Chapter 2 - Mackenzie Valley, Southern Territories and Interior Plains

Southern Northwest Territories and Southeastern Yukon

<table>
<thead>
<tr>
<th>Age</th>
<th>Cambrian to Cretaceous</th>
</tr>
</thead>
<tbody>
<tr>
<td>Depth to Target Zone</td>
<td>700 to 4500 m</td>
</tr>
<tr>
<td>Maximum Basin Thickness</td>
<td>In excess of 5000 m in foothills belt, shallowing to east</td>
</tr>
<tr>
<td>Hydrocarbon Shows</td>
<td>Oil and gas shows in many formations from Devonian to Cretaceous</td>
</tr>
<tr>
<td>First Discovery</td>
<td>1955 (Briggs Rabbit Lake No. 1 O-16; Slave Point Gas)</td>
</tr>
<tr>
<td>Discovered Resources</td>
<td>Gas: Aggregate in 16 fields: 17.4 x E9 m³ (615 bcf) Oil: Aggregate oil in 1 field: confidential to date</td>
</tr>
<tr>
<td>Production</td>
<td>Gas: 9.5 x E9 m³ (336 bcf) from Pointed Mountain, Kotaneelee fields Oil: Test production from Cameron Hills</td>
</tr>
<tr>
<td>Basin Type</td>
<td>Precambrian rifts; Paleozoic continental margin; Mesozoic foreland basin</td>
</tr>
<tr>
<td>Depositional Setting</td>
<td>Paleozoic: shallow marine shelf to shelf margin. Mesozoic: alluvial to shallow-water marine shelf (foreland basin)</td>
</tr>
<tr>
<td>Reservoirs</td>
<td>Middle Devonian carbonates (Upper Devonian carbonates, Mississippian and Cretaceous sandstones)</td>
</tr>
<tr>
<td>Regional Structure</td>
<td>Thrust folds in west; normal faulting and possible wrench faulting in the plains</td>
</tr>
<tr>
<td>Seals</td>
<td>Thick Devonian shales, some anhydrite, tight carbonates</td>
</tr>
<tr>
<td>Source Rocks</td>
<td>Mature Devonian shales, carbonates, evaporites; Mississippian and Cretaceous shales</td>
</tr>
<tr>
<td>Depth to Oil/Gas Window</td>
<td>Approximately 800 m</td>
</tr>
<tr>
<td>Total Number of Wells</td>
<td>400 (386 exploratory, 14 delineation)</td>
</tr>
<tr>
<td>Average Well Density</td>
<td>1 per 464 km²</td>
</tr>
<tr>
<td>Seismic Coverage</td>
<td>7228 km since 1974; from 60-61°N data coverage is good but sparse farther north</td>
</tr>
<tr>
<td>Pipelines</td>
<td>Norman Wells oil pipeline to Zama. Point Mountain/Kotaneelee gas pipeline to Westcoast Transmission System in B.C. Gas pipelines to Hossitl and July Lake fields are within a few kilometres of the border with the Northwest Territories</td>
</tr>
<tr>
<td>Area</td>
<td>180,000 km²</td>
</tr>
<tr>
<td>Area under Licence (km²)</td>
<td>1100 km² held by Significant Discovery Licences or leases</td>
</tr>
</tbody>
</table>

(Exploration conditions are comparable to northern Alberta and to the foothills of British Columbia. There is a railhead at Hay River on Great Slave Lake and population/service centres at Fort Liard, Fort Simpson and the territorial capital at Yellowknife.)

This northern extension of the prolific Western Canada Sedimentary Basin shares several prospective exploration plays with northern Alberta and northeastern British Columbia. The Liard Plateau in southeastern Yukon and southwestern Northwest Territories is a gas producing region already connected to the Westcoast pipeline system. Exploration drilling targeted at the numerous untested fault slices in the large thrust-faulted structures of the Liard Plateau (foothills), will undoubtedly add to the stock of gas in the region. Farther east, on the plains, gas has been discovered in 17 exploratory wells and gas shows in 20 other wells. This indicates potential for a density of gas discoveries comparable to adjacent areas of British Columbia and Alberta. Recently, test production of oil from Cameron Hills has vindicated regional geochemical studies which indicated oil potential in the shallower eastern part of the region north of the Alberta border.
Geological Setting (Figs. 8, 9)

The late Precambrian saw the opening of the proto-Pacific along the length of the North American craton. Extensional tectonics during this period created a horst and graben fabric in the Precambrian basement across which sediments of the evolving passive margin of western North America were subsequently deposited. The basement fabric has since had a major influence on depositional patterns and structural development of the region.

The southern Northwest Territories and southeastern Yukon overlie a cross-section of the Paleozoic continental margin. Evaporitic and clastic sediments were deposited in a proximal setting fringing the Canadian Shield, while shelf carbonates and shales were deposited in a distal setting along the outer rim of the carbonate platform.

Early Cambrian deposition was predominantly clastic, with quartz-rich sandstones filling valleys and thinning onto the flanks of hills on the deeply eroded Precambrian surface. Cambrian sediments appear to have been largely removed or were not deposited across much of the southern Territories save in the deep rift of the Root Basin in the west of the area.

Clastic deposition was superseded by shelf and bank carbonate deposition which was more or less continuous from the Middle Cambrian to the Middle Devonian. The Tathlina High - an east-west topographic high lasting until the Late Devonian - fixed the northern margin of Middle Devonian (Givetian) carbonate deposition. The thick reefs localized above the Tathlina High constitute the Presqu’ile Barrier. North of the Presqu’ile Barrier, water depths increased into the Horn River basin where shale deposition predominated. Towards the end of the Devonian a widespread shale basin with intermittent carbonate deposition developed, which persisted through the Mississippian.

Uplift of the Cordillera began in the Early Cretaceous. Folding and thrusting of the thick Paleozoic sequence created the foothills belt in the western part of the region and transformed the Paleozoic oceanic margin into the continental seaway, which characterized the Mesozoic. Subsequent deposition was in a foreland basin setting.

The eastern limits of the disturbed belt are known only approximately: south of 61°N the northward strike of the Bovie Lake structure provides a convenient limit but orogenic influence has certainly extended east of

Figure 8. Exploration regions of northwest mainland Canada.
Figure 9. Table of formations for the northwest mainland Canada.
here within the area of the Liard-Celibeta Structural Belt (figure 22 in Reinson et al., 1993). Between 61° and 62°N, the eastern limit is poorly defined (in the absence of modern seismic lines) but is probably controlled by the Liard High (Meijer Drees, 1990), on trend with the Bovie Lake structure.

In post-Paleozoic time, the region between 61° and 62°N was uplifted. This is the La Martre Arch from which Cretaceous cover has been largely stripped (with the exception of Horn Plateau) exposing Middle Devonian strata. Mississippian sediments were uplifted and eroded in all but the southwestern corner of the region.

Extreme crustal shortening due to thrusting caused major subsidence in British Columbia beneath the tectonically thickened pile of Cordilleran rock. Thick piles of Cretaceous sediments were deposited in the rapidly subsiding basin. Gentle folding and thrusting north of 60°N developed a wider orogenic belt. This dispersed the load on the crust resulting in less basin subsidence, less accommodation of Cretaceous sediments and ultimately less preservation of Cretaceous strata. Preserved Cretaceous rocks are largely limited to the area south of 61°N.

East of the disturbed belt the carbonate platform remained relatively unstructured. It now underlies the comparatively featureless Northern Interior Plains. Tectonic structuring is limited to orthogonal patterns of normal faults of small throw, and northeasterly directed wrench faults of Precambrian age in the underlying craton.

**Exploration History (Figs. 10, 11)**

Although two wells were drilled on oil seeps near Great Slave Lake in the 1920s, sustained exploration only started in 1946. The first gas discovery was made at Rabbit Lake in 1955. Drilling was most active from 1966 to 1971, coinciding with discoveries in the adjacent Zama and Rainbow basins in Alberta. Exploration has continued at a low level during the last 20 years. Only 400 wells have been drilled between 60° and 63°N, compared with many thousands in the Western Canada Sedimentary Basin of northern Alberta and British Columbia.

Twenty-three wells have been designated “significant discoveries”. Six of these, including the three largest, are in the Liard Plateau of the Rocky Mountain foothills, extending as far east as Bovie Lake. Two of these fields are currently being produced; a third has been depleted. The remaining 17 discoveries are scattered across the Interior Plains as far east as Hay River. Eight of these are concentrated in the Cameron Hills area.

In addition to the recognized discoveries, some 20 wells have tested gas. Although pressure data and flow data suggest that most of these gas shows are from low volume accumulations, uncontrolled flows from two wells, Grumbler G-63 and Mink Lake 1-38, indicate good reservoir pressure and permeability.

The largest gas discovery in the basin is the Pointed Mountain field in the Northwest Territories, formed by thrust-folded and fractured Middle Devonian carbonates. About 80% of the projected 10.2 x 10⁹ m³ (360 bcf) of gas has been produced from this pool. Beaver River (largely in British Columbia but extending into the Yukon) is a similar gas field, which is near the end of its economic life. Kotaneelee field, in Yukon Territory, is in the early stages of production.

The Devonian Structural/stratigraphic gas pools east of the deformed belt average more modest reserves of about 0.3 x 10⁹ m³ (10 bcf), although stacked pay zones are possible. None of these discoveries have been developed, although the gas pipeline network in northeastern British Columbia extends to a few kilometres of the border with the Northwest Territories. Wells in the Cameron Hills area have undergone extensive testing as oil and gas producers, but have yet to be put on production.

**Stratigraphy (Figs. 9, 12)**

Basal clastics overlie crystalline basement across all but the most prominent basement highs throughout the region. The age of these sandstones is difficult to determine: in the Root Basin and Great Bear Basin they underlie Ordovician-Silurian carbonates and are of Cambrian age. Fringing the Tathlima Arch, the basal clastic underlie the Middle Devonian Keg River Formation and are equivalent to the Granite Wash of northeastern British Columbia.

Deposition of shelf and bank carbonates started on the western portion of the continental margin in Ordovician time and backstepped towards the craton with transgressing Devonian seas. The western bank edge of the Nahanni Formation marks the position of the carbonate-shale transition zone during the early Middle Devonian. The Nahanni is equivalent to the Keg River platform to the east and to the Lonely Bay Formation to the northeast. In the late Middle Devonian, the carbonate bank edge retreated eastward to form the Presqu’ile Barrier, which continued to grow...
DISCOVERIES
1. La Biche
2. Pointed Mountain
3. Kotaneelee
4. Beaver River
5. Liard
6. Bovie Lake
7. Arrowhead
8. Netla
9. Celbeta
10. Island River
11. Trainor Lake
12. Tathliina
13. Rabbit Lake
14. Cameron Hills

Figure 10. Geological features, gas discoveries, and pipelines, southern mainland Northwest Territories.

Figure 11. Drilling history, southern mainland Northwest Territories and adjacent Yukon.
in the shallow waters across the Tathlina High. However, the barrier edge is not well delineated, particularly where it borders the Arrowhead Salient. Behind the barrier, Chinachaga, Keg River, Muskeg and Sulphur Point cyclical carbonates and evaporites were deposited in a semi-restricted environment. Coeval Horn Plateau pinnacle and patch reefs have been found in the basinal areas north of the barrier, overlying the Lonely Bay platform.

Subaerial exposure and erosion terminated this carbonate cycle prior to Watt Mountain deposition. Slave Point reefal limestones were deposited during the subsequent transgression. They have remained undolomitized except at bank margins where hydrothermal flow occurred. Late Devonian transgression drowned the carbonate banks and deposited massive Horn River/Besa River shales. Note that formation names in the area are commonly mixtures of Alberta, B.C., and northern usages.

Carbonate sedimentation resumed intermittently during the Late Devonian, depositing the Jean Marie, Tetchal and Kotcho limestones. All are predominantly tight shelf-carbonates. The Jean Marie has a trend of reef mounds along its western margin of deposition: the trend is well delineated in British Columbia and strikes north across the Arrowhead Salient into the Northwest Territories.

The Mississippian succession of carbonates and shales is comparable to that of Alberta (Pekisko, Debolt and Flett formations). These are overlain by clastics (Mattson Formation) in the western part of the region. The Permian Fantasque sandstone (= Belloy) unconformably overlies the Mississippian in the southwest corner of the map area. A major unconformity separates the Permian from overlying Cretaceous sandstones and shales.

**Potential Reservoirs**

The Nahanni and Arnica formations are tight shelf-carbonates. The Manetoe dolomite is a diagenetic facies - a hydrothermally dolomitized equivalent of these formations – and the main reservoir in the foothills. Average porosity in the dolomitic reservoirs is only

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![Figure 12. Schematic cross-section, southern mainland Northwest Territories.](image-url)
3.5%, with permeability ranging from an average of 7 mD to 200 mD. Permeability is enhanced by fracturing. Active water drive ensures efficient production in the Pointed Mountain and Kotaneelee fields. Better porosity in the Manetoe was encountered at Bovie Lake (up to 6%), the easternmost of the foothills structures.

La Biche is an exception among foothills discoveries in that the reservoir consists of lenses of porous siltstone inter-fingering with limestone. The siltstone has an average porosity of 18% and good horizontal permeability.

The Slave Point Presqu'ile Barrier edge is a fair gas reservoir rock, averaging 7% porosity in patchy, leached and mineralized limestone at Celibeta and Netla respectively. Bank-interior Slave Point, Sulphur Point and Keg River limestones and dolomites have so far proven better reservoirs with an average porosity of 9% (maximum 15%) and permeability of 7 mD (reaching 200 mD). Paramount Resources Ltd. has reported oil flows of 25.4 m³/d (160 bopd) from the Slave Point in Cameron M-73 (Daily Oil Bulletin, 17 June 1993).

Keg River dolomite reservoirs behind the Prequ'ile Barrier average 4% vuggy porosity, with effective porosity and permeability enhanced by fractures close to reactivated fault zones. Horn Plateau pinnacle and patch reefs are undolomitized and relatively tight, although 6% porosity and permeability is certainly present in these rocks at Mink Lake l-38. The Lonely Bay platform also contains a dolomitized zone with good porosity in this well.

Upper Devonian carbonate reservoirs are low porosity and poorly productive in northeastern B.C. Porous zones in the Jean Marie, Kotcho and Tetcho formations may have enhanced reservoir characteristics over fault zones in the Liard-Celibeta Structural Belt.

Carboniferous to Cretaceous clastic rocks have fair to excellent reservoir characteristics. Porosity in basal Cretaceous sandstones is in excess of 20%.

Structure, Traps and Seal

By far the most prolific hydrocarbon traps in this basin are the foothills plays in the west. Devonian carbonates, folded and thrust during the Laramide orogeny, form large traps with relatively low porosity but excellent fracture permeability. The best example for this play type is the Pointed Mountain gas field. Diagenetic, and structural and stratigraphic traps occur along a zone of interplay between the eastern limit of orogenic structuring and western limits of the Presqu’ile Barrier in the Arrowhead Salient and north of the Presqu’ile Barrier along the trend of the Liard High.

The eastern Slave Point, Sulphur Point and Keg River plays are usually formed by a combination of structural (normal faulting controlling basement topography) and stratigraphic trapping. The top seal for the Nahanni and Slave Point pools are the thick Horn River/Besa River shales. Sulphur Point accumulations are sealed by the Watt Mountain shale. Keg River dolomite traps can be formed by Muskeg anhydrite top seals. Structural control – increasingly subtle at higher stratigraphic levels – has produced three stacked Middle Devonian reservoirs in the Cameron Hills area.

Source Rocks

The main source rock in this basin is the Fort Simpson/Horn River/Besa River shale, in direct contact with the Nahanni and Slave Point reservoirs. The basal shale (Muskwa) is bituminous and has the highest organic carbon content. Immature in the extreme east, the Muskwa is a mature oil source rock in the centre of the map area and a gas source rock in the west. The Keg River carbonates and Muskeg evaporites are source rocks for Keg River hydrocarbons in the Rainbow basin of Alberta and may contribute to Keg River reserves in the southern Territories.

Superior source rocks in terms of Total Organic Carbon content exist in the upper Devonian, Mississippian (e.g. Exshaw) and Cretaceous. These source rocks are overmature in the Liard basin with generation and migration of oil occurring as early as the Late Paleozoic (Morrow et al., 1993). Subsequent generation of gas and cracking of migrated oil to gas is likely to have continued throughout the Mesozoic with secondary migration of gas into the existing accumulations occurring during and after Laramide deformation.

Potential

The Geological Survey of Canada has released a resource assessment of Devonian gas resources in the Western Canada Sedimentary Basin (Reinson et al., 1993). Five mature plays with a combined potential possibly exceeding 1 tcf of gas extend north of 60°N towards the northern margin of the Presqu’ile Barrier. It is noteworthy that the structural plays of the Liard Plateau were not assessed and neither was the oil potential of this area. These endow considerable additional potential.
Table 1. Significant discoveries in the foothills of the Southern Northwest Territories and Yukon

<table>
<thead>
<tr>
<th>Location</th>
<th>Year</th>
<th>Type</th>
<th>Initial Reserve (E6 m³)</th>
<th>Production to 06/30/93 (E6 m³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pointed Mountain (NWT)</td>
<td>1967</td>
<td>Producing</td>
<td>10200</td>
<td>8545</td>
</tr>
<tr>
<td>Kotanelee (Y U K)</td>
<td>1977</td>
<td>Producing</td>
<td>5012</td>
<td>1038</td>
</tr>
<tr>
<td>Beaver River (BC/YU K)</td>
<td>1969</td>
<td>Depleted</td>
<td>218</td>
<td>218</td>
</tr>
</tbody>
</table>

Probability levels

<table>
<thead>
<tr>
<th>Location</th>
<th>Year</th>
<th>Type</th>
<th>Probability levels</th>
<th>Probability levels</th>
<th>Probability levels</th>
</tr>
</thead>
<tbody>
<tr>
<td>Liard (NWT)</td>
<td>1986</td>
<td>Undeveloped</td>
<td>95%</td>
<td>688</td>
<td>2628</td>
</tr>
<tr>
<td>Liard (NWT)</td>
<td>1986</td>
<td>Undeveloped</td>
<td>50%</td>
<td>1171</td>
<td>5225</td>
</tr>
<tr>
<td>Liard (NWT)</td>
<td>1986</td>
<td>Undeveloped</td>
<td>5%</td>
<td>175</td>
<td>239</td>
</tr>
</tbody>
</table>

(Note: recoverable gas resource estimates for undeveloped pools are subject to a high degree of uncertainty and have been estimated using a probabilistic method.)
Source - National Energy Board

Table 2. Significant discoveries of the Interior Plains of the Southern Northwest Territories

<table>
<thead>
<tr>
<th>Location</th>
<th>Year</th>
<th>Type</th>
<th>Probability levels</th>
<th>Probability levels</th>
<th>Probability levels</th>
</tr>
</thead>
<tbody>
<tr>
<td>Arrowhead G-69</td>
<td>1985</td>
<td>GAS</td>
<td>95%</td>
<td>71</td>
<td>115</td>
</tr>
<tr>
<td>Arrowhead B-41</td>
<td>1989</td>
<td>GAS</td>
<td>50%</td>
<td>1171</td>
<td>5225</td>
</tr>
<tr>
<td>Cameron Hills M-31</td>
<td>1979</td>
<td>GAS</td>
<td>5%</td>
<td>175</td>
<td>239</td>
</tr>
<tr>
<td>Cameron Hills F-51</td>
<td>1969</td>
<td>GAS</td>
<td>95%</td>
<td>71</td>
<td>115</td>
</tr>
<tr>
<td>Cameron Hills field</td>
<td>1986</td>
<td>GAS &amp; OIL</td>
<td>50%</td>
<td>1171</td>
<td>5225</td>
</tr>
<tr>
<td>Celebreta H-78</td>
<td>1960</td>
<td>GAS</td>
<td>5%</td>
<td>175</td>
<td>239</td>
</tr>
<tr>
<td>Netla C-07</td>
<td>1961</td>
<td>GAS</td>
<td>95%</td>
<td>71</td>
<td>115</td>
</tr>
<tr>
<td>Rabbit Lake O-16</td>
<td>1955</td>
<td>GAS</td>
<td>50%</td>
<td>1171</td>
<td>5225</td>
</tr>
<tr>
<td>South Island River M-41</td>
<td>1964</td>
<td>GAS</td>
<td>5%</td>
<td>175</td>
<td>239</td>
</tr>
<tr>
<td>South Island River M-41</td>
<td>1964</td>
<td>GAS</td>
<td>95%</td>
<td>71</td>
<td>115</td>
</tr>
<tr>
<td>Tathlina N-18</td>
<td>1973</td>
<td>GAS</td>
<td>50%</td>
<td>1171</td>
<td>5225</td>
</tr>
<tr>
<td>Trainor Lake C-39</td>
<td>1965</td>
<td>GAS</td>
<td>5%</td>
<td>175</td>
<td>239</td>
</tr>
</tbody>
</table>

*Wells still confidential as of 1 January 1994.
(Note: none of these discoveries have been developed: recoverable gas resource estimates are based on single well discoveries for the most part and are subject to a high degree of uncertainty.)
Source - National Energy Board
The main phase of exploration in the shallow eastern plays used 1960s to 1970s seismic data. Although the Presqu’île Barrier appears to be continuous with present seismic information, small embayments are likely, trapping small to medium size oil and gas fields. Proven and still moderately prospective play types are combined structural and stratigraphic traps along the Keg River Cordova Embayment, along the main barrier system, or in the interior areas of the carbonate bank. Horn River reefs drilled north of the barrier contain little oil or gas, possibly due to a migration problem between source and reservoir rock and, in some cases, to breaching of the reservoir. Further exploration of this play may find local areas where conditions for migration, porosity development and preservation have been more favourable.

Jean Marie reef mounds are the reservoir for the producing gas field at July Lake, B.C. Comparable reservoir facies are likely to exist within the Cordova Embayment north of 60°N. A seismically defined Jean Marie barrier-reef-trend is located along a north-south trend between latitudes 122° to 123°W. This is an extension of the reef trend in Northeastern B.C. which has producing gas wells. Faulting along the western margin of the Arrowhead Salient and fracturing due to tensional drape of overstepping carbonates across underlying bank edges may augment permeability in the Jean Marie and in other upper Devonian carbonates.

The greatest remaining potential for large gas pools lies in the foothills where Devonian carbonates are folded and thrust into huge structural traps. Surface geology can identify prospective areas, but modern seismic is necessary to pick the best subsurface drilling locations: all of the foothills discoveries lack good subsurface control. This foothills play should extend north to 61°N as a broad fairway, and as a narrower, more easterly trend near longitude 123°W, all the way to 62°30′N. The western limit of the play in the Yukon is the carbonate-shale transition: this is ill-defined in the subsurface. Farther to the north and west, the Devonian section is at outcrop. The existence of a gas pipeline to the Pointed Mountain gas field makes further exploration along this broad trend economically attractive.

Largely unexplored potential remains within Mississippian and younger rocks of the deepest part of the basin west of 120°W where the Cretaceous cover has not been removed by erosion. Play types here may range from Mississippian or Permian subcrop plays to Cretaceous fluvial channels.

Key Reading and References


Figure 13. Geological and geographical features of Mackenzie Plain and adjacent areas.
### MACKENZIE PLAIN

<table>
<thead>
<tr>
<th><strong>Age</strong></th>
<th>Proterozoic to Early Cretaceous</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Depth to Target Zones</strong></td>
<td>500 to 4500 m</td>
</tr>
<tr>
<td><strong>Maximum Basin Thickness</strong></td>
<td>Cretaceous and younger – 3000 m</td>
</tr>
<tr>
<td><strong>Hydrocarbon Shows</strong></td>
<td>Subsurface oil and gas shows in Devonian to Cretaceous rocks, surface oil seeps</td>
</tr>
<tr>
<td><strong>First Discovery</strong></td>
<td>1920 (Northwest Discovery No. 1; Middle Devonian Kee Scarp Formation – oil)</td>
</tr>
</tbody>
</table>
| **Discovered Resources** | Gas: (gas shows)  
Oil: Norman Wells (37.5 x E6 m$^3$; 235 mmbbls recoverable) |
| **Production** | Gas: (none)  
Oil: 18 x E6 m$^3$ |
| **Basin Type** | Cretaceous-Tertiary foreland basin over Paleozoic continental margin |
| **Depositional Setting** | Shallow-water carbonate shelf (early Paleozoic) clastic shelf (Late Devonian); fluvial to marine shelf (Cretaceous-Tertiary) |
| **Reservoirs** | Middle Devonian carbonates, potentially Ordovician-Silurian carbonates, Cretaceous sandstones |
| **Regional Structure** | Westward dipping monocline, uplifted and thrusted in west. Salt related swells and withdrawl structures. Well defined zones of wrench faulting. Deep-seated thrust detachments |
| **Seals** | Thick Devonian shales, Cretaceous shales |
| **Source Rocks** | Mature Devonian shales (oil-prone); Lower Cretaceous shales (oil-prone) |
| **Depth to Oil/Gas Window** | Devonian – at surface  
Cretaceous – ?1000 m |
| **Total Number of Wells** | 76 exploratory; 345 development at Norman Wells |
| **Seismic Coverage** | Good coverage |
| **Pipelines** | Norman Wells oil pipeline to Zama, Alberta |

(Forrested, low-relief flood plain bordered by rugged mountains. Easy access for heavy equipment by barge on the Mackenzie River or by winter road. Population and service centres at Norman Wells and Fort Norman. Skilled local labour force and contractors.)

Relatively well explored in pursuit of a second Norman Wells oilfield, Mackenzie Plain lies in the accessible mid-section of the Mackenzie Valley, north and south of Norman Wells. Although exploration has been focused on the discovery of further pools of Norman Wells type, other plays exist, notably in Cretaceous sandstones, which interfinger with oil-prone source rock. A high degree of structuring creates much variation in source rock maturity and juxtaposition of diverse potential reservoir units, both clastic and carbonate. Potential for further discoveries in this area ranges from moderate to high. Pool sizes are expected to show an extreme range and contain a variety of hydrocarbon types ranging from heavy to light oil, and possibly gas in the deepest parts of the basin. The area is close to an existing oil pipeline and service centre.)
Geological Setting (Fig. 14)

Mackenzie Plain overlies the southern Peel Trough between the arc of the Cordillera (Mackenzie Mountains) to the west and the flank of the Keele Arch (Franklin Mountains) to the east. A westward thickening wedge of Cretaceous-Tertiary strata overlies a broad Lower Paleozoic syncline with a gently dipping eastern limb and a more steeply dipping western limb rising to outcrop as the front ranges of the Mackenzie Mountains. Lower Paleozoic strata outcropping in the Franklin Mountains border the Peel Trough to the east. The trough widens to the northwest where the Mackenzie Foldbelt in this northern area extends beneath Mackenzie Plain. To the south, the trough becomes increasingly constricted as the Keele Arch reaches a terminus close to the Mackenzie Mountain front at about 64°N. The entire region has been affected by compressional tectonics, expressed as long wavelength folds (especially in the north), bedding-parallel detachments (beneath Mackenzie Plain), and thrust faults outcropping in the Franklin Mountains.

Exploration History (Fig. 15)

Oil seeps along the banks of the Mackenzie River have long been known and used by people of the Dene nation. They were recorded by Alexander Mackenzie during his descent of the river in 1789. The seepages at Norman Wells first attracted commercial interest in 1891 when they were pointed out to J.K. Cornwall of the Northern Trading Co. In 1919 Imperial Oil Co. acquired the Norman Wells prospect and in the following year drilled Northwest Discovery No. 1. Subsequent delineation has proved 37.5 x 10^6 m³ (235 million barrels) of recoverable oil pooled in the up-dip end of a Middle Devonian Kee Scarp reef within 600 m of the surface.

In the early 1940s the Canol Project involved the construction of a pipeline from Norman Wells to a refinery at Whitehorse (Yukon Territory) in support of the war effort in the Pacific theatre. Flow through the pipeline peaked at 700 m³ (4400 barrels) per day but ceased after the war and the pipeline was dismantled. Post-war production supported the refinery at Norman Wells, which processed an average of 425 m³ (2675 barrels) per day.
In the early 1980s, a major expansion of the Norman Wells field was undertaken, which together with the construction of a 305 mm (12") pipeline to Zama (Alberta), completed in 1986, has enabled this field to become one of the top producing fields in Canada.

Exploration activity increased in the late 1960s and 1970s and a total of 76 exploratory wells were drilled in the Mackenzie Plain, most in a narrow corridor close to the river. Farther to the east and west exploration has been sparser. In the early to mid-eighties exploration focused on the Middle Devonian reef complex northwest of Norman Wells but declined in the last half of the decade because land issuance was suspended during land claim negotiations. The limited drilling in the late 1980s concentrated in the region south of Fort Good Hope and on the Mackenzie Plain southwest of Fort Norman. In 1994, the Government of Canada issued a Call for Nominations, which included the Mackenzie Plain area and may presage renewal of exploration.

A good reconnaissance grid of seismic has been shot over the extent of the Kee Scarp play in the vicinity of Norman Wells. Farther northwest and south of Fort Norman there have been fewer seismic programs. Only one 3-D seismic program has been shot in the area (at Norman Wells).

**Stratigraphy (Fig. 16)**

A basal Cambrian clastic section overlies Proterozoic rocks throughout the region - at considerable depth in the Peel Trough, rising to outcrop east of the region. Sandstones of the Mount Clark Formation are gas-bearing in the Colville Hills to the northeast and are likely to exist at depth beneath the Mackenzie Plain. Cambrian deposition culminated in the deposition of evaporites - the Saline River Formation - which were superseded by widespread carbonate deposition for the remainder of the Early Paleozoic.

The Lower Paleozoic carbonate platform in the Northwest Territories comprises the Ordovician Franklin Mountain and Silurian Mount Kindle formations overlain by Lower Devonian platform carbonates, reefs and associated evaporitic facies - the Bear Rock, Arnica, Landry and Hume formations. Reef-forming carbonates of Keg River, Sulphur Point and Slave Point formations, present in the southern Northwest Territories, are represented by the shaley Hare Indian Formation in the Norman Wells area. Conditions favourable to reef development returned to the Norman Wells area and much of Sahtu in the late Middle Devonian which saw the growth of Ramparts Formation (Kee Scarp) reefs. Reef development was terminated by deposition of Canol shale in the late Devonian, followed by the thick clastic wedge of the Imperial Formation. The Jungle Ridge Formation is a thin limestone marking a mid-Imperial hiatus in clastic input to the basin.

Albian and Upper Cretaceous strata are widely preserved and overlie the Imperial Formation above a major unconformity. Potential reservoir sandstones include the Slater River, Little Bear and East Fork formations. Local deltaic influx is evident from clinoforms visible on seismic in some of these units. The lower Tertiary Summit Creek Formation is locally preserved in the vicinity of Fort Norman. Cretaceous depositional patterns may have been influenced by syndepositional structuring related to limited mobilization of Saline River salt.

Permo-Triassic, Jurassic and pre-Albian strata are absent from the area.

**Potential Reservoirs**

The Middle Devonian Kee Scarp Formation at Norman Wells is the sole producing reservoir in the region. The field is in foreslope, reef margin and reef interior lagoonal facies of an atoll-type reef, which built up to 150 m above a regional limestone platform. Porosity development in the Kee Scarp reservoir at Norman Wells is unusual - micro-leaching has developed a chalky porosity ranging from 12-20% with fine but consistent pore throat size. The reservoir has good horizontal but poor vertical permeability and production is closely tuned to geological zonation of the reservoir. Thin bioclastic shoals are associated with the leeward side of the Norman Wells reef. These may have a more widespread if discontinuous distribution across the regional platform and may be comparable to patchily distributed bioclastic sandstone encountered immediately above the reef and below the Canol shale - the Charhue sandstone. Where highly fractured, the Canol shale has potential as a low volume producer in its own right.

Most of the recent wells in the Middle Devonian reef facies have penetrated back reef or lagoonal facies; one well flowed salt water at good rates (PCI Morrow Creek J-71), and cores from PCI Hoosier N-22 and AT&S Carcajou O-25 bled oil. Gas with a heavy salt water spray flowed from a fractured zone in AT&S Carcajou D-05.
The Lower Devonian Bear Rock carbonates and evaporites are extensive in the subsurface of Mackenzie Plain. The Bear Rock commonly has cavernous porosity in subsurface occurrences. Minor oil staining has been reported in the Bear Rock near the western transition from anhydrite to carbonate. All porous zones tested to date have flowed water, but this unit is potentially an excellent reservoir if isolated from the regional aquifer. Other Lower Devonian formations also have reservoir potential – either in intergranular and vuggy porosity developed in platform carbonates, or locally as pinnacle reefs building from the Hume platform. A shallow and breached example of the latter was drilled by the Atlantic Col Car Manitou Lake L-61 well near Fort Good Hope.

Candel East Mackay B-45 had pipe recovery of 20° API oil from fractured cherts of the Upper Cambrian-Ordovician Franklin Mountain Formation. Potential for fractured reservoir development is fair in Laramide structures containing brittle Lower Paleozoic units. There is also a possibility of deeper clastic reservoirs in the Cambrian beneath the Saline River but, if similar to the Colville Hills gas reservoirs, they are unlikely to have porosity exceeding 12%.
Structure, Traps and Seal

Laramide deformation of the previously mildly deformed Paleozoic margin developed a variety of fold, thrust and wrench structures, each of which is quite localized and separated by areas where deformation is minimal. The area and style of deformation is linked to the distribution of the Saline River salt, which forms a major decollement surface. Bedding-parallel detachment and eastward translation of broad panels of post-Cambrian strata are demonstrated by mapped overthrusts east of the Norman Range.

Large amplitude folds related to a deep-seated detachment are apparent in the Mackenzie Mountains, which border on the west of the region. These structures extend beneath Mackenzie Plain in the north; for instance, at the Imperial anticline. In the central part of the valley, west and southwest of Norman Wells, the regional dip is to the west. As the Mackenzie Mountain front is neared, a dip reversal occurs above a deep triangle zone comprising imbricate thrust panels.

South of Fort Norman a major discontinuity is apparent in the alignment of mountain ranges and the course of the river. This discontinuity marks a zone of wrench faulting, which runs at an oblique angle across the fold axes of the Mackenzie and Franklin mountains towards the Smith Arm of Great Bear Lake (the “Fort Norman Structure” of Aitken and Pugh, 1984). Major thrust folds are associated with this wrench system, which follows the trend of pre-Cretaceous extensional faulting. Structural deformation in the area is influenced by the Cambrian salt: swells and withdrawal collapse structures are apparent, but no diapirs have been noted.

Lower Paleozoic strata are upturned and truncated along the western flank of the Keele Arch. Sub unconformity traps may be created in this area by overlying Cretaceous shales.

Source Rocks

Norman Wells oil is derived from the Canol Shale draping the reef. The Canol is responsible for most of the oil seeps along the Mackenzie River. The Canol is widely developed and geochemical studies demonstrate that its potential as a source rock for oil is sustained throughout most of the region. A lithologically similar but older unit – the Bluefish Member of the Hare Indian Formation – is also a rich, oil-prone source rock. Both of these source rocks are just within the oil window at the current subsurface depth of the Norman Wells field although the oil is more mature, indicating a source at greater depth of burial. Higher maturation levels, possibly to beyond the lower limit of the oil window are likely in deeper parts of the basin nearer the Mackenzie Mountains.

Oil recovered from the Franklin Mountain Formation at East Mackay correlates to a source rock in the Cretaceous Slater River Formation (Feinstein et al., 1988). This unit is regionally extensive and its variable depth throughout the basin suggests a spectrum of maturity. Oil staining has also been observed in Cretaceous sandstones in several wells (for example, oil cut mud (25-30° API) recovered from Mesa Hanna River J-05.

Potential

Large reefal developments north of Norman Wells have been partially delineated by existing seismic and wells. The exploration potential of these areas for pools of Norman Wells type has been summarized by G.K. Williams (1986). There remain opportunities to discover oil pools along the up-dip edges of the reef masses and within the complex architecture of the reef where source, seal and porosity development coincide. Proximity to outcrop in the Franklin Mountains with risk of reservoir breaching, biodegradation of oils, and uneven porosity development are the principle risks in this play.

In the vicinity of the Norman Range, the prospective Middle Devonian section may be repeated beneath the thrust sheet carrying the Norman Wells field. Low relief shoals developed above the regional carbonate platform may be additional targets for small oil accumulations: these are barely resolved by seismic.

Imbricate thrusting close to the Mackenzie Mountain front, Laramide thrust folds and pre-Laramide folds and fault blocks are less explored structural targets. The Cretaceous section has potential for oil pools in structural/stratigraphic traps which may be of interest because of the close proximity of production facilities at Norman Wells. Potential for good quality reservoir rock in the Cretaceous is high.

Key Reading and References


**PEEL PLAIN AND PLATEAU**

<table>
<thead>
<tr>
<th>Age</th>
<th>Paleozoic, Cretaceous</th>
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<tr>
<td>Depth to Target Zones</td>
<td>1000-4000 m</td>
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<td>Maximum Basin Thickness</td>
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<td>Potential Reservoirs</td>
<td>Lower Paleozoic platform and shelf-edge carbonates; Imperial/Tuttle sandstones; Cretaceous sandstones</td>
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<tr>
<td>Regional Structure</td>
<td>Southwestward dipping monocline bordered to west and south by orogenic belts</td>
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<td>Seals</td>
<td>Lower and upper Paleozoic shale tongues; Cretaceous marine shales</td>
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<td>Source Rocks</td>
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<td>Seismic Coverage</td>
<td>Sparse reconnaissance</td>
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<td>Area under Licence</td>
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(Accessible from population centres at Fort MacPherson and Fort Good Hope. Barge transport of heavy equipment on the Mackenzie River. Terrain: low elevation, muskeg, incised river valleys.)

Fifty-two wells have been drilled in this region with some significant shows of gas reported. Overall potential increases from low to moderate in the northeast to moderate to high in the southwest as the sedimentary succession increases in thickness and completeness, and as maturity of potential source rocks increases with depth of burial. Potential for large structural traps is localized in zones paralleling the Richardson and Mackenzie mountains: elsewhere potential lies in stratigraphic traps transverse to regional dip in fluvial, valley fill and possibly deltaic Cretaceous sandstones, in shelf sandstones of the Imperial Formation or in deltaic sandstones of the Paleozoic Tuttle Formation. Reefs of middle Devonian age are known to exist near the eastern edge of Peel Plain and the presence of isolated reefs building from the Hume platform is likely.

**Geological Setting** (Fig. 17)

North of 65°N, the Cordillera swings to the west and relatively undisturbed sedimentary strata are preserved across a broad area west of the Mackenzie River. This area, known as the Peel Plain and Plateau, is underlain by a wedge of Cretaceous strata thickening to the west and south that was deposited in a foreland basin setting, typical of the Western Canada Sedimentary Basin. The Mesozoic strata overlie Paleozoic strata preserved within the Peel Trough, the axis of which is sub-parallel and outboard of the Mackenzie Foldbelt. A wedge of upper Paleozoic strata is preserved in the southwest corner of the region.
The western and southern margins of the region border the Richardson Mountains and Mackenzie Mountains respectively. Significant structuring of the Paleozoic and younger rocks appears limited to relatively narrow zones bordering the mountain belts.

**Exploration History (Fig. 18)**

The first well to be drilled on Peel Plain was Richfield Oil Corp. et al. Grandview Hills No. 1 A-47 spudded in 1959. The well was abandoned at 1998 m after penetrating to the Franklin Mountain Formation. The main phase of drilling lasted a decade, beginning in the mid-sixties, but with no significant success. The most significant show was encountered while drilling the Shell Tree River H-38 where flows of sweet gas, estimated at 17.7 x 10^6 m³ (0.5 mmcfd) occurred during loss of well control at 721 m (2366 ft.). Several lost circulation zones were encountered while drilling. The logs indicate good porosity in the Devonian carbonate section.

Drilling has been concentrated in corridors close to the Mackenzie River, and in the Peel River drainage area in the Yukon. The central area of Peel Plain is sparsely drilled.

**Stratigraphy (Fig. 19)**

The Cambrian section is deeply buried beneath the Peel Plateau: units include thin distal equivalents of the Mount Clark, Mount Cap and Saline River formations, which are included as undivided Cambrian sediments at outcrop in the Richardson Mountains. Deposition of the Franklin Mountain Formation (Ordovician, 600-1000 m) marked the establishment of a broad early Paleozoic shelf dominated by carbonate deposition. The Franklin Mountain is overlain by
carbonates of the Mount Kindle and Peel formations (Silurian 300-800 m), in turn by the Devonian carbonate assemblage, comprising the Arnica, Landry and Hume formations (approximately 1000 m). The lower Paleozoic carbonate platform extends from the outcrop areas in the Franklin Mountains east of the Mackenzie River to a zone of carbonate/shale transition that parallels the Richardson Mountains. Shale
equivalents (Road River and Prongs Creek formations) of these formations were deposited in the ancient Richardson Trough - later the focus of uplift and structural deformation.

Upper Devonian Canol shales drape the carbonate platform throughout the Peel area. They are over lain and interfinger with the overlying Imperial Formation clastics. The Imperial reaches over 600 m in thickness in the Peel Trough and approaches 2000 m close to the Richardson Mountains. The sandstones, interbedded with siltstones and shales and deposited on shelf edge clinoforms, are typically fine grained with low reservoir potential.

The Tuttle Formation (latest Devonian to Mississippian) is represented by repeated cycles of fine to coarse grained fluvio-deltaic sandstones and conglomerates. The formation reaches an overall thickness of 800 m in the subsurface of the lower Peel River area.

Overlying and partially a distal facies equivalent of the Tuttle is the Ford Lake Shale. The remainder of the Carboniferous to Triassic succession (Hart River Formation and younger) is absent east of the Richardson Mountains.

Cretaceous strata mask older rocks across most of Peel Plain and Plateau except along the eastern margin of the area. Here, the cores of anticlines emerge from Cretaceous cover and the Mackenzie River has cut down to Upper Devonian strata. The Cretaceous thickens from about 500 m in the east to a little over 2000 m close to the Mackenzie Mountains. Basal Cretaceous fluvial or valley fill sandstones of the Gilmore Lake Member occupy river meander belts incised into upper Devonian strata. Over most of the area, however, the Devonian is overlain by glauconitic and carbonaceous sandstones of the transgressive basal beds of the Arctic Red Formation which quickly fine upwards into marine shales and siltstones. Sandstones of the younger Trevor Formation outcrop across the Peel Plateau.

Potential Reservoirs

With no significant discoveries there are no proven reservoir rocks within the Peel area. Vuggy porosity has been noted in the Devonian and older carbonates but no systematic trend of enhanced porosity has been noted: the platform limestones fringing the Richardson Trough are typically tight. Farther east, porosity is present in the dolomitic platform facies but the absence of thicker porosity in reefal facies is discouraging. Porous zones occur in the Bear Rock Formation. Reefal development from the Hume platform is possible (as encountered in Manitou Lake L-41), but this situation may be limited to the extreme east of the region.

Sandstones of the Imperial and Tuttle formations have some potential as reservoirs, although porosity is typically low in both units. The Imperial sandstones have been thin where encountered, but enhanced amplitudes apparent on seismic suggest the possibility of thicker sand development. Thin Imperial sandstones appear to be gas charged on logs in Chevron Ramparts River F-46. Fairways with enhanced porosity in the Tuttle are of restricted extent. Tuttle sandstones are generally poorly sorted, with kaolinitic matrix and have low porosity and permeability. Sorting and potential reservoir quality improve to the south where fine to medium grained sandstones have porosities up to 15% in Taylor Lake Y.T. K-15. Basal Cretaceous sandstones also are potential reservoirs, but where encountered they have indifferent and variable reservoir quality.

A risk with all reservoirs in the western Peel Plateau is the possibility of early oil migration and the subsequent plugging of porosity with bitumen. Secondary porosity development related to Laramide structural movements post-dates this early phase of hydrocarbon migration.

Structure, Traps and Seal

The change from carbonate to shale that occurs as the Richardson Mountains are approached is accompanied by a marked change in structural style. The north-south Trevor Fault marks the surface transition from a relatively unstructured platform in the east to the thrusts and folds of the Richardson Mountains. Seismic coverage in this area is reconnaissance in nature and inadequate to fully define structural complexity.

The structural traps of the region are Late Cretaceous and younger, corresponding with Laramide tectonics. This would appear to post-date the onset of oil generation in lower Paleozoic rocks. Potential oil source rocks in younger formations may have been in the oil window subsequent to trap formation. Stratigraphic and diagenetic traps of Upper Devonian and Lower Cretaceous rocks are more likely to have formed coeval with oil generation and migration from older source rocks.
Source Rocks

Pugh (1983) notes that thousands of metres of black shale of the Road River Formation lie in the Richardson Mountain belt. These basinal shales are juxtaposed against shelf carbonates. High TOC (2.5 to 9.6%) and Type I or II kerogen have been reported from Road River shales suggesting that certain intervals within this sequence were once excellent oil-prone source rocks. Unfortunately, maturation studies indicate that these source rocks generated hydrocarbons as early as the Late Devonian and are now overmature – this is likely to be particularly true in the deeper areas of the Peel Trough. Lower to Middle Devonian rocks may have some potential in eastern Peel Plateau as a source rock, as does the overlying Canol Formation. In western Peel Plateau, the Devonian is probably overmature for oil generation, as evidenced by the bitumen encountered in several wells.

Samples from the Upper Devonian Imperial Formation are reported as mature with fair to good gas source potential. Ford Lake shales have fair to good gas and some oil potential in eastern Eagle Plain and it is probable that similar potential exists in western Peel Plateau.

The Lower Cretaceous Arctic Red Formation is generally lean in organic carbon with terrestrial Type III kerogen predominant. On the basis of limited data, the basal Cretaceous enters the oil window at depths below 750 m.

Potential

The localization and stacking of shelf edge carbonates creates multiple potential targets adjacent to and inter-fingered with potential source rocks and seals. It is unlikely that much oil potential remains in the pre-Upper Devonian source rocks, however, these will have continued to generate gas. The major risk in this play is poor porosity development and overmaturity of source rock.

East of the shelf edge there is patchy porosity development within the carbonate platform. The controlling factors for such porosity are not clear but there is potential for significant potential pay thickness. Large diagenetic/stratigraphic traps may occur. This play is poorly explored by drilling to date.

The Tuttle Sandstone may develop favourable reservoir characteristics in the southwestern corner of the region. This constitutes an interesting target over a limited area, principally in the eastern Yukon. The stratigraphic proximity of the Tuttle to potential oil source rocks in the Mississippian is encouraging.

An Early Cretaceous drainage system developed during the Late Aptian across a pre-Mesozoic peneplain. Potential sandstone reservoirs could occur in stratigraphic traps in this play. Oil potential in Gilmore Lake prospects may be restricted to areas where the Canol subcrops the basal Cretaceous unconformity. Arctic Red sandstones are widely distributed, although these have modest potential as low productivity gas reservoirs. Because they are marine sheet-sandstones they lack stratigraphic trapping potential and are generally unstructured.

The structural complications associated with the carbonate/shale transition create opportunities for structural/stratigraphic traps, diagenetic porosity development and migration.

Key Reading and References


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<th>Age</th>
<th>Cambrian, Ordovician, Early to Middle Devonian</th>
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<td>Ashland et al. Tedji Lake K-24 (1974-Gas)</td>
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<td>Area under Licence</td>
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This large and sparsely explored area contains several gas discoveries in Cambrian sandstones in the Colville Hills. Prospects include large low-relief structures at depths ranging from 1100 to 7400 m. Of the three discoveries, Tweed Lake contains sweet dry gas; Tedji Lake and Bele contain substantial condensate reserves in addition to gas. Overall potential for additional gas discoveries is very high in this play with pool sizes in the range 25-300 bcf (recoverable). Oil source rocks are also present in the Paleozoic and may contribute light oil or condensate to the largely gas accumulations. The potential for small to medium sized oil pools in undrilled structures appears high.

### Geological Setting (Fig. 20)

Following the development of a regional peneplain in the late Precambrian, a shallow intra-cratonic basin began to subside, flanked by the Precambrian shield to the east and the Mackenzie Arch to the west. The basin filled with a clastic to evaporitic succession of Cambrian sediments, culminating in widespread deposition of Saline River salt in the Late Cambrian. Silurian-Ordovician uplift of the Keele Arch inverted the central part of the Cambrian basin. Subsequent clastic input to the area was minimal - as elsewhere along the craton margin. There followed a long period of carbonate platform deposition lasting until the end of the Middle Devonian. Clastic deposition predominated from Late Devonian onwards, with a major gap in the stratigraphic record between the end of the Devonian and the Cretaceous. Cretaceous strata were deposited throughout the region but have subsequently been stripped from the Colville Hills.

The influence of Laramide tectonics is apparent in the Colville Hills area as shallow, detached, wrench, compressional and extensional faults overlying reactivated deeper crustal scale faults (MacLean and Cook, 1992). Loading by the growing Cordillera began to tilt the continental margin to the west from the Cretaceous onwards, establishing a regional up-dip migration route for hydrocarbons generated in the deeper parts of the basin.
Figure 20. Well locations and geographic limits of Mount Clark sandstone, Colville Hills area.

Exploration History

Although large structural domes visible on aerial photographs have stimulated exploration in the Colville Hills, a larger population of prospects have no surface expression. Ashland et al. Tedji Lake K-24, the first well to discover hydrocarbons in the area, was drilled on a subsurface structure identified by seismic.

Following the issuance of exploration licences in the early eighties, exploration in the Colville Hills became particularly active. Two additional discoveries confirmed the basal Cambrian Mount Clark sandstone as regionally extensive and a potential reservoir throughout the area. Eleven wells have been drilled in the Colville Hills resulting in three gas discoveries (two with condensate). No oil accumulations have been found although oil-staining is common. A total of 25 wells have penetrated the Mount Clark Formation throughout the Interior Plains.

Significant discoveries have been made at:

- PCI Canterra Bele O-35 (1986)

In addition, there was a significant gas show in PCI Canterra Nogha O-47 (1986).

Oil seeps in Cretaceous sandstones are common in the area and have attracted exploration interest, notably at Rond Lake, west of the Colville Hills. The expectation that the seep at Rond Lake overlay a buried Devonian reservoir was disproved by drilling.

Stratigraphy (Fig. 21)

Below the base of the Cambrian is a very thick section of Proterozoic strata with stratiform reflectors evident on seismic to depths of over 10 km. Lithologies encountered in wells include dolomite and basalt. A map of the Proterozoic subcrop beneath the Cambrian is given in MacLean and Cook (1992).

Lower Cambrian Mount Clarke Formation sandstones and siltstones up to 65 m thick overlie
Precambrian basement (Hamblin, 1990). They are in turn overlain by Lower to Middle Cambrian shales, siltstones and thin carbonates of the Mount Cap Formation (up to 270 m), and Middle to Upper Cambrian evaporites and carbonates of the Saline River Formation (approximately 200 m). There is a gradual transition into Ordovician carbonates of the Franklin Mountain Formation (approximately 500 m) which are overlain by the Middle Devonian Bear Rock Formation above a major unconformity. Progressively younger Devonian formations subcrop the pre-Mesozoic unconformity to the west. These are the Ramparts, Canol and Imperial formations respectively.

Albian sandstones of the Gilmore Lake member of the Langton Bay Formation overlie a major unconformity, which truncates the underlying Devonian and older rocks across the Keele Arch. The basal sandstones fine upwards into the shales and siltstones of the Crossley Lakes member. The Cretaceous has been stripped from the axis of the Keele Arch, but is exposed at outcrop along the flanks of the Arch both to the east in the Great Bear Basin and to the west.

**Potential Reservoirs**

The Mount Clarke Formation consists of interbedded sandstone and siltstone up to 65 m in gross thickness with potential – as indicated by seismic stratigraphy – to increase in thickness off-structure. Mount Clarke sandstones are the principal reservoir rocks in the area (Hamblin, 1990). The basal Cambrian sandstone is extensive but thin – averaging less than 10 m of pay in the existing discoveries. Pay is also present in thin sandstone stringers above the basal sandstone. Average porosity in the discovered reservoir is 12%, with water saturations of 30%. Core studies indicate the better reservoir to be fine to medium grained sandstones with permeability ranging up to 500 mD, and averaging 25 mD. At Tweed Lake, gas flows up to 156,000 m³/d with condensate were tested from a 15 m interval.

Thin dolostone and sandstone stringers are common in the Mount Cap Formation. These are in intimate association with source rock but porosity and permeability are low and potential pay zones are thin.

Vuggy and fracture porosity have been reported in the Cherty Member of the Franklin Mountain Formation, and good vuggy porosity is common in the Bear Rock Formation. Proterozoic dolomites also may develop sufficient fracture porosity to be potential reservoirs.

**Structure, Traps and Seal**

Structural prospects are associated with faults and anticlines of the Keele Arch. Laramide normal and reverse faults have shallow detachments in the upper Proterozoic and occur above pre-existing crustal scale faults rooted within the Proterozoic (MacLean and Cook, 1992). Seismic lines traversing some of these faults display flower structures typical of local transpressional stress. It is noteworthy that several episodes of deformation/re-activation have affected the region and that pre-Laramide structures have yet to be drilled.

The Cambrian shales are effective barriers to the vertical migration of gas from the underlying basal Cambrian sandstones. At the top of the Cambrian section the salt is a seal of regional extent, capping a Cambrian petroleum system containing source and reservoir rock (Jones et al., 1992). Lower Paleozoic strata above the salt lack good seals.

**Source Rocks and Oil Seeps**

Thin source rocks rich in alginite have been identified in the Mount Cap Formation. These confirm the presence of oil-prone source rocks within the Cambrian succession. Where analyzed (in Colville D-45) these strata are barely mature. Although absent from other wells in the vicinity, there is a possibility that thicker source rock intervals at higher levels of maturity occur southeast of the Colville Hills, in the Great Bear Basin or localized in grabens within the Colville Hills area. Oil staining and bleeding of light oil or condensate was observed on most cores taken from the basal Cambrian in this area. Oil staining was also noted in fractured Proterozoic dolomites in Forward et al. Anderson C-51.

Several oil seeps have been noted in Cretaceous sandstones. The bitumen may have originated from Cretaceous shales or possibly Devonian source rocks at greater depths in the basin west of the Colville Hills.

The source of gas in Cambrian reservoirs is problematic. Variation in hydrocarbon composition, the anomalously high nitrogen content in Tweed Lake, and the presence of traces of helium suggests contribution from varied sources, probably in the Precambrian. Long distance up-dip migration of the bulk of the lighter hydrocarbons, possibly from Cambrian or younger source rocks deeper in the basin to the west is also likely.
Potential

The Colville Hills are structurally high and an excellent area for accumulating migrating hydrocarbons from surrounding basins. Better understanding of the timing of migration from these basins and the nature of the migrating hydrocarbons may lead to improved prediction of fills in different categories of structural trap. No significant oil accumulations have been discovered despite a known oil-prone source rock in the Cambrian, associated with reservoir below and seal above.

While the structures are very large in this play, the pay thicknesses in the Mount Clarke are typically thin, less than 10 m (although syn-depositional thickening may locally increase pay thickness). The known resources are spread over a large area and are inadequately delineated. Median aggregate recoverable resources for these pools (ranging from 990.5-5094 x E6 m³; 35-l 80 bcf) are therefore associated with considerably higher upside figures (2830-8490 x E6 m³; 100-300 bcf at the 25% level). Precambrian dolomites, if fractured within the strands and tensional bulges of the wrench systems, are also potential gas reservoirs.

Several prospects drilled east of the main axis of the Keele Arch were wet and may indicate that gas migration is occurring up-dip from deeper parts of the basin to the west. Several structures on the western flank of the Keele Arch remain untested. Possibilities also exist for stratigraphic and structural stratigraphic traps involving the pinch-out of Mount Clarke sandstones, possibly against basement highs.

Key Reading and References


Acknowledgement

**GREAT BEAR BASIN**

<table>
<thead>
<tr>
<th>Age</th>
<th>Early Paleozoic; Cretaceous</th>
</tr>
</thead>
<tbody>
<tr>
<td>Depth to Target Zones</td>
<td>500-1500 m</td>
</tr>
<tr>
<td>Maximum Basin Thickness</td>
<td>1000 m Cretaceous</td>
</tr>
<tr>
<td>First Discovery</td>
<td>No discoveries</td>
</tr>
<tr>
<td>Hydrocarbon Shows</td>
<td>Oil shows in the basal Cretaceous along the Keele Arch (at NSM Mirror Lake N-33 to the west of the basin)</td>
</tr>
<tr>
<td>Basin Type</td>
<td>Precambrian to early Paleozoic rifts; early Paleozoic continental margin; Cretaceous foreland basin (shallow eastern margin)</td>
</tr>
<tr>
<td>Depositional Setting</td>
<td>Marine/continental</td>
</tr>
<tr>
<td>Potential Reservoirs</td>
<td>Cambrian sandstones, lower Paleozoic carbonates, Cretaceous sandstones</td>
</tr>
<tr>
<td>Regional Structure</td>
<td>Westward dipping monocline; minor extensional faulting</td>
</tr>
<tr>
<td>Seals</td>
<td>Saline River salt, Cretaceous marine shales</td>
</tr>
<tr>
<td>Source Rocks</td>
<td>Cambrian: mature oil source rocks, if developed. Cretaceous: possibly immature</td>
</tr>
<tr>
<td>Total Number of Wells</td>
<td>16</td>
</tr>
<tr>
<td>Seismic Coverage</td>
<td>Sparse regional reconnaissance</td>
</tr>
<tr>
<td>Area</td>
<td>approximately 100,000 km²</td>
</tr>
<tr>
<td>Area under Licence</td>
<td>None</td>
</tr>
</tbody>
</table>

(The terrain is low-relief tundra. Winter working conditions are cold, summers buggy. Fort Franklin is the sole population centre in the region. There is a road link to Fort Norman and the Mackenzie River.)

**Great Bear Plain (and Lake)** occupy a shallow basin between the Franklin Mountains and the Canadian Shield. Cretaceous strata up to 1000 m thick overlie lower Paleozoic and Proterozoic rocks. Paleozoic rocks outcrop along a belt 20 km broad fringing the Canadian Shield. Few wells have been drilled and no discoveries made. There is low to moderate potential for oil and gas pools in this area. Large pools are unlikely, except in stratigraphic traps.

**Geological Setting** (Fig. 22)

Great Bear Basin is a shallow Cretaceous basin overlying lower Paleozoic strata. The limits of the basin are controlled by gentle upwarp of the underlying Paleozoic strata south of 63°N (across the La Martre Arch) and north of 67°30'N (approaching the Coppermine Arch). To the east, strata outcrop along the edge of the Canadian Shield. To the west, the basin is sharply delineated by the easternmost thrust of the Franklin Mountains, which exposes lower Paleozoic rocks. North of Smith Arm of Great Bear Lake, the margin of the Cretaceous basin runs along the eastern flank of the Keele Arch.

**Exploration History** (Fig. 23)

Wells have been drilled in three areas of the Great Bear Basin. Most have been drilled in the western half of the basin in anticipation of a thicker sedimentary column. Six wells have been drilled north of the Smith Arm of Great Bear Lake, east of the crest of the Keele Arch; 8 wells between, Smith Arm and the Great Bear River, and 10 wells scattered across southern Great Bear Plain south of Great Bear Lake. The target of the northern group has been the Cambrian section, which is gas bearing in Colville Hills. Farther south, the principal objectives have been basal Cretaceous sandstones and underlying Middle Devonian carbonates.
Stratigraphy (Fig. 24)

The Paleozoic stratigraphy has been described for the Colville Hills in a previous section. Paleozoic strata overlie a thick Proterozoic sedimentary succession. The Cambrian Mount Clarke Formation is thicker than in the Colville Hills. At BP Losh Lake G-22, one of the most easterly wells, Hamblin (1990) reports 65 m of clean sandstone. The Mount Clarke Formation is truncated south of 63°N by the La Martre Falls Formation, a unit of mixed clastic and carbonates equivalent to the Mount Cap and Saline River formations further north. Further south, across the La Martre Arch, the Cambrian is absent. The Middle Devonian Bear Rock and Hume formations are truncated across the Keele Arch and only locally preserved north of the Smith Arm of Great Bear Lake. Ordovician and older strata form the country rock through most of this northern area. South of Great Bear Lake, Middle Devonian formations subcrop beneath the Cretaceous at shallow depths.

Because of the Keele Arch, the Cretaceous strata of the Great Bear Basin are not readily correlated with the established stratigraphy of the Peel Trough. The succession is of comparable age, ranging from early Albian to Maastrichtian/Paleocene and the units that have been informally designated in the subsurface by G.K. Williams (1978) may be partially equivalent to the Sans Sault, Arctic Red, Slater River, Little Bear and East Fork formations of the Peel Trough. A conglomeratic basal Cretaceous sandstone is widespread across the Keele Arch and in the Great Bear Basin. This is overlain by a deltaic succession of fine grained sandstones, siltstones and shales.

Potential Reservoirs

The Cambrian Mount Clark and Mount Cap sandstones thicken towards the east. The sandstones are very clean, fine to medium, and locally coarse grained, friable in part, with visual estimates of porosity (in porous streaks) of 15-20%. Minor intergranular porosity has been noted in the lower Paleozoic carbonate sequence.

The basal Cretaceous sandstone is the most porous in the Cretaceous succession. Porosity and permeability measurements on 8 m of core from Losh Lake G-22 indicate an average weighted porosity of 17.5% (with the better sandstones in the 20-23% range) and permeability in the range 150-300 mD. It is a medium to coarse grained quartzose sandstone. The unit averages 25 m in gross thickness, massive in the basal few metres above the unconformity, and overlain by interbedded sandstones and siltstones. Seven drillstem tests have been run across this zone, all have had significant pipe recoveries of mud and salt water. Sandstones higher in the Cretaceous are fine grained and siltly with poor porosity.
Structure, Traps and Seal

East of the Keele Arch, geological structure is confined to relatively minor fault displacement along northeast-trending principal fractures and subsidiary orthogonal faults. This fault pattern is inherited from fractures in the underlying Proterozoic. The basal Cambrian play consists of small fault-bounded structures combined with stratigraphic pinch-out of Cambrian sandstones.

Subcrop of Cambrian through Middle Devonian units beneath the basal Cretaceous unconformity provides possibilities for sub-unconformity traps. In the deepest part of the basin, near the Keele Arch, the Hume, Arnica and Bear Rock formations subcrop under the Cretaceous, but seal integrity in the overlying basal Cretaceous is likely to be poor due to the sandy nature of the section.

The basal Cretaceous sandstones vary considerably in thickness. Structural/stratigraphic traps related to the underlying paleo-topography may be anticipated. The streaky nature of porosity in the Cambrian sandstones suggests the possibility of intra-formational up-dip seal.

Source Rocks

Oil-prone source rocks of the Cambrian Mount Cap Formation in the Colville Hills may occur at greater depths (and at higher level of organic maturation) in the Great Bear Basin. It is probable that restricted conditions, favourable to preservation of organic matter, were present throughout much of the early Paleozoic basin, which subsequently accommodated thick salt deposition.
The Upper Cretaceous Slater River source rock of the Mackenzie Plain may extend into the western part of the Cretaceous basin but at an average depth of 600-800 m it is doubtful that it is sufficiently mature to generate oil.

The preferred migration route for gas in the Colville Hills reservoirs calls for regional up-dip migration from deeper parts of the basin to the west. The Great Bear Basin is isolated from this migration path. However, there remains the possibility that mature gas source rocks occur in the Proterozoic section.

**Potential**

The presence of oil-prone Cambrian source rocks (suggested by wells in the Colville Hills) at somewhat greater depth (and maturity) than in the Colville Hills, combined with greater thickness of basal Cambrian sandstones of the Mount Clarke Formation favour a possible oil play in the Great Bear Basin. The presence and volumetric significance of a source rock in the Cambrian is a significant risk in this play. Exposure to infiltration of the reservoir by meteoric waters becomes an increasing risk towards the eastern outcrop zone, which largely lies beneath Great Bear Lake.

East of the Keele Arch, potential reservoir in the Cretaceous is limited to the basal Cretaceous sandstone. The reservoir is generally thin but with good porosity and permeability. The play has some potential for small oil discoveries, with presence and maturity of source rock a major risk.

**Key Reading and References**


The Anderson and Horton plains lie north and east of the Mackenzie River, extending to the shores of Liverpool Bay and Amundsen Gulf. Drilling objectives include the equivalent lower Paleozoic succession present in the Colville Hills (but less structured), Upper Devonian imperial formation, and Cretaceous sandstones in the shallow Anderson Basin. Surface oil shows occur in Cretaceous sandstones (at Rond Lake) and a gas show in sandstones at the Cretaceous/Devonian unconformity (at Russell H-23). Well and seismic control is sparse. No discoveries have been made.

Geological Setting (Fig. 25)
Cretaceous sediments of the Anderson Basin fill a crustal downwarp between the Carnwarth Platform to the southeast and the Eskimo Lakes Arch to the northwest. The northwestern margin is delineated by faults flanking the Eskimo Lakes Arch. The eastern flank of the basin rises gently to outcrop along the flank of the Coppermine Arch.

Exploration History
Seven wells have been drilled along the southern flank of the Eskimo Lakes Arch. These penetrate Cretaceous strata to depths of up to 2000 m. They overlie Imperial Formation sandstones and shales. Two wells have been drilled on the Cape Bathurst Peninsula.

Only four wells have been drilled in central Anderson Plain. All, with the exception of Mobil Gulf Sadene D-02, were spudded in the Imperial Formation. Twelve wells have been drilled to Devonian targets in southern Anderson Plain. A cluster of wells at Rond Lake were drilled in the hope of discovering a Devonian accumulation underlying a surface oil seep in Cretaceous sandstones.

There is sparse reconnaissance seismic in the region with large gaps evident in the coverage.

Stratigraphy (Fig. 26)
Cretaceous strata unconformably overlie the Upper Devonian Imperial Formation in the western part of the region and progressively older units farther east, across the Carnwarth Platform. Upper Cretaceous strata outcrop on the Bathurst Peninsula (notably in the Smoking Hills along the eastern coast of Cape Bathurst). More extensive outcrops of the Langton Bay Formation and Albion Horton River formations occur to the south...
and east. East of 125°W, Cretaceous strata occur as scattered outliers and the country rock comprises Cambrian to Ordovician strata of the Mount Clark, Mount Cap, Saline River, Franklin Mountain, Mount Kindle, Bear Rock and Hume formations. Lower Paleozoic rocks are truncated at the edge of the Canadian Shield and along the flanks of the Coppermine Arch.

Proterozoic sedimentary rocks of the Shaler Group are exposed across the Coppermine Arch.

Potential Reservoirs

The Cambrian Mount Clarke sandstones are well developed in outcrop close to the Coppermine Arch. These are potential reservoirs beneath Horton Plain but become increasingly fine grained with poorer reservoir potential to the west.

The lower Paleozoic carbonate succession subcrops at the base of the Cretaceous. Development of secondary porosity is probable along the strike of susceptible carbonate facies. Potential for development of reefs appears limited. Older carbonate units demonstrate some porosity development with bitumen reported in vugs. However, reservoir breaching is likely to have flushed or biodegraded most oil.

Sandstones in the Imperial Formation and Cretaceous strata are potential reservoir rocks although thick potential reservoir intervals have not been discovered and porosity is generally low.

Source Rocks

Excellent oil-prone source rocks are present in the Upper Cretaceous section but are immature. The bocannes (outcrops of burning bituminous shale) evident in the Smoking Hills are the result of oxidation of pyrite and/or organic matter in the bituminous Smoking Hills Formation. Vitritine reflectance values of the shales away from the bocannes fall well below the oil window (Mathews and Bustin, 1984).

Organic matter in the Imperial Formation is terrestrially derived with maturity falling within the oil window (thermal alteration indices of 2 +). The Imperial is gas prone and is the most likely source of the gas show at Imp Cigoli Russell H-23.

Potential

In the eastern part of the region, the Cambrian section contains good reservoir sandstones and a potentially effective regional seal. Principal risks are lack of an
effective source rock and reservoir invasion close to the outcrop zone.

The northward trend of Devonian and older units beneath the pre-Cretaceous unconformity defines the eastward limits of potential targets and fairways for sub-unconformity traps across the Carnwarth Platform. Perhaps most significant is the Canal/Ramparts subcrop, which strikes due north close to longitude 130°W. These units are proven oil source rocks and reservoirs farther south. Principal risks are reservoir development and reservoir breaching.

Sandstones in the shale-dominant Imperial Formation are potential reservoirs in the Anderson Basin. However, the formation consists of thin interbedded sandstones, siltstones and some conglomerates, and potential pay is likely to be thin and of indifferent quality. Across the Carnwarth Platform, Cretaceous sandstones are close to the surface and contain biodegraded oil. However, some Cretaceous potential exists in the Anderson Basin where the Lower Cretaceous section underlies Upper Cretaceous shales, which form an effective top seal for hydrocarbons. Although most marine shelf sands in the Anderson Basin are thin and have poor reservoir potential, there exists the possibility of an incised drainage system on the sub-Cretaceous unconformity. If present it could contain alluvial sandstones with good reservoir potential.

Key Reading and References
