River. Exposures are of greenish-grey, grey, and pale brown shale, with thin beds of calcareous siltstone and fossiliferous limestone, especially near the top of Hare Indian Formation.

Ramparts Formation outcrops fairly widely in the northeast corner of the study area. Outcrops occur at the Ramparts on Mackenzie River, Ramparts Plateau west of Loon Lake, between Rorey and Manuel lakes, and along Yeltea Lake and Tieda River. The platform member is characterized by medium-bedded, brown, partly argillaceous limestone, with abundant tabulate corals (Aitken et al., 1969). The Kee Scarp member is thick-bedded to massive, pale brown limestone with abundant globular stromatoporoids.

The mapped pattern of Canol Formation bedrock outcrop forms a narrow band along Mackenzie River in the northeast part of the study area. Actual outcrops are rare, occurring mainly on the river banks downstream from Tieda River. The unit in outcrop is composed of dark grey to black bituminous shales with some silty beds, clay-ironstone concretions, and pyrite nodules (Aitken et al., 1969). Yellow and red iron oxide staining coats outcrops. Better exposures display closely spaced joints resulting in a blocky appearance.

Imperial Formation outcrops mainly in Mackenzie River valley downstream from Fort Good Hope. Exposures consist of brown and greenish-brown fissile shale, with subordinate brown fine-grained sandstone and siltstone beds (Aitken et al., 1969). Several outcrops occur on lower Ontaratue River (Cook and Aitken, 1975).

Cretaceous beds subcrop throughout Interior Platform in the south-central and western parts of the study area, and in outlying plateaus around Yeltea Lake, southeast of Loon Lake, south of Fort Good Hope and around Chick Lake. Cretaceous beds overlie Paleozoic beds in obvious unconformity. Near Rorey Lake, over 120 m of relief on the sub-Cretaceous unconformity is apparent (Aitken et al., 1969). About 17 km northwest of Fort Good Hope, Aitken et al. (1969) observed a Cretaceous channel filled with sandstone and conglomerate, cut into underlying Hare Indian Formation.

Basal Cretaceous sandstone (Martin House Formation or Sans Sault member of Arctic Red Formation) is commonly white and quartzose, and locally oil-stained. Grain size, and relative abundance of chert and quartz varies between beds. Calcite cement is common. The basal sandstone is overlain by shale that outcrops very rarely. Exposures on lower Ramparts River are dark grey to black, slightly silty, blocky-weathering with abundant ironstone concretions. On lower Mountain River, Arctic Red Formation shale, siltstone, and minor sandstone are exposed in a series of gently dipping beds outlining open folds.

Additional Cretaceous outcrops occur along Ontaratue River, Arctic Red River, southern Grandview Hills, Yellow Hills, and Lichen Ridge.

Cordillera

Outcropping rock is widespread in the Cordillera, as more resistant lithologies are brought near the surface by folds and faults, and beds may dip at steep angles, exposing considerably thick sedimentary sections. Most of the units described above in the stratigraphy section are exposed in the Cordillera portion of the study area, and will not be described again here. The Mackenzie Mountains feature great expanses of Precambrian sedimentary rocks brought to surface on fault planes and in the cores of large folds. Sills and northwest trending dykes of medium-grained, greenish-black gabbro intrude Tsezotene Formation and Katherine Group. These are the only known intrusive rocks in the study area. In northern Franklin Mountains, faults bring to surface rocks as old as Franklin Mountain Formation. Devonian strata outcrop on East and West mountains, Carcajou Ridge, and Imperial Hills.

Structural Geology

Interior Platform

Generally, beds in the Interior Platform are little deformed. The regional structural style is a southwest dipping monocline. Minor faults and structures have been outlined in the subsurface by seismic surveys. As the Cordilleran front is approached, deformation becomes more pronounced. Gentle open folds trending northeast and northwest, but generally parallel to the mountain front, were mapped in Cretaceous beds at Sans Sault Rapids and along lower Mountain River (Aitken and Cook, 1974). Lichen Syncline is a broad, gentle warp, cored by Cretaceous strata, that extends along the Mackenzie Mountain Front west of Imperial Hills. Only rarely have minor faults been mapped or interpreted near surface in Cretaceous strata.

Cordillera

Generally, larger structures of the Mackenzie Mountains in the study area are of typical fold-and-thrust morphology. Structures are interpreted to have resulted from Laramide (plus Columbian?) orogenies in the Cretaceous. Earlier deformational features are not seen at 1:250,000 map scale.

Structural trend of northern Franklin Mountains swings markedly to the west in the study area, from a northwest trend further south. North and south-directed thrust faults, and open to slightly overturned folds characterize the large-scale structures in the region.

The Beavertail Anticline is overturned to the south and associated with a south-directed thrust, while the East Mountain anticline and its associated fault are north verging (Aitken et al., 1982). Reversals in vergence along strike have been interpreted to be the result of salt tectonics southeast of the study area (MacLean and Cook, 2000). East Mountain anticline is doubly plunging, trends almost due east, and may be traced across Mackenzie River to West Mountain, which trends northeast. Along strike from West Mountain is the Whirlpool Fault, a southeast directed thrust fault that carries a sliver of Imperial Formation, exposed in its hanging-wall where it crosses Mountain River (Aitken et al., 1982).

The Imperial Hills comprise a large anticlinorium outboard of the main Mackenzie ranges in the southeast part of the study area. The north flank of the anticlinorium dips steeper than the south. A number of sub-parallel folds make up the anticlinorium, which is cored by Mount Kindle Formation (Aitken et al., 1982). Several west to northwest trending faults cut the flanks of the constituent folds.

The Imperial syncline, a broad gentle down-warp, separates the Imperial Hills from the main Mackenzie Mountains. At its west end, the south-directed Southbound Fault carries Lichen Syncline up against the north limb of Imperial Syncline (Aitken et al., 1982).

The mountain front is marked by Stony Anticline, which is a broad open fold cored by Precambrian strata, in the southeast part of the study area. Stony Anticline is bounded to the south by the comparatively tight Houdini Synclinorium, and Tawu Anticline (Aitken et al., 1982).

The southwestern part of the study area is dominated by Tawu Anticline, and to the southwest, a number of northeast and southwest-directed thrust faults and associated folds, in a typical fold-and-thrust structural pattern. The steeper northeast flank of Tawu Anticline is marked by the southwest-directed Tabasco Fault, which repeats the fold limb. A number of northwest, and lesser west- or north-trending faults have been mapped in Proterozoic sedimentary rocks (Aitken et al., 1982). Some faults, such as Grand Forks Fault, offset beds as young as Middle Devonian (Aitken et al., 1982).

PETROLEUM RESOURCE ASSESSMENT

Regional and Local Petroleum Occurrences

Norman Wells oil field, located approximately 140 km southeast of Fort Good Hope, was discovered in 1920. Imperial Oil carried out major expansion of development in the mid-1980s, and a pipeline to Zama, Alberta was completed in 1985. At Norman Wells, oil is produced from Middle Devonian Kee Scarp member of Ramparts Formation. This is Canada's fourth largest oil field, with 105 $x10^6$ m^3 (660 million barrels) of oil originally in place, 38 $x10^6$ m^3 (240 million barrels) of which were classed as reserves. Production in 2004 amounted to 1.19 $x10^6$ m^3 (7.5 million barrels) and cumulative production totals 34.7 $x10^6$ m^3 (218 million barrels, National Energy Board, 2005). Natural gas is also produced (104$x10^6$ m^3, 3.7 Billion cubic feet in 2004) for local industrial and domestic use (National Energy Board, 2005).

Approximately 150 km east-northeast of Fort Good Hope, natural gas has been discovered in the Colville Hills. Three original discoveries made in the mid-1970s to mid-1980s have been followed-up by recent discoveries (Paramount Resources, 2004). The main reservoir is basal Cambrian Mount Clark Formation sandstone, with minor reservoir capacity in overlying Mount Cap Formation (Janicki, 2004).

Within the study area, 44 exploration wells (including re-entries) were drilled between 1944 and 1991 (Figure 4). Drilling has not been distributed evenly across the study area, and is heavily weighted to the southeast quadrant, especially in the area between Mountain and Mackenzie rivers and the mountain ranges to the south. One of the wells is classified as a suspended gas well (Carcajou D-05); the rest are mainly classified as drilled and abandoned. Shows of oil and/or gas, however, have been found in several wells.

Many wells were evaluated with drill stem tests (DST), which measure the flow of fluids from intervals of rock that are judged to be potential reservoirs. DSTs were mainly to evaluate zones of Middle Devonian carbonate rocks. Upper Devonian (Imperial Formation) and Cretaceous sandstones, and early Paleozoic (Franklin Mountain and Mount Kindle formations) dolostone horizons were also tested. Many of the DSTs indicated good permeability in tested horizons, and small amounts of hydrocarbons have been recovered.

In addition to DST results, petroleum is indicated by natural surface and near surface gas and oil seeps that occur within the study area. A surface gas seep sourced in Cretaceous rocks is known from the Ontaratue River area in the north part of Ts' ude niline Tu' eyeta (Kunst, 1973). North of Airport Creek D-72, a gas seep was discovered when drilling a shallow shot hole for a seismic survey. Oil seeps were also reported along Mackenzie River in the Grandview Hills region (Figure 7).

Table 4 lists indications and shows of hydrocarbons from drilling in the study area. Among the larger shows are:

1. Carcajou D-05, classified as a suspended gas show. The well was spudded in 1984 by AT&S Exploration Ltd. The well kicked gas while pulling a core from Ramparts Formation. The well was perforated and flow tested. After the well was swabbed, sweet gas flowed at rates of up to 33,980 m^3/day (1.2 Mmcf/day) on a 48/64 inch choke (Dudus, 1985). The well flowed for 31 hours, eventually began to produce more water and less gas, and was suspended. As an indication of the tested volume, 1.2 Mmcf would be enough to heat six homes for a year.

2. Ramparts I-55 was drilled in 1960 near Fort Good Hope. A DST over a three m interval of Hume Formation was estimated to flow at 7,110 m^3/d (251,000 Mcf; Soul, 1960).

3. Mountain River H-47, gas was estimated to flow at 2,493 m^3/d (88,000 Mcf) from Landry Formation limestone (Holmes and Koller, 1972a).

4. A small amount of oil (39.2° API) was recovered on DST from Landry Formation in Shoals C-31 (Evans, 1966).

Within the Ts' ude niline Tu' eyeta candidate protected area proposed boundaries, 20 exploration wells have been drilled (Figure 4, Table 5). The majority of these wells were drilled in the 1960s and 1970s, with 5 wells completed since 1990 by Chevron Canada Resources Ltd.

Currently active exploration licenses (EL) within the study area include EL 415 held by Hunt Oil Co. of Canada and EL 401, held by EOG Resources Canada (Figure 7). The reader is referred to the Northern Oil and Gas Directorate of Indian and Northern Affairs Canada for up to date status and location of existing Exploration Licenses, Significant Discovery Licenses and Production Licenses (website address: http://www.ainc-inac.gc.ca/oil/index_e.html).

Well Name and Grid Number	Formation or Group	Depth interval (m)	Hydrocarbons noted
Ramparts I-55 (P-55) 66-20-128-30	Hume Hume	285-288 288-295	Gas flow on DST estimated at 7,108 m^3/d (251 Mcf/d) Occasional live oil stain in core
SW Airport Creek D-72 66-30-129-00	Hume Arnica, Landry		Oil stain Oil stain
North Circle River A-37 66-30-129-30	Hume Arnica, Landry		Oil stain Oil stain
Circle River K-47 66-30-130-00	Hume Arnica, Landry		Oil stain Oil stain
Manitou Lake L-61 66-30-128-45	Hume Kee Scarp member		Oil stain Oil stain
Shoals C-31 66-00-128-45	Landry ? Landry Ronning	815-877 851-860 1232-1238	39.2° API oil (1.5 m recovered) and water on DST #1 Oil stain noted Oil stain noted
Hume River A-53 66-10-129-00	Ramparts	254-255	Live oil stain
Carcajou L-24 65-40-128-45	Ramparts	1160-1189	Gas flow on DST #1, TSTM
Hume River O-62 66-00-129-00	Ramparts	497-520	Gas flow on DST #1, estimated at 425 m^3/d (15,000 Mcf/d)
Hume River D-53 66-00-129-00	Ramparts Arnica Cretaceous Ramparts	490-535 1113-1146 419-433 527-530	Gas cut, slightly oil cut mud on DST #1 Gas cut water on DST #4 Oil stain noted Abundant oil stain
Mountain River A-23 65-50-129-15	Imperial ?	427	Gas blowout (flow not measured, 1.2 m flare)
Grandview L-26 66-40-130-15	Hume Arnica, Landry		Oil stain Oil stain
Carcajou D-05	Ramparts Ramparts	566.5-568.5 564-733	Perforated interval, gas on flow test #3 estimated at 33,980 m^3/d (1.2 Mmcf/d) Live and dead oil stain locally noted in core and samples

Cont.

Hanna River J-05 65-50-128-15	Cretaceous Bear Rock Ronning	192-199 591-650 823-985	Oil cut water on DST #2 (2-3% 25-30° API oil) Oil flecked water on DST #1 Oil stained water on DST #3
Carcajou K-68 65-40-128-00	Hume, Ft. Norman Arnica	183-186, 457-460 220-235, 247-250	Gas shows on gas detector Live oil stain locally
Mountain River H-47 65-50-129-00	Landry Ramparts Arnica	585-654 207-208.5 748.5-767	Gas flow on DST #1 estimated 2492 m^3/d (88 mcf/d) Live oil stain noted Live and dead oil stain locally noted
Hume River L-09	Fort Norman Hume ?	2324-2329 1637 ?	Gas cut water on DST #4 Blowout, gas cut mud
Beavertail G-26 66-00-128-30	Arnica ?	326-350	Slight oil stained mud on DST #1
Loon River H-79	Landry Landry	288 286.5-288.5	Sour (?) gas cut water flowed from well Oil stain
Carcajou O-25 65-40-128-15	Ramparts Ramparts	599-619 600.4-660	Gas flow on DST #1 TSTM Live oil stain noted
Ramparts River F-46 65-50-130-00	Martin House Trevor, Martin House, Imperial	 431-440, 955-971, 1095-1098	Gas flow on DST #1 estimated 3 m^3/d (0.106 mcf/d) Gas shows on gas detector
East Hume River N-10 66-00-129-30	Arctic Red, Martin House Martin House, Canol	284-316 311-313, 375-379	Gas flow on DST #2 estimated 62 m^3/d (2.19 mcf/d) Gas shows on gas detector
Hume River I-66 66-00-129-30	Arctic Red Arctic Red	470-486 341-345	Gas cut drilling fluid on DSTs #2,3 Gas shows on gas detector
East Hume River I-20 66-00-129-15	Arctic Red Martin House	297-303 310-320	Gas cut drilling fluid on DST #1 Gas shows on gas detector
Sperry Creek N-58 65-40-129-15	Trevor, Arctic Red, Imperial, Canol-Hare Indian, Hume, Landry, Arnica, Mount Kindle	623-624, 844-845, 906-907, 1329-1346, 1469-1470, 1536-1537, 1742-1743, 1889-1896	Gas shows on gas detector

Cont.

Mountain River O-18 65-40-129-00	Imperial, Hare Indian, Hume, Landry, Fort Norman	129-131, 474-478, 549-555, 589-594, 853-855	Gas shows on gas detector
Ramparts River F-46	Martin House Trevor, Martin House, Imperial	960-973 431-440, 955-971, 1095-1098	Gas on DST #1 Gas shows on gas detector
Maida Creek 2O-65	Ramparts	549-573	Gas on DST #1, TSTM, gas cut mud and gas cut water
Sammons H-55	Arnica Mount Kindle	152-176, 316-320, 395-401 435-445	Live oil stain locally Live oil stain locally

Table 4. *Gas and oil shows and indications from exploratory drilling within the study area. Well locations shown in Figure 4. DST= drill stem test, TSTM= too small to measure, °API= American Petroleum Institute gravity. Oil stains observed in core or well cuttings, other shows from gas detector or DST results*

Well name and grid number	Operator	Spud Date	TD (m)	Formation at TD
SANS SAULT H-24	IMPERIAL	15-Jun-45	1003.1	ARNICA
SW AIRPORT CK D-72	ATLANTIC	21-Nov-60	726.9	ARNICA
NORTH CIRCLE R A-37	ATLANTIC	21-Dec-60	690.7	ARNICA
CIRCLE RIVER K-47	ATLANTIC	26-Jan-61	810.8	HARE INDIAN
ONTARATUE K-04	ATLANTIC ET AL.	14-Nov-64	2728.0	PROTEROZOIC
HUME RIVER A-53	TRIAD BP ARCO CC	7-Apr-69	1158.2	MOUNT KINDLE
HUME RIVER O-62	TRIAD BP ARCO CC	9-Feb-70	1402.1	MOUNT KINDLE
HUME RIVER L-09	MOBIL	16-Dec-70	2606.0	ARNICA
MOUNTAIN RIVER H-47	ARCO CLARKE ET AL.	3-Dec-71	1044.5	MOUNT KINDLE
HUME RIVER D-53	ARCO CLARKE ET AL.	20-Jan-72	1267.7	MOUNT KINDLE
GRANDVIEW L-26	CANDEL ET AL MOBIL	9-Mar-72	2395.7	PROTEROZOIC
MOUNTAIN RIVER A-23	CANDEL ET AL SOBC	25-Mar-72	1553.6	MOUNT KINDLE
ONTARATUE I-38	DECALTA TRAN OCEAN GCOA	9-Sep-72	2287.5	FRANKLIN MOUNTAIN
ARCTIC RED F-47	CANDEL ET AL. TEXACO	23-Dec-72	2371.3	IMPERIAL
NORTH RAMPARTS A-59	CANDEL MOBIL ET AL.	22-Jan-73	3205.0	FRANKLIN MOUNTAIN
EAST HUME RIVER N-10	CHEVRON	16-Feb-90	445.0	HARE INDIAN
HUME RIVER I-66	CHEVRON	24-Feb-90	745.0	HARE INDIAN
EAST HUME RIVER I-20	CHEVRON	12-Mar-90	365.0	IMPERIAL
SPERRY CREEK N-58	CHEVRON	4-Jan-91	2160.0	FRANKLIN MOUNTAIN
RAMPARTS RIVER F-46	CHEVRON	24-Feb-91	1510.0	HUME

Table 5. *Exploration wells from within proposed boundaries of Ts' ude niline Tu' eyeta candidate protected area. Well names highlighted in dark grey were associated with gas shows, light grey highlight indicates oil show. Well locations shown in Figure 4. Wells are listed in the order in which they were completed. TD=total depth*

Petroleum Plays and Petroleum Geology

Canadian Gas Potential Committee (2001) outlined five stratigraphically defined play groups that could host natural gas in the area. Kunst (1973) and Meding (1998) also proposed various oil and gas plays in regions that included the study area. Osadetz et al. (2005) evaluated the Peel Plateau and Plain area of Yukon, west of the study area, and identified eight plays in three domains. Gal (2005) outlined petroleum plays in the Sahtu and Gwich'in settlement areas.

In the present study, plays have been developed based on past work, and current knowledge of petroleum geology. The number of plays and play type in a given area is at the core of the assessment methodology, with established plays ranking higher than conceptual plays. For example, if all other factors are equal, an area with three possible plays has more potential for discovery than an area with only one possible play. Consideration must also be given to the exploration risk of each play relative to the others. A total of seven conceptual plays have been identified in the study area.

This section focuses on elements necessary to form and retain hydrocarbon deposits in the study area. These include: porosity and permeability development in potential reservoir rocks, possible source rocks and their level of thermal maturity, seal rocks, and trapping styles and mechanisms. In this context, significant strata are described from oldest to youngest. Petroleum plays within the stratigraphic interval being considered are then reviewed. The reader is referred to the Table 3.

Late Proterozoic to Lower-Middle Cambrian Petroleum Geology

Reservoir

Basal sandstones of Cambrian Mount Clark Formation are possible reservoirs in the study area. In addition, sandstone and oolitic dolostone (Meding, 1998) in overlying Mount Cap Formation and Proterozoic sandstone could act as reservoirs. The probable depositional edge of Mount Clark Formation sandstone occurs in the far eastern part of the study area, although its distribution is not well known, and basal sands could extend farther west. Additionally, the distribution of the formations is probably discontinuous, being restricted to paleo-depressions on Precambrian basement surface. Porosity in Proterozoic sandstones southeast of the study area was low due to silica cement (Tassonyi, 1969).

Eight wells in the study area penetrated Saline River Formation strata or lower; five bottomed in Proterozoic beds (Figure 16). The Sammons H-55 in the southeast part of the study area was drilled with the basal Cambrian and Proterozoic sands as the prime target (Rose, 1984). A very fine to medium-grained sandstone was encountered from 1303 m, but it was well cemented with silica, and hence lacked porosity. The operator picked this as Proterozoic Katherine Group, lying below Saline River Formation. On well logs, a series of thin, rather shaly sandstones are apparent. No hydrocarbon shows were encountered in the target horizon. Tassonyi (1969) also cited silica cementation as reducing porosity in Proterozoic sandstones.

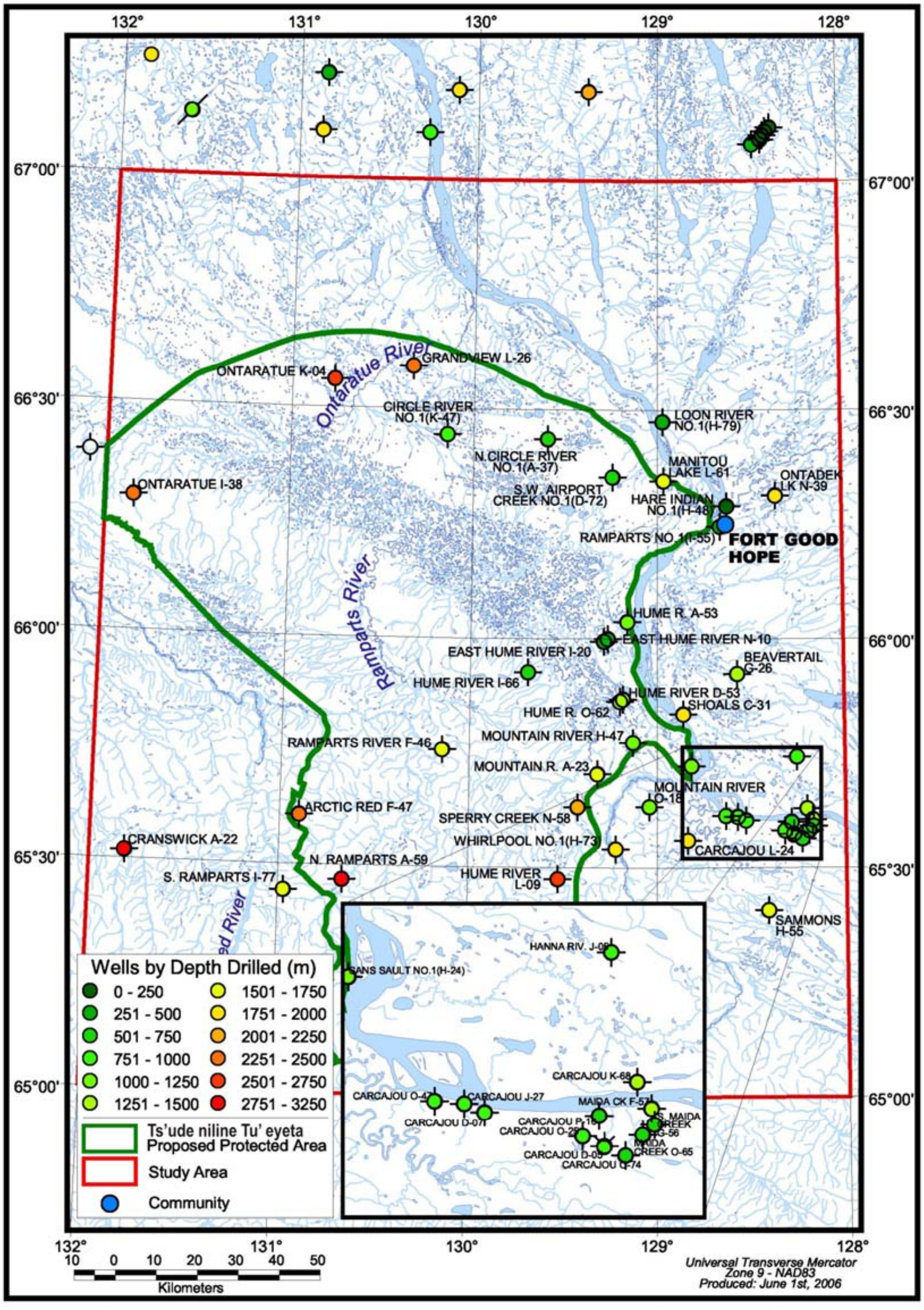

Figure 16. *Exploration wells in the study area by depth drilled. Most wells are relatively shallow, with deeper wells restricted to the southern and western parts of the study area*

In Ontaratue K-04, strata that might belong to Mount Clark Formation (below 2654 m) were described as "varicoloured quartzites, dominantly reddish brown and greenish grey" (Atlantic Refining Co., 1972). A cored interval (2671-2678 m) was described as "Cambrian quartzites and pseudo slate". Little porosity can be anticipated from these brief descriptions. However, a coarsening-upward, five metre thick sandstone is apparent from gamma and sonic logs at top Mount Clark Formation. This interval was not tested (Figure 17).

In Cranswick A-22, the bottom 6.1 m (from 2263 m) was described as very fine to fine-grained white to light grey quartzite; pyritic, dense, tight, with minor dolomite (Cannon, 1972a). Little porosity is indicated by this description, and the sonic log indicates shale possibly, with a slower travel time than overlying Franklin Mountain dolostone.

In Grandview L-26, possible Proterozoic dolostone, minor shale, and limestone well cuttings were described below a thick Cambrian salt section (Smith, 1972).

Source

Possible source rocks include Proterozoic shale (Williams, 1986a), Mount Cap (Wielens et al., 1990), and Saline River formations. Thick organic-rich shale sequences are generally not present in the Lower Cambrian section, so generation of sufficient hydrocarbons may have been difficult to achieve. Petroliferous sediments have been reported in the upper 30 m of Katherine Group in McDougall Canyon, southeast of the study area (Tassonyi, 1969). Total organic carbon (TOC) and Rock-Eval analysis values from Cambrian and Proterozoic potential source rocks are summarized in Table 6.

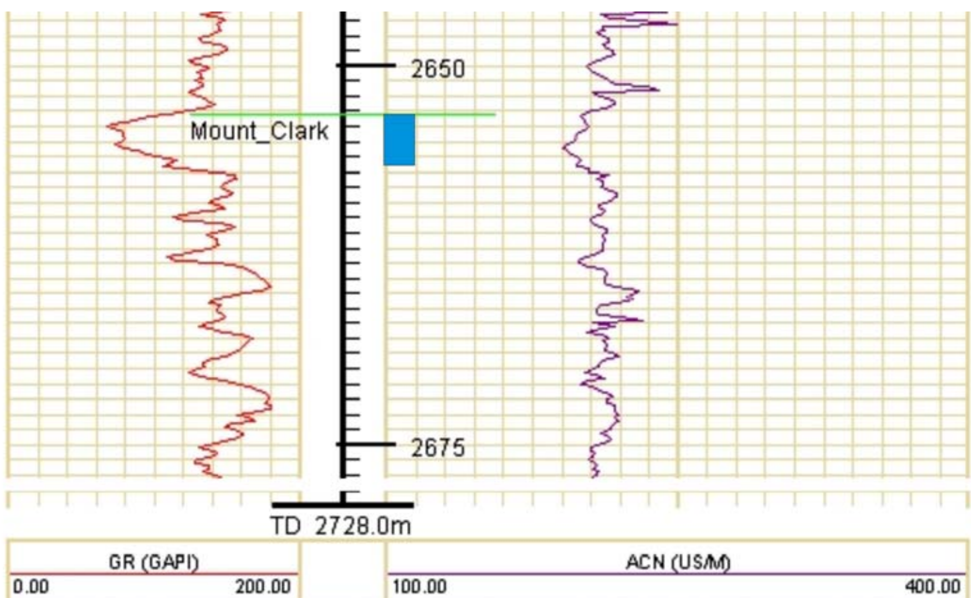

Figure 17. *Gamma (red) and sonic (purple) logs from bottom of Ontaratue K-04 well (300K04664013045). The gamma log indicates an untested coarsening-upward sandstone interval (blue bar) at top of Mount Clark Formation. Well depths in m, sonic travel time (microseconds per m) and gamma (API units) indicated by respective scale bars*

Well	Reference *	Depth (m)	Formation (number of samples)	TOC (%)	S_1 (ml/mg)	S_2 (ml/mg)	Tmax (°C)	Comments
		Maximum values of TOC, S_1, and S_2 are given where depths are stated as a range (and multiple samples indicated)						
Ontadek Lake N-39	1	1707-1756	Mount Cap (17)	0.44	nr	0.39	un	Poor source rock potential
		1756-1793	Proterozoic (12)	0.15	nr	0.07	un	Poor source rock potential
Ontadek Lake N-39	3	1768.3	Proterozoic	5.97	1.71	3.41	435	Analyzed material was bitumen seam with included country rock. Difficult to interpret Rock-Eval values.
Ontadek Lake N-39	3	1793	Proterozoic	0.03	0.09	0.00	na	Poor source rock potential
Ontadek Lake N-39	2	1646-1738	Mount Cap (4)	0.56	na			--
		1768-1793	Proterozoic (2)	0.17	na			--
Sammons H-55	5	1310-1710	Proterozoic (39)	0.42	0.90	0.64	un?	Generally poor source rock potential
Ontaratue K-04	3	2467	Saline River	0.16	0.06	0.00	na	Poor source rock potential
		2671-2677	Mount Clark or Proterozoic (3)	0.21	0.06	0.34	om	Poor source rock potential
Ontaratue K-04	4	2467-2591	Saline River, Mount Cap (3)	0.36	0.17	0.16	om	Poor source rock potential
		2673-2677	Mount Clark or Proterozoic (2)	0.38	0.0	0.32	om	Poor source rock potential
Ontaratue K-04	2	2561-2729	Mount Cap, Mount Clark (7)	0.38	na			--
Ontaratue H-34	3	2895-3054	Mount Cap, Mount Clark (4)	0.24	0.17	0.24	om	Poor source rock potential
		3233-3461	Proterozoic (4)	0.67	0.01	0.20	un, om	Poor source rock potential
Ontaratue H-34	2	2927-3079	Mount Cap, Mount Clark (6)	0.48	na			--
		3110-4073	Proterozoic (33)	2.56	na			6 samples yielded > 1% TOC
Ontaratue H-34	4	3052-3055	Mount Clark (3)	0.81	0.00	0.30	om	Poor source rock potential
		3171-4055	Proterozoic (4)	2.26	1.20	0.71	om, un	Marginal to fair gas source rock
* Reference: 1= Weir and Ross (1970), 2= Geochem Laboratories and AGAT Consultants (1977), 3= Macauley (1987), 4= Feinstein et al. (1988), 5= Snowdon (1990)								
nr=not reported, un=unreliable value, om=overmature, na=not applicable)								

Table 6. *Rock-Eval and TOC analyses from Proterozoic and Lower to Middle Cambrian formations*

In Ontaratue H-34, equivalent vitrinite reflectance of 2.45% (calculated from pyrobitumen reflectance) of a sample from 3384 m indicated overmaturity (dry gas generation) at the Proterozoic level (Feinstein et al., 1988). Macauley (1987) indicated overmaturity for Mount Cap Formation and lower beds for all but the northeast corner of the study area.

Low TOC values in thermally overmature beds may mean that depositional TOC was considerably higher, and hydrocarbon generation may have been much better than indicated.

In summary, the current data available suggest that Lower Cambrian and Proterozoic source rocks are of rather poor quality, but good horizons are present locally. They are overmature, and hence would have generated dry gas. Geochem Laboratories and AGAT Consultants (1977) rated the bulk of Mount Cap sediments as a poor to fair source rock. Whether or not there was a large enough volume of suitable source rock deposited in the Upper Proterozoic to Lower-Middle Cambrian section is debatable.

Seals, migration, and traps

Shale and anhydrite within the Cambrian section (Mount Cap and Saline River formations) could make effective seal rocks for Mount Clark or Mount Cap reservoirs. Shale sections within the Proterozoic could seal reservoirs of that age. Fault seals against basement are also possible. Intraformational seals due to facies changes, or diagenetic variations in porosity, are likely.

The discontinuous distribution of basal Cambrian sandstones suggests the possibility of stratigraphic traps, especially depositional and erosional stratigraphic pinch-outs against basement uplifts, and local accumulations in basement downwarps. Lateral facies changes from reservoir sand to sealing shale (or oolitic dolostone in Mount Cap Formation), and diagenetic controls on porosity forming intra-formational traps are also likely. Structural traps are very likely, particularly drapes over basement uplifts and fault controlled traps.

The period of time represented by the sub-Cambrian unconformity likely means that petroleum generated in the Proterozoic would have migrated only into Proterozoic reservoirs. It is possible, however, that Cambrian gas could have migrated into structurally juxtaposed Proterozoic sands.

Basal Cambrian play

In the Colville Hills east of the study area, Mount Clark and/or Mount Cap formations hold natural gas in three fields (Janicki, 2004), with several additional recent discoveries. This play should be considered conceptual in the study area (Gal, 2005).

The play includes all pools and prospects hosted in basal Cambrian Mount Clark Formation sandstone. Additional possible reservoir strata in Cambrian Mount Cap Formation and Upper Proterozoic quartz sandstones of Katherine Group can be grouped here, although Proterozoic strata were likely part of a separate Proterozoic petroleum system (if such a system existed at all). The play area determined by Gal (2005) is the distribution of Mount Clark Formation basal sandstone (Figure 18). This restricts the play to the eastern edge of the study area, although the distribution of Mount Clark sandstone is not fully understood due to sparse well coverage. The play area may in fact extend further west (Lariviere and Gal, 2005). Arctic Red West G-55 at 133.17° W longitude, reportedly intersected Mount Clark Formation (Osadetz et al., 2005).

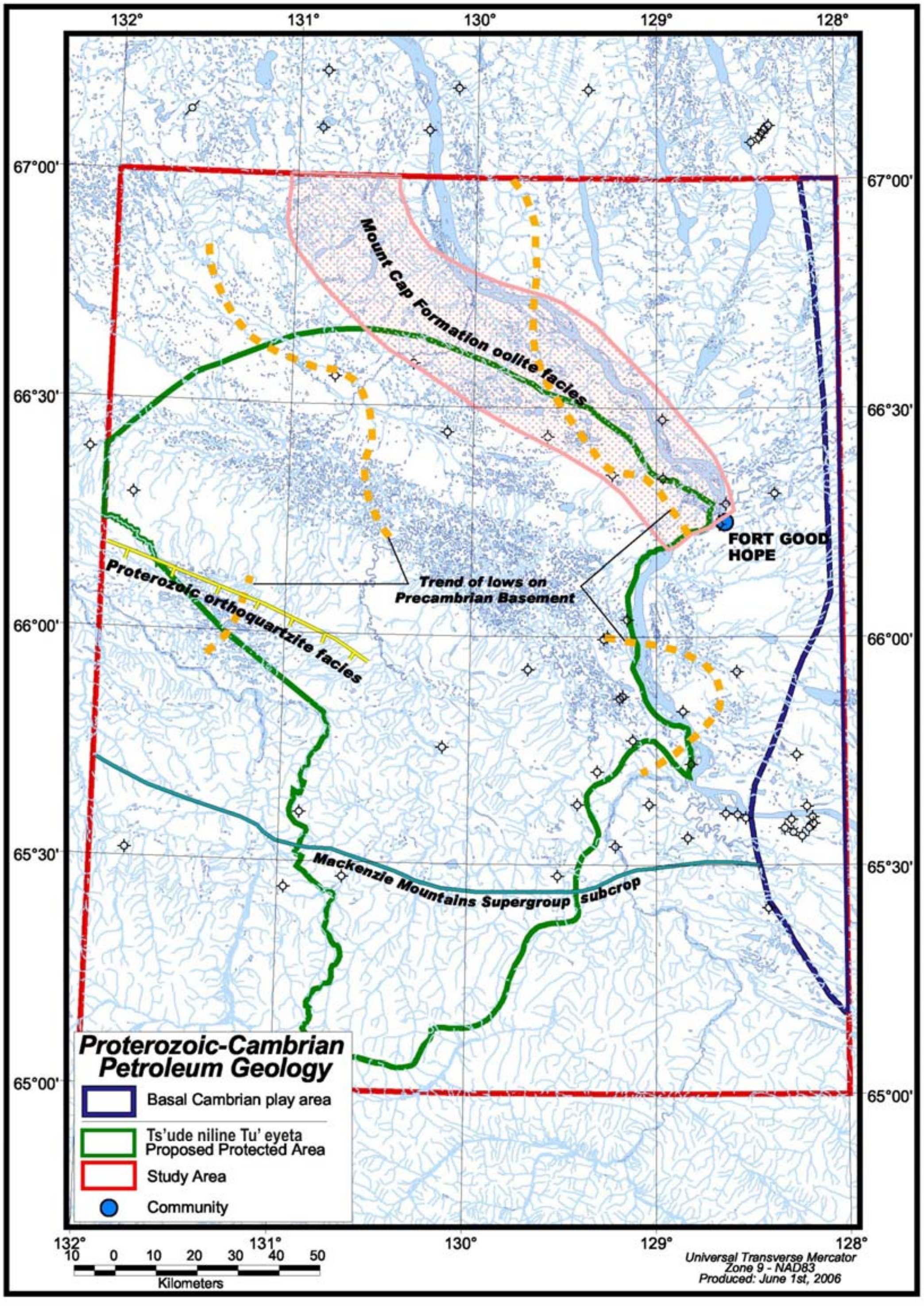

Figure 18. *Basal Cambrian play map. The play area is restricted to the eastern margin of the study area, after Gal (2005). Mount Cap Formation oolitic facies is indicated (after Meding, 1998), as is a facies limit of Proterozoic "orthoquartzite" (Pugh, 1983) and the interpreted subcrop limit of Mackenzie Mountains Supergroup, which includes Katherine Formation (after MacLean, 1999). Also indicated are the trend lines of lows on the basement surface interpreted from seismic (MacLean, 1999). Such lows may have been depocentres for Mount Clark equivalent sandstones*

Certainly the play extends further west if considering the distribution of possible reservoir beds other than Mount Clark Formation. Meding (1998) described the Mount Cap Formation oolitic dolostone as occurring as far west as 131° W in the northern part of the study area (Figure 18).

Risks for this play would be deposition and distribution of potential reservoirs, development and/or preservation of porosity, communication with source rocks and sufficient volume of source rocks to generate enough gas, and viability of top and lateral seals. Timing of petroleum generation, and subsequent migration is not well understood for this interval, but the long interval represented by the sub-Cambrian unconformity effectively isolated Proterozoic sources from Cambrian reservoirs (though the reverse is not necessarily true). Furthermore, several long periods of post Cambrian uplift, erosion, and exposure (particularly at the Mount Clark subcrop edge) have increased the chances of breached or degraded reservoirs.

The potential of this play in the study area is low/low to moderate (probably higher in the east part of the study area), with low confidence due to the general lack of information on Cambrian strata in the study area (Rank EF-4, Table 2).

Upper Cambrian to Silurian Petroleum Geology

Reservoir

Potential reservoirs are Franklin Mountain and Mount Kindle formation dolostones. These are widely distributed in a thick (> 500 m) package throughout the study area.

Vuggy, intercrystalline, and fracture porosity is possible in these dolostones. Diagenetic dissolution of chert may increase porosity in the cherty member of Franklin Mountain Formation (Norford and Macqueen, 1975). Tassonyi (1969) considered Mount Kindle Formation and upper part of cherty member of Franklin Mountain Formation to potentially have good reservoir characteristics. Porosity due to dissolution related to unconformities is possible in upper parts of both formations. Cavernous porosity related to karsting has been noted in Franklin Mountain Formation (Damte et al., 2003).

Several drill stem tests (DSTs) in Mount Kindle and Franklin Mountain formations have recovered large amounts of mainly formation waters, indicating good permeability and porosity. These include Hume River L-09, Mountain River H-47, Ontaratue K-04, Manitou Lake L-61, Hume River O-62, Ontaratue I-38, and Shoals C-31. Lost circulation zones while drilling through these units (e.g., in Mountain River A-23 and Sammons H-55) may also indicate porous and highly permeable zones. Well logs from Ontadek N-39 indicate possible permeable zones that were not tested with some high resistivity that could indicate gas (Figure 19).

Well cuttings generally revealed poor to moderate porosity. Scattered intercrystalline and vugular porosity was noted in the Mount Kindle Formation in Shoals C-31 (Evans, 1966). In Sperry Creek N-58, fair to good intercrystalline and vuggy porosity was seen in places, but samples showed mostly poor porosity (Chevron Canada Resources, 1991a). In Sammons H-55, poor to occasionally fair porosity was noted from samples near the top of Mount Kindle Formation (Rose, 1984). In Ontaratue I-38, samples from Franklin Mountain Formation had poor to good porosity mainly in vugs and fractures, as well as some intercrystalline porosity that generally increased down hole (Ontko, 1973).

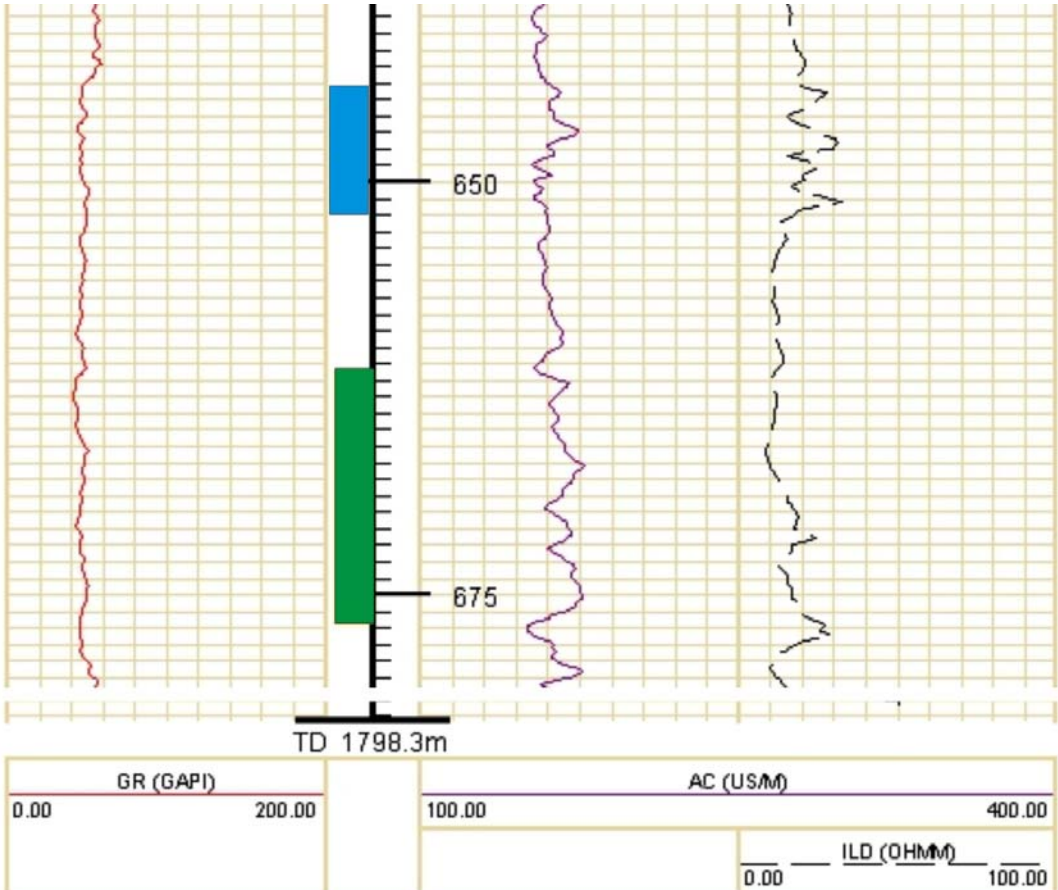

Figure 19. *Gamma (red), sonic (purple), and resistivity (black dashed) logs from Ontadek Lake N-39 well (300N39662012815). Interval shown is near base Mount Kindle Formation. DST #2 (green bar) recovered 213.4 m sulphurous water and 3.1 m mud. The blue bar may have been a better interval to test. There are several examples in this well of relatively higher resistivity, and SP log indicated permeability through Mount Kindle and Franklin Mountain formations that were untested. Well depths in m; sonic travel time (microseconds per m), resistivity (ohm-metres), and gamma (API units) indicated by respective scale bars*

It is probable that the high permeabilities and porosity inferred from DST results is at least in part from fractured zones or possibly cavernous porosity, which may not always be apparent from examining drill cuttings.

Core samples from Mount Kindle and Franklin Mountain formations have been cut from a few wells, and porosities and permeabilities measured quantitatively in laboratories. Mount Kindle core in Mountain River O-18 had measured porosities up to 12.7% over 1.38 m (range mainly 4-9%) but a weighted average of 3.3% over a 17 m interval (Chevron Canada Resources, 1990a). Calculated permeabilities of over 200 millidarcies (mD) were measured in two intervals, while the weighted average was 21 mD over the 17 m. A core of Mount Kindle Formation from Cranswick A-22 well had very low measured porosities, except for a single one foot section at 4.3% (Cannon, 1972a). In the Mountain River H-47, an 8 m core cut from Mount Kindle

Formation showed very little porosity, and fractures and vugs were filled with calcite (Holmes and Koller, 1972a).

Source

Suitable source rocks in this section are not widespread, as this is dominantly a dolostone package. Meijer Drees (1975) suggested dark grey (organic-rich?) dolostones of the lower Mount Kindle as the only possible source rock in this part of the section.

Vitrinite reflectance data is summarized in Table 7.

Well	Reference	Depth (m)	Formation	$\%R_o$	Comments
Hume River L-09	1	2561	Mount Kindle	2.69	overmature
North Ramparts A-59	1	2957	Mount Kindle	2.39	overmature
1=Geochem Laboratories and AGAT Consultants (1977). Reflectance determined from random sample.					

Table 7. *Vitrinite reflectance measurements from Mount Kindle Formation*

Measurements of total organic carbon (TOC) and Rock-Eval pyrolysis analyses of Mount Kindle and Franklin Mountain formation well cutting samples are compiled in Table 8.

In general, the source rock potential of Mount Kindle and Franklin Mountain formations seems to be poor, with limited areas and/or beds of good potential (e.g., Cranswick A-22). Maturity from Rock-Eval data is difficult to interpret but the strata are likely overmature through much of the study area (however, live oil stain was observed in Sammons H-55 samples, and oil-flecked water was obtained in a Hanna River J-05 DST). Geochem Laboratories and AGAT Consultants (1977) interpreted Mount Kindle strata as mature in the north and east parts of the study area, and overmature to the southwest. In the same study, Franklin Mountain Formation was considered overmature in all but the northeast corner of the study area. Both formations were generally rated as generally poor source rocks, although thin shale interbeds in Mount Kindle Formation may have been a good, local, effective source.

It seems more likely that effective source rocks would be Devonian or Cretaceous strata, structurally juxtaposed against Franklin Mountain or Mount Kindle formations to facilitate migration. Southeast of the study area, in the East Mackay B-45, Franklin Mountain Formation hosts oil that was sourced from Cretaceous shales (Geochem Laboratories and AGAT Consultants, 1977; Morrell, 1995). Devonian and Cretaceous source rocks are discussed below.

Seals, migration, and traps

Devonian evaporites or evaporitic dolostone (Fort Norman, Bear Rock formations) would make excellent seals for reservoir rocks of the upper Mount Kindle Formation, except where porous Bear Rock breccias overlie Mount Kindle Formation. Other seals (top and lateral) might be from intra-formational low permeability zones. Tight basal Mount Kindle Formation could seal unconformity-related porosity in upper Franklin Mountain Formation.

Well	Reference*	Depth (m)	Formation (number of samples)	TOC (%)	S1 (mg/ml)	S2 (mg/ml)	Tmax (°C)	Comments
		Maximum values of TOC, S_1, and S_2 given where depths are stated as a range (and multiple samples indicated)						
Sammons H-55	3	430-1220	Mount Kindle, Franklin Mountain (37)	0.71	0.42	1.55	un	Poor source rock potential, likely gas prone
Hume River L-09	1	2561-2607	Mount Kindle (3)	0.29	na			Overmature
Ontadek Lake N-49	1	579-1250	Mount Kindle, Franklin Mountain (23)	0.08	na			---
Ontaratue K-04	2	2363	Franklin Mountain	0.12	0.02	0.00	un	Poor source rock potential
Ontaratue K-04	1	1226-2409	Mount Kindle, Franklin Mountain (40)	1.55	na			Average Franklin Mountain Fm 0.57% TOC. Average Mount Kindle Fm 0.21% TOC
North Ramparts A-59	1	2805-3201	Mount Kindle, Franklin Mountain (14)	0.61	na			---
Cranswick A-22	1	1921-2622	Mount Kindle, Franklin Mountain (24)	0.19	na			Overmature
Cranswick A-22	3	2110-2686	Mount Kindle, Franklin Mountain (78)	2.60	1.34	0.53	un	11 samples analyzed over the lower 91 m of Mount Kindle Fm averaged 1.93%, contamination of samples suggested by Rock-Eval data (L. Snowdon, personal communication, 2005)
Ontaratue H-34	1	1921-2835	Mount Kindle, Franklin Mountain (31)	0.87	na			Max TOC sample possibly bituminous, most samples <0.2% TOC
Ontaratue H-34	2	1982-2835	Mount Kindle, Franklin Mountain (5)	0.16	0.11	0.01	un	Poor source rock potential
* References: 1= Geochem Laboratories and AGAT Consultants (1977), 2= Feinstein et al. (1988), 3= Snowdon (1990)								
nr=not reported, un=unreliable value, na=not applicable								

Table 8. *Rock Eval and TOC analyses from Mount Kindle and Franklin Mountain formations*

Potential traps include banks or buildups, porosity lenses, structured porous beds, and unconformity related traps (including pinch-outs) beneath the pre-Devonian or pre-Mount Kindle unconformities (e.g., Tassonyi, 1969). Stratigraphic traps are likely to be more important than structural traps, although traps related to pre-Devonian faulting, folding and drapes over basement highs are possible. Structural traps related to salt solution and salt flowage in underlying Saline River Formation (in the eastern part of the study area), pre-Devonian faulting, and drapes over basement highs are possible.

It seems most likely that gas can be expected given the age of the rocks and their burial history (Canadian Gas Potential Committee, 2001). Tassonyi (1969) noted that hydrocarbons produced could have migrated into more favourable Lower Devonian reservoirs. Meijer Drees (1975) indicated that gas could have been generated and trapped in the Paleozoic succession, sealed by Devonian evaporites, and preserved in pre-Laramide traps.

Cambro-Silurian platform play

Several minor oil and gas shows from this interval have been found through exploratory drilling (Table 4). This conceptual play includes all pools and prospects in the Cambrian-Ordovician Franklin Mountain and Ordovician-Silurian Mount Kindle formations (Canadian Gas Potential Committee, 2001; Gal, 2005). The play area extends virtually throughout the study area, being limited by outcropping beds in the Mackenzie and north Franklin mountains (Figure 20).

The major exploration risks are in the suitability of reservoir rock, the availability of source rocks (and/or lack of juxtaposition of younger more favourable source rocks), unconformities in the sequence, timing of trap formation relative to hydrocarbon migration, and the possible breaching of reservoirs. The largest and most obvious Laramide structures are often breached, and would in any case likely post-date hydrocarbon generation. Younger oil or gas sources, juxtaposed against porous dolostones, would present less of a risk with respect to migration and timing, but the distribution of these arrangements is not well understood.

Osadetz et al. (2005) grouped this play together with all structural and stratigraphic plays in Hume Formation or older Paleozoic platform carbonates (their Paleozoic Carbonate Platform Play) in the Peel Plain of Yukon, west of the study area. They cited timing of trap formation relative to hydrocarbon migration and closure of traps as major exploration risks, and noted the lack of success to date in this stratigraphic interval. Osadetz et al. (2005) considered the total petroleum potential of their Paleozoic Carbonate Platform Play to be unattractive.

This play has low to moderate potential, increasing westward and southward with increasing thickness of the section. Potential and confidence ranking is D-3 (Table 2).

Lower Devonian Petroleum Geology

Devonian rocks have been the main exploration targets in the region, and are the major source of current and past oil and gas production in the Western Canada Sedimentary Basin. Discussion of Middle and Upper Devonian petroleum geology follows this section.

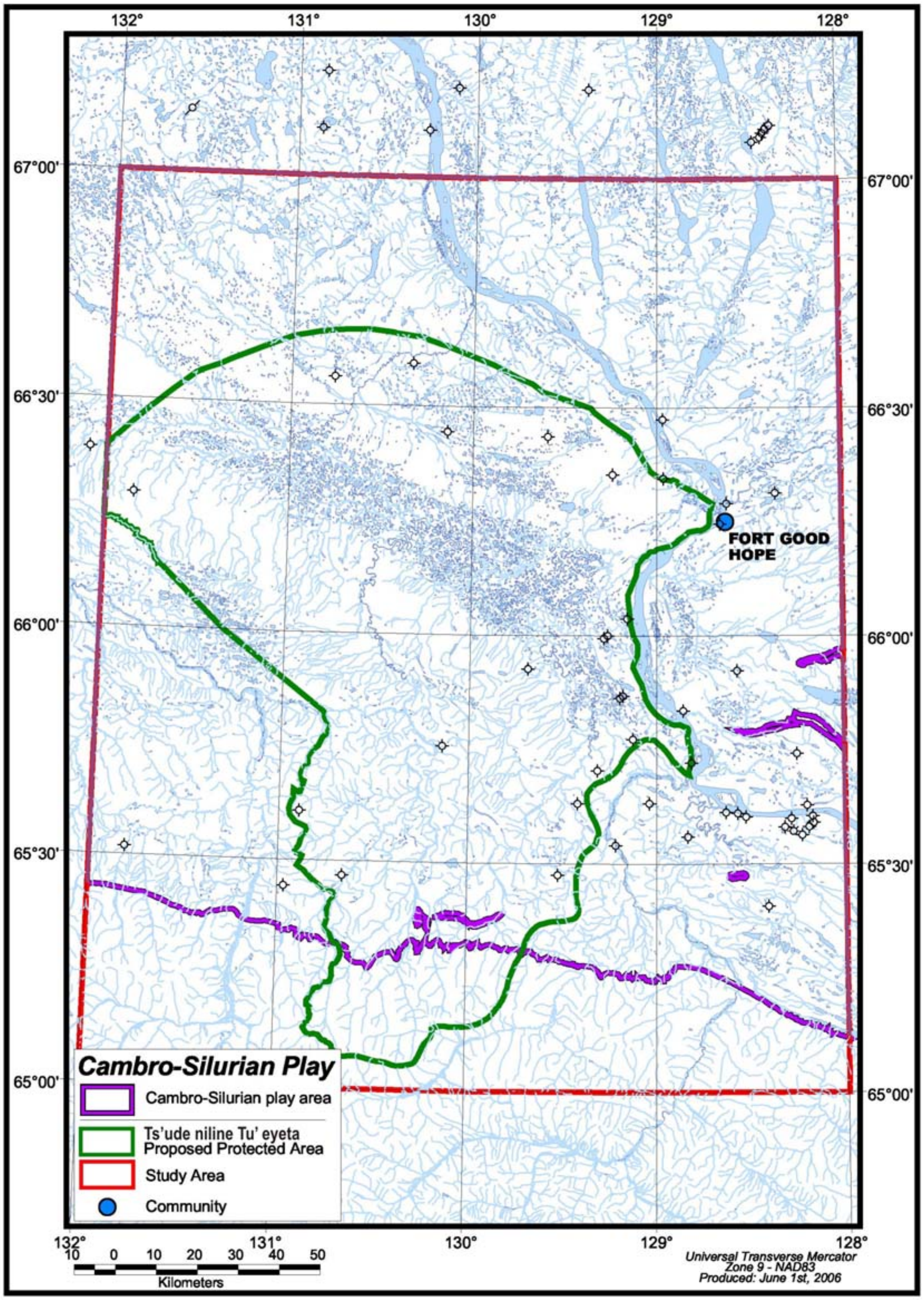

Figure 20. *Cambro-Silurian platform play map. The play area covers most of the study area*

Reservoir

Potential reservoir rocks in the Lower Devonian include the Peel, Arnica, and Landry formations. Peel Formation dolostone is restricted to the western half of the study area. Little is known of its reservoir properties, with no cores sampled. In Ontaratue I-38, permeability may be indicated on well logs by the SP curve at the top of the formation. Arnica Formation is a regionally extensive dolostone that often exhibits intercrystalline and locally vuggy porosity, and good to excellent reservoir potential in many areas (e.g., Chevron Canada Resources, 1990b). Diagenetic coarse hydrothermal "Manetoe" dolomitization that makes Arnica Formation an attractive reservoir south of the study area near Fort Liard area does not extend north of 63°30' latitude (Morrow et al., 1990).

For example, a porous zone (4-10 %) in Arnica Formation 46 m thick is apparent from neutron logs in Mountain River A-23. The upper part of this interval recovered water on DST (Figure 21). Langton (1989) describes Arnica Formation carbonates as having intercrystalline, vuggy, and fracture porosity, ranging from 6-12 %. There is evidence within Arnica Formation indicating periods of subaerial exposure, and solution breccias, in the eastern study area near the facies transition to Fort Norman Formation (e.g., Langton, 1989; Stephanian, 1999). In Hume River D-53, selective dolomitization of Arnica Formation has resulted in excellent intercrystalline and vuggy porosity (Stephanian, 1999). Multiple generations of dissolution and precipitation are apparent in some wells (e.g., Beavertail G-26; Stephanian, 1999).

Landry Formation limestone is often tight, but lost circulation zones (e.g., Mountain River A-23, at 1087 m) indicate possible cavernous porosity or permeable fracture zones. Pelletoidal facies of Landry Formation limestone locally shows evidence of leaching that increases porosity (Tassonyi, 1969). High water flow on DST in Landry Formation in Loon River H-79, with no porosity noted in core or cuttings, also indicates a fractured zone (Sproule and Associates, 1960).

The gas show from Landry Formation in Mountain River H-47 was from a DST over a very wide test interval (68.3 m). Logs show an SP deflection and increased resistivity, but only one narrow interval (1.2 m) of porosity (10%) from the neutron log, thus, fracturing may be important in this show.

In Sammons H-55, Arnica Formation cuttings displayed poor to good intergranular and vuggy porosity, and circulation was lost in this formation (Rose, 1984). Fair to poor intercrystalline and vuggy porosity was noted throughout Arnica Formation well cuttings in Shoals C-31 (Evans, 1966). Well cuttings from Sperry Creek N-58 had only traces of intercrystalline porosity and pinpoint vugs in Arnica Formation, and less porosity in Landry Formation (Chevron Canada Resources, 1991a). Well cuttings from Arnica Formation in Carcajou K-68 showed little porosity (maximum 2%) but DST in the Landry and upper Arnica interval suggested high permeability (Cannon, 1972b).

In Hume River D-53, 15.2 m of core was cut in Arnica Formation. Porosities and permeabilities were quite high, with a weighted average of 5.05% porosity and 8.20 mD permeability over the 12 m of core that was analyzed (Holmes and Koller, 1972b). A few individual porosity measurements were over 10%, and permeabilities ranged up to 133 mD.

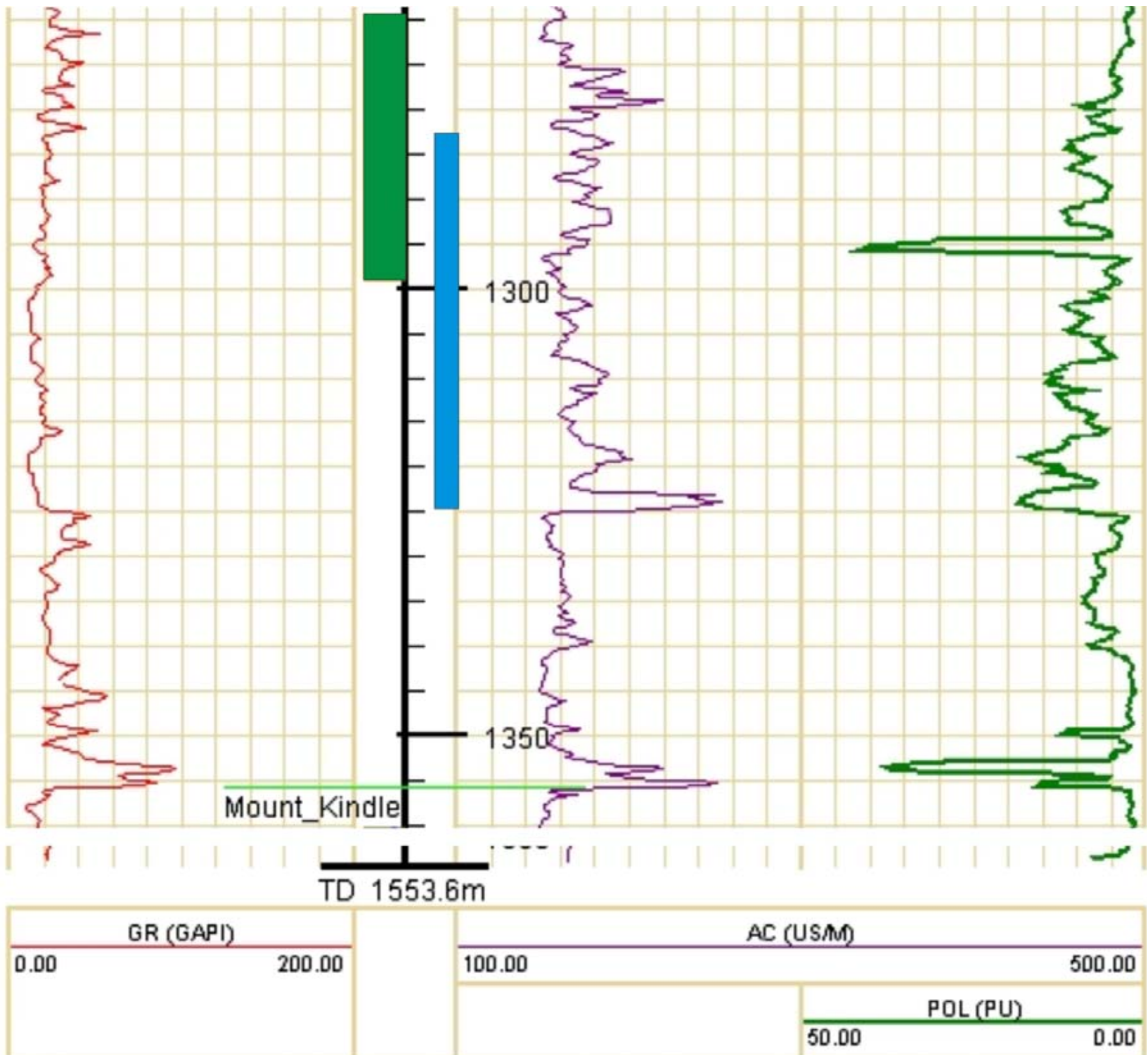

Figure 21. *Gamma (red), sonic (purple), and neutron porosity (green) logs from Mountain River A-23 well (300A23655012915). The porosity log indicates a porous zone from 1270-1296 m (blue bar). The green bar indicates a DST that recovered 1174m of salt water and muddy salt water. Well depths in metres; neutron porosity units (% porosity), sonic (microseconds per m) and gamma (API units) indicated by respective scale bars*

An 18 m core cut through Arnica Formation in the Mountain River H-47 was found to be highly brecciated and fractured, with poor porosity (Holmes and Koller, 1972a). Fractures were partly filled with calcite and dolomite, but were also found to be bleeding oil. Laboratory measurements of this core yielded a weighted average of 2.43% porosity and 1.59 mD permeability over the 5.7 m analyzed, including an interval of 3.61% weighted average porosity over 1.68 m (Holmes and Koller, 1972a).

In Mountain River O-18, an 8 m core cut in Arnica Formation yielded porosities up to 13%, with a weighted average 2% over the entire interval. Measured permeabilities were up to 819 mD, with a weighted average 5.05 mD. The high values were thought to be affected by fractures (Chevron Canada Resources, 1990a).

Well cuttings from Landry Formation in Shoals C-31 had only scattered pinpoint porosity and fine to very fine vugular porosity (Evans, 1966). A 10.85 m core of Landry Formation from the Shoals C-31 was examined and found to be without porosity (Evans, 1966). Fractures and brecciated intervals were noted, however, and perhaps this explains the oil recovery on DST from Landry Formation in this well. Fracture sets, and hydrocarbons in post-fracture "seams" were also noted by Stephanian (1999) in Shoals C-31. A small core sample (18 cm) from Landry Formation in Airport Creek D-72 yielded 3.0 % porosity (Atlantic Refining Company, 1961). An 11.6 m core of Landry Formation from Loon River H-79 was described as dense with stylolitic partings (Sproule and Associates, 1960).

Source

Potential source rock within the Lower Devonian section is probably limited, as the lithologies are dominantly carbonates. Shale interbeds and muddy limestones within Landry or Fort Norman formations may offer the best potential. Shale interbeds within Landry Formation were postulated as source beds by Langton (1989). Fort Norman Formation, however, is mainly anhydrite, with very poor potential (e.g., in Sammons H-55; Snowdon, 1990). Tatsieta Formation in the western part of the study area is shaly. Middle Devonian rocks are possible hydrocarbon sources. Vitrinite reflectance data from Arnica and Landry formations are compiled in Table 9. Rock-Eval and TOC data is compiled in Table 10.

Well	Reference *	Depth (m)	Formation	$\%R_o$	Comments
Shoals C-31	1	823	Landry	0.90	mature
Hume River L-09	1	1646	Arnica	1.17	mature
		1799	Arnica	1.62	overmature
Ontaratue K-04	2	1000	Arnica	0.88	mature
Ontaratue H-34	2	1103	Landry	1.11	mature
		1158	Landry	1.07	mature
		1216	Landry	1.18	mature
Cranswick A-22	1	1616	Arnica	3.30	overmature
North Ramparts A-59	1	2591	Arnica	2.65	overmature
Ontaratue H-34	1	1156	Landry	1.19	mature
* References: 1= Geochem Laboratories and AGAT Consultants (1977). AGAT determined $\%R_o$ from random sample. 2= Stasiuk and Fowler (2002)					

Table 9. *Vitrinite reflectance ($\%R_o$) measurements from Arnica and Landry formations*

Well	Reference *	Depth (m)	Formation (number of samples)	TOC (%)	S1 (ml/mg)	S2 (ml/mg)	Tmax (°C)	Comments
		Maximum values of TOC, S_1, and S_2 given where depths are stated as a range (and multiple samples indicated)						
Sammons H-55	3	130-420	Landry, Arnica, Fort Norman (30)	0.54	1.24	0.75	450	Five Arnica Fm samples averaged 0.46% TOC. Poor to locally good source rock potential, immature to just within the oil window, based on useable Tmax values. Possibly contaminated samples (high Production Index)
Shoals C-31	1	823	Landry	0.82	na			---
Hume River L-09	1	1677-2530	Landry, Arnica, Fort Norman? (29)	0.64	na			Overmature
Ontadek Lake N-49	1	305-518	Landry, Arnica (8)	0.52	na			0.13% TOC average.
Ontaratue K-04	2	726-1000	Landry, Tatsieta (2)	0.16	0.23	0.14	441, un	Poor source rock, mature
Ontaratue K-04	1	610-1189	Landry, Arnica, Tatsieta (20)	0.49	na			---
North Ramparts A-59	1	2317-2774	Landry, Arnica, Tatsieta, Peel (16)	1.36	na			0.41% TOC average
Cranswick A-22	1	1341-1890	Landry, Arnica, Tatsieta, Peel (19)	0.54	na			Overmature
Cranswick A-22	3	1323-1909	Landry, Arnica, Tatsieta, Peel (65)	3.40	6.41	4.02	443, un	72% of samples yielded 1 % or better TOC. Higher TOC in the lower Arnica, Tatsieta, and Peel formations. Many unreliable T_{max} values, but others indicate immature, to just within oil window. Poor to good, gas prone source rock (Tatsieta Fm best). Low maturity contradicted by reflectance data
Ontaratue H-34	1	1128-1890	Landry, Arnica, Tatsieta, Peel (26)	0.74	na			Landry Fm best, averaged 0.50% TOC
Ontaratue H-34	2	1104-1216	Landry (3)	0.48	0.80	0.41	448	Average TOC 0.42%. Poor to fair source rock potential, mature, hydrocarbons have migrated?
References: 1= Geochem Laboratories and AGAT Consultants (1977), 2= Feinstein et al. (1988), 3= Snowdon (1990)								
un=unreliable value, na=not applicable, AGAT= Geochem Laboratories and AGAT Consultants (1977)								

Table 10. *Rock Eval and TOC analyses from Lower Devonian formations*

Cranswick A-22 has the best reported TOC values in Lower Devonian rocks, likely because of its location in the western part of the study area, closer to the carbonate shelf edge, where shale tongues could extend shelfward.

Geochem Laboratories and AGAT Consultants (1977) interpreted the Lower Devonian to have poor source rock potential, mature throughout most of the study area, except the southwestern portion. This is in agreement with the vitrinite reflectance data.

In summary, good source rock is probably limited in this section, but perhaps is better in the western part of the study area. Rocks are mature, probably ranging to overmature in the southwest. More effective source rocks are present in the Middle or Upper Devonian.

Seals, migration and traps

Probable effective seals are found throughout the section. Tatsieta Formation shales would seal underlying Peel Formation dolostone. Landry Formation is characterized as tight (e.g., Tassonyi, 1969), and may be an effective seal for underlying Arnica reservoirs. Shaly lower Hume Formation would likely seal any Landry reservoir. Fort Norman anhydrite and anhydritic dolostone could form both top and lateral seals for Arnica and Landry formations. Porous Fort Norman breccias are possible (similar to Bear Rock Formation), particularly in the shallower subsurface in the eastern part of the study area. Intraformational seals are possible as units shale out west of the study area, and grade into evaporite facies in the east western part of the study area.

Traps in Lower Devonian strata could be stratigraphic and structural. These include pinch-outs or gradational changes of Arnica (and possibly Landry) formations at subcrop edge, where they are sealed by Fort Norman anhydrite (Aitken et al., 1982). Porous Bear Rock breccias can also act as a conduit for hydrocarbons, however, rather than a seal. Langton (1989) proposed reef growth in Arnica Formation, coupled with subaerial exposure and dolomitization, as a trap style. Intraformational porosity traps are also possible.

A further possibility is structurally influenced uplifts in Arnica Formation, or fracture porosity associated with folds and faults. Structural traps would be more common closer to the Mackenzie and Franklin mountains, but pre-Laramide structures are possible. Structures could enable dissolution and/or dolomitization. Widespread hydrothermal dolomitization of these units, while common south of the study area along the Cordilleran margin (Manetoe dolomite), is not known within the study area.

Seismic evidence for an antiformal structural trap, with Arnica Formation thrust over potential Hare Indian Formation source rock, was the basis for drilling Mountain River O-18 (Chevron Canada Resources, 1990a).

Arnica-Landry platform play

This conceptual play includes all pools and prospects hosted in Arnica and Landry formation platform carbonates, as well as Peel Formation dolostone. This play was evaluated by Canadian Gas Potential Committee (2001). Shows of oil and gas have been obtained from tests of Arnica and Landry formations within the study area (e.g., Landry Formation gas in Mountain River H-47; oil in Shoals C-31)

The play occurs throughout the study area, except in the south where possible reservoir units outcrop or are eroded (Figure 22).

Risks for this play include isolation from effective source rocks, formation of effective traps, and timing of migration with respect to structural traps (National Energy Board, 1996). Reservoir quality is a lesser risk, but the lack of Manetoe-type regional hydrothermal dolomitization is a negative factor (Osadetz et al., 2005).

The play is given moderate/moderate to high potential, with possibly the best areas in the east part of the study area, and along the south (proximal to the Mackenzie and Franklin mountains). Confidence level is 3 giving a rank of C/D-3 (Table 2).

Middle Devonian petroleum geology

Reservoir

The Middle Devonian has been the most tested horizon in the region, chiefly because the 240 million barrel Norman Wells oil field is hosted in a Middle Devonian limestone reef (Kee Scarp member of Ramparts Formation).

Among other Middle Devonian formations, there is some potential in Hume Formation platform limestone, and reefal banks buildups are apparent (Tassonyi, 1969; Gilbert, 1973). Stromatoporoid buildups are possible at the western platform edge of Hume Formation, west of study area (Meding, 1998). Osadetz et al. (2005) mention reefs rooted in Hume Formation, at the margin of the Hume platform (again west of the study area), as a conceptual play in Yukon west of the study area. These would be analogous to Horn Plateau reefs, known from well south of the study area (e.g., Gal and Lariviere, 2004b). Figure 23 shows a possible small Hume reefal buildup interpreted from reflection seismic surveys.

Logs from Beavertail G-26 indicate possible permeability (SP deflection) in the upper Hume Formation (Figure 24). Generally Hume Formation is argillaceous and tight, especially in the lower part, and has poor prospects as a reservoir (Williams, 1986b). Hume Formation core from the Ramparts I-55 was described as dense to microcrystalline, with no mention of porosity (Soul, 1960). Porosity in the upper Hume Formation in Sammons H-55 was described as tight to very poor (Rose, 1984).

Hare Indian Formation has siltstone or possible sandstone in its upper part, and gas shows are known from the Grandview Hills north of the study area (Tassonyi, 1969; Devlan Exploration Ltd., 2003). Canol Formation shale, the prime source rock in this package, is a potential reservoir where fractured sufficiently. A gas show was encountered in Canol Formation in Tree River H-38 north of the study area (Imperial Oil Enterprises Ltd., 1967; Lariviere and Gal, 2005). Minor production at Norman Wells has come from Canol Formation (Tassonyi, 1969).

Ramparts Formation porosity is variable. In the Norman Wells oil field, micro-scale leaching of the rock has resulted in porosity of 12-20%, with small but consistent pore throat sizes (Morrell, 1995). Several cores have been taken from Ramparts Formation in wells in the study area; measured porosities and permeabilities are summarized in Table 11.

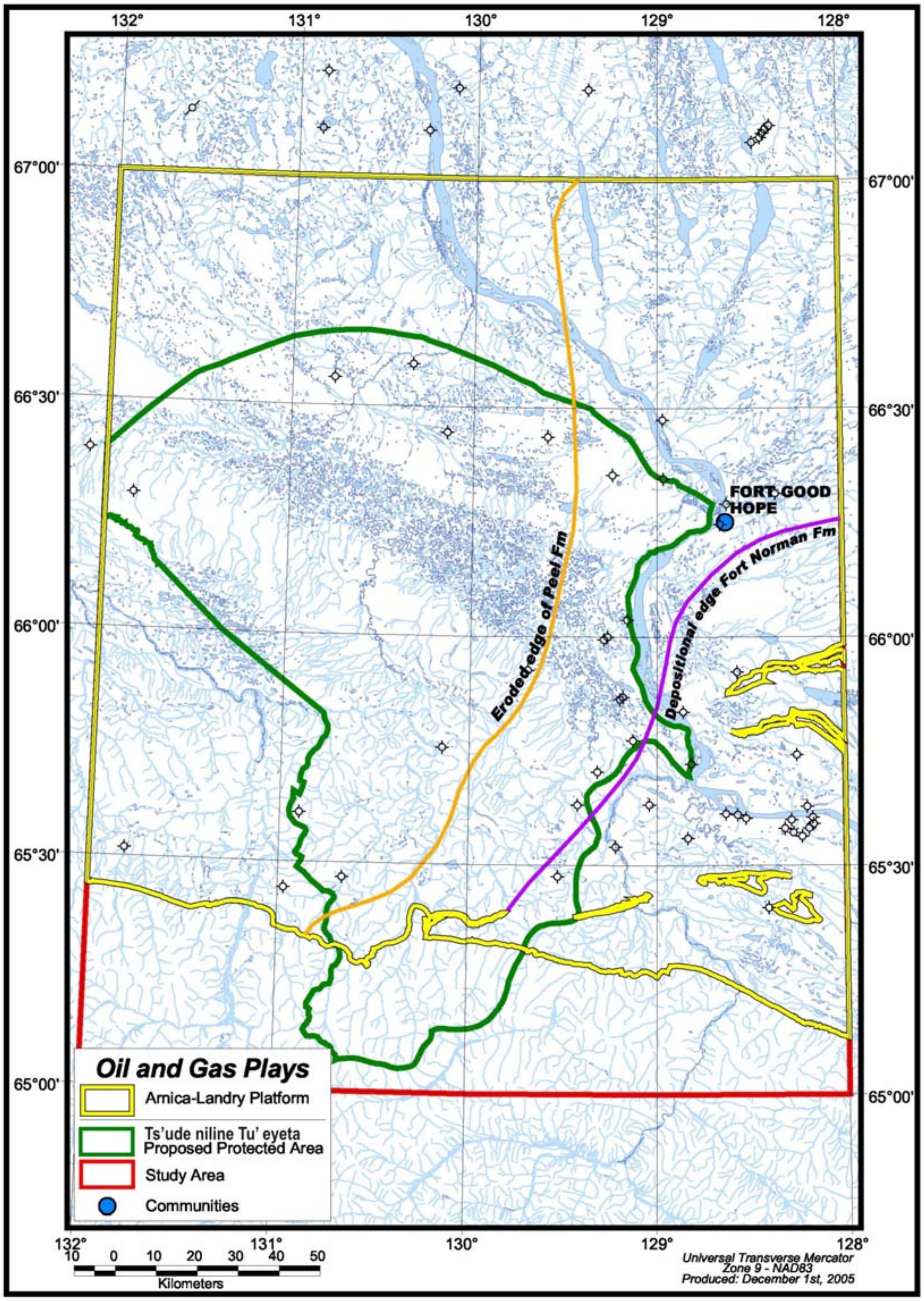

***Figure 22.** Arnica-Landry platform play map. The play area covers most of the study area. The eastern limit of Peel Formation (additional possible reservoir) is indicated (after Pugh, 1983). Facies transition stratigraphic plays related to the interfingering Fort Norman Formation may be concentrated along the western depositional edge indicated (after Pugh, 1983, 1993)*

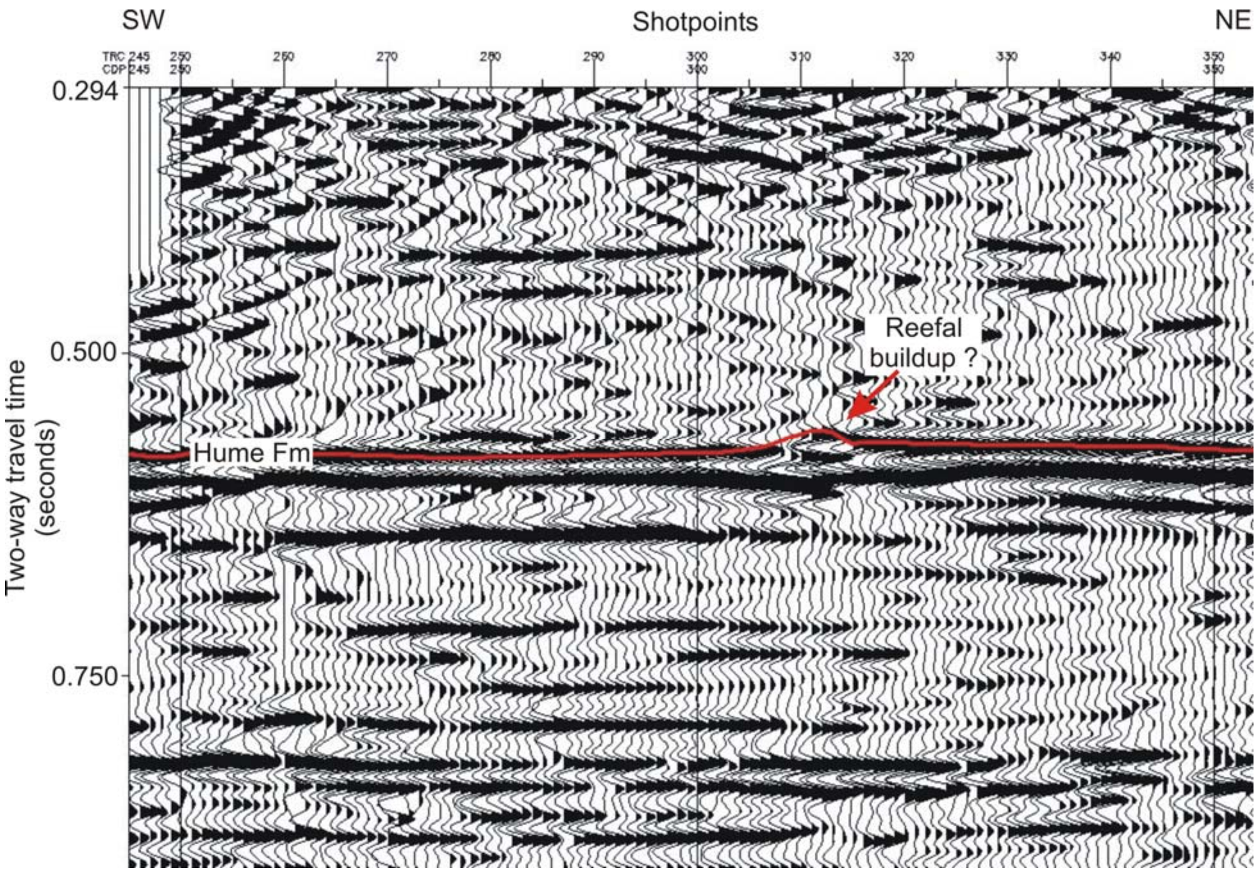

Figure 23. *Seismic reflection survey line c4-8e-20x, survey 9229-c4-8e, Chevron Canada Resources Limited (1989). The Hume Formation reflector shows a possible buildup or bank*

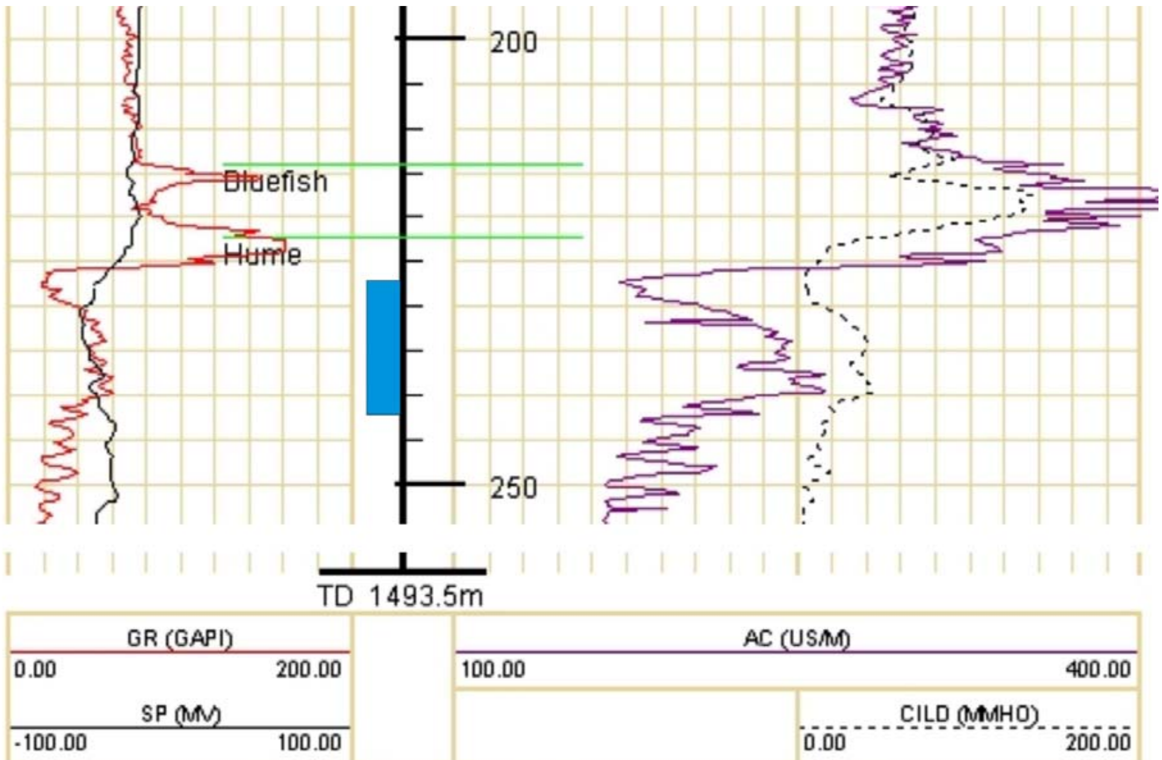

Figure 24. *Gamma (red), self potential (black), sonic (purple), and deep induction (black dashed), logs from Beavertail G-26 well (300G26660012830). Note the weak SP deflection at top Hume Formation and resistivity response. Well depths in metres; gamma (API units), SP (millivolts), deep induction resistivity (ohm metres) and sonic travel time (microseconds per m) indicated by respective scale bars*

Well Name	Depth (m)	Porosity (%)	Permeability (to gas, mD)	Comments
Hume River A-53	252.9-257.5	11.6 max 9.56 wtd. avg.	92.10 max. 6.96 wtd. avg.	--
Maida Creek F-57	464.3-480.8	8.8 max. 6.37 wtd. avg.	1.4 max 0.36 wtd. avg.	Only 10.82 m of interval analyzed
Maida Creek G-56	526.2-565.5	9.8 max 3.83 wtd. avg.	0.73 max. 0.10 wtd. avg.	97% of core interval analyzed
Airport Creek D-72	112.8-121.9	9.3 max 7.32 wtd. avg.	29.0 max. 8.9 wtd. avg.	Only 1.28 m of interval analyzed. High permeability in fractured interval
Hume River O-62	504.0-520.4	7.3 max. 1.87 wtd. avg.	0.58 max. 0.06 wtd. avg. hz	Only 9.02 m of interval analyzed. Core described as having undergone solution and re-cementation by calcite and silica, reducing permeability and porosity. Minor intercrystalline, fracture, and intra-organic porosity with live oil stain
Mountain River O-18	194.0-212.0	1.8 max. 1.2 wtd. avg.	55.8 max 1.66 wtd. avg.	High permeability in fractured interval
Carcajou D-05	546.0-563.7	2.9 max. 1.4 wtd. avg.	17.4 max. 2.27 wtd. avg. hz	Only 3.33 m of interval analyzed. Core described as tight, but 3-12% porosity in fractures and vugs from 555.1-562.8 m
Mountain River H-47	205.8-211.9	Core not analyzed		Core described as dense, scattered fine fractures
Carcajou O-25	601.0-619.0	Core not analyzed		Core described as no effective porosity, tight
Maida Creek O-65	547.0-573.0	Core not analyzed		Core described as tight, but good to excellent intercrystalline (+ vuggy) porosity from 550.64-550.84 m. Rare fracture and pinpoint porosity 553-555 m, and spotty vug porosity to 560.57 m

Table 11. *Measured porosities and permeabilities from Ramparts Formation core. max= maximum, wtd .avg.= weighted average, hz= horizontal*

Source

Source rocks in the Middle Devonian include widespread Hare Indian Formation shale. At the base of Hare Indian Formation is the organic-rich Bluefish Member. Lowermost Upper Devonian Canol Formation black shales are a proven prolific source. In Ontaratue K-04, Hume Formation showed source rock potential (Table 12).

Stasiuk and Fowler (2002) compiled thermal maturation data (vitrinite reflectance and equivalent) for Middle Devonian formations and Canol Formation. Mature samples (within the oil window) lie in northwest-trending belts across the study area for both sample groups (Figures 25, 26). Samples are overmature (i.e., gas-generating) to the southwest.

Geochem Laboratories and AGAT Consultants (1977) rated the basal shale of Hume Formation and Hare Indian Formation as fair to very good, and Canol Formation as very good to excellent source rocks, in terms of richness and effectiveness.

Source rocks of this age (Tables 12, 13, 14) are widespread, rich (especially Canol Formation and Bluefish Member), and mature throughout most of the study area (but overmature in the southwest corner).

Seals, migration and traps

Widespread Hare Indian Formation shales form a good regional seal to any Hume reservoirs, and lateral seal for Ramparts Formation. Canol Formation also provides top and lateral seals to Ramparts Formation reservoirs. Prospects for seals are poor where Canol is eroded and Cretaceous sandstone beds overlie Ramparts Formation.

Traps in Ramparts Formation are mainly stratigraphic. The Kee Scarp reef complex and some related reefs have been studied, explored, and outlined fairly well by seismic surveys (Williams, 1985). Much of the past drilling has been focused on structural highs within the Kee Scarp member or at reef margin. Internal architecture and subtle facies variations which may control porosity are not as well understood. Stratigraphic traps may be found in specific reef-related facies; such as back reef shoals (Morrell, 1995), fore-reef allochthonous debris beds shed off the main body (Chevron Canada Resources, 1990b), and vuggy dolomitized bodies in back-reef environments (Chevron Canada Resources, 1990a). A thin bioclastic sandstone member that lies above Kee Scarp member also has reservoir potential (Morrell, 1995). Simple reefal buildups probably remain to be found, and may be present in Hume Formation, as mentioned above. For example, an untested structural high was identified seismically by Mobil Oil Canada Ltd. northwest of the Ontaratue River, at about 65°45’N and 130°30W. It is approximately 480 m by 180 m, with at least 30 microseconds of closure (Ray Geophysical Ltd., 1970).

More subtle stratigraphic traps involving diagenetic development of porosity through dissolution or local dolomitization are possible. In addition, structural features may contribute to trapping geometries, particularly near the mountain fronts.

Well	Reference *	Depth (m)	Formation (number of samples)	TOC (%)	S1 (ml/mg)	S2 (ml/mg)	Tmax (°C)	Comments
		Maximum values of TOC, S_1, and S_2 given where depths are stated as a range (and multiple samples indicated)						
Sammons H-55	3	40-120	Hume (9)	0.55	0.47	0.73	454	Poor to fair source rock, gas prone, mature (within oil window). Nine Hume Formation samples averaged 0.36% TOC
Shoals C-31	1	430-793	Hare Indian, Hume (14)	1.06	na			---
Hume River L-09	1	1250-1585	Canol, Ramparts, Hare Indian, Hume (11)	1.08	na			---
Ontadek Lake N-49	1	168-274	Hare Indian, Hume (4)	7.49	na			---
Carcajou D-05	3	550-740	Ramparts, Hare Indian (20)	0.82	0.78	0.90	457	Poor to fair source rock, gas prone, mature (within oil window). Nineteen of the samples from Ramparts Formation
Carcajou O-25	3	600-760	Canol, Ramparts, Hare Indian (17)	2.15	1.13	4.24	451	Poor to very good source rock potential, mature (within oil window), mostly gas prone but some oil prone, Maximum S_1 and S_2 values from lower Ramparts Formation
Maida Creek O-65	3	530-685	Canol, Ramparts, Hare Indian (16)	2.36	2.64	6.67	451	Canol and Hare Indian formations fair to good source rock, mature, mixed gas and oil prone
Ontaratue K-04	2	274-576	Canol, Ramparts, Hare Indian, Hume (11)	12.43	5.44	37.90	447	Canol, upper Hume formations very good source rock, mature, oil prone mainly. Canol average 5.54% TOC (4 samples)
Ontaratue K-04	1	274-579	Canol, Ramparts, Hare Indian, Hume (11)	6.24	na			---
North Ramparts A-59	1	2043-2287	Canol, Hare Indian, Hume (9)	4.93	na			---
Cranswick A-22	1	1098-1311	Canol, Hare Indian, Hume (8)	4.79	na			---
Cranswick A-22	3	1076-1314	Canol, Hare Indian, Hume (20)	6.27	0.05	0.10	446, un?	Excellent TOC through lower Canol, Hare Indian formations (average 4.52 % TOC for both fms). PI, T_{max} indicate immaturity to within oil window, but these values suspect. S_1, S_2 and S_3 all very low.
Ontaratue H-34	1	915-1098	Canol, Hare Indian, Hume (7)	3.94	na			---
Ontaratue H-34	2	918-1043	Canol, Hare Indian, Hume (8)	4.89	3.63	4.40	469	Good to very good source rock potential, maturity near top of oil window, mixed gas and oil prone, migration took place
* References: 1= Geochem Laboratories and AGAT Consultants (1977), 2= Feinstein et al. (1988), 3= Snowdon (1990)								
nr=not reported, un=unreliable value, om=overmature, na=not applicable, AGAT= Geochem Laboratories and AGAT Consultants (1977)								

Table 12. *Rock Eval and TOC analyses from Middle and Upper Devonian formations*

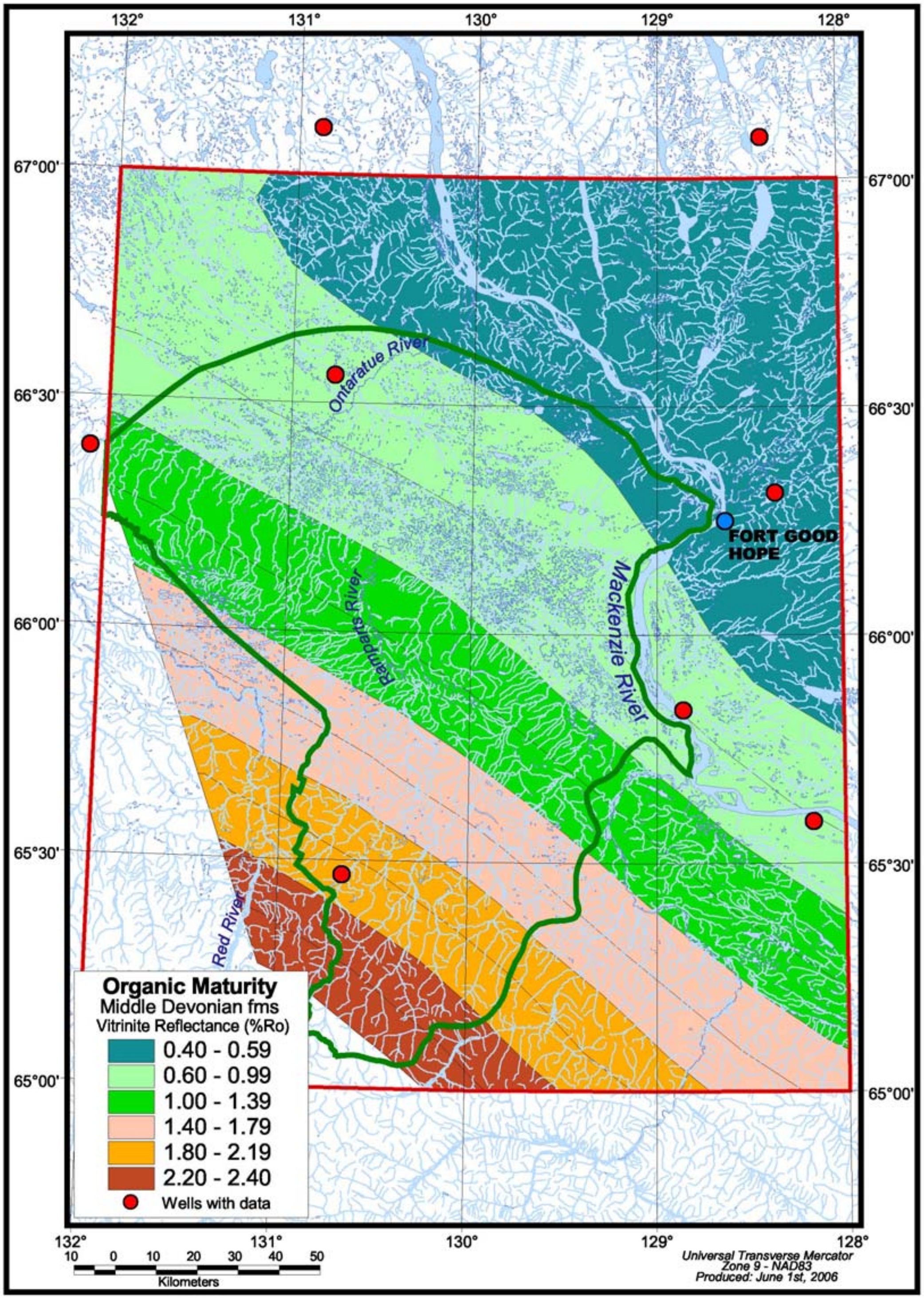

Figure 25. *Contour map of source rock maturity based on vitrinite reflectance from Middle Devonian formations (after Stasiuk and Fowler, 2002). Mature rocks within the oil window are generally accepted to have reflectance values of 0.6-1.4% R_o. Ts' ude niline Tu' eyeta is outlined in green, the study area in red. Wells from which samples were analyzed and used to construct contours are indicated by red dots*

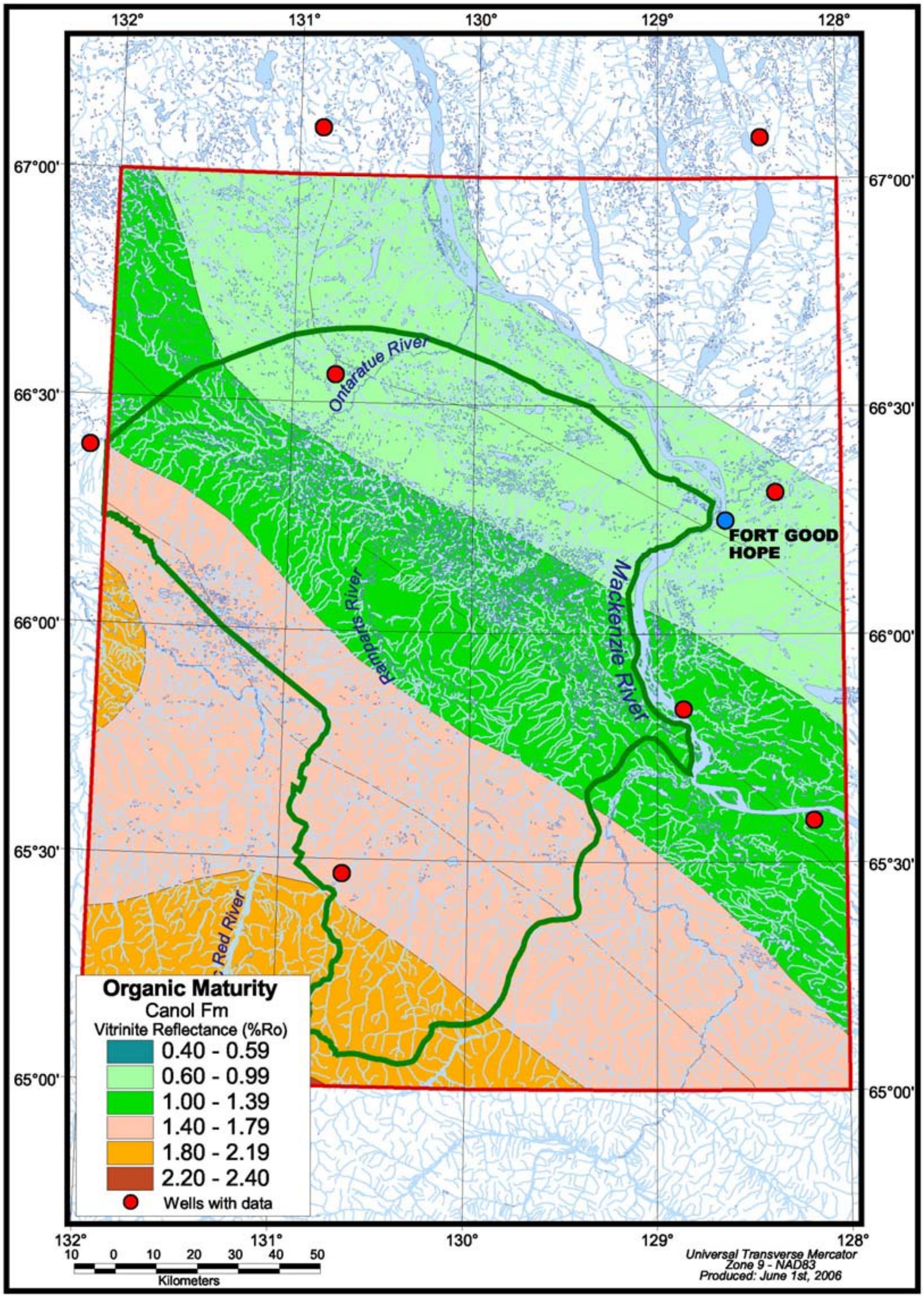

Figure 26. *Contour map of source rock maturity based on vitrinite reflectance from Canol Formation (after Stasiuk and Fowler, 2002). Mature rocks within the oil window are generally accepted to have reflectance values of 0.6-1.4%* R_o. *Ts' ude niline Tu' eyeta is outlined in green, the study area in red. Wells from which samples were analyzed and used to construct contours are indicated by red dots*

Well	Reference *	Depth (m)	Formation	%R_o	Comments
Shoals C-31	1, 2	488	Hare Indian	0.52	Low mature
		579	Hare Indian	0.52	Low mature
		634	Hare Indian	1.08	Mature
		701	Hume	0.72	Mature
Maida Creek G-56	2	549	Ramparts	0.83	Mature
Ontadek Lake N-39	2	183	Hume	0.51	Low mature
Hume River L-09	1	1280	Hare Indian	1.52	High mature to overmature
		1463	Hare Indian	1.44	High mature to overmature
Ontaratue K-04	1	488	Hare Indian	0.68	Mature
Ontaratue K-04	2	399	Hare Indian	0.68	Mature
		488	Hare Indian	0.68	Mature
		502	Hume	0.76	Mature
		576	Hume	0.69	Mature
North Ramparts A-59	1	2256	Hume	2.29	Overmature
North Ramparts A-59	2	2173	Hare Indian	2.0	Overmature
		2255	Hume	2.12	Overmature
Ontaratue H-34	2	945	Hare Indian	1.24	High mature
* References: 1= Geochem Laboratories and AGAT Consultants (1977). AGAT determined %R_o from random sample. 2= Stasiuk and Fowler (2002)					

Table 13. *Vitrinite reflectance measurements from Hume and Hare Indian formations*

Well	Reference	Depth (m)	%R_o	Comments
Maida Creek G-56	1	518	0.73, 0.90	Mature
		519	0.91	Mature
		521	0.93	Mature
		523	0.93	Mature
		526	0.93	Mature
		529	0.96	Mature
South Ramparts I-77	1	716	1.55	Overmature
		783	1.68	Overmature
Ontaratue K-04	1	277	0.62	Mature
		283	0.60	Mature
Cranswick A-22	2	1159	2.30	Overmature
Cranswick A-22	1	1106	1.44	High mature to overmature
		1170	1.61	Overmature
Ontaratue H-34	1	902	0.98	Mature
		978	1.17	Mature
Reference: 1= Stasiuk and Fowler (2002), 2= Geochem Laboratories and AGAT Consultants (1977)				

Table 14. *Vitrinite reflectance measurements from Canol Formation*

Kee Scarp play

The play includes all prospects and pools hosted in Middle Devonian Ramparts Formation, particularly Kee Scarp Member. Hume and Canol formations are secondary potential reservoirs that can be grouped here as well. This play is established through discovery of reserves and production at Norman Wells. In Gal (2005), a fairway was outlined to represent the established play, and the balance of the play area was treated as conceptual. This established play fairway extends to just southeast of the present study area.

Within the study area, several oil and gas shows have been found (e.g., Carcajou D-05, Hume River O-62). Ramparts Formation has often been the primary target of exploration wells, but apparently in some cases the best intervals indicated by logs have not always been tested (Figure 27).

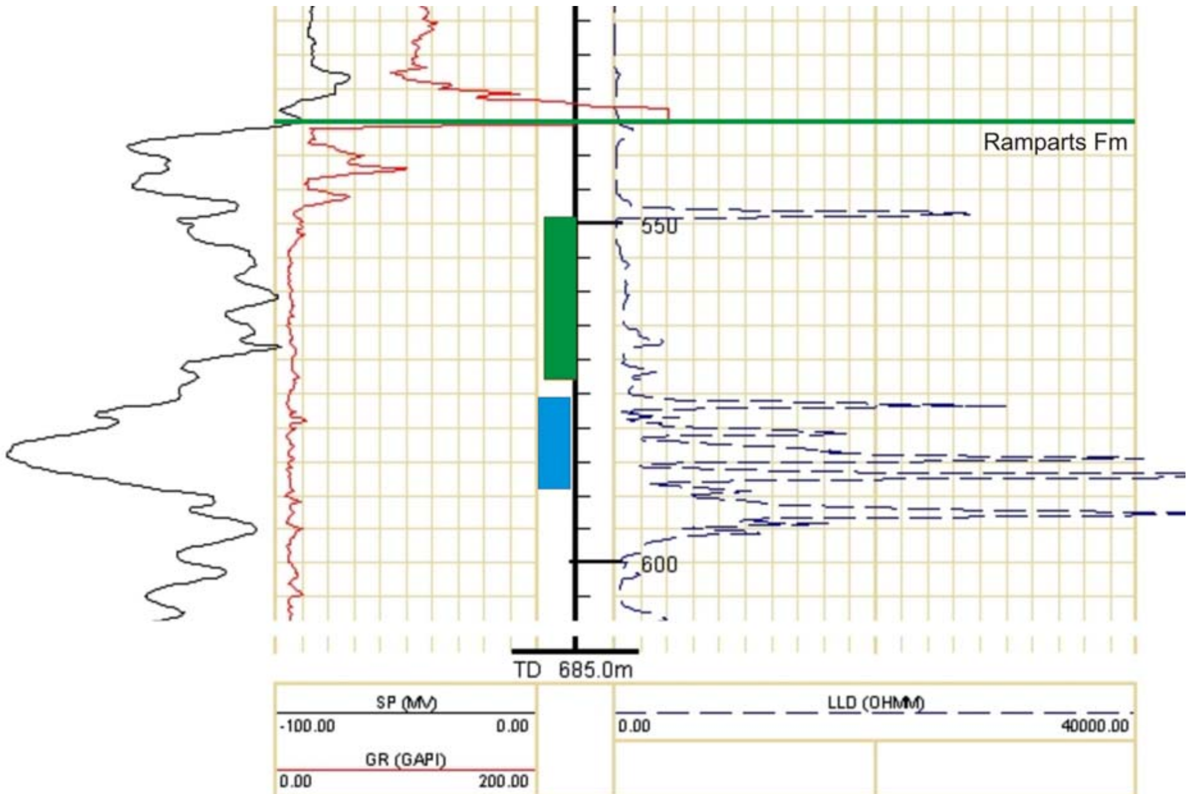

Figure 27. *Gamma (red), self potential (SP; black solid), and deep resistivity (black dashed) logs from Maida Creek O-65 (300O65400012800). Top Ramparts Formation indicated by green line. The green bar from about 550 m indicates the interval tested by DST #1, which recovered 48 m gas-cut mud, 189 m slightly gas-cut mud, and 93 m muddy water. The SP deflections and resistivity kicks further downhole (blue bar, 550-580 m) perhaps suggest a better test interval. Well depths in metres; gamma (API units), SP (millivolts), deep induction resistivity (ohm metres) readings indicated by scale bars*

The play area is bounded on the east and northeast by outcropping Ramparts Formation and erosional boundaries (Figure 28). In the central western part of the study area, play boundaries are depositional limits of Ramparts Formation. To the south the play is limited by outcrop in Mackenzie Mountains.

Exploration risks include trap development and reservoir quality, that is, development of porosity and permeability. Breaching of reservoirs, and degradation of hydrocarbons, are risks because the unit is close to surface in the eastern part of the study area. This play is ranked as high, and with a fair amount of well and seismic information available in the study area, a rank (Table 2) of B-2 is assigned.

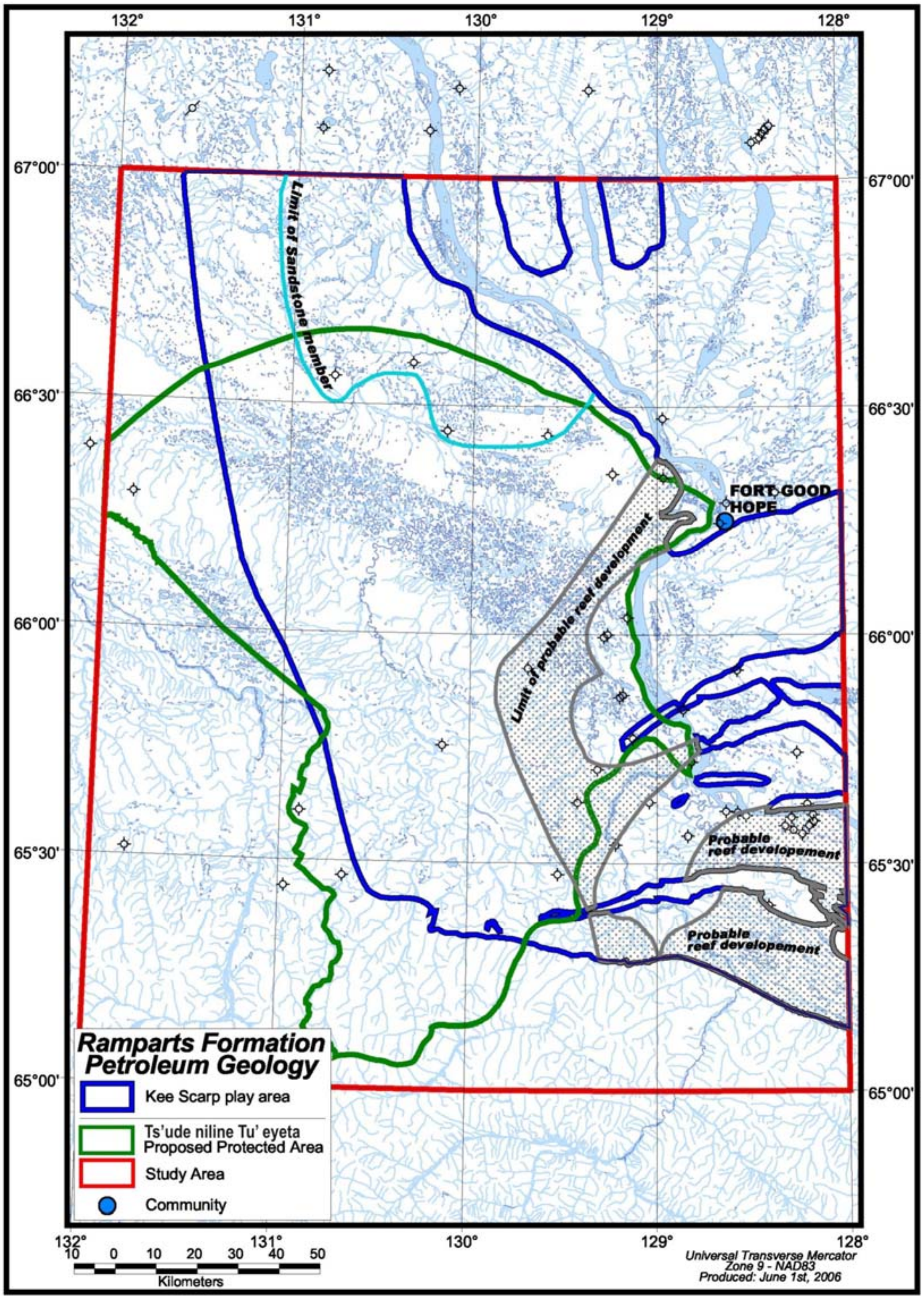

Figure 28. *Kee Scarp play map. The play area covers the central and eastern parts of the study area. The zone of known and probable reefal development (Kee Scarp member) is indicated (after Williams, 1985). The southern limit of Ramparts Formation sandstone member is also indicated (after Williams, 1985)*

Upper Devonian petroleum geology

Reservoir

Upper Devonian as discussed here comprises Imperial Formation, a thick sequence of siltstone, shale, and sandstone that unconformably overlies Canol Formation. There is some reservoir potential here, particularly in the western part of the study area, where the unit becomes sandier overall (Pugh, 1983). Very minor production has come from this unit at Norman Wells, where oil has migrated upward from Ramparts Formation (Tassonyi, 1969).

Anomalous gas levels were detected while drilling Ramparts F-46 (Chevron Canada Resources, 1991b). In the lower part of Imperial Formation, a series of sandstone beds appear from the logs to contain gas, although the intervals were never tested (Morrell, 1995).

In the Hume River I-66, a 5 m interval in upper Imperial Formation may hold gas, but was not tested (Figure 29). A neutron-density cross over is apparent in Imperial Formation in the Maida Creek O-65, which probably indicates bypassed gas (Figure 30). Weak suggestions of neutron-density crossover are also apparent in logs for the Cranswick A-22 and South Ramparts I-77.

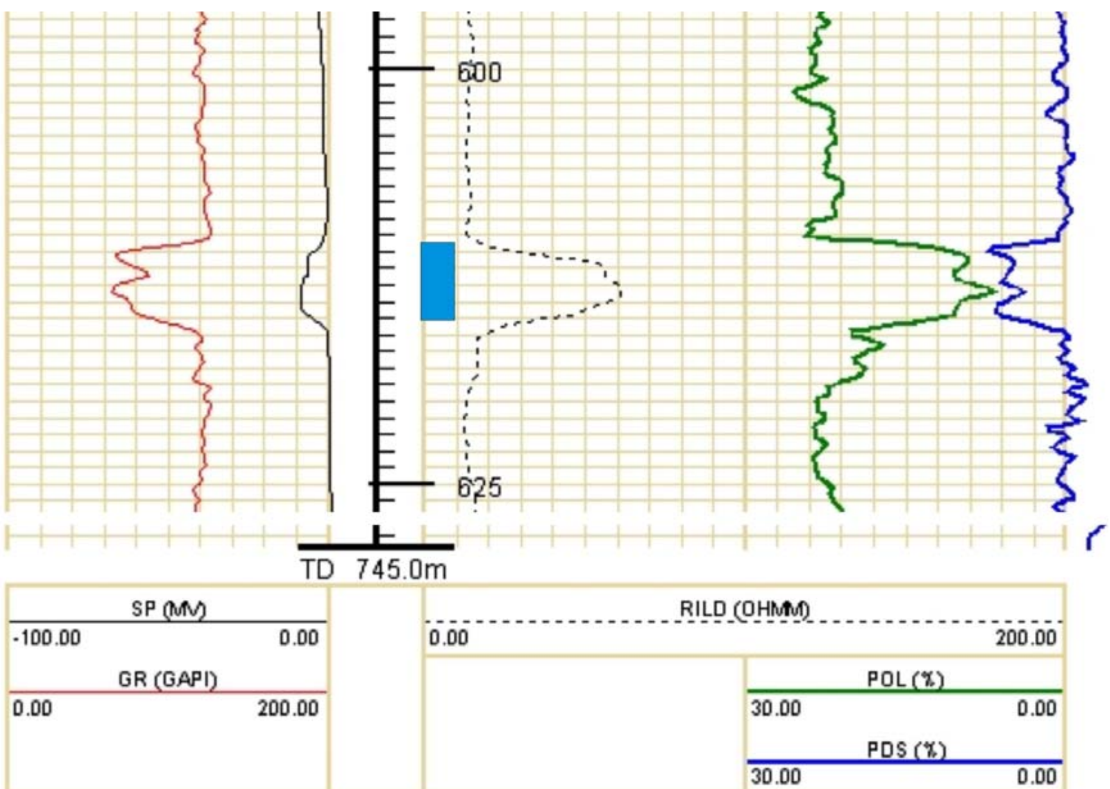

Figure 29. *Gamma (red), Self Potential (SP; black solid), deep resistivity (black dashed), density (blue), and neutron (green) logs from Hume River I-66 well (300I66660012930). The resistivity kick and behaviour of the porosity logs may indicate a gas-charged sand that was not tested. Well depths in metres; gamma (API units), SP (millivolts), deep induction resistivity (ohm metres), density and neutron porosity (percent porosity) scales indicated. Note that only the density porosity log was calibrated to sandstone*

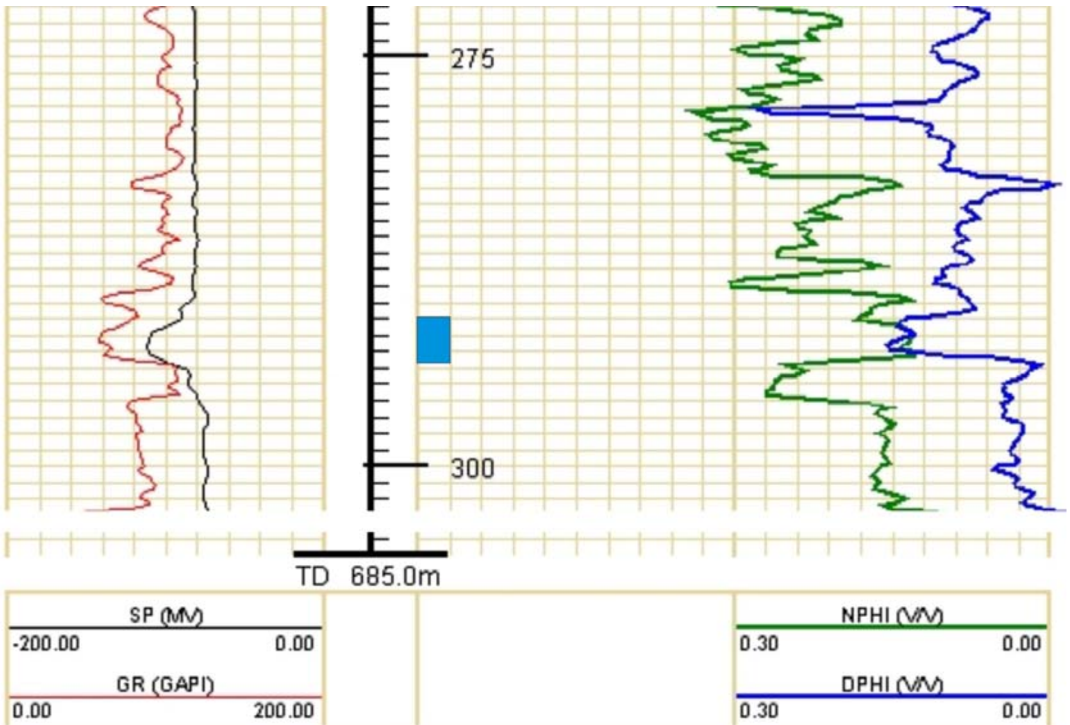

Figure 30. *Gamma (left, red), Self Potential (SP; left, black), neutron (right, green), and density (right, blue) logs from Maida Creek O-65 well (300O65654012800). The green rectangle marks a neutron-density crossover coincident with a gamma deflection indicating sand in Imperial Formation; this zone may hold gas, but was not tested. Well depths in metres (1 m per division); gamma (API units), SP (millivolts), density and neutron porosity (volume over volume) scales indicated*

Minor porosity has been noted in fine-grained sandstones in cuttings from a few wells, notably Hume River D-53 (trace to fair porosity described in samples over a 13.7 m interval; Holmes and Koller, 1972b), and Arctic Red F-47 (fair to good porosity described in samples over a 6.1 m interval ; Haddow, 1973b). Few core samples of Imperial Formation have been taken. The top 13.75 m of Imperial Formation was cored Sperry Creek N-58, with only one 10 cm sandstone stringer exhibiting porosity. The top 13 m of Imperial Formation was cored in East Hume River N-10, and topmost 2.5 m in Hume River I-66, but the lithologies were shale in both cases.

In summary, clastic beds coarser than mud in Imperial Formation may exhibit porosity and there are examples of apparent gas-charged beds. Overall, finer grained sediments dominate, and the challenge is to find porous beds with significant net thickness. In Mountain River A-23, 71.6 m of very fine-grained sandstone is present at top of Imperial Formation (at 1415 m; Brown, 1972).

Source

Tables 15 and 16 list reflectance and Rock-Eval data for samples from Imperial Formation.

Well	Depth (m)	$\%R_o$	Comments
Maida Creek G-56	305	0.80	Mature
	427	0.88	Mature
	518	0.71	Mature
	549	0.83	Mature
Hume River L-09	762	0.88	Mature
	854	0.91	Mature
	1067	1.14	Mature
Ontaratue K-04	122	0.67	Low mature
North Ramparts A-59	1921	2.40	Overmature
Cranswick A-22	823	2.46	Overmature
Ontaratue H-34	488	1.04	Mature

Table 15. *Vitrinite reflectance measurements from Imperial Formation (from Stasiuk and Fowler, 2002)*

Well	Reference *	Depth (m)	Formation (number of samples)	TOC (%)	S1 (ml/mg)	S2 (ml/mg)	Tmax (°C)	Comments
		Maximum values of TOC, S_1, and S_2 given where depths are stated as a range (and multiple samples indicated)						
Hume River L-09	1	640-1220	Imperial (20)	0.95	na			---
Carcajou D-05	2	290-540	Imperial (31)	1.02	1.13	1.42	444	Generally poor to fair (but locally very good) source rock potential, maturity just within oil window. Average 0.68 % TOC for all samples
Carcajou O-25	2	200-590	Imperial (40)	2.23	1.35	4.20	449	Mainly fair source rock potential, maturity just within oil window, average TOC 0.69% for all samples
Maida Creek O-65	2	210-520	Imperial (32)	1.23	0.64	2.30	447	Mainly poor, locally fair source rock potential, maturity to just within oil window
Ontaratue K-04	1	30-244	Imperial (8)	2.33	na			Maximum TOC was coal sample (not shown here). 1.88% TOC average of remaining samples
North Ramparts A-59	1	1372-2012	Imperial (22)	1.53	na			---
Cranswick A-22	1	244-1067	Imperial (28)	2.29	na			Overmature
Cranswick A-22	2	223-1067	Imperial (92)	3.38	0.15	0.70	un, om?	Mostly fair to good potential in terms of TOC; 6 samples representing a 46 m interval in middle Imperial Formation averaged 2.84 % TOC. S1 and S2 values mainly very low, Rock-Eval parameters difficult to interpret, sample contamination?
Ontaratue H-34	1	273-884	Imperial (21)	1.52	na			---
* References: 1= Geochem Laboratories and AGAT Consultants (1977), 2= Snowdon (1990)								
un=unreliable value, om=overmature, na=not applicable								

Table 16. *Rock Eval and TOC analyses from Imperial Formation*

Stasiuk and Fowler (2002) compiled vitrinite reflectance data from Imperial Formation (Table 15). Mature samples trend northwest and west across the study area (Figure 31). Through the northern third of the study area, Imperial Formation is immature, while in the southwest corner it is overmature. The average TOC in six sampled wells from within (or very near) the study area ranged between 0.55-2.84% (Geochem Laboratories and AGAT Consultants, 1977; Snowdon, 1990). Geochem Laboratories and AGAT Consultants (1977) rated the Imperial Formation as fair to moderately good source rocks, in terms of richness and effectiveness. They interpreted Imperial to be overmature in the southwest corner of the study area along the Mackenzie Mountains front (Cransick A-22 and Ramparts A-59), but mature through most of the study area. Generally, Imperial Formation appears to have poor to moderate potential as a source rock, but is mature through much of the study area.

Seals, migration and traps

Shales within Imperial Formation would effectively seal any interbedded sandstone reservoir. Traps within Imperial Formation can be expected to be mainly stratigraphic, related to the depositional environment of sand beds (e.g., distributary channels) contained within the shale-siltstone package, and pinchouts of sandstone bodies. Sandstone is likely more common in the northwest part of the study area. Traps related to pre-Cretaceous unconformity may be present, although the basal Cretaceous is generally sandy, with poor sealing properties. Near the Mackenzie Mountain front, a structural influence is possible, for example, minor folds on the flank of the Imperial Anticline. Traps are likely to be subtle, and small.

Imperial play

This conceptual play includes all pools and prospects hosted in Imperial Formation sandstones. A gas kick encountered while drilling Mountain River A-23 was believed to be coming from Imperial Formation (Brown, 1972), and several examples of possible gas in Imperial Formation have been shown in logs.

The play area is restricted to the western and central parts of the study area (Figure 32). In much of the north and east, Imperial Formation is either missing through erosion, or outcrops, or is too shallow and thin to be an effective reservoir. In the southern part of the study area, the unit is at outcrop in the mountain front, or older rocks lie at surface. Even where Imperial Formation subcrops, if the unit is thick enough, deeper reservoirs may be protected from breaching. Gal (2005) used the 500 m isopach as a play boundary, where Imperial Formation was at outcrop or beneath Quaternary cover.

The main exploration risks are insufficient reservoir (stacked sand beds), reservoir quality, and trapping configurations. Breaching and/or degradation of shallow reservoirs presents a further risk, particularly toward the eastern side of the play area.

Osadetz et al. (2005) grouped Imperial and Tuttle formations together in their Upper Paleozoic Siliciclastics play in the Peel Plain of Yukon. They rate the play lower than corresponding plays in the Peel Plateau, chiefly because reservoir porosity is likely to be lower, and prospects smaller due to the lack of Laramide structural influence.

The play is given moderate potential, with possibly the best potential in the west and southwest parts, and along the margin of Cordilleran deformation (proximal to the Mackenzie and Franklin mountains). The overall potential ranking (Table 2) is D-3.

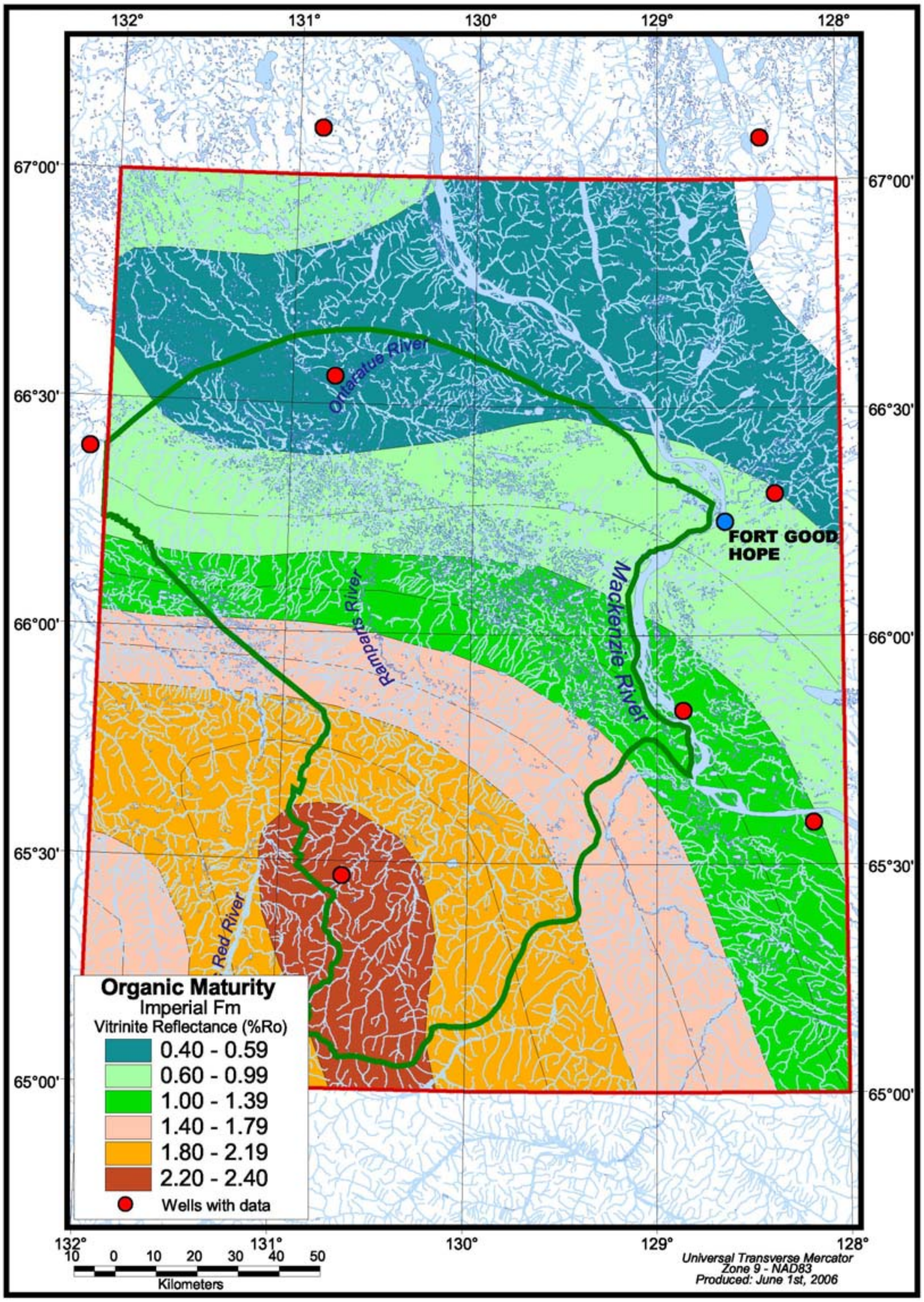

Figure 31. *Contour map of source rock maturity based on vitrinite reflectance from Imperial Formation (after Stasiuk and Fowler, 2002). Mature rocks within the oil window are generally accepted to have reflectance values of 0.6-1.4% R_o. Ts' ude niline Tu' eyeta is outlined in green, the study area in red. Wells from which samples were analyzed and used to construct contours are indicated by red dots*

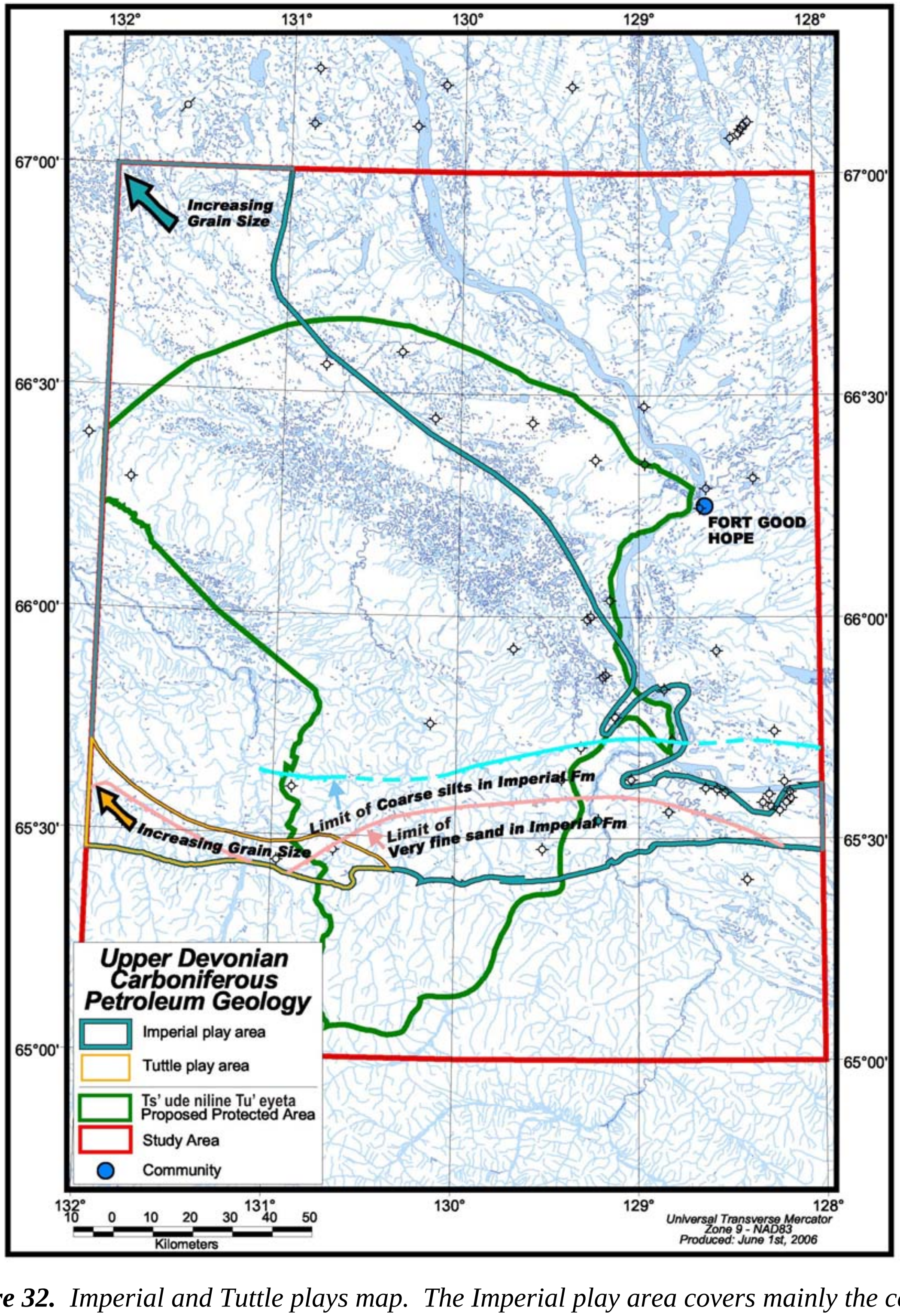

Figure 32. *Imperial and Tuttle plays map. The Imperial play area covers mainly the central and western parts of the study area, Tuttle play from current mapping is restricted to the southwest. The direction of overall increasing grain size in siliciclastic rocks of Imperial and Tuttle formations is indicated (after Pugh, 1983). In addition, coarse silt to fine sand is known from Imperial Formation along the Mackenzie Mountain front, as indicated (after Pugh 1983)*

Carboniferous Petroleum Geology

Reservoir

Mississippian Tuttle Formation is a possible reservoir in the study area, although distribution is highly restricted to a wedge along the Mackenzie Mountains in the southwest part of the study area. The best sandstones in this formation lie west of the study area (e.g., Meding, 1998).

Tuttle Formation was intersected in two drill holes in the study area. In Cranswick A-22, the unit was dominantly shale with very fine-grained, somewhat glauconitic sandstone at the top, and a basal siltstone (Figure 33). In Ramparts A-59, Tuttle Formation included thin very coarse-grained sandstone, and basal sandstone with some fracture porosity (partly filled by quartz). Morrell (1995) characterized Tuttle Formation sands as generally poorly sorted, kaolinitic, with poor porosity and permeability. Kunst (1973) noted the unit was generally unfavourable for petroleum accumulations in the Peel Plateau. Good reservoir rock has not been definitively identified in wells in the study area, but is present to the west.

Source

Geochem Laboratories and AGAT Consultants (1977) analysed a small number of Tuttle Formation samples for source rock maturity. Vitrinite reflectance of Tuttle Formation in Cranswick A-22 was 1.50 %Ro. Mississippian sequence was interpreted to have poor to good, richness and effectiveness as source rocks. Rock–Eval data (Table 17) indicates that Tuttle Formation is mature in the extreme southwest corner of the study area, of poor to fair quality, and probably gas prone.

Seals, migration and traps

Shale sequences within Tuttle Formation could act as seals to any reservoir beds. Imperial Formation might form a lateral seal near the Tuttle erosional subcrop edge. Overlying Cretaceous sediments are often sandy and would make a poor seal.

Traps within Tuttle Formation can be expected to be mainly stratigraphic, related to the distribution of sand bodies. Diagenetic effects may be important in creating secondary porosity. Traps related to pre-Cretaceous unconformity are possible, although the basal Cretaceous has generally poor sealing properties. There may be some structural influence on traps from late-stage tectonic activity, because Tuttle Formation was shed off Cordilleran uplands as a clastic wedge.

Well	Reference *	Depth (m)	Formation (number of samples)	TOC (%)	S1 (ml/mg)	S2 (ml/mg)	Tmax (°C)	Comments
		Maximum values of TOC, S_1, and S_2 given where depths are stated as a range (and multiple samples indicated)						
North Ramparts A-59	1	1341	Tuttle	0.94	na			---
Cranswick A-22	1	152-213	Tuttle (3)	2.24	na			---
Cranswick A-22	2	140-213	Tuttle (9)	3.13	0.36	0.39	479, un?	9 samples averaged 1.80 % TOC. Generally poor source rock material. Wide range in T_{max} makes interpretation difficult, possible sample contamination
References: 1= Geochem Laboratories and AGAT Consultants (1977), 2= Snowdon (1990)								
nr=not reported, un=unreliable value, om=overmature, na=not applicable								

Table 17. *Rock Eval and TOC analyses from Tuttle Formation*

Tuttle play

This conceptual play includes all pools and prospects hosted in Tuttle Formation reservoirs. Gas has been tested from Tuttle Formation to the west of the study area, in Peel Plateau of Yukon (Osadetz et al., 2005). The play area is restricted to a narrow wedge along the Mackenzie Mountains in the southwestern part of the study area (Figure 32). The section is variable in thickness, but mainly thin. Figure 33 shows a sandstone at base Tuttle Formation in the Cranswick A-22 well indicated by logs.

The main exploration risks are insufficient reservoir quality and size, and trapping configurations. Breaching and/or degradation of shallow reservoirs are further risks, as is timing of hydrocarbon generation with respect to pre-Cretaceous uplift and erosion.

The play is given low or low to moderate potential, with the greatest potential in the west, and increasing west of the study area. Confidence level (Table 2) is 4 (overall rank EF-4) because there is very little information from within the study area.

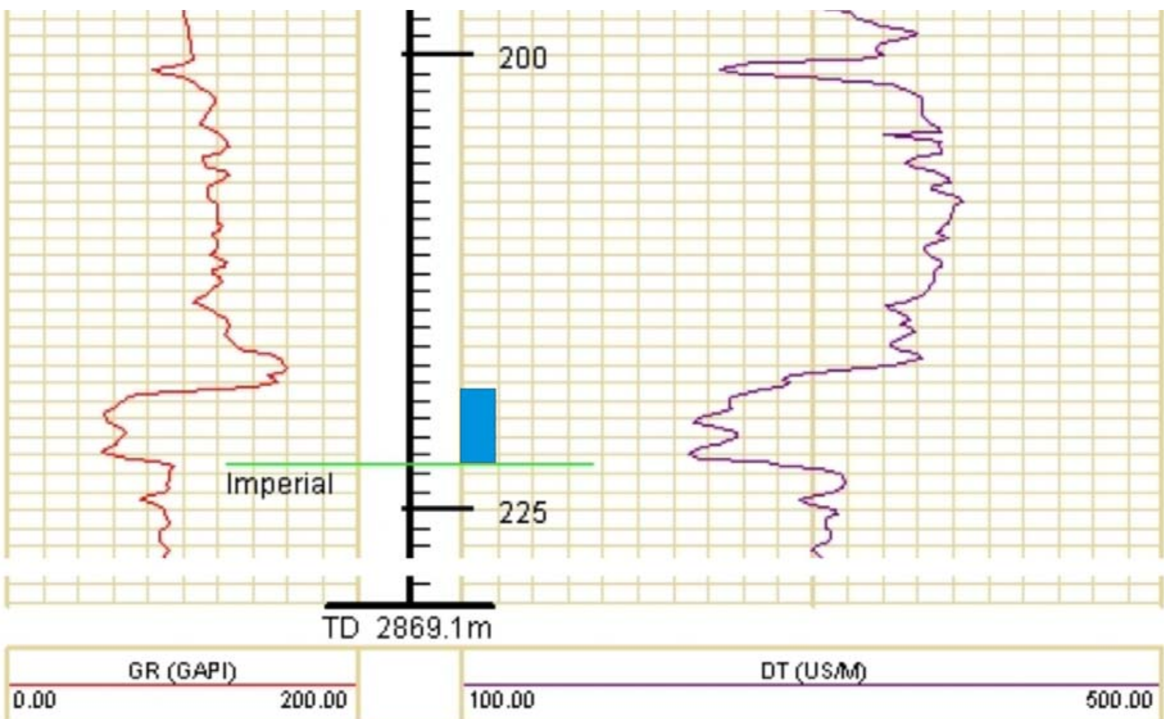

Figure 33. *Gamma (left) and sonic (right) logs from Cranswick A-22 well (300A22654013145), indicate a basal Tuttle Formation sandstone (blue bar. In well history report the sample is described as siltstone. Well depths in metres; gamma (API units) and sonic (microsecond/m) scales as shown*

Cretaceous Petroleum Geology

Reservoir

Cretaceous prospects have been an important target of exploration in the study area, particularly the drilling by Chevron in the 1990's (e.g., Hume River I-66, East Hume River N-10). These tests have been partly successful, with gas at Carcajou D-05. Logs from Hanna River J-05 show a 4.9 m thick sand with neutron-density crossover above the basal Martin House Formation sand; this could be Sans Sault member (Figure 34). Figure 35 shows a sandstone within Martin House Formation (operator called it Sans Sault) with excellent neutron-density crossover and high resistivity. The interval was perforated and tested, but yielded only a trace of gas.

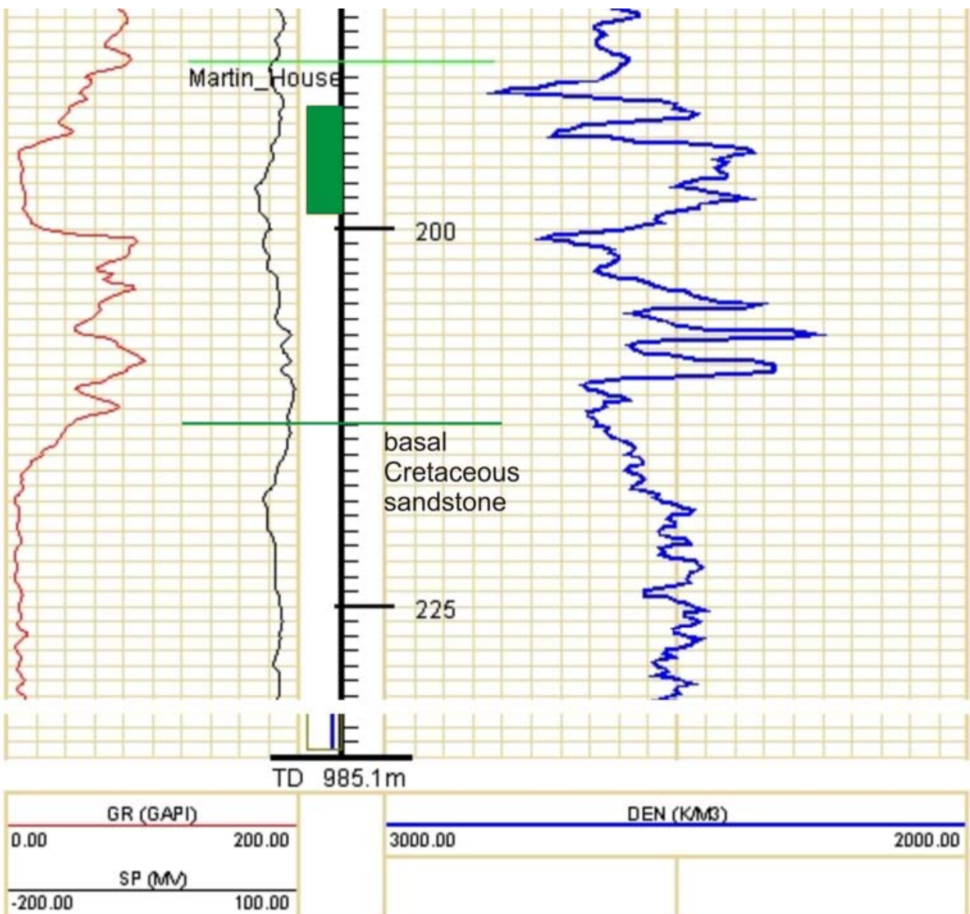

Figure 34. *Gamma (red), Self Potential (SP; black), and bulk density (blue) logs from Hanna River J-05 well (300J05655012815). Green bar denotes interval of sandstone investigated by DST #2, which recovered 18.3 m of oil-cut fresh water. This sandstone is above the basal Cretaceous sandstone. Gamma (API units), SP (millivolts), and density (kg/m^3) scales indicated*

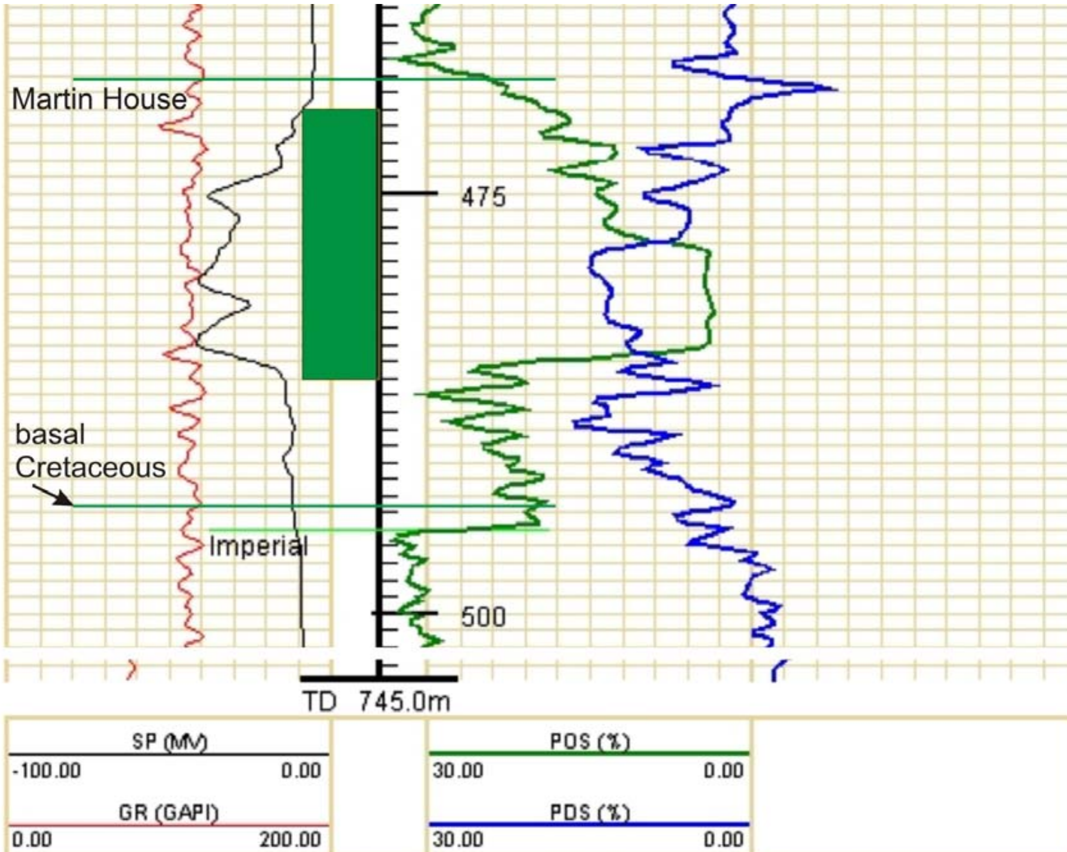

Figure 35. *Gamma (red), Self Potential (SP; black), density porosity (blue), and neutron porosity (green) logs from Hume River I-66 well (300I66660012930). Green bar denotes interval of sandstone investigated by DSTs #2 and 3, which recovered gas. The interval was also perforated, but ultimately yielded only minor gas. Well depth in metres; gamma (API units), SP (millivolts), density (porosity %,) and neutron (porosity %) scales indicated*

The basal sandstone of Martin House Formation is variably developed through most of the study area. Sans Sault Member of Arctic Red Formation is present in the southeast part of the study area, at or near the base of Arctic Red Formation. These two sandstone units are the primary potential reservoirs in the study area, though they may be confused in the subsurface. Regardless of nomenclature, the basal Cretaceous beds intersected by several wells have proved to be siltstone and sandstone with variable reservoir qualities (Table 18).

Well	Thickness (m)	Lithology
Hanna River J-05	61	Sandstone overlying Ramparts Formation. The lower 30.5 m is medium-grained with excellent porosity
Sans Sault H-24	39	Fine-grained, dense and shaly sandstone, with 3 m of coarse sand near the bottom
Ramparts A-59	35	Siltstone with subordinate very fine to medium-grained, slightly glauconitic sand, basal 3 m very coarse sand
Cranswick A-22	21.3	Very fine to medium-grained sandstone, trace to 5% intergranular porosity
Arctic Red F-47	19.8	Sandstone; fair to good porosity in the bottom 6.1 m of very fine to coarse-grained sandstone
Circle River A-37	18	Sandstone indicated by well logs
Maida Creek F-57	9.1	Very fine to fine-grained sandstone, tight
Hume River O-62	3	Fine to very coarse-grained, carbonate cemented sandstone with low porosity. Twenty-one metres up section is fine-grained, glauconitic and calcareous sandstone, 12.8 m thick, with some good porosity
Hume River D-53	?	Very fine to fine-grained sandstone, trace to fair porosity, and oil stain
Manitou Lake L-61	?	Very fine-grained to granular sandstone above Ramparts Formation

Table 18. *Description of basal Cretaceous sandstone intersected by wells*

There are younger Cretaceous sandstone reservoirs possible, such as Trevor Formation, but these are too shallow to have potential in most places. In Arctic Red River F-47 in the southwestern corner of the study area, however, there are several coarsening-upward sandstone beds lying above Arctic Red Formation, at depths between 340 m and 600 m (Figure 36).

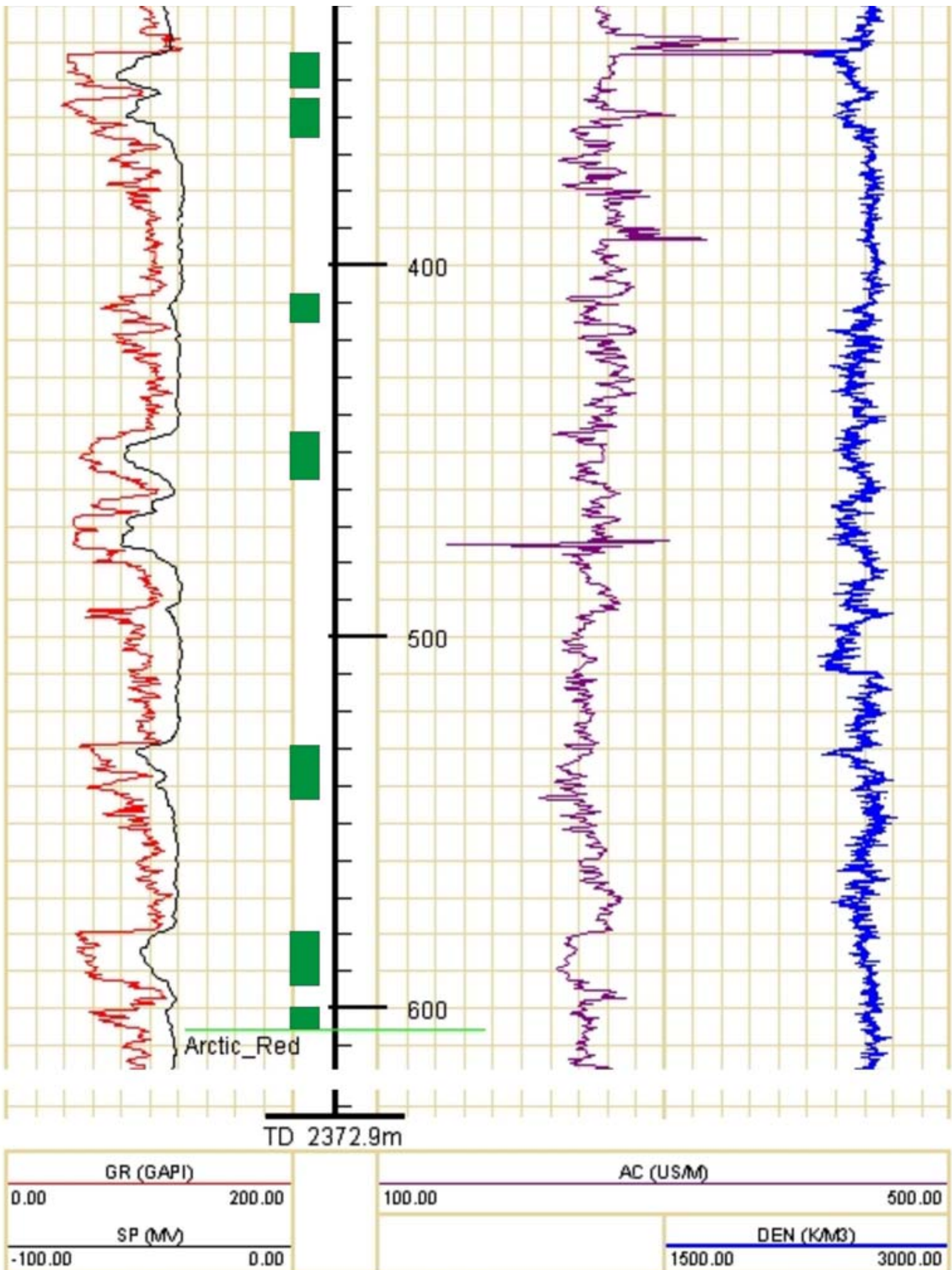

Figure 36. *Gamma (red), Self Potential (SP; black), sonic (purple), and bulk density (blue) logs from Arctic Red River River F-47 well (300F47654013045). Gamma log indicates a number of coarsening-upward sandstone beds in Trevor Formation, some of which are indicated by green bars. Well depths in metres; gamma (API units), SP (millivolts), sonic (microseconds per m), and density (kg/m^3) indicated by respective scale bars*

Cores have been taken from several Cretaceous units and measured for porosity and permeability (Table 19).

Well Name	Depth (m)	Porosity (%)	Permeability (to gas, mD)	Comments
North Circle River A-37	Sidewall cores between: 35.7-45.4	26.6 max. 22.5 avg.	999 max. 444 avg.	Ten sidewall cores taken through the interval
East Hume River I-20	Sidewall cores at: 299.5, 300.25, 302, 305	13.2, 11.5, 12.8, 14.2. (12.9 avg.)	71.2, 15.3, 62.8, 10.4. (39.9 avg.)	Values for each sidewall core listed. High permeabilities enhanced by fractures
Hume River I-66	456-497.6	12.9 max 7.5 wtd. avg.	4660 max. 48.3 wtd. avg.	Maximum permeability enhanced by fractures
East Hume River N-10	308-335	9.3 max. 5.6 wtd. avg.	22.4 max. 0.687 wtd. avg.	Only 22.35 m of interval analyzed. Maximum permeability enhanced by fractures
Sperry Creek N-58	845-848.1	--	--	Core described as tight

Table 19. *Measured porosity and permeability from Cretaceous formation cores*

Source

Thermal maturity of source rocks within Lower Cretaceous beds were compiled by Stasiuk et al. (2002; Tables 20, 21). Maturity generally increases toward the south, in zones parallel to the northwest to west-trending Mackenzie Mountain front (Figure 37). One shallow sample (91.4 m) from Cranswick A-22 in the southwestern corner of the study area was overmature (1.59 $\%R_o$). In addition, a strong maturity gradient with depth is evident in Cretaceous sediments near the mountain front (e.g., North Ramparts A-59), due to tectonic effects (Stasiuk et al., 2002). Cretaceous sediments in the study area span the spectrum from immature in the north to overmature in the south, and additionally display a strong maturity gradient with depth in the southern part of the study area, where Cretaceous is thick and in proximity to the Mackenzie Mountains. Younger Cretaceous source rocks (e.g., Slater River, East Fork formations) are also important, but probably more so southeast of the study area.

Geochem Laboratories and AGAT Consultants (1977) interpreted Cretaceous source rocks as mature everywhere in the study area except the NE corner, with a range in richness and effectiveness from poor to very good in effectiveness and richness.

Well	Reference *	Depth (m)	%R_o	Comments
Maida Creek G-56	1	61	1.28	Mature
Hume River L-09	1	549	1.19	Mature
Ontaratue K-04	2	30	0.56	Low mature
		122	0.67	Mature
		125	0.63	Mature
North Ramparts A-59	2	274	0.58	Low mature
		427	0.59	Low mature
		549	0.61	Low mature
		1067	1.46	High mature
North Ramparts A-59	1	98	0.54	Low mature
		274	0.58	Mature
		427	0.61	Mature
		549	0.59	Mature
		1067	1.46	High mature
		1311	1.83	Overmature
Cranswick A-22	1, 2	91	1.59	Overmature
Ontaratue H-34	1	213	1.05	Mature
Ontaratue H-34	2	40	0.59	Mature
		110	0.55	Low mature
		213	0.65	Mature
* References: 1= Geochem Laboratories and AGAT Consultants (1977). AGAT determined %R_o from random sample. 2= Stasiuk et al. (2002)				

Table 20. *Vitrinite reflectance measurements from Cretaceous formations*

Well	Reference *	Depth (m)	Formation (number of samples)	TOC (%)	S1 (ml/mg)	S2 (ml/mg)	Tmax (°C)	Comments
		Maximum values of TOC, S_1, and S_2 given where depths are stated as a range (and multiple samples indicated)						
Hume River L-09	1	491-549	Cretaceous (3)	1.37	na			0.69 % average TOC
Maida Creek G-56	1	30-274	Cretaceous (9)	1.20	na			0.82% average TOC
Carcajou D-05	3	190-280	Cretaceous (10)	0.88	0.10	0.65	440, un?	Poor to fair source rock, TOC average 0.71 %, immature, to just entering oil window
Ontadek Lake N-39	1	30-152	Cretaceous (5)	0.68	na			---
Ontaraue K-04	2	30-268	Cretaceous (5)	1.88	3.62	2.00	445	S_1, S_2, and TOC values indicate some were fair to good gas-prone source rocks, with PI and T_{max} indicating maturity within the oil window. A coal sample (42.49 % TOC) not considered here
North Ramparts A-59	1	49-1311	Cretaceous (43)	2.28	na			Average 1.61 % TOC
Cranswick A-22	1	30-122	Cretaceous (4)	1.25	na			---
Cranswick A-22	3	30-131	Cretaceous (11)	1.61	0.25	0.46	485	Arctic Red Formation poor to fair source rock, averaged 1.22 % TOC (5 samples over 37 m). mature (?) to overmature?
Ontaratue H-34	1	30-244	Cretaceous (8)	2.14	na			
References: 1= Geochem Laboratories and AGAT Consultants (1977), 2= Feinstein et al. (1988), 3= Snowdon (1990)								
nr=not reported, un=unreliable value								

Table 21. *Rock Eval and TOC analyses from Cretaceous formations*

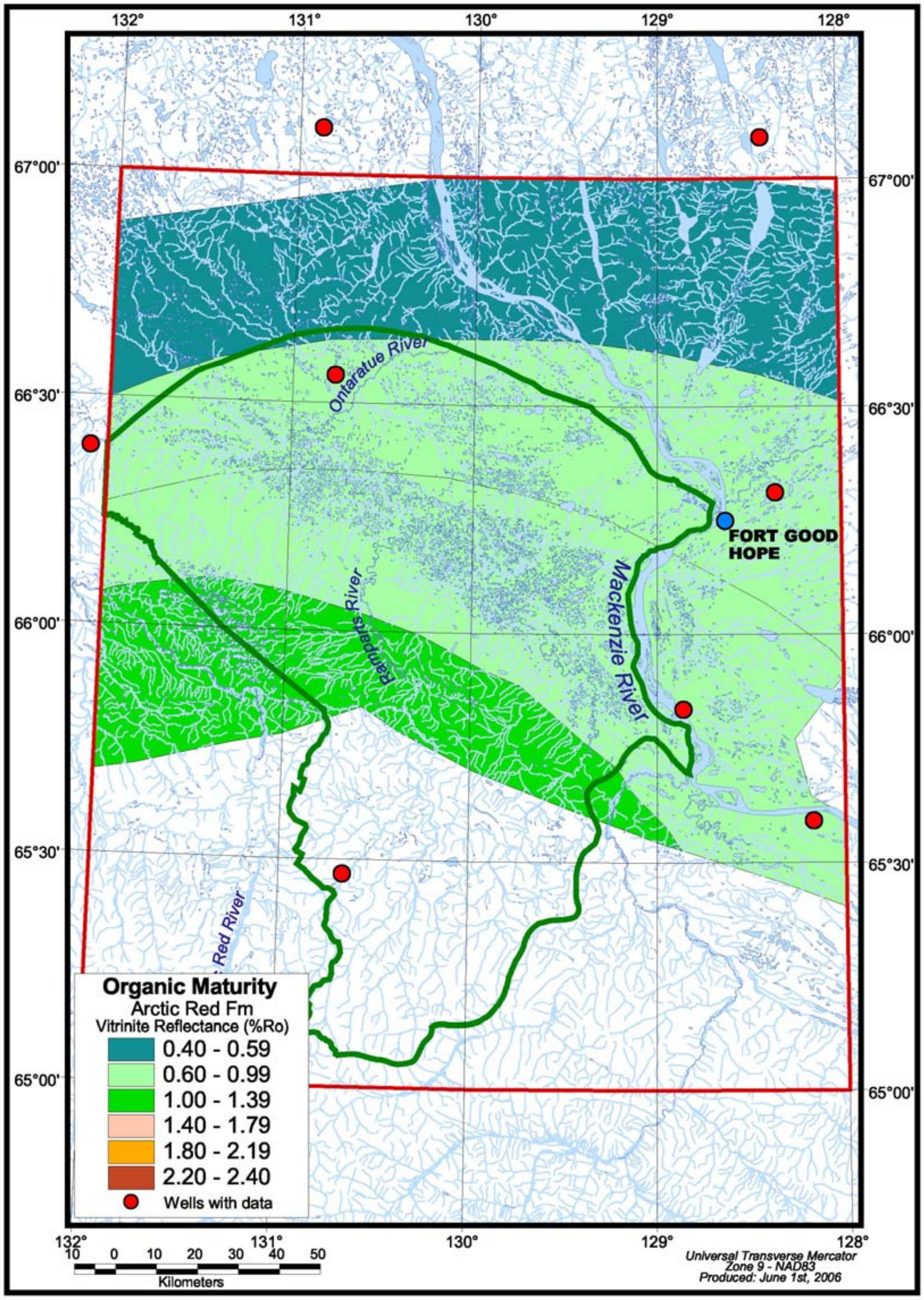

Figure 37. *Contour map of source rock maturity based on vitrinite reflectance from Arctic Red Formation (after Stasiuk et al., 2002). Mature rocks within the oil window are generally accepted to have reflectance values of 0.6-1.4% R_o. Ts' ude niline Tu' eyeta is outlined in green, the study area in red. Wells from which samples were analyzed and used to construct contours are indicated by red dots*

Seals, migration and traps

Cretaceous sandstones are commonly oil stained, indicating that oil has resided in them at some point. Probable effective seals are found within thick Lower Cretaceous shale packages, such as Arctic Red Formation. Coal beds are locally present above the basal Cretaceous sandstone and may be effective seals if thick enough. Upper Cretaceous shale (Slater River Formation) is most likely an ineffective seal because it is too shallow and thinly distributed.

Traps would likely be stratigraphic, such as sandstone channels incised on pre-Cretaceous unconformity, or sandy facies in marine, shallow shelf, and near shore environments. Other stratigraphic traps are sandstone facies pinch-outs, and local intra-formational facies changes from sand to shale.

Structural traps are possible, in places well away from the mountain front. Campbell (1960) interpreted a gentle northeast trending and southwest plunging antiform in the basal Cretaceous sand in the Ontaratue River area from outcrop and airphoto data (Figure 38).

Adjacent to the Cordilleran margin, a variety of trapping geometries possibly involving Lower Cretaceous strata are possible. Draping of basal Cretaceous sandstones over differentially eroded Paleozoic rocks has been identified in the study area, and these antiformal features could form traps (Sproule and Associates, 1960).

Cretaceous play

This conceptual play includes all pools and prospects hosted in Cretaceous sandstones, generally the basal sandstone of Martin House Formation, or the Sans Sault member of Arctic Red Formation. Carcajou D-05 is a suspended well with gas tested from Cretaceous sandstone. Overall the best possibilities may be in Peel Plateau, in the southwest part of study area, where a thick wedge of Cretaceous sediments lies at Mackenzie Mountains front.

The play area is restricted to depositional and erosional limits of subcropping Cretaceous sandstone, and a reasonable thickness of overlying Cretaceous (Figure 39). Gal (2005) used a thickness of 250 m in delineating the Cretaceous clastic play in Sahtu Settlement Area.

The main exploration risks are breaching and/or degradation of shallow traps, sufficient reservoir permeability, and trapping configurations.

Osadetz et al. (2005) called this play “Mesozoic Clastics”. They noted that prospects are likely to be smaller than in their corresponding “Peel Plateau Mesozoic Siliciclastics” play, although reservoir characteristics may be improved. They rated it the most attractive play, in terms of expected number of accumulations and total gas-in-place; favouring it over Paleozoic prospects. Further, they stated that east of the Mackenzie Mountains front, the Cretaceous section should be the focus of exploration.

The play is given moderate to high, to high potential, with the greatest potential in the southwest where the Cretaceous section is markedly thicker. Confidence level is 2 giving a rank of BC-2 (Table 2).

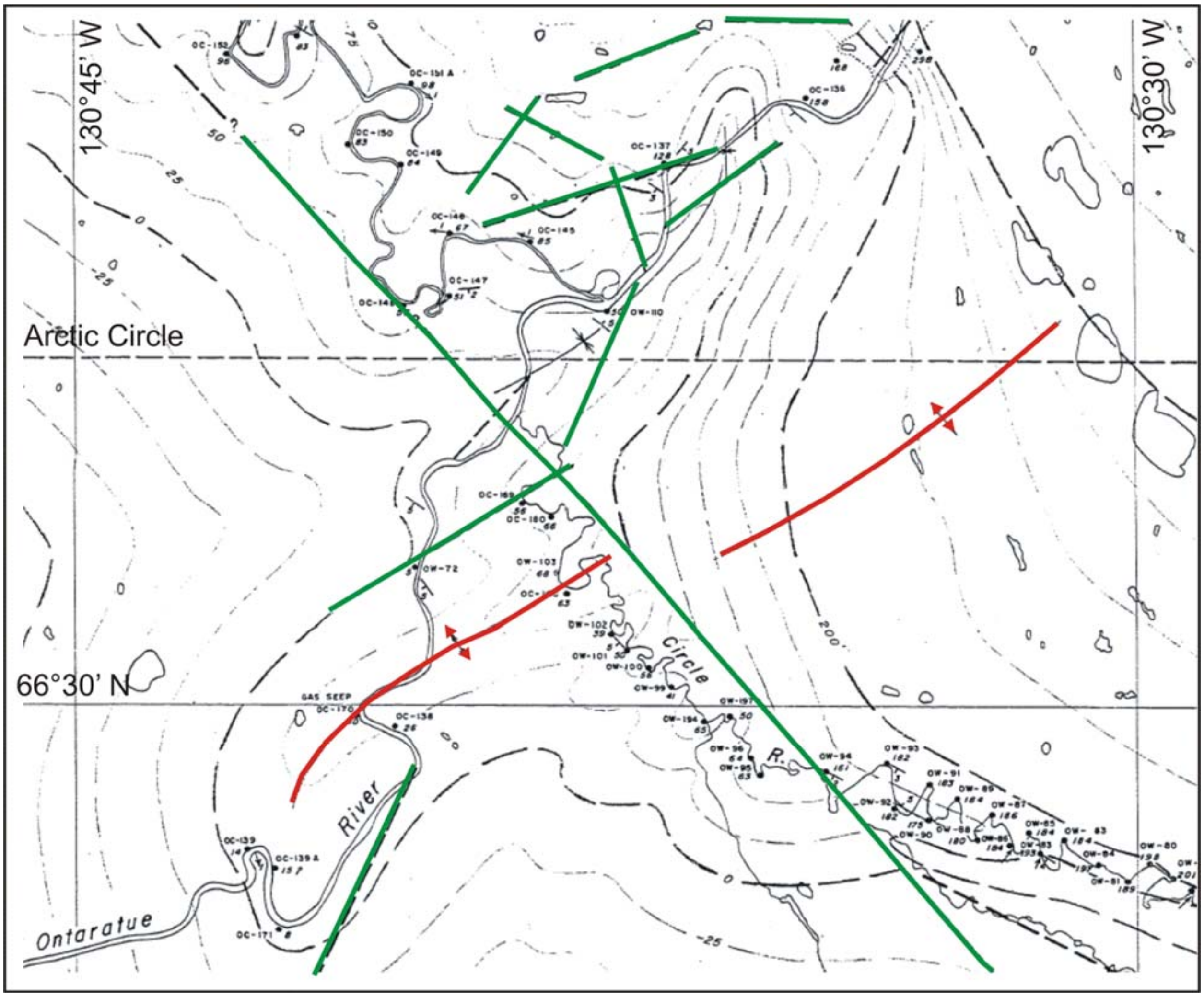

Figure 38. *Structure contours (contour interval 25 feet, sea level datum) on top of basal Cretaceous sandstone in the Ontaratue River area. Inferred faults and lineaments in green, axis of anticline in red. This structure was identified from outcrop (stations identified by labeled dots) and airphoto data. While this example is breached (note the gas seep location), similar Cretaceous structural traps are possible in the area. After Campbell (1960)*

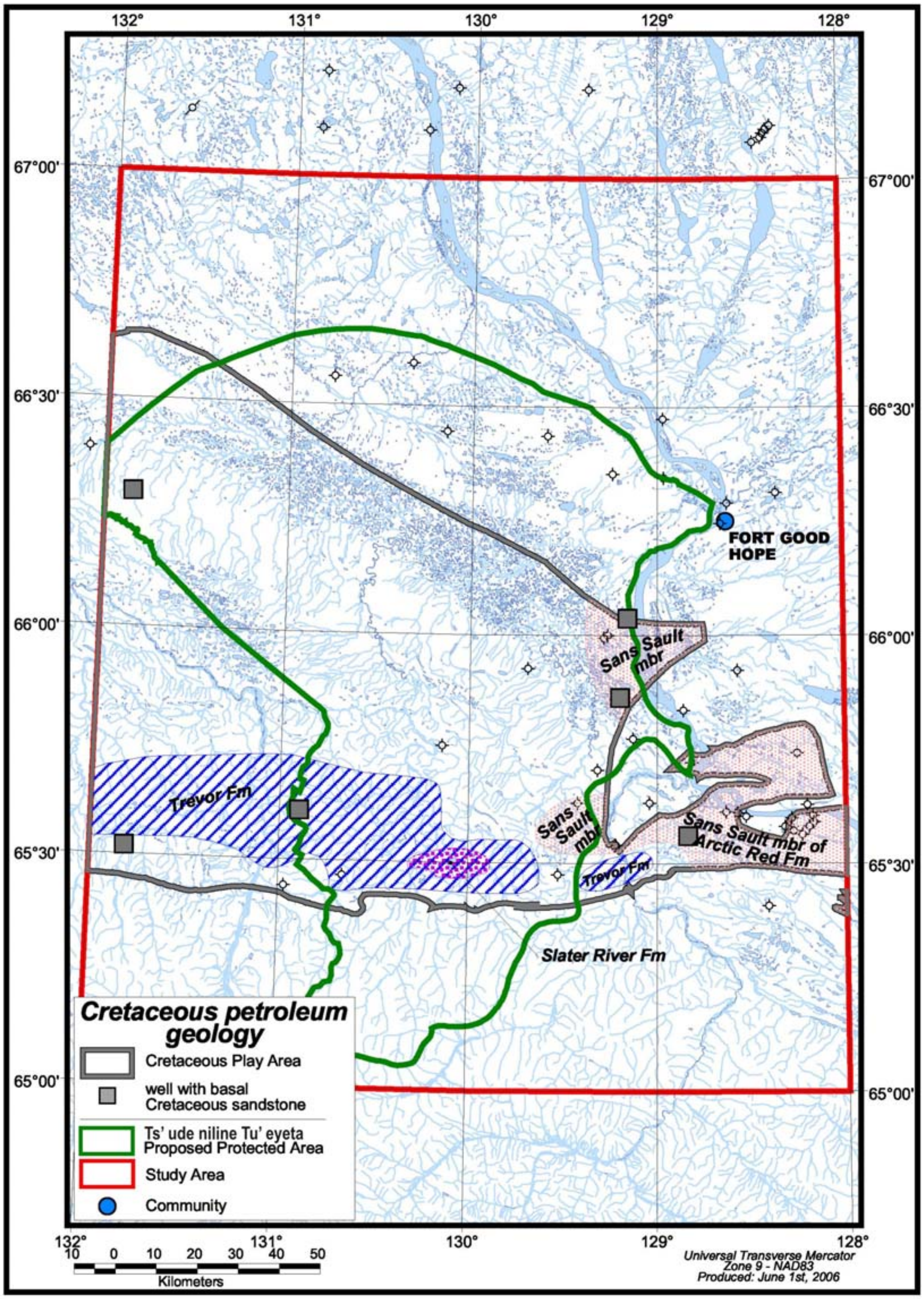

Figure 39. *Cretaceous play map. The play area covers the central parts of the study area. Outcrop of Upper Cretaceous Trevor (blue lines) and Slater River (magenta squares) formations are indicated (after Yorath, 1976). Subcrop extent of Sans Sault member of Arctic Red Formation (pink dots) is also indicated (after Yorath, 1976). Grey squares indicate identification of basal Cretaceous sandstone in well cuttings, from well history report sample descriptions*

Summary of hydrocarbon potential

Individual hydrocarbon plays (Table 22, Figure 40) are ranked, in which Middle Devonian Kee Scarp, Lower Devonian Arnica/Landry platform, Upper Devonian clastic, and Cretaceous basal clastic plays are considered to have the greatest potential. Two plays with the lowest potential (basal Cambrian, Tuttle) do not have any associated occurrences within the study area, although they do outside the study area. Known occurrences of hydrocarbons in the study area are considered, but they are not the major criteria for determining petroleum potential of an area.

The overall petroleum potential methodology is based predominantly on the number of plays occurring in a given area, and whether those plays are established or conceptual (Table 2). The aggregate distribution of mapped plays is then determined, and represented by a qualitative degree of potential based on criteria as outlined in Table 2. An overall petroleum potential map for the study area based this assessment (Figure 41) shows the highest potential is in a southeast to west-trending, westward expanding band across the study area. The lowest potential is in the Mackenzie Mountains in the south.

Other authors have illustrated petroleum potential in areas adjacent to and including the study area. Gal (2005) qualitatively evaluated the Sahtu and Gwich'in Settlement areas using similar criteria, albeit in less detail than this study. Consultants Kee Scarp Ltd. produced a hydrocarbon potential map of Sahtu Settlement Area (Sahtu Land Use Planning Board, 2001), based primarily on historic levels and areas of activity (T. Burlingame, personal communication, 2005). This work showed areas of high potential in the northwest and southeast corners of the study area, and low in the mountain areas in the south (Figure 42). The Economic Geology Division (1980) of the GSC produced an oil and gas potential map of the north including the study area (Figure 43). The southeast corner is described as high, and the mountain area in the south and southwest, as moderate potential. The balance of the area is described as unexplored or for which very little information is available.

No quantitative estimates of petroleum potential are available for the study area. Osadetz et al. (2005) made quantitative estimates for the Peel Plateau and Plain only within Yukon Territory. Plays described in that study were correlative with the all but the basal Cambrian and Kee Scarp plays in this study. Data given in Table 23 are not meant to suggest any quantitative estimate for plays in this study, but rather to indicate which plays could be considered to have the most potential.

Play Name	Reservoir Rock	Source Rock	Seal Rock	Trap Formation and style	Hydrocarbon generation, migration, and preservation. Exploration risks
Kee Scarp	Ramparts Fm (Kee Scarp member, possibly clastic member, or allochthonous reef debris beds of Canol Fm. Include possibly Hume Fm reefal buildups	Canol, Hare Indian fms	Canol, Hare Indian fms	Stratigraphic, reef and intra-reef facies or diagenetic porosity traps. Possible structural traps near mountain front	Oil, gas. Norman Wells 240 million barrel oil field. Ramparts Fm restricted to east margin of study area.
Cretaceous siliciclastics	Martin House, Arctic Red (Sans Sault member) fms, Trevor Fm?	Arctic Red Fm, Slater River Fm, Devonian shale (?)	Martin House Fm shale, Arctic Red Fm	Stratigraphic, incised channel fill, shore sands, facies pinch-outs, unconformity related. Structural, domes and folds related to Laramide tectonism in disturbed belt	Gas, oil. Basal Cretaceous sand is commonly oil-stained. Much of Cretaceous is possibly too shallow for effective preservation. Best potential in southern part of study area, at mountain front
Arnica/Landry platform	Arnica, Landry, possibly Peel fms, possibly Bear Rock breccia	Hare Indian Fm, Hume Fm, Landry Fm	Landry, Hume, Fort Norman fms	Stratigraphic/diagenetic–(dolomitized). Reactivated faults provide structure and fracturing (and dolomitization?). Possible stratigraphic buildups, and updip pinchouts/truncations, draped structures over sub-Devonian unconformity, structural traps near mountain front	Gas, oil. Minor oil from Landry Fm in Shoals C-31
Upper Devonian siliciclastics	Imperial Fm interbedded silt/sandstone	Canol, Hare Indian, Imperial fms	Imperial Fm interbedded shale	Structural/stratigraphic, onlap and pinch-outs against basement highs. Isolated or stacked sand bodies. Facies related (turbidite?) traps	Gas, oil. Logs indicate gas charge in sandstone beds in Ramparts River F-46. Most of section appears to have poor reservoir characteristics. Widespread exposure increases risk of breaching. Best potential in the west and southern (mountain front) part of study area
Cambro-Ordovician platform	Mount Kindle, Franklin Mountain fms	Devonian (?), Mount Kindle (?)	Mount Kindle, Franklin Mountain fms	Structural, fault-bounded highs, folds near mountain front. Stratigraphic, reefal buildups, intra-formational porosity traps, diagenetic, porosity through dissolution of chert, fossils	Gas
Basal Cambrian siliciclastics	Mount Clark, Mount Cap, possibly Proterozoic fms	Mount Cap Fm, Proterozoic shale (?)	Mount Cap, Saline River fms, Proterozoic shale	Structural/stratigraphic, onlap and pinch-outs against basement highs. Isolated sand bodies. Unconformity related	Gas. Probably restricted to east margin of area of interest
Tuttle Formation	Tuttle Fm	Imperial Fm, Cretaceous shales	Cretaceous shale, Imperial Fm, shales in Tuttle Fm	Stratigraphic; channel sands, porous facies pinch-outs. Structural, related to Laramide tectonism in disturbed belt	Oil, gas

Table 22. *Summary of petroleum plays in study area, arranged in order of those judged to be most favourable*

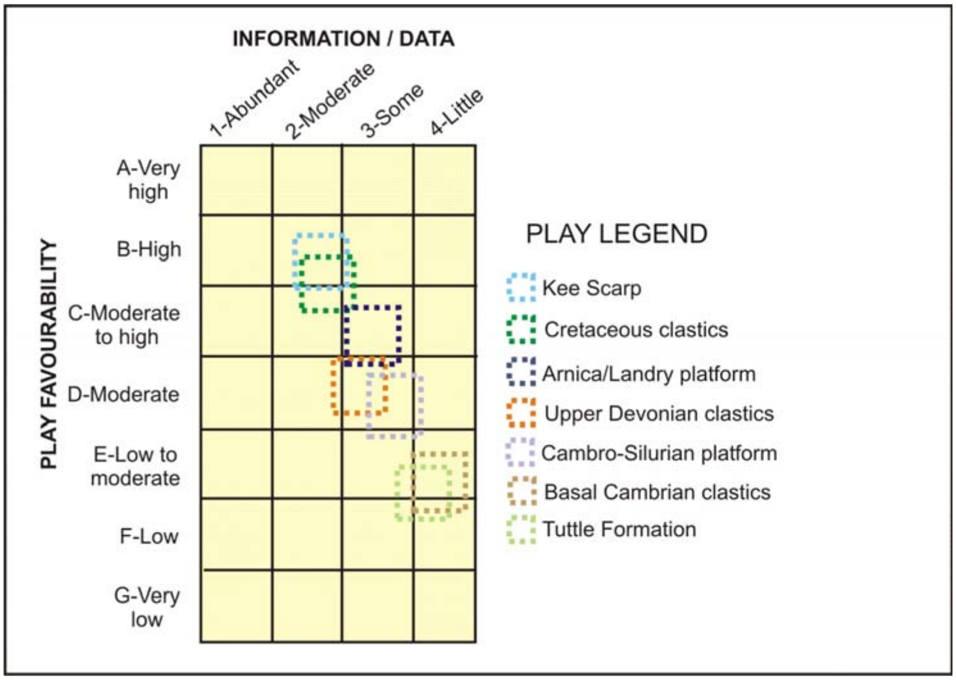

Figure 40. *Individual hydrocarbon plays in the study area rated qualitatively on the basis of overall favourability and quality and amount of associated information available. Generally, the higher rated plays have more information associated with them*

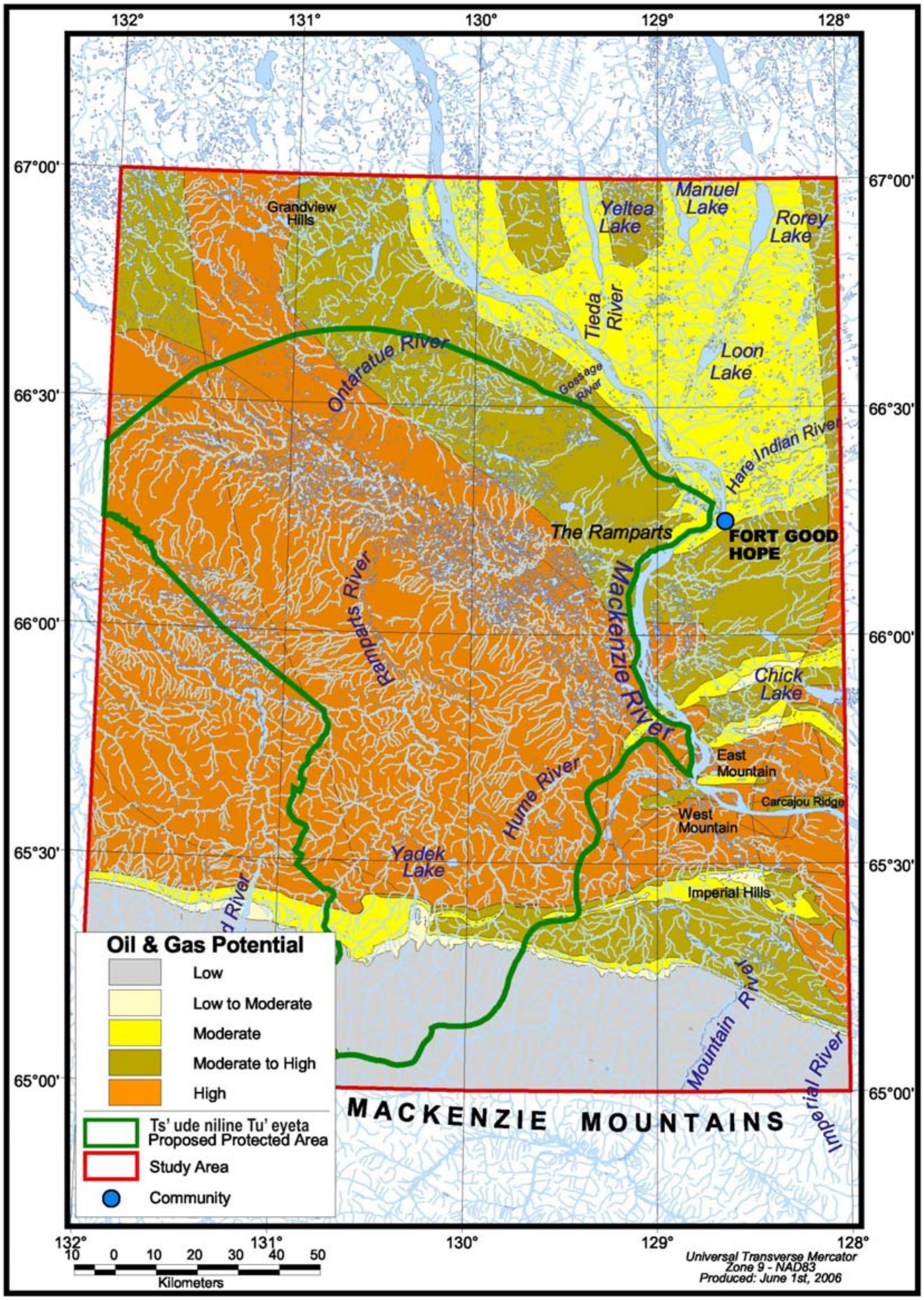

Figure 41. *Qualitative and comparative petroleum potential for the study area. Criteria for high to low potential are as outlined in text and Table 2*

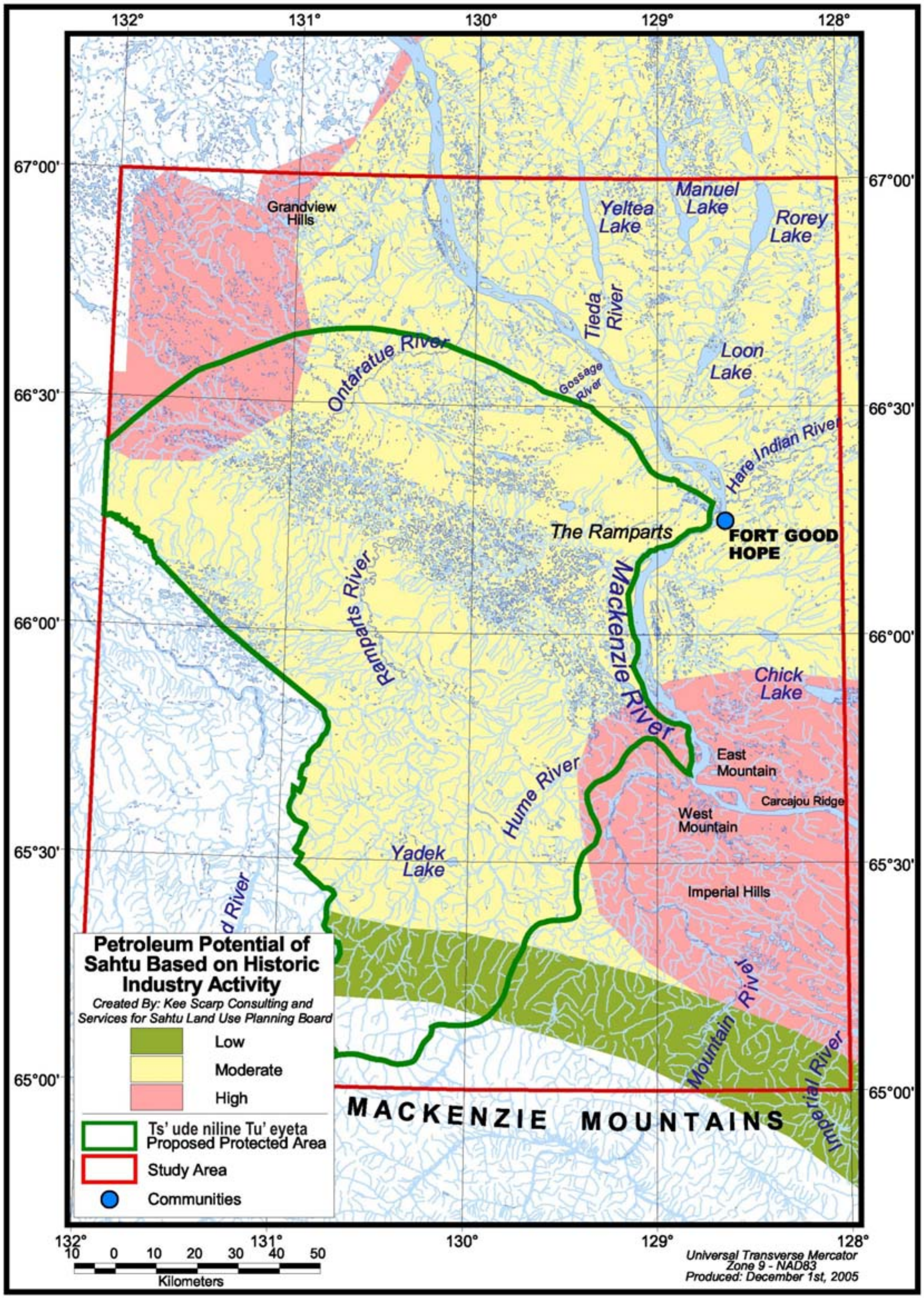

Figure 42. *Hydrocarbon potential from a Sahtu-wide study by Kee Scarp Consulting and Services Ltd. for Sahtu Land Use Planning Board (source: SLUP web site, June 1, 2006). Low, moderate, and high potential areas were determined based upon geological considerations and historic exploration activity levels (T. Burlingame, personal communication)*

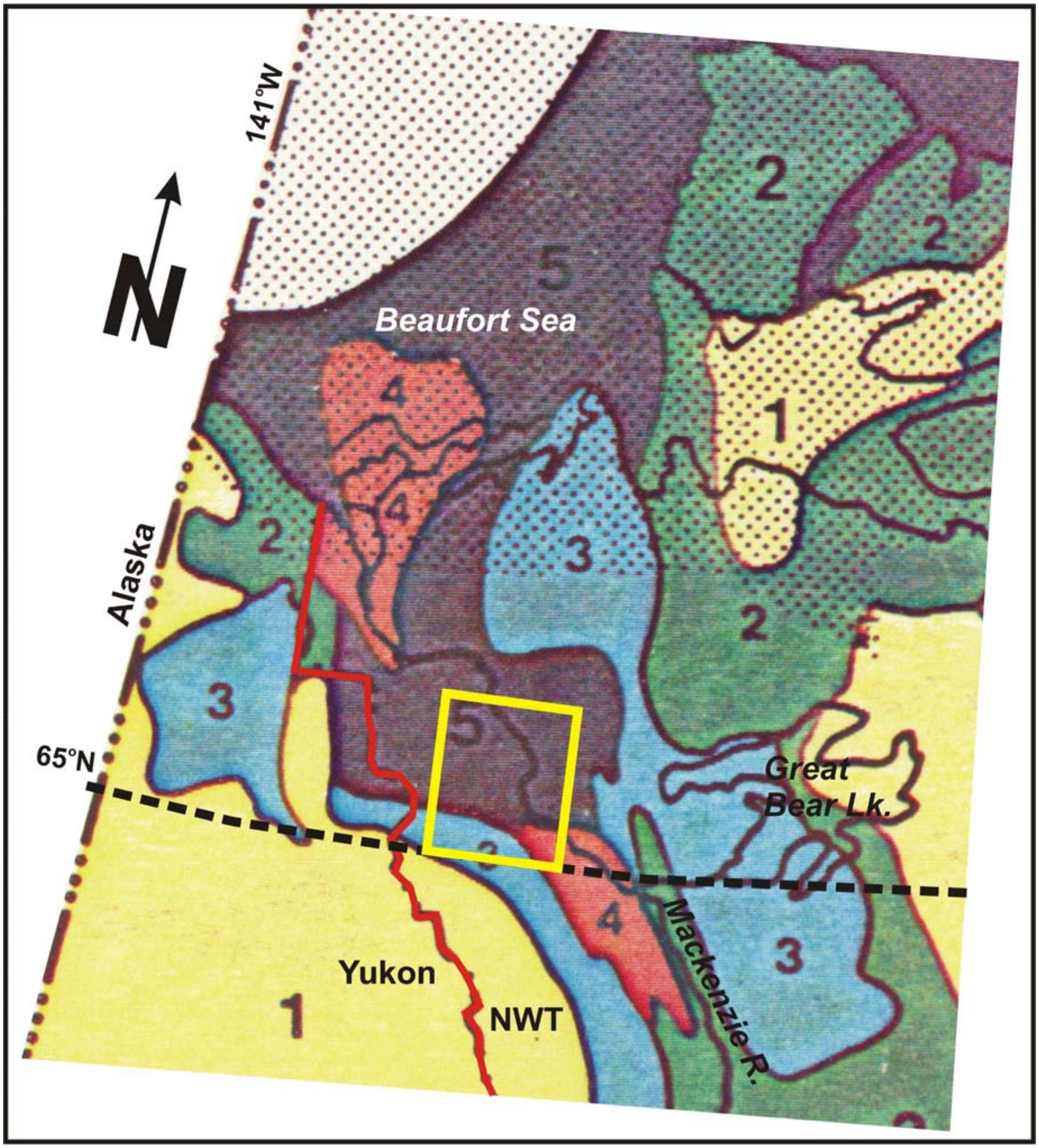

Figure 43. *Oil and gas potential for northern Canada (Economic Geology Division, 1980). This map shows broad scale, relative hydrocarbon potential in northern Canada, including the study area (approximate outline in yellow). The Yukon-NWT boundary is outlined in red. The colour coded and numbered categories are as follows: 1= zero potential (primarily areas where Precambrian rocks are exposed at surface). 2= low potential, 3= moderate potential, 4= regions with demonstrated discoveries and high potential, 5= areas that are essentially unexplored or for which very little information is available. Exploration could occur in these areas and advance them to moderate or high potential (categories 3 or 4). Note that in much of the study area, the potential is largely unknown*

Yukon Peel Plateau and Plain Play Name (Osadetz et al., 2005)	Expected number of accumulations (mean)	Median play potential (gas in place, $x10^6m^3$)	Median of largest field size (gas in place, $x10^6m^3$)	Analogous play, this study
Peel Plain Mesozoic siliciclastics	55	46447 (1640 Bcf)	3356 (119 Bcf)	Cretaceous siliciclastics
Peel Plateau Mesozoic siliciclastics	12	12018 (424 Bcf)	2861 (101 Bcf)	
Peel Plain Upper Paleozoic siliciclastics	9	6726 (238 Bcf)	1352 (48 Bcf)	Upper Devonian siliciclastics, Tuttle Formation
Peel Plateau Upper Paleozoic siliciclastics	2	5684 (200 Bcf)	5517 (195 Bcf)	
Peel Plain Paleozoic carbonate platform	1	153 (5 Bcf)	218 (7.7 Bcf)	Arnica-Landry platform, Cambro-Ordovician platform

Table 23. *Quantitative estimates of expected number of accumulations, largest field size, and total play potential, for selected plays evaluated in Peel Plateau and Plain of Yukon (Osadetz et al., 2005). The Peel Plateau and Plain of Yukon is located west of the study area. These estimates are presented here as an illustration of the relative potential of the plays examined by Osadetz et al. (2005) in Yukon. Bcf= billion cubic feet*

Reinson and Drummond (2001) estimated an undiscovered resource potential of $125x10^9m^3$ (4.4 trillion cubic feet (Tcf)) gas in the Peel Plain region, which spans the Yukon and Northwest Territories, and includes the study area. Canadian Gas Potential Committee (2001) estimated resources for the entire basal Cambrian play (only a tiny portion of which overlaps the east side of the study area) at 134 $x10^9$ m^3 (4.7 Tcf) nominal initial marketable gas, but little of this can be expected in the study area.

CONCLUSIONS

There are several criteria that must be evaluated in estimating petroleum resource potential using the methodology.

In the Ts' ude niline Tu' eyeta study area, the overall geological environment is favourable. The study area is part of a sedimentary basin that developed on a stable craton margin, and was followed by foredeep sedimentation in response to orogenic uplift. The resulting thick sedimentary package is a favourable environment for the accumulation of hydrocarbons. Orogenic deformation in Mackenzie and Franklin mountains increases the probability of structural traps near the mountain fronts. Potential reservoir, source, and seal rocks are known to exist. Middle and Upper Devonian shales are particularly prolific source rocks. Petroleum generation is known to have occurred, at least within the Middle-Upper Devonian and Cretaceous systems. A Lower Paleozoic petroleum system is also likely.

Seven conceptual plays are present through the study area. One of these plays (Kee Scarp) is a direct extension of an established play fairway, thus its designation as established or conceptual in the study area can be debated. The Cretaceous basal clastic, Upper Devonian clastic, and Arnica-Landry platform plays are considered to be quite prospective. The remaining Tuttle Formation, Cambro-Silurian platform, and basal Cambrian clastic play areas are considered less prospective, although the latter play is particularly hampered by a lack of information.

Closures have been identified and mapped in the study area. Many of the most obvious, large structures have been tested by drilling. Laramide deformation has created many structural trapping possibilities, associated with classic fold and thrust type deformation. More subtle structures are likely to exist, that might be resolved by seismic surveys. Most of the plays, however, are connected with stratigraphic traps. Generally these are more subtle and more varied than structural traps. They may be resolved through seismic surveys as well as careful geological investigations.

Nineteen of 44 wells in the study area have oil or gas indications from DST or well blowouts. There are some significant shows in Ramparts Formation, Cretaceous sandstone beds, and Lower Devonian platform carbonate rocks, as well as untested indications of gas in Upper Devonian sandstone beds. Within the Ts' ude niline Tu' eyeta candidate protected area proposed boundaries there have been hydrocarbon shows in 9 of 20 wells. These shows are, of course, indicators of petroleum potential of the area. Table 24 summarizes the petroleum potential of the Ts' ude niline Tu' eyeta candidate protected area (see also Figure 41).

POTENTIAL Ranking	CONFIDENCE Ranking			
	Rank 1: Abundant reliable information	Rank 2: Moderate amount of information	Rank 3: Some information	Rank 4: Very little and/or unreliable information
Rank A: Very High:				
Rank B: High:		NE Mackenzie Plain, SE corner of study area.	Peel Plain and Plateau, Central Grandview Hills, west-central part of study area; lowlands between Chick Lake and Mackenzie River.	
Rank C: Moderate to High:			NE margin Peel Plain and western Grandview Hills; area south of Ft. Good Hope and lower Mountain River area.	
Rank D: Moderate:			Mackenzie River and to the NE, north of Ft. Good Hope; East side of Beavertail, East Mtn., Imperial anticline structures; Carcajou anticline; Imperial syncline; front margin of Mackenzie Mtns.	
Rank E: Low to Moderate:			West side of Beavertail, East Mtn., and Imperial anticline structures; SE quadrant of study area	
Rank F: Low:				Mackenzie Mountains main ranges; southern margin of study area
Rank G: Very Low:				
Rank H: Not Assessed:				

Table 24. *Ts' ude niline Tu' eyeta candidate protected area petroleum potential summary (see also Figure 41)*

INFORMATION GAPS

This petroleum resource assessment is based upon currently available and accessible information. The most critical knowledge gaps are outlined below, with suggestions for collecting additional new data to improve the assessment of petroleum resource potential. Many of the knowledge gaps (geochemistry surveys in particular) have a stronger bearing on mineral exploration and evaluation, and will not be dwelt upon here, although they are mentioned because the lack of this data will have a very strong impact on any future mineral evaluation.

Geochemistry

There is no regional till, stream sediment or lake sediment geochemistry data coverage. Geochemical data would greatly enhance confidence in and quality of mineral potential estimates. Specialized geochemical surveys (similar to mobile metal ion leaching) can detect trace amounts of hydrocarbons and may be effective in localizing concentrations.

Geophysics

No electromagnetic or radiometric survey coverage exists. New regional surveys would greatly enhance the confidence and quality of mineral potential estimates.

There is a considerable amount of seismic survey data in the southeastern quadrant of the study area, of recent vintage. The balance of survey lines are mostly in the northwest and northeast quadrants, but are generally of poor quality and of limited use for subsurface geological interpretation. New seismic surveys would aid in evaluating subtle structures and stratigraphic anomalies that might be expected through the northern half of the study area.

Geology

Existing bedrock geology maps were published at 1:250,000 scale and are essentially reconnaissance in nature. Much of the mapping in the mountains was done using air photo interpretation, with only scattered traverses in the field. The fieldwork dates to the late 1960s and 1970s, and since that time stratigraphic and sedimentological sciences have advanced. The northern part of the study area, in the Interior Platform, suffers from poor and widely spaced bedrock exposures. Little can be done to improve bedrock exposure, which underscores the need for other survey methods (geophysical, geochemical).

Oil and Gas

A number of wells have been drilled in the study area; 20 within the Ts' ude niline Tu' eyeta candidate protected area proposed boundaries. The southeastern quadrant of the study area has been explored more intensively than the remaining prospective ground.

RECOMMENDATIONS FOR PHASE II

A number of recommendations are presented in order of relative priority, to address some of the information gaps and increase the level of confidence of this study. The lack of geochemistry surveys will strongly hamper any future mineral potential study, but recommending these surveys is beyond the scope of this report, which is concerned with conventional petroleum. Some gaps are not expected to be readily remedied due to their high cost, and are hence given low priority.

1. Examination of known outcrop areas by prospecting, structural mapping, stratigraphic and paleontological studies, and lithogeochemical sampling to increase knowledge of the area, and may reveal new sites to follow up on.

2. Bedrock mapping of the region at 1:50,000 scale. This would be preceded by examination of remotely sensed satellite images, aerial photographs, and existing aeromagnetic geophysical surveys to develop a remote predictive map (RPM). The RPM would help focus the follow-up detailed work.

3. Reflection seismic surveys have proven effective in mapping out subsurface structures, stratigraphic changes, and other features that could be related to petroleum traps. Several areas that require additional modern surveying to evaluate petroleum potential are found throughout the study area, particularly in the western half of the study area.

At the time of writing, the Northwest Territories Geoscience Office is leading a multi-year, multi-disciplinary, and multi-agency regional geoscience study on the Peel Plain and Plateau, focusing on petroleum potential. The Peel Plateau and Plain includes much of the current study area. New results and interpretations from this project will surely increase the knowledge base of the region, and will assist future non-renewable resource assessments. Pyle et al. (2006) provide a thorough review of the Peel Plateau and Plain, and further information on the project can be found at http://www.nwtgeoscience.ca/petroleum/PeelPlateau.html.

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