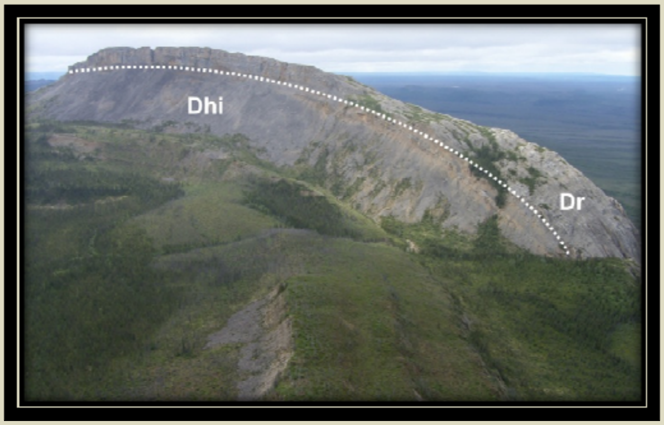

Regional Geoscience Studies and Petroleum Potential, Peel Plateau and Plain, Northwest Territories and Yukon: Project Volume

NWT Open File 2009-02 / YGS Open File 2009-25

Leanne J. Pyle and Adrienne L. Jones (editors)

Regional Geoscience Studies
& Petroleum Potential,
Peel Plateau & Plain

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Regional Geoscience Studies and Petroleum Potential of Peel Plateau and Plain, Northwest Territories and Yukon: Project Volume

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Cover illustrations (clockwise from top left):

- Interbedded shale and limestone of the Paleozoic Road River Group, west of Snake River.
- View north from the front of the Mackenzie Mountains to the Peel Plateau, showing weathered outcrop of lower Paleozoic Franklin Mountain Formation to lower Landry Formation.
- Trace fossil *Diplocraterion* in Cretaceous upper Martin House Formation, Imperial River.
- View to the west of the north limb of the Imperial anticline at Stratigrapher Cliffs, with the dashed line denoting the stratigraphic contact between the middle Devonian Hare Indian and overlying Ramparts formations.
- Hemispherical stromatoporoid in a thin packstone unit of the middle Devonian Ramparts Formation in core from the Hume River A-53 well.

EXECUTIVE SUMMARY

Peel Plateau and Plain (Peel area), a prospective petroleum area in the Northwest Territories and Yukon, lies south of Beaufort Sea-Mackenzie Delta, north of the Mackenzie Mountains, and east of the Richardson Mountains. The eastern limit of Peel Plain parallels the route of the proposed Mackenzie Gas Project natural gas pipeline, which could provide infrastructure for potential new gas discoveries in the area. A total of 74 exploratory wells have been drilled in Peel area. None of these wells have been productive, but there have been several encouraging petroleum shows, as well as gas seeps, oil stained outcrops, and bitumen occurrences. This volume presents results of a four year project (2005-2009), *Regional Geoscience Studies and Petroleum Potential, Peel Plateau and Plain* (Peel Project), including improved knowledge of the Phanerozoic stratigraphic succession and geological data from petroleum systems that are potentially important in Peel area. The project has yielded 90 publications, including this volume and accompanying digital atlas, interim reports, conference abstracts and workshop proceedings documents. The result is a publicly available, comprehensive body of geoscience work for Peel area of use in oil and gas exploration and resource development, as well as in regional land use and business planning endeavours.

Regional Structure (Chapter 2)

Peel area includes parts of three tectonic elements: the Northern Interior Platform, Mackenzie Fold Belt, and Richardson Anticlinorium. Peel Plain is largely underlain by flat-lying and relatively undeformed Cretaceous sandstone and shale; Devonian strata are locally exposed in structural uplifts near the Mackenzie River or along the front of the deformed belt. Peel Plateau is an erosional remnant capped by Cretaceous sediments. The most important tectonic event recorded in the subject region was the Laramide Orogeny (late Cretaceous-Paleocene), which deformed the thick Proterozoic and Paleozoic sedimentary cover, creating the Mackenzie and Franklin mountains in southern Peel area. A marked change in structural style, primarily due to the regional depositional edge of Cambrian Saline River Formation evaporites, occurs in southern Peel area. Here, broad anticlines with intervening narrow synclines in the northern Mackenzie Mountains contrast with linear and narrow ridges in the northern Franklin Mountains. Richardson Anticlinorium, a broad north-northwest-trending structure, forms a narrow and linear range of low mountains bordering the west side of Peel area and approximates the position of Paleozoic Richardson Trough.

Regional Stratigraphy

The Phanerozoic succession of Peel area accumulated within four tectono-stratigraphic phases: 1) Cambrian epicontinental marine basin; 2) Cambro-Ordovician to Late Devonian “passive” continental margin setting; 3) Late Devonian to Carboniferous foreland basin (Ellesmerian Orogeny); and 4) Cretaceous foreland basin (Columbian and Laramide orogenies).

Cambrian strata (Mount Clark/Mount Cap and Saline River formations; Chapter 3) outcrop only in southeastern Peel area because facies pinch out westward against the Cambrian Mackenzie Arch. Quartz sandstone above the prominent, regional sub-Cambrian unconformity is assigned tentatively to Mount Clark Formation. Mount Cap Formation consists of sandstone, shale, and

dolostone and conformably overlies Mount Clark sandstone or unconformably overlies Proterozoic strata. Saline River Formation consists of shale, siltstone, and minor sandstone that unconformably overlies Mount Cap Formation. Distribution of Cambrian strata across Peel area is poorly known due to sparse well data. Sediments were deposited in a range of marginal marine, marine, and evaporitic basinal settings.

Platform carbonates (peritidal and subtidal in origin) of the Cambrian-Ordovician to Silurian Franklin Mountain and Mount Kindle formations (Ronning Group; Chapter 4) are widespread in Peel area (Mackenzie-Peel Shelf). Correlative deeper water formations of Road River Group were deposited to the west and southwest (Richardson Trough and Misty Creek Embayment). Franklin Mountain Formation rests unconformably on Proterozoic rocks or on Saline River Formation where it is present east of Mackenzie Arch. The contact between Mount Kindle and Franklin Mountain formations is a regional unconformity that diminishes in magnitude westward. The upper contact of Ronning Group is a regional sub-Delorme unconformity.

Delorme Group (Silurian to ?Lower Devonian; Chapter 5) consists of silty carbonate rocks assigned to Peel and Tatsieta formations. The succession thickens westwards across Peel area. Delorme Group is bound by a sub-Delorme unconformity and overlain by a transgressive surface at the base of Arnica Formation. Silty carbonate rocks of supratidal to subtidal origin have limited potential as reservoir rocks for hydrocarbons (rare zones of sucrosic dolostone in Peel Formation) and no potential as source rocks.

The Lower to Middle Devonian succession (Chapter 6) consists of Fort Norman Formation (Bear Rock facies), Arnica Formation, Landry Formation, Mount Baird Formation, Hume Formation, and Road River Group. From east-southeast to west across Peel area, this succession records evaporitic to carbonate platform deposition, and deeper basinal settings in the far west of the study area. Middle to Upper Devonian rocks are assigned to Horn River Group (Hare Indian, Ramparts, and Canol formations). These rocks record two phases of starved basin conditions (Bluefish Member of Hare Indian Formation and Canol Formation), separated by development of a siliciclastic bank (Hare Indian Formation) upon which a carbonate bank and reef of Ramparts Formation developed. The succession represents marine transgression throughout the Devonian.

Upper Devonian Imperial Formation (Chapter 7) records marine siliciclastic deposition broadly sourced to the north and east (in eastern Peel area) by uplifts of the Ellesmerian Orogeny. The base of Imperial Formation in eastern Peel area consists of laterally extensive submarine fan deposits (intercalated sandstone lobe and lobe fringe deposits representing turbidites). Overlying slope facies are shale-dominant, but also include turbidites. At the eastern edge of Peel area (type section at Imperial River), shallow marine shelf deposits are preserved above and below slope deposits. In eastern Peel Plateau (Flyaway Creek), Imperial Formation is composed mainly of shale, with local variations to sandstone further west.

Upper Devonian to Lower Carboniferous Tuttle Formation (Chapter 8) extends over most of Peel Plateau in the subsurface and crops out along the western and eastern flanks of the Richardson Mountains and possibly along the northern Mackenzie Mountains. Tuttle Formation consists of alternating packages of sandstone and shale deposited by turbidity currents. It is distinguished from adjacent and time equivalent units (portions of underlying Imperial Formation, Ford Lake Shale, and map unit “M0”) by the presence of coarse-grained facies which are also good potential hydrocarbon reservoirs. Similar to deposits of Imperial Formation, Tuttle Formation siliciclastics were transported mainly from a northern or northwestern orogenic source.

Cretaceous strata (Chapter 9) in Peel area are divided by two large-scale unconformities into an Albian Martin House-Arctic Red formations succession and Cenomanian-Turonian Slater River and Trevor formations succession. A new informal member of Martin House Formation (Tukweye member) consists of fluvial and floodplain sediments deposited in an approximately north-trending paleovalley. Keele Arch (to the east of Peel area) was a paleohigh during marine deposition of Martin House and lower Arctic Red formations. New biostratigraphic data based on foraminifera indicate a disconformity between Albian Arctic Red Formation and Cenomanian Slater River Formation (newly recognized in Peel area). Above the sub-Cenomanian unconformity, Trevor Formation deposits indicate an eastward-dipping basin geometry, opposite to that during Albian time.

Petroleum Potential

Data for seven conceptual petroleum plays are summarized in chapters of this volume and in the tables below. These plays are: Basal Cambrian clastics play; Lower Paleozoic platform play; Arnica-Landry and Kee Scarp plays; Imperial Formation and Tuttle Formation plays; and the Basal Cretaceous Sandstone play. These plays are related to petroleum systems (Chapter 10) based on associations between potential reservoir and source rocks.

Play	**Basal Cambrian Clastics play**
Age, Unit	Early to Middle Cambrian, Mount Clark and Mount Cap formations.
Depositional Setting	Epicontinental marine basin.
Potential Reservoirs	• Sandstone of Mount Cap and Mount Clark fms (4.4% porosity; 0.03mD permeability, based on outcrop of Mount Cap sandstone); • Gross thicknesses <15 m.
Potential Source Rocks	• Thin, organic layers within Mount Clark/Mount Cap Fm <0.5% TOC; • Overmature in Peel area.
Seal Rocks	• Top seal of shale, dolostone, anhydrite, and salt (Mount Cap, lower Saline River fms); • Fault seals and lateral seals against Proterozoic shale.
Potential Traps	• Stratigraphic (updip pinch-outs against paleotopographic highs, intraformational facies changes, diagenetic changes affecting porosity); • Structural (faulted anticlines related to Laramide deformation).
Hydrocarbon Indications	Oil stained Devonian samples yielded geochemical evidence for a probable Cambrian-Ordovician oil (Mount Cap Fm).
Petroleum Systems	Mount Cap-Mount Clark (known); analogue is Colville Hills.
Burial History, Generation, and Migration	Basal Cambrian entered the oil window in the early Late Devonian; later gas generated under Cretaceous burial could have post-dated Laramide structures, and thus have migrated into structural traps.
Exploration Risks	Low potential; exploration risks include reservoir rock quality, adequate source, and communication with source.

Table 1. *Summary of the petroleum potential of the Basal Cambrian Clastics play.*

Play	Lower Paleozoic Platform play
Age, Unit	• Latest Cambrian to late Early Ordovician, Franklin Mountain Formation; • Late Ordovician to Silurian, Mount Kindle Formation.
Depositional Setting	Marine carbonate shelf.
Potential Reservoirs	• Porous or fractured dolostone of Franklin Mountain and Mount Kindle fms; quartz sandstone in basal Franklin Mountain Fm; • Outcrop of Franklin Mountain dolostone (1.7 - 9.4% porosity; 0.02 - 1.07mD permeability); subsurface weighted average porosities up to 6.7%; • Outcrop of Mount Kindle dolostone (1.5 - 9.7% porosity; range of 0.005 - 1.51mD permeability); subsurface weighted average porosities up to 6.7%, permeabilities to 21mD; • Gross thicknesses of tens of metres.
Potential Source Rocks	• Road River Gp shale, up to 6.14% TOC; • Overmature, likely dry gas generating.
Seal Rocks	• Top and lateral seals of Road River Gp shale at western platform edge; overlying tight Delorme Gp dolostone or Fort Norman Fm evaporites; • Fault seals and lateral seals against Proterozoic shale.
Potential Traps	• Stratigraphic (e.g., interfingering facies at the platform edge, possible build-ups at shelf edge); • Simple structural traps (faulted anticlines in southern Peel area).
Hydrocarbon Indications	• Peel Y.T. H-71 well: gas to surface, DST of the interval 2726 m to 2893 m (basal Peel Fm equivalent and upper Mount Kindle Fm) with an estimated flow rate of 1841 m^3 per day; • Hanna River J-05: oil-cut salt water recovered from the top of Mount Kindle Fm (823 m) on a DST; • oil staining: Shoals C-31 (Franklin Mountain Fm from 1232 m to 1238 m), Hume River A-53 (Mount Kindle Fm), Tree River C-36 (1538 m to 1628 m, basal part of Peel Fm and Mount Kindle Fm), Cranswick YT A-42 (3426 m to 3429 m, Mount Kindle Fm); • Bitumen, Franklin Mountain and/or Mount Kindle fms in stylolites, vugs, and/or fractures (Cranswick A-22, Stony I-50, Ontaratue I-38, and Arctic Red West G-55).
Petroleum Systems	Road River-Ronning (hypothetical).
Burial History, Generation, and Migration	Road River Group entered the middle oil window in late Paleozoic time; oil and/or gas were probably generated, and migrated as early as late Paleozoic time, under burial by the Imperial/Tuttle Fm siliciclastic rocks; burial by Albian and later siliciclastic rocks likely generated dry gas; increased maturation, re-migration, and displacement of oil by gas may have occurred in the latest Cretaceous.
Exploration Risks	Low potential; exploration risks include distribution of potential reservoirs, communication with source rocks, formation of closures, viability of top and lateral seals over time to preserve hydrocarbons, and timing of trap formation relative to hydrocarbon migration.

Table 2. *Summary of the petroleum potential of the Lower Paleozoic Platform play.*

Play	Arnica-Landry play
Age, Unit	Early Devonian, Arnica and Landry formations.
Depositional Setting	Carbonate shelf.
Potential Reservoirs	• Porous dolostone (Arnica Fm) and carbonate breccia (Bear Rock facies); porosities of 3 - 10%, 1 - 2mD permeability; gross intervals of tens of metres; • Porous limestone of Landry Fm, 4 - 6% in metre-scale intervals.
Potential Source Rocks	Devonian shale (Canol Fm, Bluefish Member, Hare Indian Fm; see Kee Scarp play below).
Seal Rocks	• Top and lateral seal by Fort Norman Fm anhydritic dolostone; • Top seal by tight carbonate facies of Landry Fm.

Potential Traps	• Stratigraphic (e.g., up-dip pinch outs; patch reefs in Arnica Fm at eastern facies change; westward carbonate to shale transition); • Structural (e.g., faulted anticlinal folds and domes at margins of Mackenzie and Franklin mountains).
Hydrocarbon Indications	• Geochemical evidence for a Devonian "Norman Wells-type" oil (Horn River Group source rock) in Arnica Fm and equivalents; • Summit Creek B-45 well: discovery of gas and light oil/condensate in Mackenzie Plain; • Mountain River H-47: gas estimated to flow at 88 Mcf/day from Landry Fm; • Shoals C-31: oil (39.2° API) recovered on DST in Landry Fm; • Ontaratue H-34: slightly gassy water and mud recovered on DST, near top Arnica Fm (1351-1359 m); • Hume River D-53: gas cut water obtained on DST, Arnica Fm (1113-1146 m); • Loon River No. 1 (H-79): gas cut water obtained on DST, near top Landry Fm (288 m); • Grandview Hills No. 1 (A-47): gas cut mud found on DST at 770-780 m, Landry Fm; • Beavertail G-26: oil stained mud observed on DST from 326-350 m (Arnica and Landry fms); • Oil stained Bear Rock breccias at Powell Creek, Stratigrapher Cliffs area, and Loretta Canyon southeast of Peel area.
Petroleum Systems	Horn River-Arnica (known); possible analogue is Summit Creek B-45 well in Mackenzie Plain.
Burial History, Generation, and Migration	See Kee Scarp play (below).
Exploration Risks	• Moderate potential; lowest-risked area of the play is within the zone of Canol Fm maturity, and in relative proximity to the fronts of the Franklin and Mackenzie mountains based on structural juxtaposition of Horn River Group shale with Arnica (or Landry) reservoirs; • Prospect level risks include: failed preservation due to post-Albian and post-Tertiary erosion which may have caused breaching of reservoirs, failure of top seals due to shallow overburden and proximity to outcrop, and isolation from effective source rocks.

Table 3. *Summary of the petroleum potential of the Arnica-Landry play.*

Play	**Kee Scarp play**
Age, Unit	Middle Devonian (Givetian), Kee Scarp member, Ramparts Fm.
Depositional Setting	Carbonate shelf and reef.
Potential Reservoirs	Limestone, Ramparts Fm and Kee Scarp member (1.2 – 14.9% porosity, up to 6.96 mD permeability in core samples); in intervals 10-20 m thick.
Potential Source Rocks	• Canol Fm, average 4.85% TOC, immature to post-mature; • Bluefish Member, average 6.68% TOC; mature to overmature; • lower Ramparts organic-rich shale, Carcajou marker beds, 5.07% TOC; mature to overmature; • For the most part, source rocks are oil prone.
Seal Rocks	Canol and Imperial fms shale and siltstone.
Potential Traps	Stratigraphic (Kee Scarp reefal margins, reefal foreslopes, Charrue sandstone member on the flanks of the reefal buildup, and siltstone lenses within Hare Indian Fm).
Hydrocarbon Indications	• Geochemical evidence for a Devonian "Norman Wells-type" oil (Horn River Group source rock) in Ramparts Fm; oil staining in outcrop; • Hume River D-53 well: gas cut, slightly oil cut mud on DST (490-535 m); • Hume River O-62: gas flow on DST, (497-520 m; 15,000 Mcf/day);

	• Maida Creek 2O-65: gas on DST, too small to measure (549-573 m); • Carcajou D-05 (SE of Peel area): gas flow on DST (566.5-568.5 m; 1.2 Mmcf/day).
Petroleum Systems	Horn River-Ramparts (known); analogue is Norman Wells.
Burial History, Generation, and Migration	Horn River Group entered the middle oil window soon after deposition of Albian and younger foreland trough sediments. Expulsion and migration of Horn River-sourced oil, possibly as late as Eocene, would post-date the earliest Laramide structural traps. In western Peel area; maturation, expulsion, and migration may have occurred somewhat earlier; Canol Fm entered the oil window after burial by a thick package of Imperial and Tuttle fms. Initial oil was followed by dry gas generation, perhaps with burial by Cretaceous sediments after an early to middle Mesozoic depositional hiatus.
Exploration Risks	Moderate potential; lowest-risked part of the Kee Scarp stratigraphic play in Peel area, where reefal rocks are overlain by Canol Fm seal, is a rather restricted area. Additional significant risk of insufficient reservoir development and poor stratigraphic trapping. Laramide tectonic tilting may have negatively affected stratigraphic traps that had only poorly developed lateral seals.

Table 4. *Summary of the petroleum potential of the Kee Scarp play.*

Play	**Imperial Formation play**
Age, Unit	Late Devonian, Imperial Formation.
Depositional Setting	Foreland basin, fan-slope complex.
Potential Reservoirs	Imperial Fm tight sandstones (porosities as high as 24.7%, generally 11% to 19%, and very low permeabilities, from outcrop and core samples).
Potential Source Rocks	Imperial Fm 1% to 1.5 % TOC; mature in eastern Peel to overmature in central and western Peel area.
Seal Rocks	Canol and Imperial fms.
Potential Traps	Stratigraphic sandstone bodies, sealed in shale, with or without a structural component.
Hydrocarbon Indications	• Hume R. O-62 well: gas to surface, too small to measure on DST (496.8-520.3 m); • Ramparts River F-46: gas shows on gas detector (971; 1095-1098 m); • Sperry Creek N-58: dry gas on gas detector (870-871.2; 906-907; 1062.4-1064.4 m); • Minor gas shows possibly occur in three Yukon wells (Satah River Y.T. G-72, Peel Y.T. L-19, and Peel Y.T. F-37); • Oil stained outcrop samples (Imperial River, Katherine Creek); • Massive bitumen hosted in Imperial Fm near the northern margin of Peel area (north of community of Tsiigehtchic).
Petroleum Systems	Imperial-Imperial (hypothetical).
Burial History, Generation, and Migration	Imperial Fm probably generated gas in latest Paleozoic time in Peel Plateau, but perhaps not until late Cretaceous time in eastern Peel Plain. In both cases, however, it is probable that the peak petroleum generation and migration occurred in the late Cretaceous to Tertiary.
Exploration Risks	Low to moderate potential; exploration risks at play and prospect levels include reservoir, seal, stratigraphic trap closure, and shallow depths.

Table 5. *Summary of the petroleum potential of the Imperial Formation play.*

Play	**Tuttle Formation play**
Age, Unit	Late Devonian (mid-Famennian) to Early Carboniferous (early Tournaisian), Tuttle Formation.
Depositional Setting	Foreland basin
Potential Reservoirs	Tuttle Fm sandstones (5 - 26% porosity and 0.1 - 100 mD permeability).

Potential Source Rocks	• Tuttle Fm shale (0.48 - 40.25% TOC, with most values between 1 - 2%); type III, gas-prone kerogen with lesser type II, oil- and gas-prone kerogen; within the oil window through much of Peel Plateau, with maturity increasing westward toward the Richardson Mountains; • Ford Lake Shale averages 4.63% TOC; mainly type II kerogen; mature, to just within the oil window; • 'M0' shale (2.10-11.31% TOC; type III kerogen).
Seal Rocks	Canol and Imperial fms.
Potential Traps	Potential traps may be stratigraphic sandstone bodies, sealed in shale, with or without a structural component.
Hydrocarbon Indications	• Oil stained samples from Tuttle Fm and Ford Lake Shale (suggest potential Upper Paleozoic marine source rock); • Peel River Y.T. B-06 well: gas to surface too small to measure on DST (312.4-430.4 m); • Peel River Y.T. B-06A: partly gasified water on DST (789.4 m); gas to surface in 45 minutes (798.3-866.9 m); • Taylor Lake Y.T. K-15: mud-cut gassy fresh water on DST (729.4-737.0 m); • Peel River Y.T. M-69: gas to surface too small to measure on DST (1742.8-1799.8 m); • Peel River Y.T. L-01: slightly gasified water on DST (640 m); • Sainville River D-08: gas to surface too small to measure on DST (898.6-907.7 m).
Petroleum Systems	Tuttle-Tuttle (hypothetical).
Burial History, Generation, and Migration	Tuttle-Tuttle petroleum system possibly was in operation in western Peel area. Tuttle Fm entered the upper oil window in early Late Cretaceous time, generating petroleum after largely gas-prone source rocks were buried under a thick pile of Albian and younger siliciclastic rocks. Oil stained samples are likely sourced in the Late Paleozoic (Canol, Imperial, Tuttle, Ford Lake fms, or 'M0' unit).
Exploration Risks	Moderate potential in western Peel Plateau; exploration risks at play level include shallow depths, seals, stratigraphic trap closures.

Table 6. *Summary of the petroleum potential of the Tuttle Formation play.*

Play	**Basal Cretaceous Sandstone play**
Age, Unit	Albian Martin House Formation; Tukweye member.
Depositional Setting	Marine and fluvial (Tukweye member).
Potential Reservoirs	• Martin House Fm marine sandstone (porosities up to 21.5%); Tukweye member fluvial sandstone (porosities up to 12.9%); Trevor Fm shoreface sandstone (porosity up to 17%); • Tens of metres thick.
Potential Source Rocks	• Albian Arctic Red Fm and Cenomanian-Turonian Slater River Fm (average 1.64% and 1.8% TOC, respectively); • Increasing in maturity from east to west across the southern Peel area (immature to just within oil window at the Imperial River section just southeast of Peel area, mature along Hume River section, overmature in Arctic Red River area, and post-mature in Snake River area); • Types I/II and III kerogen.
Seal Rocks	Shale of Arctic Red and Slater River fms.
Potential Traps	• Stratigraphic (fluvial channels of Tukweye member and inferred marine barrier bar sandstones of basal sandstone Martin House Fm). • Structural and structural/stratigraphic (strike-parallel Laramide anticline or fault).
Hydrocarbon Indications	• Geochemical evidence for Cretaceous oil in Peel Plateau, found in oil stained basal Cretaceous clastic rock; • Gas shows in Peel Plateau (Peel River Y.T. B-06) and southeast Peel area

	(e.g., Hume River I-66, East Hume River I-20).
Petroleum Systems	Arctic Red-Martin House (known); analogues are Stewart D-57 and East MacKay B-45 wells in Mackenzie Plain.
Burial History, Generation, and Migration	Step-wise sequence of burial, then uplift and erosion and/or non-deposition, resulted in thermal maturity in Arctic Red Fm that was likely not reached until the very latest Cretaceous and Tertiary. Migration may not have occurred until the Tertiary, post-dating or syntectonic with Laramide structures.
Exploration Risks	Moderate to high exploration potential; prospect-level risks include trap (closure and seal) and preservation (breaching, leaking, biodegradation, and water washing) factors, as well as shallow reservoirs.

Table 7. *Summary of the petroleum potential of the Basal Cretaceous Sandstone play.*

Digital Atlas

This volume is accompanied by a digital atlas (Pierce and Jones, 2009, NWT Open File 2009-03). The atlas contains Geographic Information System-ready files that encompass all of the spatial data associated with the project research. These data include: field and core photographs, interpreted seismic profiles, core and measured section descriptions, geochemical analyses, isopach and structural maps, and other pertinent data linked to a spatial database of wells, seismic tracklines, and field-based locations.

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Chapter 1 – Introduction

Leanne J. Pyle[1] and Adrienne L. Jones[2]

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ABSTRACT

Initiated by the Northwest Territories Geoscience Office, the project *Regional Geoscience Studies and Petroleum Potential, Peel Plateau and Plain, Northwest Territories and Yukon* (2005 to 2009) involved partners from the Yukon Geological Survey, Geological Survey of Canada, as well as universities and industry. The research addresses the need for modern petroleum geoscience data and interpretation in this underexplored and prospective area of Canada's North in close proximity to the proposed Mackenzie Gas Project pipeline route. The findings from this study will help to stimulate future resource exploration and development, bringing economic benefits to the region. The research team coupled field-based studies with subsurface analytical techniques to evaluate the study area's hydrocarbon potential. Over 70 interim publications have been produced. Key 2009 final deliverables include: a) this volume which compiles chapters devoted to several stratigraphic petroleum plays, along with structural and petroleum systems elements; and b) a digital geodatabase (or atlas) of spatially based data collected during the course of the project. The result is a comprehensive body of geoscience work for Peel area which will be useful to in oil and gas exploration and for regional land use and business planning endeavours.

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PROJECT BACKGROUND AND RATIONALE

The Northwest Territories (NWT) economy is dominated by resource-based industries including oil and natural gas exploration and production, mineral exploration, and mining. Geoscience is the foundation of these industries and drives the economy. In 1999, mining and oil and gas extraction accounted for 29% of the GDP of the NWT; in 2006, this number rose to 50%. In Yukon, one mining operation along with some natural gas production (two wells) in the southeast of the territory indicates high exploration potential. There are also a number of advanced mineral exploration projects and some potential energy developments. The future impact of these new developments on the region is very positive for an economy currently based largely on tourism and government for employment.

The availability of a publicly available, modern, and accurate geoscience data framework attracts private investment dollars to the mineral and petroleum sectors, providing employment and benefits firstly for the citizens of the North and the entire of the country. In addition, the results of geoscience research have wide ranging applications, including land use planning, small and major business planning, in land claim negotiations, and for assertion of Canadian sovereignty in the northern frontier. Support of government geoscience programs is a crucial part of northern economic development. It is clear that the North is rich in mineral and petroleum resources, many that have yet to be discovered. The first step in the discovery process is sound geoscientific data collection and research, and the collation and interpretation of this data using modern paradigms. The second step is to ensure that this information and interpretation is publicly available and widely disseminated for the use of all stakeholders.

From 2005 to 2009 the Government of Canada's Northern Oil and Gas Science Research Initiative (vetted through Indian and Northern Affairs Canada, NWT Region) helped to fund the Northwest Territories Geoscience Office (NTGO) research project *Regional Geoscience Studies and Petroleum Potential, Peel Plateau and Plain, Northwest Territories and Yukon* (Peel Project). The intent of this study was to further the knowledge of hydrocarbon potential in Peel Plateau and Plain (Peel area), a prospective but underexplored region in the northwestern NWT/northeastern Yukon (Figure 1). Peel area is in the vicinity of the proposed Mackenzie Gas Project (MGP) natural gas pipeline route and has been speculated to have widespread hydrocarbon potential. Being largely underexplored, the region's geological history is poorly understood. To the date of this volume, only 74 wells have been drilled in this area of 55,000 square kilometres (an area about 8.5% the size of Alberta). This is about one well per 743 square kilometres. Even though the well density is sparse, encouraging hydrocarbon shows have been reported. To date, however, a major discovery has not been made.

The MGP, a 1220 km long Mackenzie Valley-parallel gas pipeline anchored by three major natural gas fields in the Mackenzie Delta, was proposed in 2004 by Imperial Oil Ltd. and its partners the Aboriginal Pipeline Group, ConocoPhillips, Shell, and ExxonMobil (Mackenzie Gas Project, 2008). The proposed route of the MGP parallels the eastern limit of Peel Plain (Figure 1) and such a pipeline could provide infrastructure for shipping of new natural gas and natural gas liquids discoveries from Peel area.

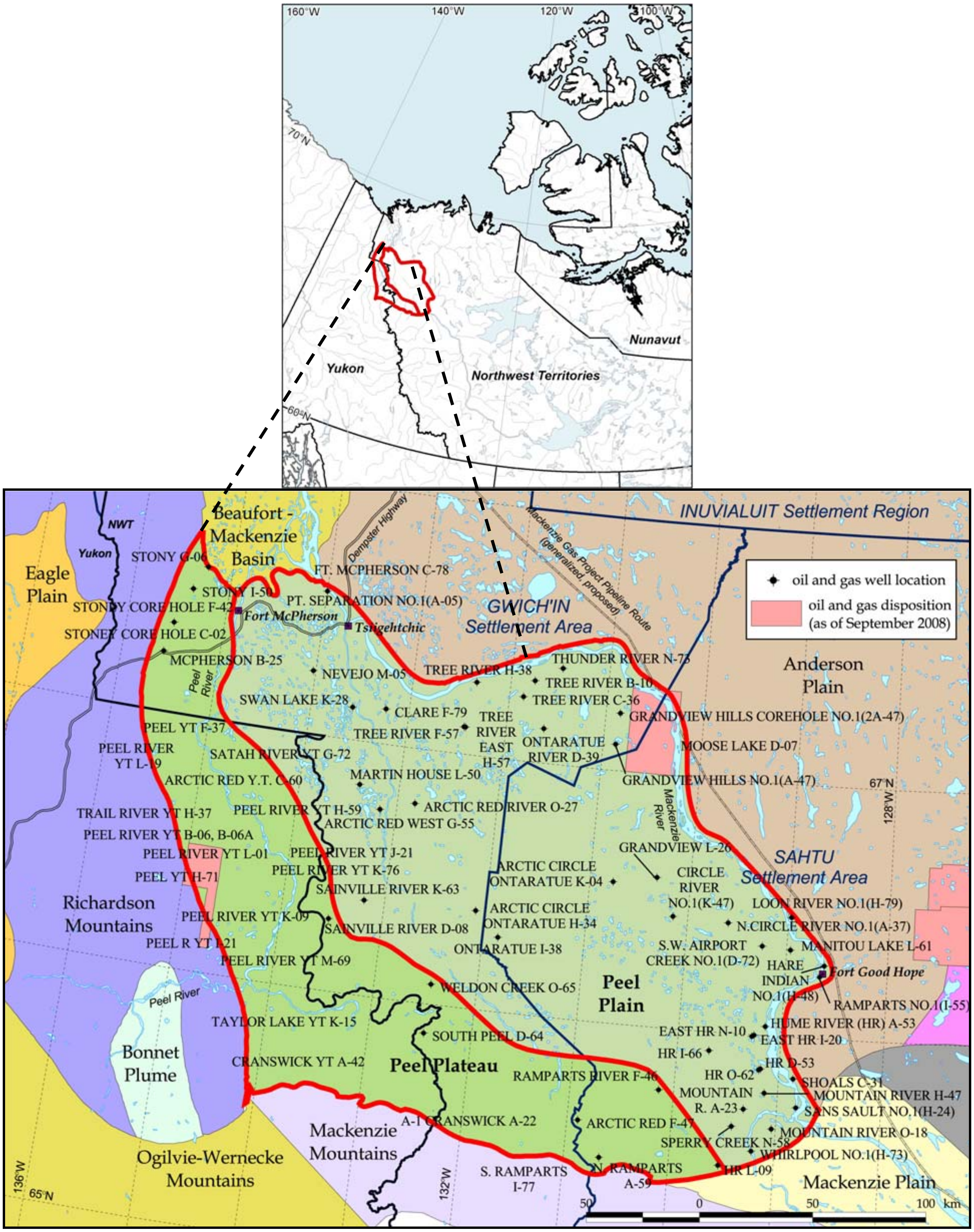

Figure 1. *Location of Peel Plateau and Plain in northwestern NWT/northeastern Yukon (top). Detailed map (below) of Peel area showing surrounding exploration areas (from Mossop et al., 2004), historical oil and gas exploration wells, current exploration licenses and the generalized route of the proposed Mackenzie Gas Project pipeline.*

The primary objective of this multidisciplinary, collaborative project was to improve knowledge of the regional geology, including the stratigraphy, sedimentology, regional correlations, depositional and tectonic histories, basin evolution, as well as the petroleum geology and potential. New geological knowledge in Canada's North is necessary to stimulate petroleum exploration, industry investment, and economic development for Northerners' and national benefit.

The Peel Project was a successful NTGO partnership with the Geological Survey of Canada (GSC) and Yukon Geological Survey. The project also benefited from cooperation with students and professors at the Universities of Alberta and Calgary and Carleton University, as well as with industry representatives. The research team addressed the project objectives by defining sub-projects along stratigraphic and structural lines. This resulted in a fuller examination of Peel area from a basin analysis and petroleum potential stand-point. Interim publications were released throughout the project (see Appendix A). This project volume contains several thematic chapters and is linked to a Geographic Information System-based digital atlas (or geodatabase; Pierce and Jones, 2009). All outputs are available at the project website: *www.nwtgeoscience.ca/petroleum/PeelPlateau.html*.

LOCATION AND REGIONAL GEOLOGY

Peel Plateau and Plain are physiographic regions defined by Bostock (1948, 1970) and are prospective petroleum exploration areas within the Interior Plains exploration region (of Morrow et al., 2006) of the NWT and Yukon. Peel Plateau and Plain lie between 65°N and 68°N latitude, bounded to the south by the Mackenzie Mountains, to the north by the Mackenzie Delta, and eastward by Anderson Plain. Peel Plain consists of lowlands with elevations of 150 m to 450 m while Peel Plateau is an erosional remnant with Cretaceous sandstone terraces up to 950 m in elevation (Stott and Klassen, 1993) and uplifted regions of the Trevor Range (Kunst, 1973). The Mackenzie Mountains on the southwest and west rise to elevations of more than 1800 m while the Richardson Mountains to the north and northwest have a maximum elevation of 1350 m (Morrow, 1999). The Gwich'in and Sahtu land claim settlement areas of the NWT partly overlie the project area (Figure 1).

The project area extends southwest from Mackenzie River (128°30'W) to its western limit (136°W) at the deformation front of the Richardson Mountains (Figure 1) and includes the northwestern Interior Plains to deformed strata of the Northern Canadian Cordillera (Mackenzie and Richardson mountains). These mountain ranges expose stratigraphy that is contiguous with Peel area. Eastward from the mountains, within the Interior Plains, the outcrop is fairly limited as it is mantled by relatively undeformed Cretaceous, Tertiary and Quaternary strata (Aitken et al., 1982). Some Devonian strata are exposed in structural uplifts adjacent to the Mackenzie River (Aitken et al., 1969; Stott and Klassen, 1993).

A Phanerozoic correlation chart shows the stratigraphy of Peel Plateau and Plain and proximal regions of the Cordillera (Richardson and Mackenzie mountains; Figure 2). The supracrustal wedge of sediment has a cumulative thickness ranging from a depositional/erosional edge at the Canadian Shield in the east to 7 km at the interface between the Interior Platform and Cordillera to up to 20 km within the orogen (D.K. Norris, 1985a). Proterozoic to Lower Cretaceous rocks generally represent a rift to post-rift "passive" continental margin succession (Norris 1983, 1997) that Norris and Hughes (1996) assigned to two tectono-stratigraphic packages: 1) Lower to Middle Paleozoic Franklinian Assemblage, and 2) the Upper Paleozoic Ellesmerian Assemblage. The overlying Lower Cretaceous to Paleogene assemblage (Brookian Assemblage of Norris and Hughes, 1996) was deposited in a foreland basin setting akin to the Western Canada Sedimentary Basin.

This project examines Cambrian to Cretaceous stratigraphy. The thick underlying Proterozoic succession has a complex tectono-stratigraphic history that influenced development of Phanerozoic tectonic elements (Cook and MacLean, 2004).

The Cambrian to Devonian Franklinian Assemblage generally represents a phase of "passive" margin sedimentation within Mackenzie-Peel Shelf to Richardson Trough (Gabrielse, 1967; D. K. Norris, 1985a; Morrow and Geldsetzer, 1988). Cambrian to Devonian Formations in Peel area include: Cambrian Mount Clark and Mount Cap formations; Cambrian Saline River Formation; Cambrian-Ordovician Franklin Mountain Formation; Ordovician-Silurian Mount Kindle Formation; Silurian-Devonian Delorme Group; Lower to Middle Devonian Bear Rock, Arnica, and Landry formations; Middle Devonian Hume Formation; and Middle to Late Devonian Horn River Group (Hare Indian, Ramparts, and Canol formations). These formations pass westward and southward to correlative slope and basinal facies preserved in the Richardson and Mackenzie mountains, and Peel Plateau (Norford, 1996; Morrow, 1999; Figure 2).

The Ellesmerian Assemblage represents the onset of the Ellesmerian Orogeny (Lane, 2007) and the transition from Mackenzie-Peel Shelf to Mackenzie Basin. Synorogenic, siliciclastic sediments of the Upper Devonian to Mississippian Imperial and Tuttle formations and Ford Lake Shale were deposited during this phase (Richards et al., 1996). The succession is truncated by a sub-Cretaceous unconformity that has locally removed a substantial portion of the section (Aitken et al., 1982; Figure 2).

The Brookian Assemblage is mainly composed of Cretaceous rocks in Peel Plateau and Plain and adjacent areas and represents a phase of foreland basin sedimentation that includes the Lower to Upper Cretaceous Martin House, Arctic Red, and Trevor formations (Figure 2). During the deposition of this assemblage, extension and compression related to the mid-Jurassic to Tertiary Cordilleran and Laramide orogenies (Norris, 1997) formed the Peel Trough, a paleogeographic feature with large sediment accommodation space (Yorath and Cook, 1981; Dixon, 1999).

EXPLORATION HISTORY

First Nations people in northern Canada used bitumen found at surface as a canoe sealant. Alexander Mackenzie made record of these "petrolium" seepages in the Ramparts area of his namesake Mackenzie River in 1789. Geological exploration began with the Peel River area traverses of R.G. McConnell of the GSC in the late 1800s. Following the discovery of oil in 1920 at Norman Wells, the GSC published a series of reports based on reconnaissance field studies in Peel area. Major large-scale mapping of the frontier regions by the GSC began in 1957 and continued into the early 1960s; Peel Plateau and Plain was covered by mapping during Operation Norman and Operation Porcupine. More detail on government exploration history of Peel area is contained in the Previous Work section of this chapter.

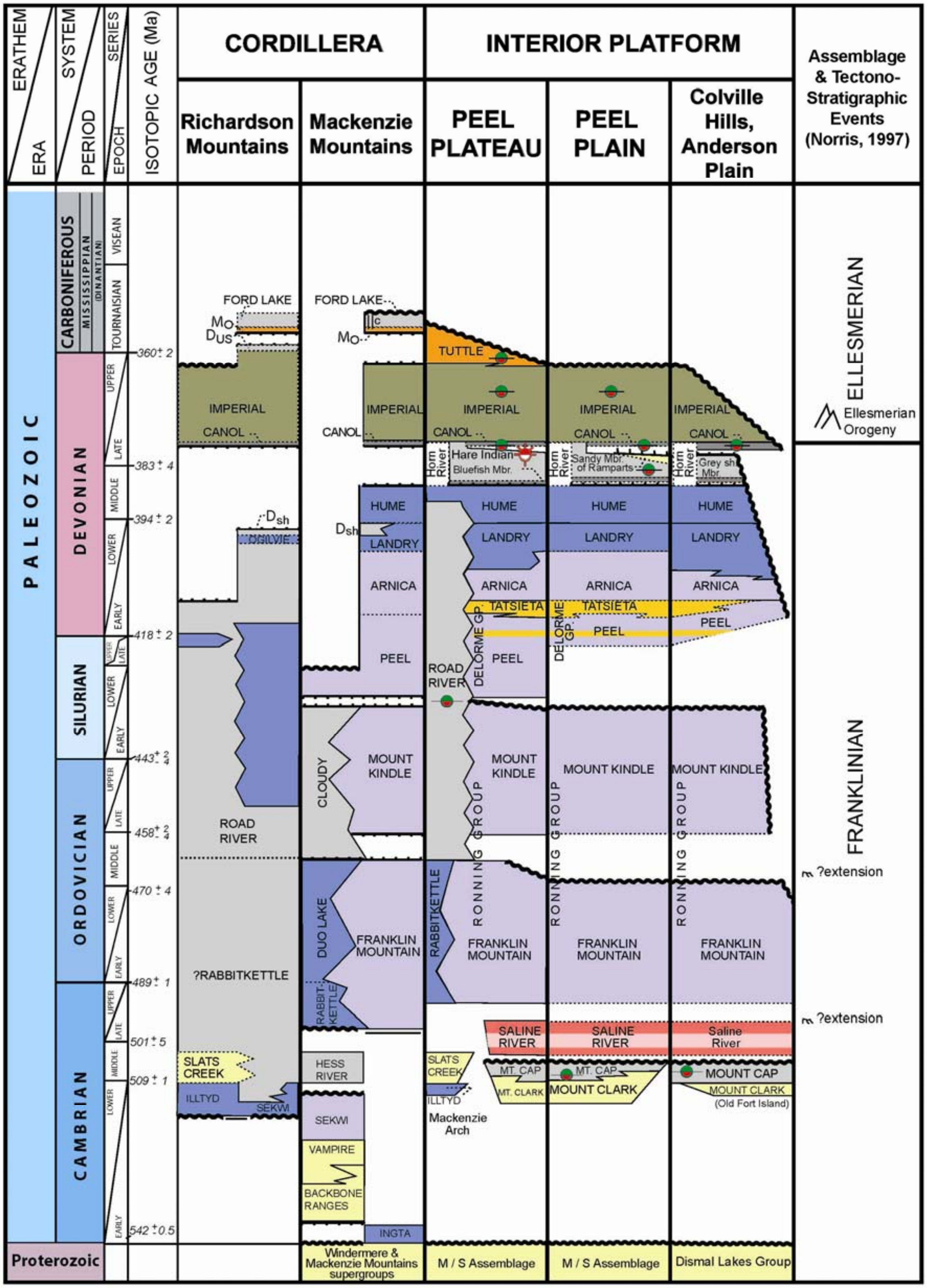

Figure 2. *Paleozoic and Mesozoic table of formations for Peel Plateau and Plain and proximal regions. Timescale after Okulitch (2004); stratigraphic data after Norris (1983, 1997) and Jones and Gal (2007).*

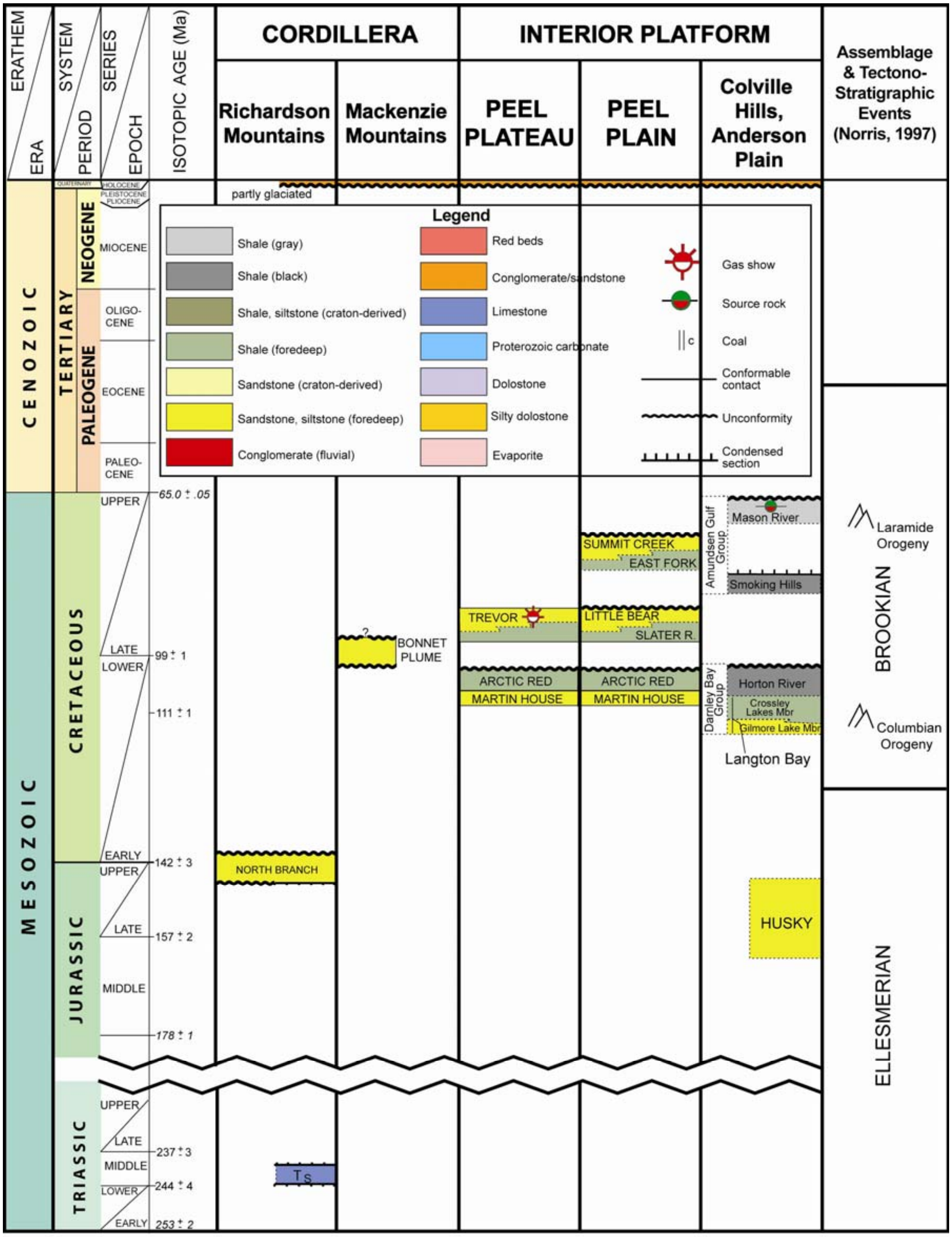

***Figure 2.** Table of formations continued.*

Despite a proximity to Norman Wells, only 74 wells have been drilled in Peel area across two territories (57 in the NWT, 17 in Yukon; Appendix B). Wells with hydrocarbon shows are summarized in Table 1**.** Subsurface formation tops and cored intervals for these wells are presented in appendices C and D, respectively. Osadetz et al. (2005) summarized the exploration history and distribution of reflection seismic surveys in western Peel area.

Well Name	Unique Well ID	Total Depth (m)	Formation	Show/Accumulation
NWT				
Ramparts River F-46	300F466550130000	1510.0	Martin House, Trevor, Imperial	gas shows
Hume River L-09	300L096530129300	2606.0	Fort Norman	gas cut water
Mountain River O-18	300O186540129000	1120.0	Imperial, Hare Indian, Hume, Landry, Fort Norman	gas shows
Sperry Creek N-58	300N586540129150	2160.0	Trevor, Arctic Red, Imperial, Canol-Hare Indian, Hume, Landry, Arnica, Mount Kindle	gas shows
Mountain River A-23	300A236550129150	1553.6	Ramparts	bitumen
			Imperial?	gas blowout
Mountain River H-47	300H476550129000	1044.5	Arnica, Landry, Ramparts	gas flow; oil stain
Shoals C-31	300C316600128450	1981.2	Landry	oil, small amount; oil stain
			Ronning	oil stain
Hume River D-53	300D536600129000	1267.6	Ramparts	gas cut mud
			Arnica	gas cut water
			Ramparts and Cretaceous	oil stain
Hume River O-62	300O626600129000	1402.1	Ramparts	gas flow
East Hume River N-10	300N106600129150	445.0	Arctic Red, Martin House, Canol	gas flow; gas show
East Hume River I-20	300I206600129150	365.0	Arctic Red, Martin House	gas cut drilling fluid; gas shows
Hume River I-66	300I666600129300	745.0	Arctic Red	gas cut drilling fluid; gas shows
Hume River A-53	300A536610129000	1158.2	Ramparts	oil stain
Ramparts No.1 I-55	300I556620128300	470.6	Hume	gas flow
Manitou Lake L-61	300L616630128450	1724.3	Hume, Kee Scarp	oil stain
SW Airport Creek No. 1 (D-72)	300D726630129000	726.9	Hume, Arnica, Landry	oil stain
North Circle River No. 1 (A-37)	300A376630129300	690.7	Hume, Arnica, Landry	oil stain
Ontaratue I-38	300I386620131450	2287.5	Franklin Mtn.	bitumen
Circle River No. 1 (K-47)	300K476630130000	810.8	Hume, Arnica, Landry	oil stain
Grandview L-26	300L266640130150	2395.6	Hume, Arnica, Landry	oil stain
Sainville River D-08	300D086620133300	2651.8	Imperial	GTS-TSTM
Arctic Circle Ontaratue H-34	300H346630132000	4075.2	Arnica	gas cut mud; gas cut salt water
Martin House L-50	300L506650133150	2407.9	Arnica	gas cut salt water
Nevejo M-05	300M056720134000	2378.7	Imperial	gas cut oil cut mud
Stony G-06	300G066740135150	2529.8	Hume, Arnica, Landry	bituminous
Tree River F-57	300F576710132150	1979.7	Mount Kindle	oily odour
Tree River H-38	300H386720132150	1279.2	Canol	gas blowout
Grandview Hills No. 1 (A-47)	300A476710130450	1998.0	Ramparts	oil stain
Loon River No. 1 (H-79)	300H796630128450	299.9	Landry	gas cut water; oil stain

Well Name	Unique Well ID	Total Depth (m)	Formation	Show/Accumulation
Yukon				
Cranswick YT A-42	300A426550133000	4267.2	Landry	GTS-TSTM
Taylor Lake K-15	300K156600133000	2378.7	Arnica tongue	gas cut salt water
			Tuttle	gas cut water
Peel River M-69	300M696610133450	3272.6	Tuttle	GTS-TSTM
Peel River I-21	300I216620134150	2072.6	Tuttle	gas cut water
Peel H-71	300H716630134300	3392.1	Mount Kindle	gas to surface
			Landry	kicked gas
Peel River L-01	300L016640134450	1834.9	Tuttle	gas cut water
Peel River B-06	300B066640134450	1066.8	Martin House to Tuttle	GTS-TSTM
Peel River B-06A	302B066640134450	1066.8	Tuttle	gas cut salt water
Trail River H-37	300H376640134450	3721.6	Hume	bitumen
Peel River L-19	300L196650135150	1981.2	Mount Kindle	gas cut mud
Peel F-37	300F376700134450	3368.0	Mount Kindle	gas cut salt water

Table 1. *Summary of wells with hydrocarbon shows in NWT and Yukon (GTS=gas to surface; TSTM=too small to measure).*

The earliest drilling was two wells by Imperial Oil (Whirlpool No. 1 [H-73] and Sans Sault No. 1 [H-24]) in the mid-1940s during the war effort and the Canol Pipeline construction. The vast majority of wells, however, were spudded during the 1960s and 1970s; it has been suggested that this "flurry" of drilling activity was in response to the GSC's major mapping efforts in the North and the release of reconnaissance geological maps of the Canadian frontier (Northern Oil and Gas, 1993). This period is also the vintage for most of the 2-D seismic surveys and the resultant dataset available for Peel area. A lengthy exploration hiatus in exploration activity followed due to low commodity prices and ongoing land claim negotiations. After further seismic data acquisition, six additional wells were drilled in the southeast corner of Peel Plain in the early 1990s by Chevron Canada Resources.

Rights issuance and retention of licenses has been sporadic over recent years with several parcels reverting back to the Crown on the NWT side. As recently as 2001 to 2004, drilling has occurred in the Grandview Hills of the northeast Peel Plain by operating companies such as Devlan Exploration Inc. and Dual Exploration Inc. The sole current exploration license (EL #413 or "Little Chicago") on the NWT side of the study area is located in this area (Figure 1). Now operated by Kodiak Energy, Inc., the license has seen 2-D seismic programs conducted most recently with a subsequent evaluation of potential resources including delineation of prospects, production feasibility and infrastructure options (Chapman Petroleum Engineering Ltd., 2008) and a proposed (but not executed) drilling program for the winter of 2008/2009 (Kodiak Energy, Inc., 2008).

On the Yukon side of Peel Plateau, a new oil and gas disposition (Permit #0018; Figure 1) was issued in the fall of 2007 to AustroCan Petroleum Corporation. This parcel is located west of Permit #0004, which was issued to Hunt Oil Company of Canada Inc. in 2002, but has since lapsed due to lack of exploratory work.

PREVIOUS WORK

In Peel area, the earliest geological reports are those based on R.G. McConnell's traverse up Peel River to Fort McPherson and west across the Richardson Mountains (McConnell, 1891; McConnell and Ogilvie, 1891). A series of GSC reports followed discovery of oil at Norman Wells (Bosworth and Kindle, 1921, 1922; Kindle and Bosworth, 1921, 1922; Williams, 1922, 1923; Hume, 1923a, b; Hume and Williams, 1924a, b). Results of geological work related to the Canol Project were compiled by Hume and Link (1945) and Hume (1954). Early descriptions of the tectonic framework include those of Martin (1961) and Gabrielse and Wheeler (1961).

Large-scale GSC mapping projects, *Operations Norman* and *Porcupine*, provided 1:250,000 scale coverage of Peel Plateau and Plain, the northwest extremity of the Mackenzie Mountains, and the Richardson Mountains (Table 2, Figure 3). Mapping was initiated in the NWT in 1957 with *Operation Mackenzie* between 60°N and 64°N and *Operation Norman* north of 64°N. *Operation Porcupine* began in 1961 and extended from the western boundary of *Operation Norman* at 132°W to the Yukon/USA border. A summary map by D.K. Norris (1985b) covers northern Yukon and northwestern NWT. Seismic and aeromagnetic surveys as well as geochemical data maps for or near Peel area are listed in Table 3.

Author(s)	Title	Date	Journal/ Report	Map No.	Map Scale	NTS Area
Aitken, J. D., Cook, D. G., Yorath, C. J.	Upper Ramparts River (106G) and Sans Sault Rapids (106H) map areas, District of Mackenzie	1982	GSC Memoir 388	1452A 1453A	2 maps 1:250,000 1 map 1:500,000	106A; 106B /09, /10, /13; /14, /15, /16; 106G; 106H, 106J/01 to /08
Aitken, J. D., Ayling, M. E., Balkwill, H. R., Cook, D. G., Mackenzie, W. S.,Yorath, C. J.	Fort Good Hope, District of Mackenzie	1969	GSC Preliminary Map	4-1969	1 map 1:250,000	106I
Cook, D. G., Aitken, J. D.	Ontaratue River (106J), Travaillant Lake (106O), and Canot Lake (106P) map-areas, District of Mackenzie, Northwest Territories	1975	GSC Paper 74-17	1408A 1409A 1410A	3 maps 1:250,000	106J, O, P
Norris, D.K.	Geology, Snake River, Yukon-Northwest Territories	1982	GSC "A" Series Map	1529A	1 map 1:250,000	106F
Norris, D. K.	Geology, Wind River, Yukon Territory	1982	GSC "A" Series Map	1528A	1 map 1:250,000	106E
Norris, D. K.	Geology: Fort McPherson, District of Mackenzie	1981	GSC "A" Series Map	1520A	1 map 1:250,000	106M
Norris, D. K.	Geology, Arctic Red River, District of Mackenzie	1981	GSC "A" Series Map	1521A	1 map 1:250,000	106N
Norris, D. K.	Geology, Trail River, Yukon-Northwest Territories	1981	GSC "A" Series Map	1524A	1 map 1:250,000	106L
Norris, D. K.	Geology, Martin House, Yukon-Northwest Territories	1981	GSC "A" Series Map	1525A	1 map 1:250,000	106K

Table 2. *Listing of GSC geological maps with coverage of Peel Plateau and Plain.*

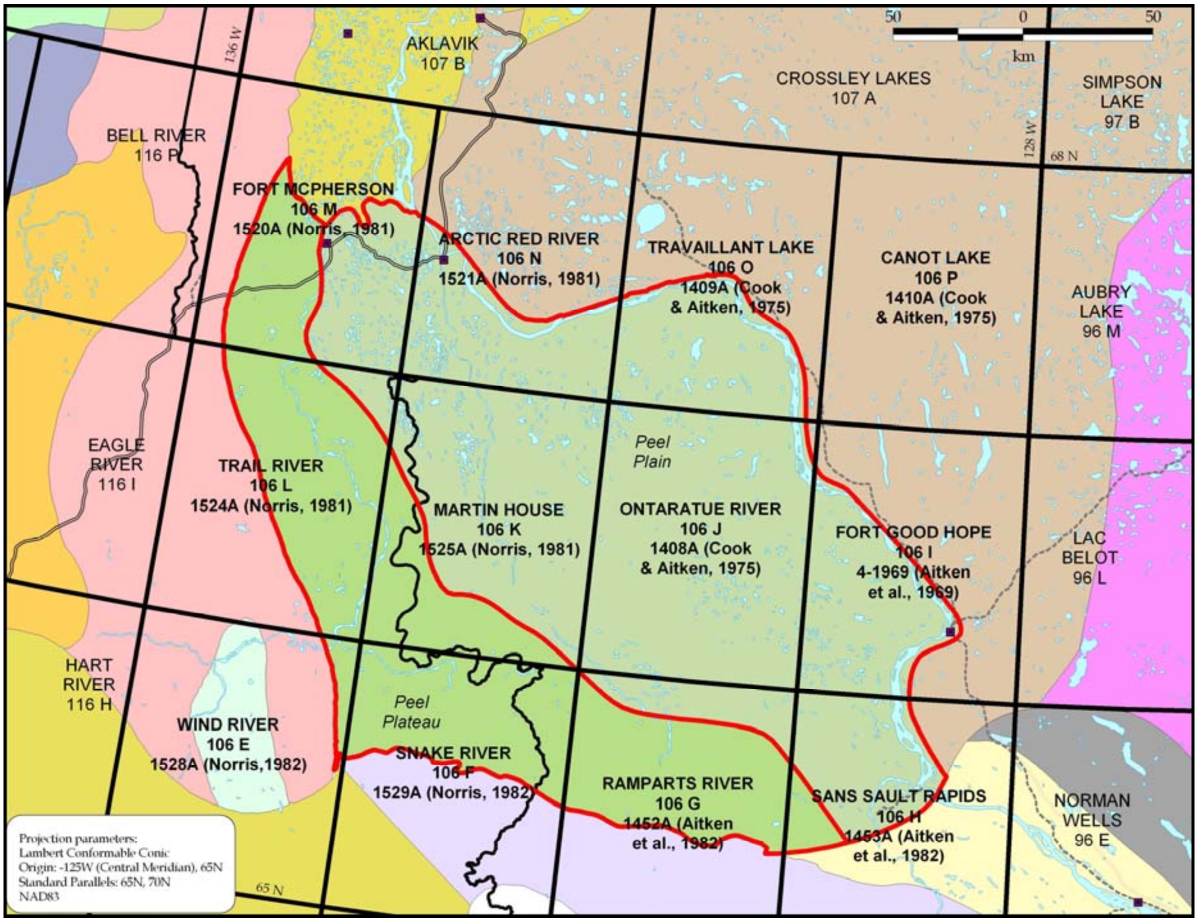

Figure 3. *NTS-based, GSC bedrock geology maps available for the Peel area. Coloured areas correspond to the exploration areas labelled in Figure 1.*

The general stratigraphic framework for Peel area is understood from regional mapping and stratigraphic studies (e.g., Aitken and Cook, 1974; Aitken et al. 1973, 1982; Cecile, 1982; Cecile and Norford, 1993; Dixon and Stasiuk, 1998; Fritz, 1985; Gabrielse et al., 1973; Macqueen, 1970; Morrow 1991, 1999; Morrow and Geldsetzer, 1988, 1992; Mountjoy and Chamney, 1969; Norford and Macqueen, 1975; Norris, 1967, 1968, 1985; Norris, 1997; Williams, 1987, 1996) and from subsurface studies (Pugh 1983, 1993; Tassonyi, 1969). Much of this work was summarized by Pyle et al. (2006) and is not repeated here. General reviews of the area and its petroleum potential are provided in Kunst (1973), Morrell (1995), and Osadetz et al. (2005).

Each thematic chapter in this volume will review additional previous work. Several interim products have resulted from current research of the Peel Project (Appendix A).

Author(s)	Title	Date	Report	Map Scale	NTS Area
Cook, D. G., MacLean, B. C.	Subsurface Proterozoic stratigraphy and tectonics of the western plains of the Northwest Territories	2004	GSC Bulletin 575	21 sheets 1:1,600,000	106G, H, I, J, O, P
Day, S. J. A., Lariviere, J. M., Friske, P. W. B., NcNeil, R. J., Cairns, S. R., McCurdy, M. W., Gal, L. P.	Regional stream sediment and water geochemical data, Richardson Mountains, Northwest Territories (parts of NTS 106M, 107B, 116P and 117A) including analytical, mineralogical and kimberlite indicator mineral data from silts, heavy mineral concentrates and waters	2005	GSC Open File 4670	237 maps	106M/02 to /07, /10 to /15
Day, S. J. A., Lariviere, J. M., Friske, P. W. B., NcNeil, R. J., McCurdy, M. W.	National Geochemical Reconnaissance, regional stream sediment and water geochemical data, Travaillant Lake area, Northwest Territories (part of NTS 106N and part of NTS 106O) including analytical, mineralogical and kimberlite indicator mineral data from silts and heavy mineral concentrates	2006	GSC Open File 4951	62 maps 1:50,000	106N/01 to /02, /07 to /10, /15 to /16; 106O/02 to /07, /10 to /15
Dumont, R., Coyle, M., Oneshuck, D., Potvin, J.	Aeromagnetic total field map, 106M/NW-NE, Northwest Territories	2002	GSC Open File 3978	1 map 1:100,000	106M/09 to M/16
Dumont, R., Coyle, M. Oneshuck, D., Potvin, J.	Aeromagnetic total field map, 106N/NW-NE, Northwest Territories	2002	GSC Open File 3979	1 map 1:100,000	106N/09 to N/16
Dumont, R., Coyle, M. Oneshuck, D., Potvin, J.	Aeromagnetic total field map, Northwest Territories, NTS 106G/NW-NE	2001	GSC Open File 3980	1 map 1:100,000	106G/09 to /16
Dumont, R., Coyle, M. Oneshuck, D., Potvin, J.	Aeromagnetic total field map, Northwest Territories, NTS 106I/NW-NE	2001	GSC Open File 3982	1 map 1:100,000	106I/09 to /16
Dumont, R., Coyle, M. Oneshuck, D., Potvin, J.	Aeromagnetic total field map, Northwest Territories, NTS 106J/SW-SE	2001	GSC Open File 3983	1 map 1:100,000	106J/01 to /08
Dumont, R., Coyle, M. Oneshuck, D., Potvin, J.	Aeromagnetic total field map, Northwest Territories, NTS 106J/NW-NE	2001	GSC Open File 3984	1 map 1:100,000	106J/09 to /16

Author(s)	Title	Date	Report	Map Scale	NTS Area
Dumont, R.	Aeromagnetic total field map, Northwest Territories, NTS 106H/NW	2000	GSC Open File 3759a	1 map 1:100,000	106H
Dumont, R.	Aeromagnetic total field map, Northwest Territories, NTS 106H/NE	2000	GSC Open File 3759b	1 map 1:100,000	106H
Dumont, R.	Aeromagnetic total field map, Northwest Territories, NTS 106H/SW	2000	GSC Open File 3759e	1 map 1:100,000	106H
Dumont, R.	Aeromagnetic total field map, Northwest Territories, NTS 106H/SE	2000	GSC Open File 3759f	1 map 1:100,000	106H
Dumont, R.	Aeromagnetic total field map, Northwest Territories, NTS 96E/SE	2000	GSC Open File 3759i	1 map 1:100,000	96E/01, 02, 07, 08
GSC	Aeromagnetic total field, Bell River and part of Fort McPherson, Yukon Territory-Northwest Territories	1992	GSC Geophysical Series Map 7930G	1:250,000	106M/0304, 05, 06, 11, 12, 13, 14
Goodfellow, W. D., Lynch, J. J.	National geochemical reconnaissance release NGR 29- 1977, regional stream sediment and water geochemical reconnaissance data, central Yukon Territory	1978	GSC Open File 518	14 maps 1:250,000	106C/04 to/06; /11 to/14; 106D; 106E/01to /08; 106F/03 to /06
Hornbrook, E. H. W., Friske, P. W. B., Lynch, J. J., McCurdy, M. W., Gross, H., Galletta, A. C., Durham, C. C.	National Geochemical Reconnaissance Stream Sediment and Water Geochemical Data, East Central Yukon Territory [106d; parts of 106c, 106e and 106f]	1990	GSC Open File 2175	42 maps 1:500,000 1:250,000	106E, F, C
Kiss, F., Coyle, M., Dumont, R.	High resolution aeromagnetic total field map, Peel Plateau, Yukon (NTS 106F/NE-NW)	2004	GSC Open File 4503	1 sheet 1:100,000	106F/09 to/16
Kiss, F., Coyle, M., Dumont, R.	High resolution aeromagnetic total field map, Peel Plateau, Yukon (NTS 106L/NE-NW)	2004	GSC Open File 4504	1 sheet 1:100,000	106L/09 to/16
Kiss, F., Coyle, M., Dumont, R.	Shaded magnetic first vertical derivative map, Peel Plateau, Yukon (NTS 106F/NE-NW)	2004	GSC Open File 4505	1 sheet 1:100,000	106F/09 to/16

Author(s)	Title	Date	Report	Map Scale	NTS Area
Kiss, F., Coyle, M., Dumont, R.	Shaded magnetic first vertical derivative map, Peel Plateau, Yukon (NTS 106L/NE-NW)	2004	GSC Open File 4506	1 sheet 1:100,000	106L/09 to/16
Kiss, F., Coyle, M., Potvin, J., Dumont, R.	Aeromagnetic total field, 106K/NW-NE, Yukon Territory / Northwest Territories	2004	GSC Open File 4507	1 sheet 1:100,000	106K/09 to/16
Kiss, F., Coyle, M., Potvin, J., Dumont, R.	Aeromagnetic total field, 106M/SW-SE, Northwest Territories	2004	GSC Open File 4508	1 sheet 1:100,000	106M/01 to M/08
Kiss, F., Coyle, M., Potvin, J., Dumont, R.	Aeromagnetic total field, 106N/SW-SE, Northwest Territories	2004	GSC Open File 4509	1 sheet 1:100,000	106N/01 to N/08
Kiss, F., Coyle, M., Potvin, J., Dumont, R.	Shaded magnetic first vertical derivative, 106K/NW-NE, Yukon Territory/ Northwest Territories	2004	GSC Open File 4511	1 sheet 1:100,000	106K/09 to/16
Kiss, F., Coyle, M., Potvin, J., Dumont, R.	Shaded magnetic first vertical derivative, 106M/SW-SE, Yukon Territory/ Northwest Territories	2004	GSC Open File 4512	1 sheet 1:100,000	106M/01 to M/08
Kiss, F., Coyle, M., Potvin, J., Dumont, R.	Shaded magnetic first vertical derivative, 106N/SW-SE, Northwest Territories	2004	GSC Open File 4513	1 sheet 1:100,000	106N/01 to N/08
Kiss, F., Coyle, M., Potvin, J., Dumont, R.	Aeromagnetic total field, 106K/SE-SW, Northwest Territories	2003	GSC Open File 1541	1 sheet 1:100,000	106K/01 to/08
Kiss, F., Coyle, M., Forte, S., Dumont, R.	Magnetic first vertical derivative, 106L/SE-SW, Yukon Territory	2003	GSC Open File 1544	1 sheet 1:100,000	106L/01 to/08
Kiss, F., Coyle, M., Potvin, J., Dumont, R.	Shaded magnetic first vertical derivative, 106K/SE-SW, Northwest Territories	2003	GSC Open File 1545	1 sheet 1:100,000	106K/01 to/08
Kiss, F., Coyle, M., Forte, S., Dumont, R.	Aeromagnetic total field, 106E/SE-SW, Yukon Territory	2003	GSC Open File 1538	1 map 1:100,000	106E/01 to E/08
Kiss, F., Coyle, M., Forte, S., Dumont, R.	Aeromagnetic total field, 106E/NE-NW, Yukon Territory	2003	GSC Open File 1539	1 map 1:100,000	106E/09 to E/16

Author(s)	Title	Date	Report	Map Scale	NTS Area
Kiss, F., Coyle, M., Forte, S., Dumont, R.	Magnetic first vertical derivative, 106E/NE-NW, Yukon Territory	2003	GSC Open File 1543	1 map 1:100,000	106E/09 to E/16
Kiss, F., Coyle, M., Forte, S., Dumont, R.	Magnetic first vertical derivative, 106E/SE-SW, Yukon Territory	2003	GSC Open File 1542	1 map 1:100,000	106E/01 to E/08
NWT Geoscience Office/GSC	Airborne gravity survey, Central Mackenzie Valley, NWT	2009	NWT Open File 2009-01	Maps & digits	parts of 96 C to F and 106 H

Table 3. *Maps with geochemical and geophysical data for Peel area.*

PROJECT VOLUME COMPONENTS

This volume, authored by the Peel Project research team, is the culmination of four years of logistical planning, field and laboratory research along with extensive collaboration with partners from several federal and territorial agencies, universities and industry. The Peel Project examines key stratigraphic intervals that may contain conceptual petroleum plays in an effort to better understand the Phanerozoic evolution of the basin. As most of the region was covered by reconnaissance style studies, new field work on outcrops in Peel area and proximal mountain ranges was necessary to examine in more detail the sedimentology, stratigraphic and structural relationships, and petroleum potential.

This report is accompanied by a digital geodatabase/atlas (Pierce and Jones, 2009) which contains all of the spatial data associated with the project research. It is a demonstrative product complete with Geographic Information System-ready files, field and core photographs, interpreted seismic profiles, core and measured section descriptions, geochemical analyses, isopach and structural maps, and other pertinent data linked to a spatial database of wells, field-based location data, and seismic tracklines.

The volume is subdivided by chapters covering structural and seismic interpretations, stratigraphically defined petroleum plays, and review of petroleum systems elements for the basin as follows:

Chapter 2 - Regional Structure of Peel Plateau and Plain, by Lemieux et al., reviews the geological setting of Peel area and describes structural elements of the northern Mackenzie Mountains, Franklin Mountains, and northern Mackenzie Plain, as well as the structural style of Peel Plateau and Plain based on new detailed mapping. Phanerozoic paleogeography, which was largely controlled by Proterozoic structures, and key tectonic events of the area are described.

Chapters 3 to 9 examine Peel area by stratigraphic assemblage and their respective hydrocarbon plays, which follow those outlined by Gal (2007) in the Ts'ude niline Tu'eyeta (Ramparts River and Wetlands) Candidate Protected Area, and also those currently being evaluated by the GSC in their Mackenzie Corridor Project (Hannigan et al., 2006). The plays in Peel area are all conceptual; no discoveries or reserves are recorded yet, but these may exist according to geological analyses. Each chapter reports petroleum data, based on new outcrop samples and observations, as well as the subsurface record. Data include potential reservoir and source rocks, seals, trap types, generation, migration, accumulation, and exploration risks for each play.

Chapter 3 - Cambrian Strata and Basal Cambrian Clastics Play, by Pyle and Gal, describes the stratigraphic framework, correlation, and depositional history of Mount Clark, Mount Cap, and Saline River formations. Petroleum data, including potential reservoir rocks such as sandstone of Mount Clark and Mount Cap formations, and shale source rocks from both Proterozoic and Cambrian units, are evaluated and discussed for the basal Cambrian clastics play.

Chapter 4 - Cambrian-Ordovician to Silurian Strata and Lower Paleozoic (Ronning Group) Platform Play, by Pyle and Gal, describes the stratigraphy, correlation, facies and thickness trends, and depositional history of Franklin Mountain and Mount Kindle formations based on the subsurface record in Peel area and 16 new outcrop sections across the northern Mackenzie Mountains. Potential reservoir, mainly carbonates of the Ronning Group, and source rocks within the Paleozoic Road River Group, Devonian shale, and Cretaceous shale are discussed.

Chapter 5 - Upper Silurian-Lower Devonian Strata (Delorme Group), by Gal and Pyle, describes stratigraphy, correlation, thickness and depositional trends of the Peel and Tatsieta formations based on subsurface data and 12 new outcrop sections in the northern Mackenzie Mountains. This chapter includes a new surface reference section for the formations. Limited data on potential reservoir and source rocks are reported as the succession does not constitute a petroleum play.

Chapter 6 - Lower to Upper Devonian Strata, Arnica-Landry Play, and Kee Scarp Play, by Gal et al., describes stratigraphy within two successions: 1) Lower to Middle Devonian Fort Norman Formation (Bear Rock facies), Arnica Formation, Landry Formation, Mount Baird Formation, Hume Formation, and Road River Group; and 2) Middle to Upper Devonian Horn River Group (Hare Indian, Ramparts, and Canol formations). Correlations are illustrated and depositional trends are described for 37 new measured sections and stations. Petroleum data for the Arnica/Landry and Kee Scarp plays include evaluation of potential reservoir rocks (carbonates of Arnica, Landry and Ramparts formations) and Devonian source rocks (mainly Hare Indian and Canol formations).

Chapter 7 - Upper Devonian to Carboniferous Strata I - Imperial Formation Play, by Hadlari et al., reviews the sedimentology, depositional systems, stratigraphy, ichnology, and petroleum geology of Upper Devonian Imperial Formation. Depositional interpretations are based on field studies and seismic data. Reservoir and source rock potential for the conceptual play is evaluated based on outcrop and well log data.

Chapter 8 - Upper Devonian to Carboniferous Strata II - Tuttle Formation Play, by Allen et al., reviews the stratigraphy, palynology and petroleum potential of the Upper Devonian to Lower Carboniferous Tuttle Formation of Peel Plateau and Plain. Well cuttings and core, wireline logs, and outcrop exposures were examined to assess the reservoir and source rock potential of Tuttle

Formation. Age equivalent shale and sandstone units (Ford Lake shale and “Mo” map unit) are also discussed.

Chapter 9 - Cretaceous Strata and Basal Cretaceous Sandstone Play, by Hadlari et al., details the following aspects of Cretaceous Martin House, Arctic Red, and Trevor formations: 1) biostratigraphy, providing a new framework for the succession based on foraminifera; 2) sedimentology, including detailed cross-sections for Martin House Formation; 3) stratigraphy, including cross-sections, isopachs, and seismic stratigraphy; and 4) petroleum geology, evaluating reservoir and source potential.

Chapter 10 - Petroleum Systems Elements, by Gal et al., reviews petroleum prospectivity of Peel Plateau and Plain including surface gas seeps, oil-stained outcrops, bitumen occurrences, and shows from exploration wells. New oil chemistry data from oil-stained samples is presented. Subchapters cover the following petroleum systems: 1) Cambrian system (Mount Cap-Mount Clark); 2) Cambrian-Devonian system (Road River-Ronning); 3) Middle to Upper Devonian system (Horn River-Ramparts); 4) two probably interrelated upper Paleozoic systems (Tuttle-Tuttle and Imperial-Imperial), and 5) Cretaceous system (Arctic Red-Martin House). Each petroleum system is summarized on a theoretical events chart that includes time intervals for source and reservoir rocks, seal, overburden, trap, generation/migration/accumulation, preservation, and critical moment. Several one-dimensional burial history models that assess the timing of hydrocarbon generation in each system are presented.

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APPENDIX A

This appendix contains a comprehensive list of publications related to and produced during the course of the Peel Petroleum Project (2005-2009). Links to some of these reports are available from the project website at *www.nwtgeoscience.ca/petroleum/PeelPlateau.html*.

Allen, T.L. and Fraser, T.A., 2006. Preliminary investigations of the Upper Devonian to Lower Carboniferous Tuttle Formation, east Richardson Mountains, Yukon; Poster Abstract *in* 34th Annual Yellowknife Geoscience Forum Abstracts of Talks and Posters, compiled by A.L. Jones and D. Irwin; Northwest Territories Geoscience Office, Yellowknife, NT, YKGSF Abstracts Volume 2006, p. 64.

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Allen, T.L., Fraser, T.A., and Osadetz, K.G., 2008. Rock-Eval/TOC data for 18 wells, Peel Plateau and Plain, Yukon Territory (65° 50' to 67° 00' N; 133° 45' to 135° 15' W); Yukon Geological Survey, YGS Open File 2008-1, 14 p. plus spreadsheets.

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APPENDIX B - List of oil and gas exploration wells in Peel Plateau and Plain, NWT

Short Name	Unique Well ID	KB elev (m)	Rig in date	Current Status[1]	Full name	Depth (m)	Latitude	Long.	Northing	Easting	Grid elev (m)	Map sheet	NEB Report No.[2]
South Peel D-64	300D646600132151	558.1	1974-03-15	DA	Dome Texaco Imp South Peel D-64	1985.5	65 53.067	132 27.833	7309175	615606	553.2	106-F-16	**D-64-66-00-132-15**
N. Ramparts A-59	300A596530130300	580.5	1973-06-11	DA	Candel Mobil et al. N. Ramparts A-59	3205.0	65 28.067	130 39.783	7261415	422954	576.1	106-G-07	**A-59-65-30-130-30**
S. Ramparts I-77	300I776530130450	595.6	1973-04-14	DA	Candel et al. Mobil S. Ramparts I-77	1621.8	65 26.533	130 58.300	7258980	408571	591.3	106-G-07	**I-77-65-30-130-45**
Arctic Red F-47	300F476540130450	790.7	1973-03-07	DA	Candel et al. Texaco Arctic Red F-47	2371.3	65 36.417	130 53.883	7277228	412537	786.4	106-G-10	**F-47-65-40-130-45**
Cranswick A-22	300A226540131450	768.4	1972-03-28	DA	Amoco PCP A-1 Cranswick A-22	2869.1	65 31.017	131 48.917	7268789	369841	762	106-G-12	**A-22-65-40-131-45**
Ramparts River F-46	300F466550130000	215.6	1991-03-18	DA	Chevron Ramparts River F-46	1510.0	65 45.310	130 08.857	7292910	447415	209.5	106-G-16	**F-46-65-50-130-00**
Hume River L-09	300L096530129300	325.2	1971-04-09	DA	Mobil Hume River L-09	2606.0	65 28.517	129 31.533	7261335	475657	320	106-H-05	**L-09-65-30-129-30**
Mountain River O-18	300O186540129000	115.0	1990-01-08	DA	Chevron Mountain River O-18	1120.0	65 37.960	129 02.480	7278786	498097	109.5	106-H-11	**O-18-65-40-129-00**
Whirlpool No. 1 (H-73)	300H736540129000	105.5	1946-08-30	DA	Imperial Whirlpool No. 1 (H-73)	1955.9	65 32.417	129 13.283	7268496	489771	145.1	106-H-11	**H-73-65-40-129-00**
Sperry Creek N-58	300N586540129150	160.7	1991-02-19	DA	Chevron Sperry Creek N-58	2160.0	65 37.935	129 25.412	7278795	480500	154.5	106-H-11	**N-58-65-40-129-15**
Mountain River A-23	300A236550129150	115.5	1972-04-26	DA	Candel et al. SOBC Mountain R. A-23	1553.6	65 42.233	129 19.200	7286752	485308	110.3	106-H-11	**A-23-65-50-129-15**
Sans Sault No. 1 (H-24)	300H246550128451	100.0	1945-06-28	DA	Imperial Sans Sault No. 1 (H-24)	1003.1	65 43.323	128 49.130	7288751	508312	96.9	106-H-10	**H-24-65-50-128-45**
Mountain River H-47	300H476550129000	93.9	1972-01-13	DA	Arco Clarke et al. Mountain River H-47	1044.5	65 46.383	129 07.833	7294430	494022	89.9	106-H-14	**H-47-65-50-129-00**
Shoals C-31	300C316600128450	87.6	1966-05-22	DA	Atlantic Col Car Shoals C-31	1981.2	65 50.125	128 51.750	7301382	506281	83.8	106-H-15	**C-31-66-00-128-45**
Hume River D-53	300D536600129000	88.4	1972-02-11	DA	Arco Clarke et al. Hume River D-53	1267.6	65 52.050	129 11.000	7304963	491636	83.8	106-H-14	**D-53-66-00-129-00**
Hume River O-62	300O626600129000	86.9	1970-03-15	DA	Triad BP Arco CC Hume R. O-62	1402.1	65 51.767	129 12.067	7304439	490823	82.9	106-H-14	**O-62-66-00-129-00**
East Hume River N-10	300N106600129150	80.1	1990-03-04	DA	Chevron East Hume River N-10	445.0	65 59.965	129 15.985	7319681	487907	74.4	106-H-14	**N-10-66-00-129-15**
East Hume River I-20	300I206600129150	75.1	1990-03-24	DA	Chevron East Hume River I-20	365.0	65 59.637	129 17.277	7319075	486928	69	106-H-14	**I-20-66-00-129-15**
Hume River I-66	300I666600129300	95.3	1990-02-09	DA	Chevron Hume River I-66	745.0	65 55.565	129 41.657	7311656	468397	89.7	106-H-13	**I-66-66-00-129-30**
Hume River A-53	300A536610129000	62.8	1969-07-26	DA	Triad BP Arco CC Hume R. A-53	1158.2	66 02.200	129 09.767	7323817	492622	58.8	106-I-03	**A-53-66-10-129-00**
Ramparts No.1 I-55	300I556620128300	23.8	1960-09-23	DA	Glacier Baysel-Climax Ramparts No. 1 (I-55)	470.6	66 14.733	128 39.783	7347133	515146	21.5	106-I-02	**I-55-66-20-128-30**
Hare Indian No. 1 (H-48)	300H486620128300	45.1	1960-09-27	DA	Glacier Baysel-Climax Hare Indian No. 1 (H-48)	169.2	66 17.383	128 37.500	7352065	516827	43.9	106-I-07	**H-48-66-20-128-30**
Manitou Lake L-61	300L616630128450	131.7	1966-02-05	DA	Atlantic Columbian Carbon Manitou Lake L-61	1724.3	66 20.666	128 58.000	7358115	501493	128	106-I-07	**L-61-66-30-128-45**
Loon River No. 1 (H-79)	300H796630128450	24.4	1960-08-27	DA	Glacier Baysel-Climax Loon River No. 1 (H-79)	299.9	66 28.433	128 58.400	7372545	501188	21.9	106-I-07	**H-79-66-30-128-45**
SW Airport Creek No. 1 (D-72)	300D726630129000	149.2	1960-12-15	DA	Atlantic SW Airport Creek No. 1 (D-72)	726.9	66 21.167	129 14.733	7359065	489009	146.8	106-I-06	**D-72-66-30-129-00**
North Circle River No. 1 (A-37)	300A376630129300	150.8	1961-01-23	DA	Atlantic North Circle River No. 1 (A-37)	690.7	66 26.158	129 35.883	7368445	473320	148.4	106-I-05	**A-37-66-30-129-30**
Ontaratue I-38	300I386620131450	144.5	1972-11-06	DA	Decalta Trans Ocean GCOA Ontaratue I-38	2287.5	66 17.666	131 51.000	7355453	372172	138.7	106-J-05	**I-38-66-20-131-45**
Circle River No. 1 (K-47)	300K476630130000	89.9	1961-02-25	DA	Atlantic Circle River No. 1 (K-47)	810.8	66 26.633	130 08.833	7369670	448838	87.5	106-J-08	**K-47-66-30-130-00**

APPENDIX B (continued) - List of oil and gas exploration wells in Peel Plateau and Plain, NWT

Short Name	Unique Well ID	KB elev (m)	Rig in date	Current Status[1]	Full name	Depth (m)	Latitude	Longitude	Northing	Easting	Grid elev (m)	Map sheet	NEB Report No.[2]
Grandview L-26	300L266640130150	164.9	1972-05-11	DA	Candel et al Mobil Grandview L-26	2395.6	66 35.533	130 20.35	7386372	440634	161	106-J-09	**N/A**
Arctic Circle Ontaratue K-04	300K046640130450	103.8	1965-02-23	DA	Atlantic Columbian Carbon Arctic Circle Ontaratue K-04	2728.0	66 33.625	130 46.172	7383303	421459	99.1	106-J-10	**K-04-66-40-130-45**
Weldon Creek O-65	300O656610132150	222.8	1973-04-12	DA	Inexco et al. Weldon Creek O-65	2214.4	66 04.750	132 27.017	7330891	615344	219	106-K-01	**O-65-66-10-132-15**
Sainville River D-08	300D086620133300	203.0	1974-03-06	DA	Arco Shell Sainville River D-08	2651.8	66 17.117	133 31.65	7352297	566082	198.1	106-K-05	**D-08-66-20-133-30**
Sainville River K-63	300K636630133000	138.7	1972-01-23	DA	Shell Sainville River K-63	790.0	66 22.615	133 12.258	7362888	580290	133.8	106-K-06	**K-63-66-30-133-00**
Arctic Circle Ontaratue H-34	300H346630132000	141.7	1964-04-01	DA	Atlantic Columbian Carbon Arctic Circle Ontaratue H-34	4075.2	66 23.375	132 05.858	7366157	629683	137.2	106-K-08	**H-34-66-30-132-00**
Arctic Red West G-55	300G556650133000	44.6	1971-05-22	DA	Shell Arctic Red West G-55	3322.3	66 44.468	133 09.970	7403524	580803	39.3	106-K-11	**G-55-66-50-133-00**
Arctic Red River O-27	300O276650132450	136.6	1971-01-23	DA	Shell Arctic Red River O-27	2154.0	66 46.933	132 49.598	7408582	595599	131.7	106-K-15	**O-27-66-50-132-45**
Martin House L-50	300L506650133150	88.0	1966-06-11	DA	IOE Martin House L-50	2407.9	66 49.700	133 24.050	7412957	570216	83.7	106-K-14	**L-50-66-50-133-15**
Nevejo M-05	300M056720134000	74.4	1966-03-29	DA	IOE Nevejo M-05	2378.7	67 14.967	134 01.75	745933	541897	70.4	106-M-01	**M-05-67-20-134-00**
McPherson B-25	300B256720135300	492.3	1972-04-30	DA	Union Amoco McPherson B-25	4136.1	67 14.013	135 34.373	7457345	475260	484.6	106-M-04	**B-25-67-20-135-30**
Stoney Core Hole C-02	300C026730135300	275.8	1967-08-29	JA	IOE Stoney Core Hole C-02	177.0	67 21.017	135 31.000	7470615	477798	275.8	106-M-05	**C-02-67-30-135-30**
Stoney Core Hole F-42	300F426730135300	327.7	1967-08-11	DA	IOE Stoney Core Hole F-42	310.9	67 21.383	135 38.717	7471069	472276	327.7	106-M-05	**F-42-67-30-135-30**
Stony I-50	300I506730135150	321.9	1966-05-08	DA	IOE Stony I-50	3343.0	67 29.733	135 22.767	7486490	483792	317.3	106-M-06	**I-50-67-30-135-15**
Pt. Separation No. 1 (A-05)	300A056740134000	18.9	1960-10-16	DA	R O Corp et al. Pt. Separation No. 1 (A-05)	2445.4	67 34.100	134 00.167	7494896	542464	15.2	106-M-09	**A-05-67-40-134-00**
Fort McPherson C-78	300C786740134000	19.8	1972-07-17	DA	Skelly-Getty Amoco Fort McPherson C-78	3068.1	67 37.067	134 14.333	7500265	532343	15.8	106-M-09	**C-78-67-40-134-00**
Stony G-06	300G066740135150	56.7	1973-02-17	DA	Dome Union IOE Stoney G-06	2529.8	67 35.467	135 15.833	7497117	488773	51.8	106-M-11	**G-06-67-40-135-15**
Tree River F-57	300F576710132150	93.0	1970-12-12	DA	Shell Tree River F-57	1979.7	67 06.453	132 25.673	7445493	611633	88.1	106-N-01	**F-57-67-10-132-15**
Tree River East H-57	300H576710132150	108.2	1971-03-17	DA	Shell Tree River East H-57	1981.2	67 06.453	132 24.670	7445523	612359	103.2	106-N-01	**H-57-67-10-132-15**
Clare F-79	300F796710133000	108.7	1965-06-20	DA	IOE Clare F-79	2525.6	67 08.333	133 14.333	7447758	576345	104.5	106-N-03	**F-79-67-10-133-00**
Swan Lake K-28	300K286710133300	89.6	1967-03-02	DA	IOE Swan Lake K-28	1838.2	67 07.700	133 34.733	7446205	561635	85	106-N-04	**K-28-67-10-133-30**
Tree River H-38	300H386720132150	79.6	1967-04-23	DA	IOE Tree River H-38	1279.2	67 17.350	132 21.000	7465866	614149	75.3	106-N-08	**H-38-67-20-132-15**
Moose Lake D-07	300D076710130150	54.0	2004-08-30	N/A	Dual Moose Lake D-07	900.0	67 06.165	130 16.592	7443217	444576	49	106-O-01	**N/A**
Grandview Hills No. 1 (A-47)	300A476710130450	369.5	1960-04-02	DA	R. O. Corp et al. Grandview Hills No. 1 (A-47)	1998.0	67 06.200	130 52.500	7443940	418599	365.8	106-O-02	**A-47-67-10-130-45**
Grandview Hills No. 1 (2A-47)	302A476710130450	208.2	1961-04-11	A	R. O. Corp et al. Grandview Hills No. 1 (2A-47)	367.0	67 13.666	130 51.267	7457971	419812	206.7	106-O-02	**A-47-67-10-130-45_2**
Ontaratue River D-39	300D396710131300	244.5	2001-03-19	S	Devlan et al. Ontaratue River D-39	1250.0	67 08.203	131 37.155	7448827	386459	240.4	106-O-04	**D-39-67-10-131-30**
Tree River B-10	300B106720131450	188.1	2001-01-28	PS	Devlan et al. Tree River B-10	1294.0	67 19.238	131 45.587	7469578	381281	184.2	106-O-05	**B-10-67-20-131-45**
Tree River C-36	300C366720131450	135.0	2003-03-10	PA	Devlan Vintage Tree River C-36	1878.0	67 15.150	131 51.657	7462185	376582	131.2	106-O-05	**N/A**
Thunder River N-73	300N736730131150	124.1	2001-03-15	S	Devlan et al. Thunder River N-73	1146.0	67 22.86	131 29.265	7475809	393247	120.1	106-O-06	**N-73-67-30-131-15**

APPENDIX B (continued) - List of oil and gas exploration wells in Peel Plateau and Plain, Yukon

Short Name	Unique Well ID	KB elev (m)	Rig in date	Current Status[1]	Full name	Depth (m)	Latitude	Longitude	Northing	Easting	Grid elev (m)	Map sheet
Cranswick YT A-42	300A426550133000	620.0	1973-03-20	DA	Amoco PCP B-1 Cranswick YT A-42	4267.2	65 41.210	133 07.868	7286090	585854	613.3	106-F-11
Taylor Lake K-15	300K156600133000	468.8	1969-03-29	DA	MCD GCO Northup Taylor Lake K-15	2378.7	65 54.650	133 03.000	7311161	588805	464.8	106-F-14
Peel River M-69	300M696610133450	291.7	1974-12-04	JA	Shell Peel River YT M-69	3272.6	66 08.925	133 58.200	7336872	546474	282.5	106-K-04
Peel River K-09	300K096620134000	349.6	1967-03-07	DA	Shell Peel River YT K-09	1554.5	66 18.595	134 01.037	7354613	544061	345.6	106-L-08
Peel River I-21	300I216620134150	381.3	1966-03-30	DA	Shell Peel River YT I-21	2072.6	66 10.608	134 18.853	7339598	530911	377.3	106-L-01
Peel River K-76	300K766630134000	76.5	1965-11-25	DA	Shell Peel River YT K-76	1386.8	66 25.590	134 14.132	7367470	534117	72.5	106-L-08
Peel H-71	300H716630134300	513.0	1977-06-12	DA	Mobil Gulf Peel YT H-71	3392.1	66 20.467	134 43.567	7357770	512265	506.3	106-L-07
Peel River J-21	300J216640134000	45.7	1965-09-01	DA	Shell Peel River YT J-21	1219.2	66 30.532	134 04.388	7376749	541228	41.8	106-L-09
Peel River H-59	300H596640134300	33.5	1967-04-01	DA	Shell Peel River YT H-59	763.2	66 38.298	134 39.551	7390913	515082	29.6	106-L-10
Peel River L-01	300L016640134450	394.7	1966-02-07	DA	Shell Peel River YT L-01	1834.9	66 30.639	134 46.475	7376660	510027	390.8	106-L-10
Peel River B-06	300B066640134450	65.2	1966-12-31	DA	Shell Peel River YT B-06	1066.8	66 35.157	134 45.625	7385056	510624	61.6	106-L-10
Peel River B-06A	302B066640134450	66.4	1967-01-25	DA	Shell Peel River YT B-06A	1066.8	66 35.158	134 45.667	7385059	510593	62.5	106-L-10
Trail River H-37	300H376640134450	393.2	1974-03-26	DA	Shell Trail River YT H-37	3721.6	66 36.267	134 50.983	7387106	506659	385.3	106-L-10
Arctic Red C-60	300C606650133450	92.0	1972-03-26	DA	Skelly-Getty Mobil Arctic Red C-60	2599.9	66 49.000	133 55.317	7411165	547360	86.9	106-K-13
Peel River L-19	300L-196650135150	95.1	1966-06-12	DA	Shell Peel River YT L-19	1981.2	66 48.655	135 18.395	7410148	486528	91.4	106-L-14
Satah River G-72	300G726700134000	89.6	1967-03-09	DA	IOE Satah River YT G-72	2286.0	66 51.467	134 13.950	7415546	533661	86.0	106-L-16
Peel F-37	300F376700134450	54.6	1972-04-20	DA	Pacific et al. Peel YT F-37	3368.0	66 56.433	134 51.900	7424573	505901	48.8	106-L-15

[1]Current Status: **A**=abandoned; **DA**=dry and abandoned; **JA**=junked and abandoned; **N/A**=data not available; **PA**=plugged and abandoned; **PS**=plugged and suspended; **S**=suspended.

[2]PDF of report available at NWT Geoscience Office's *Gateway* - www.nwtgeoscience.ca

APPENDIX C - Subsurface well formation tops in Peel Plateau and Plain, NWT and Yukon

Unique Well Identifier (UWI)	Short Well Name	KB/RT	Cretaceous	Little Bear	Trevor	Arctic Red	Martin House	Tuttle	Imperial	Canol	Ramparts	Kee Scarp	Hare Indian	Bluefish Member	Hume	Landry	Arnica	Bear Rock	Fort Norman	Road River	Tatsieta	Peel	Mount Kindle	Franklin Mtn	Saline River	Mount Cap	Mount Clark	Pre-cambrian	Total Depth
300D646600132151	South Peel D-64	558.1				31.4	774.8	983.3	1091.2	1494.1				1554.5	1560.6	1702.3	1935.5												1985.5
300A596530130300	N. Ramparts A-59	580.5				74.7	4.4	1340.5	1347.2	2031.8	2109.2		2122.9		2174.1	2303.1						2747.8	2849.9	2983.4					3205.0
300I776530130450	S. Ramparts I-77	595.6					437.4		443.2	670.0	759.6		765.0		785.2	929.6	1133.9				1299.7	1341.1	1363.1	1539.2					1621.8
300F476540130450	Arctic Red F-47	790.7			4.1	606.2	2119.0		2196.4																				2371.3
300A226540131450	Cranswick A-22	768.4					68.6	138.4	222.5	1088.1			1123.2	1161.3	1173.5	1315.8	1546.9				1746.5	1795.3	1993.4	2164.1				2843.8	2869.1
300F466550130000	Ramparts River F-46	215.6					869.8		972.0	1246.0			1264.2	1443.3	1454.5														1510.0
300L096530129300	Hume River L-09	325.2				30.5	578.5		622.1	1265.8	1306.1		1323.7	1560.0	1569.1	1992.8	2294.8												2606.0
300O186540129000	Mountain River O-18	115.0				5.5	114.4	141.0			139.8		279.7	483.0	490.5	591.9	684.0		795.1		920.0	927.6	946.0						1120.0
300H736540129000	Whirlpool no. 1 (H-73)	105.5					3.0		15.2	280.5	291.2							862.2						1654.4					1955.9
300N586540129150	Sperry Creek N-58	160.7			566.0	834.0			847.5	1146.0			1158.5	1395.5	1413.0	1522.0	1687.5		1797.5				1838.0	1988.5					2160.0
300A236550129150	Mountain R. A-23	115.5				24.4	400.5		433.4	646.8	674.2			906.5	921.1	1021.7	1226.2		1346.5				1410.0						1553.6
300H246550128451	Sans Sault no. 1 (H-24)	100.0				4.0	340.8		390.1		429.2		593.8	780.9	788.9	891.5	932.7												1120.0
300H476550129000	Mountain River H-47	93.9				18.3			68.9		118.3		444.7	480.4	491.0	595.0	731.5		848.0				890.0						1044.5
300C316600128450	Shoals C-31	87.6				96.0					218.2		579.1	666.3	695.6	807.7	882.1	919.0	999.1				1047.3	1216.2	1831.8				1981.2
300D536600129001	Hume River D-53	88.4				4.6	394.7		397.5	488.0	492.9		637.9	822.2	835.5	928.7	1102.8				1194.5	1197.9	1246.6						1267.7
300O626600129000	Hume R. O-62	86.9				19.8	405.4		458.4	486.5	503.5		658.4	837.9	850.4	947.0	1123.8		1219.8				1264.0						1402.1
300N106600129150	Hume River N-10	80.1				80.0	248.0		315.0	374.8	381.1																		445.0
300I206600129150	Hume River I-20	75.1		5.5		90.0	255.0		323.0																				365.0
300I666600129301	Hume River I-66	95.3				5.6	418.0		495.0	667.0	687.5		706.6																745.0
300A536610129000	Hume R. A-53	62.8				4.0	173.7			231.3	238.4		398.7	575.5	589.2	682.8	864.7		965.3				996.7						1158.2
300I556620128300	Ramparts no. 1 (I-55)	23.8							-154.5						178.3	286.5	315.2	407.2											470.6
300H486620128300	Hare Indian no. 1 (H-48)	45.1									15.2				164.6														169.2
300L616630128450	Manitou Lake L-61	131.7				3.7	22.9				100.6				327.7	435.3	707.1						762.6	944.3	1633.1				1724.3
300H796630128450	Loon River no. 1 (H-79)	24.4									41.2				171.0	274.0													299.9
300D726630129000	S.W. Airport Creek no. 1 (D-72)	149.2				2.4				80.8	110.3		147.2	372.1	391.1	499.3	626.1												726.9
300A376630129300	N. Circle River no. 1 (A-37)	150.8				2.4	36.6		62.8	85.3	115.2		166.1		371.9	485.9													690.7
300I386620131450	Ontaratue I-38	144.5				5.8			351.7	887.0			932.0	981.5	986.3	1100.3	1444.8				1573.4	1647.1	1808.7	2076.3					2287.5
300K476630130000	Circle River no. 1 (K-47)	89.9							89.9	147.8	175.9		233.2	389.6	405.1	513.9	741.3												810.8
300L266640130150	Grandview L-26	164.9				4.0			9.1	152.4			246.9	404.8	413.9	506.0	730.9				896.1	901.0	1010.7	1230.5	2004.1	2203.7		2240.3	2395.6
300K046640130450	Arctic Circle Ontaratue K-04	103.8				4.6	35.1		131.1	266.4	287.7		302.4	496.5	507.2	604.4	812.6				986.3	1022.3	1218.9	1437.4	2420.4			2518.6	2728.0

APPENDIX C (continued) - Subsurface well formation tops in Peel Plateau and Plain, NWT and Yukon

Unique Well Identifier (UWI)	Short Well Name	KB/RT	Cretaceous	Little Bear	Trevor	Arctic Red	Martin House	Tuttle	Imperial	Canol	Ramparts	Kee Scarp	Hare Indian	Bluefish Member	Hume	Landry	Arnica	Bear Rock	Fort Norman	Road River	Tatsieta	Peel	Mount Kindle	Franklin Mtn	Saline River	Mount Cap	Mount Clark	Pre-cambrian	Total Depth
300O656610132150	Weldon Creek O-65	222.8				3.8	524.3	565.7	585.8	1252.1				1310.6	1320.7	1460.0	1676.4				2015.3	2033.0							2214.4
300D086620133300	Sainville River D-08	203.0				7.9	485.9	711.6	929.9	1702.3				1730.7	1735.2	1883.7	2422.2				2446.3	2490.2							2651.8
300K636630133000	Sainville River K-63	138.7				18.3	320.0	413.4	431.3																				790.0
300H346630132000	Arctic Circle Ontaratue H-34	141.7				4.5	253.0		259.7	890.0				971.7	983.6	1101.9	1332.0				1591.1	1642.9	1836.4	2139.7	2883.4	2899.4		2923.0	4075.2
300G556650133000	Arctic Red West G-55	44.6				5.2	65.2	75.3	92.0	1103.4					1162.8	1269.8	1510.3				1752.0	1789.5	2064.1	2507.0		3285.7	3300.7		3322.3
300O276650132450	Arctic Red River O-27	136.6				4.9			118.9	1005.8			1034.8	1061.6	1072.6	1174.4	1396.0				1642.9	1657.2							2154.0
300L506650133150	Martin House L-50	88.0				21.3	97.5		112.8	1303.4					1362.0	1465.7	1683.0				1997.7	2027.6	2285.2						2407.9
300M056720134000	Nevejo M-05	74.4								1663.5					1696.8	1786.7	2074.8				2303.5	2347.7							2378.7
300B256720135301	McPherson B-25	492.3						462.1	1014.4	2914.8					2933.1		3041.4				3445.4	3552.7	3774.7	3993.6					4136.1
300C026730135300	Stoney Core Hole C-02	275.8																											177.0
300F426730135300	Stoney Core Hole F-42	327.7																											310.9
300I506730135150	Stony I-50	321.9					36.6		262.2	2115.3					2181.5	2240.9	2450.6				2600.5	2607.3	2706.6	2993.7					3343.0
300A056740134000	Pt. Separation no. 1 (A-05)	18.9							3.7	1554.5					1583.7	1658.7	2006.5				2092.5	2112.6	2286.0						2445.4
300C786740134000	Ft. McPherson C-78	19.8							440.7	1919.6					1941.9	2019.3	2188.2				2288.4	2361.6	2636.2	3009.3					3068.1
300G066740135150	Stony G-06	56.7							49.7	1548.4					1599.6	1664.2				1857.8		2081.8	2324.7						2529.8
300F576710132150	Tree River F-57	93.0							30.5	703.8				767.2	783.3	879.0	1118.6				1359.4	1527.0	1657.5						1979.2
300H576710132150	Tree River East H-57	108.2							30.5	719.9				794.0	804.7	903.4	1159.8				1402.1	1595.6	1708.4						1981.2
300F796710133000	Clare F-79	108.7							237.7	1112.9				1179.6	1197.6	1293.7	1524.5				1845.3	1878.8	2121.2	2484.9					2525.6
300K286710133300	Swan Lake K-28	89.6							93.9	1350.3					1423.7	1516.4	1801.4												1838.2
300H386720132150	Tree River H-38	79.6							82.3	731.5					777.2	791.0	1054.6												1279.2
300D076710130150	Moose Lake D-07	54.0											5.0	172.5	193.0	284.0	525.0					723.0	780.0	846.5					900.0
300A476710130450	Grandview Hills no. 1 (A-47)	369.5							33.5	233.5	267.6		286.5	472.4	479.8	571.5	844.3				975.4	1055.8	1205.2	1434.7					1998.0
300D396710131301	Ontaratue River D-39	244.5								544.0					649.0	741.0	1115.0				1205.0								1250.0
300B106720131451	Tree River B-10	188.1							45.0	518.0					577.0	660.5		1042.0						1163.0					1294.0
300C366720131451	Tree River C-36	135.0								739.5			776.5	832.0	840.5	937.0	1143.5				1464.0	1482.0	1591.0						1878.0
300N736730131151	Thunder River N-73	124.1							70.5						501.0	585.0		952.0						1061.0					1146.0
300A426550133001	Cranswick Y.T. A-42	620.1				6.7	1104.6	1170.4	1898.9	2108.0				ABS	2159.8	2549.0	3006.2				3047.1	3130.0	3350.1	3582.0					4267.2
300K156600133000	Taylor Lake Y.T. K-15	468.8				33.5	630.9	691.9	1052.2	1303.0				1352.7	1357.6	1524.0	1904.7				2057.4	2096.7	2315.9						2378.7
300M696610133450	Peel River Y.T. M-69	291.7				9.2	457.2	934.0	1813.6	2270.8				2286.0	2300.0	2430.8	3035.2				3080.3	3125.4							3272.6
300K096620134000	Peel River Y.T. K-09	349.5				3.7	749.8	830.3																					1554.5

APPENDIX C (continued) - Subsurface well formation tops in Peel Plateau and Plain, NWT and Yukon

Unique Well Identifier (UWI)	Short Well Name	KB/RT	Cretaceous	Little Bear	Trevor	Arctic Red	Martin House	Tuttle	Imperial	Canol	Ramparts	Kee Scarp	Hare Indian	Bluefish Member	Hume	Landry	Arnica	Bear Rock	Fort Norman	Road River	Tatsieta	Peel	Mount Kindle	Franklin Mtn	Saline River	Mount Cap	Mount Clark	Pre-cambrian	Total Depth
300I216620134150	Peel River Y.T. I-21	381.2						3.9	889.2	1407.6				1446.3	1451.5	1570.9													2072.6
300K766630134000	Peel River Y.T. K-76	76.5				4.0	362.7	451.0																					1386.8
300H716630134300	Peel Y.T. H-71	513.0	6.7					31.1	762.0	1807.5				1877.6	1886.4	2020.8					2633.5	2650.8	2783.1	3004.1					3419.6
300J216640134000	Peel River Y.T. J-21	45.7				3.9	253.0	341.0																					1219.2
300H596640134300	Peel River Y.T. H-59	33.4				3.8	217.9	296.0																					763.2
300L016640134450	Peel River Y.T. L-01	394.7				3.9	617.5	683.0	1785.8																				1834.9
300B066640134450	Peel River Y.T. B-06	65.2				2.7	254.5	332.8																					430.4
302B066640134450	Peel River Y.T. 2B-06	66.4				3.9	255.7	333.4																					1066.8
300H376640134450	Trail River Y.T. H-37	393.2				7.9	566.9	646.0	1844.0	2699.3					2704.8	2792.6					3485.1	3510.7							3721.6
300C606650133450	Arctic Red Y.T. C-60	92.0				5.2	83.8	157.0	192.9	1633.7					1672.1	1777.6	2174.4				2298.2	2329.9							2599.9
300L196650135150	Peel River Y.T. L-19	95.1						3.7	1045.2																				1981.2
300G726700134000	Satah River Y.T. G-72	89.6		3.7			9.1	168.0	290.7	1811.4					1874.8	1978.5													2286.0
300F376700134450	Peel Y.T. F-37	54.6				5.8	61.0	107.0	980.5	2254.9				2286.0	2288.1	2392.7	2824.6				2946.8	2983.1	3327.2						3368.0

ABS=absent; KB=kelly bushing elevation; RT=rotary table elevation

Data from: **Hogue, B.C. and Gal, L.P., 2008.** NWT Formation Tops for Petroleum Exploration and Production Wells: 60 to 80 N; Northwest Territories Geoscience Office, NWT Open Report 2008-002; and **Fraser, T.A. and Hogue, B.C., 2007.** List of Wells and Formation Tops, Yukon Territory, version 1.0; Yukon Geological Survey, Open File 2007-5.

APPENDIX D - List of cored intervals for wells in Peel Plateau and Plain

Unique Well ID	Well	Total depth (m)	Saline River	Ronning Group		Peel	Arnica	Arnica-Bear Rock	Fort Norman	Landry	Hume	Horn River Group			Imperial	Tuttle	Tukweye	Martin House	Arctic Red
				Franklin Mountain	Mount Kindle							Hare Indian	Ramparts	Canol					
300O276650132450	Arctic Red River O-27	2154.0					1581.3-1590.1												
300G556650133000	Arctic Red West G-55	3322.3		2653.6-2662.7															
300C606650133450	Arctic Red Y.T. C-60	2599.9					2055.0-2072.0												
300F796710133000	Clare F-79	2525.6																	
														1171.7-1175.3					
											1195.4-1219.5								
											1229.0-1235.0								
											1250.6-1309.7								
										1309.7-1311.6									
										1351.8-1382.3									
										1512.7-1528.0									
							1691.6-1706.9												
							1739.5-1762.4												
							1786.1-1793.7												
						2067.2-2080.2													
				2520.1-2525.6															
300A226540131450	Cranswick A-22	2869.1									1219.2-1249.1								
						1842.8-1860.2													
					2091.5-2097.6														
300A536610129000	Hume River A-53	1158.2											242.6-264.0						
300D536600129000	Hume River D-53	1267.6											491.6-509.9						
							1140.3-1155.5												
300L096530129300	Hume River L-09	2606.0									1637.7-1642.9								
300H796630128450	Loon River No. 1 (H-79)	299.9								288.3-299.9									
300L616630128450	Manitou Lake L-61	1724.3					665.1-669.6												
			1697.7-1716.3																
300L506650133150	Martin House L-50	2407.9									1423.4-1438.7								
										1481.3-1497									
							1683.7-1699.4												
							1929.9-1943												
							1954.3-1962.5												
									1998.3-2001.9										
300H476550129000	Mountain River H-47	1044.5											205.7-211.8						
							748.3-766.6												
					1036.3-1044.5														

APPENDIX D (continued) - List of cored intervals for wells in Peel Plateau and Plain

Unique Well ID	Well	Total depth (m)	Saline River	Ronning Group		Peel	Arnica	Arnica-Bear Rock	Fort Norman	Landry	Hume	Horn River Group			Imperial	Tuttle	Tukweye	Martin House	Arctic Red
				Franklin Mountain	Mount Kindle							Hare Indian	Ramparts	Canol					
300O186540129000	Mountain River O-18	1120.0			1075.0-1092.0														
							789.0-796.8												
													146.0-157.4						
													194.0-266.0						
300H346630132000	Ontaratue H-34	4075.2					1370.1-1388.4												
300I386620131450	Ontaratue I-38	2287.5								1204.0-1219.2									
300M05672013400	Nevejo M-05	2378.7									1756.1-1797.9								
										2024.4-2038.7									
							2244.5-2261.6												
						2365.9-2379.3													
300H716630134300	Peel Y.T. H-71	3392.1		3186.7-3196.1															
300M696610133450	Peel River Y.T. M-69	3272.6								2607.3-2631.6									
300A056740134000	Pt. Separation No. 1 (A-05)	2445.4												1575.2-1582.2					
											1606.3-1615.4								
										1739.5-1999.5									
							2083.9-2089.4												
						2205.2-2212.8													
					2334.5-2340.6														
					2432.3-2436.3														
					2438.4-2445.4														
300I556620128300	Ramparts No.1 I-55	470.6									288.3-294.4								
300H246550128451	Sans Sault No. 1 (H-24)	1003.1											430						
													521.3-526.8						
												592.1-607.0							
												771.6-777.1							
											848.2-854.0								
300G726700134000	Satah River Y.T. G-72	2286.0								1981.2-1991.9									
300C316600128450	Shoals C-31	1981.2								865.6-876.3									
300D646600132151	South Peel D-64	1985.5					1971.1-1985.5												
300G066740135150	Stony G-06	2529.8								1674.3-1688.9									
300I506730135150	Stony I-50	3343.0								2260.4-2275.6									
										2313.1-2315.5									
							2461.6-2462.8												
					2725.6-2733.2														
				3085.2-3092.8															
				3335.1-3343.1															
300D726630129000	SW Airport Creek No. 1 (D-72)	726.9											112.8-121.9						
											413.0-416.7								
										594.4-598.9									

APPENDIX D (continued) - List of cored intervals for wells in Peel Plateau and Plain																			
Unique Well ID	Well	Total depth (m)	Saline River	Ronning Group		Peel	Arnica	Arnica-Bear Rock	Fort Norman	Landry	Hume	Horn River Group			Imperial	Tuttle	Tukweye	Martin House	Arctic Red
				Franklin Mountain	Mount Kindle							Hare Indian	Ramparts	Canol					
300H576710132150	Tree River East H-57	1981.2					1198.5-1291.7												
							1393.9-1486.5												
300H736540129000	Whirlpool No. 1 (H-73)	1955.9													244.8-248.4				
													291.4-296.9						
												498.0-502.6							
										803.1-808.6									
								865.6-981.5											
				1387.8-1598.4															
300L016640134450	Peel River Y.T. L-01	1834.9														1315.2-1321.3			
																1357.9-1367.0			
																1531.9-1845.9			
300K096620134000	Peel River Y.T. K-09	1554.5														1338.1-1340.2			
300J216640134000	Peel River Y.T. J-21	1219.2														614.8-617.8			
																894.3-1202.1			
300H596640134300	Peel River Y.T. H-59	763.2														578.8-588.0			
300I66660012930	Hume River I-66	745														494.65-524.6	477.6-494.65	471.5-477.6	456.0-471.5
300D08662013330	Sainville River D-08	2652														573.5-577.0		559.0-573.5	

Chapter 2 – Regional Structure of Peel Plateau and Plain

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ABSTRACT

Peel Plateau and Plain (Peel area) encompasses segments of three main tectonic elements: the Northern Interior Platform, Mackenzie Fold Belt, and Richardson Anticlinorium. In Peel area, major tectonic events have been recorded by pronounced unconformities and facies trends throughout Proterozoic and Phanerozoic strata, and by late Mesozoic-early Cenozoic, large-scale folding and faulting in the adjacent Cordilleran Fold Belt. For the most part, Peel area is underlain by largely undeformed Phanerozoic strata, but the southern portion of the study area is marked by a profound change in structural style from broad anticlines with intervening narrow synclines in the northern Mackenzie Mountains, to linear and narrow ridges in the northern Franklin Mountains. Although south-vergent structures are observed locally, the Mackenzie Mountains are dominated by north to northeast-vergent thrust faults and commonly expose Proterozoic strata in the core of broad anticlines. To the east-northeast, the northern Franklin Mountains are marked by drape folds, reversal of fold asymmetry and direction of faulting, and expose no strata older than Cambrian Saline River Formation. The marked contrast in style between the two belts has been attributed to a migration of the detachment surface from a deep structural level beneath the hinterland to a shallower one toward the foreland. Instrumental in the development of the contrasting structural style was the regional depositional edge of Cambrian Saline River evaporites.

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INTRODUCTION

The geometry and regional distribution of lithostratigraphic units in the northern Interior Platform and Mackenzie Fold Belt are products of a complex history of depositional and tectonic events from Proterozoic to Cenozoic time. In Peel Plateau and Plain (Peel area) major tectonic events have been recorded by pronounced unconformities and facies trends throughout the Proterozoic and Phanerozoic succession, and by late Mesozoic-early Cenozoic, large-scale folding and faulting in the adjacent Cordilleran Fold Belt.

This paper provides an overview of the structural framework of Peel area including the contiguous northern Mackenzie Mountains, Mackenzie Plain, and northern Franklin Mountains (Figures 1, 2) based on field data, geological sections, and interpretation of reflection seismic sections that highlight variations in structural style across the area. Deformation and structures related to the late Cretaceous-Paleocene Laramide orogeny are discussed. Pre-Mesozoic structures and tectonics are addressed briefly.

GEOLOGIC SETTING

Peel area encompasses segments of three main tectonic elements: the Northern Interior Platform, Mackenzie Fold Belt, and Richardson Anticlinorium (Figure 2; Norris, 1997). The Northern Interior Platform consists of relatively undeformed flat-lying to west-dipping Phanerozoic strata. These overlie a thick (up to 14 km) succession of Proterozoic strata deformed by crustal scale faults that were reactivated episodically throughout Paleozoic and Mesozoic time, and possibly during the Laramide orogeny (Cook and MacLean, 2004). Only locally have folds and faults been mapped in outcrop or interpreted from seismic reflection data (e.g., Kunst, 1973; Aitken et al., 1982; Cook and MacLean, 2004).

The Mackenzie Fold Belt, the northern segment of the Foreland Belt of the Canadian Cordillera, extends for approximately 950 km north of the 60th parallel. It is marked by east- to northeast and west- to southwest-directed broad box folds, thrust faults and associated oblique-slip faults. Near the 60th parallel its structural elements strike to the north, but near Peel area swing to the west-northwest, outlining an arcuate trend called the Mackenzie Arc (Aitken and Long, 1978). This arcuate geometry of first order structures is believed to have been controlled by the configuration of the Proterozoic margin (e.g., Aitken and Long, 1978).

The Mackenzie Mountains, which occupy the western part of the Mackenzie Fold Belt, are dominated by fold bundles with associated strike-slip transfer faults (Figure 2). The folds are parallel and concentric in style; they regionally display left-lateral *en échelon* geometry (Norris, 1972) and likely developed above a detachment within Proterozoic strata (Aitken et al., 1982). Near Peel area (Figure 2), steeply dipping north- and south-vergent contractional faults disrupt the folds. With the exception of the Deadend and Tabasco faults (see Structural Geology section), displacement along these faults is generally small. Well-developed transfer faults with predominant north- to northwest strike offset Proterozoic and Paleozoic strata in the Canyon Ranges (Figure 2).

The Franklin Mountains form the easternmost limit of the Mackenzie Fold Belt and consist of a series of narrow and isolated, linear to arcuate ridges separated by broad, flat-bottomed synclines underlain by recessive Cretaceous strata (Figures 2, 3). They are separated from the Mackenzie

Mountains by the Mackenzie Plain, a broad drift-filled valley along which the Mackenzie River is entrenched (Figure 1). The Franklin Mountains expose no strata older than Cambrian Saline River Formation, a structurally weak layer that acts as a regional detachment (Cook and Aitken, 1973). Dominant structures typically trend northwest-southeast, mimicking those of the Mackenzie Mountains, but swing sharply to the west and southwest near the Mackenzie River and Carcajou Ridge (Figures. 2, 3). Structures of the Franklin Mountains merge with those of the Mackenzie Mountains at Southbound and Ovis ridges (Figure 3).

The Richardson Anticlinorium, a broad north-northwest-trending structure, forms a narrow and linear range of low mountains bordering the west side of Peel area. It is cut by an array of near-vertical, north-trending, curviplanar faults of regional extent assigned to the Richardson Fault Array (Figure 2; Norris, 1997). The eastern limit of the Richardson Anticlinorium is marked by the Trevor Fault, east of which lays Peel Plateau and Plain, where no major structures have been mapped (Figure 2). The Anticlinorium coincides in position with the early and middle Paleozoic Richardson Trough (Norris, 1985).

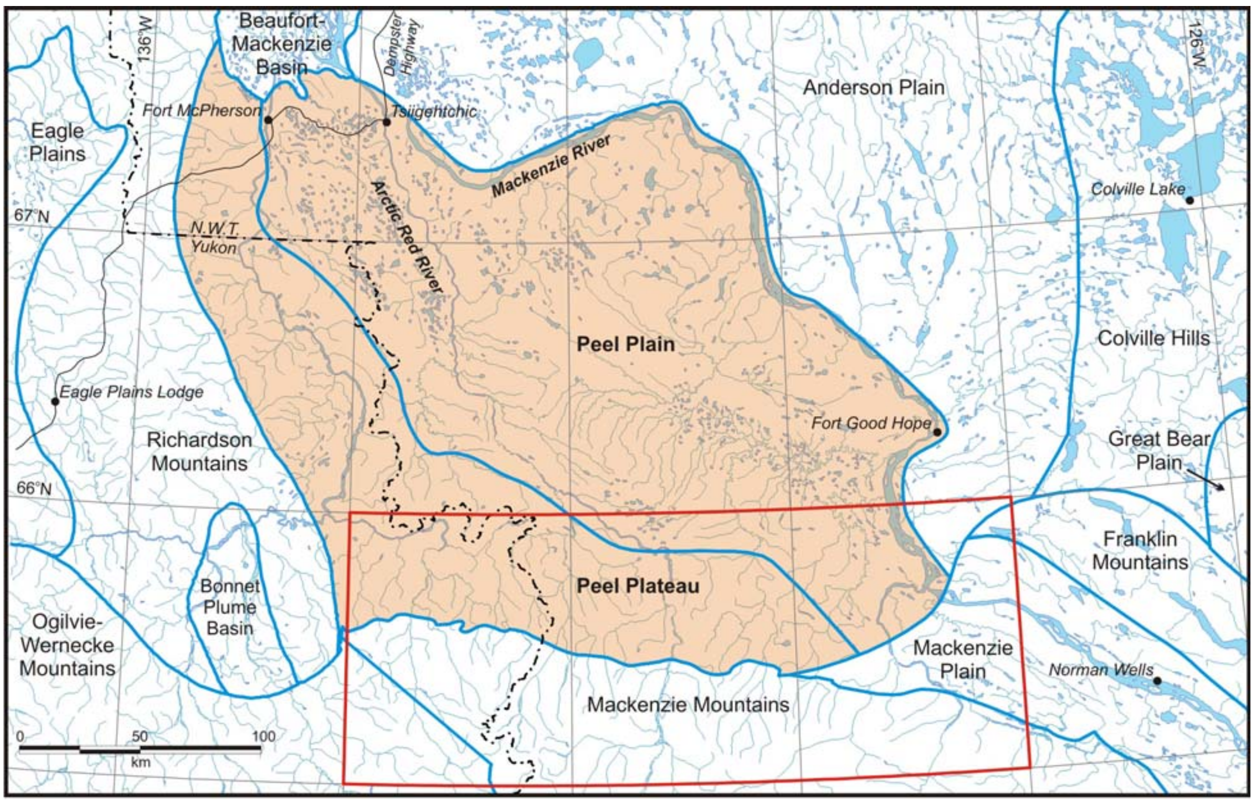


Figure 1. *Physiographic elements of Peel area (project area coloured; after Mossop et al., 2004). The red polygon highlights the extent of Figure 3.*

STRUCTURAL GEOLOGY

Peel area encompasses three subregions of distinct structural styles, namely the northern Mackenzie Mountains, the northern Franklin Mountains and Mackenzie Plain, and the Peel Plateau and Plain. The following sections describe the main structures of these subregions, focusing on Laramide structural elements. The effect of antecedent faults on the development of Laramide structures is briefly discussed.

Structural Elements of the Northern Mackenzie Mountains

Deadend Fault

The Deadend Fault, a major north-northeast-vergent thrust some 170 km long, defines the front of the Mackenzie Mountains between Arctic Red River and Ramparts River (Figures 3, 4; Aitken et al., 1982). East of Ramparts River, the fault defines the northern flank of the Tawu Anticline before merging into the southern flank of the Stony Anticline. Along most of its length, the Deadend Fault juxtaposes Proterozoic strata in the hanging wall against Paleozoic carbonate. The fault is well exposed along the mountain front near Arctic Red River, where it places quartz sandstone of Proterozoic Katherine Group over dolostone of Devonian Arnica Formation (Figure 5). Here, probable hydrothermal dolomite, marked by medium crystalline and slightly vuggy dolomitic rocks was observed within Arnica Formation in the immediate footwall of the fault zone (Chapter 6, this volume). This observation suggests that faults associated with Laramide deformation may have acted as conduits for fluids and caused alteration of surrounding carbonate strata.

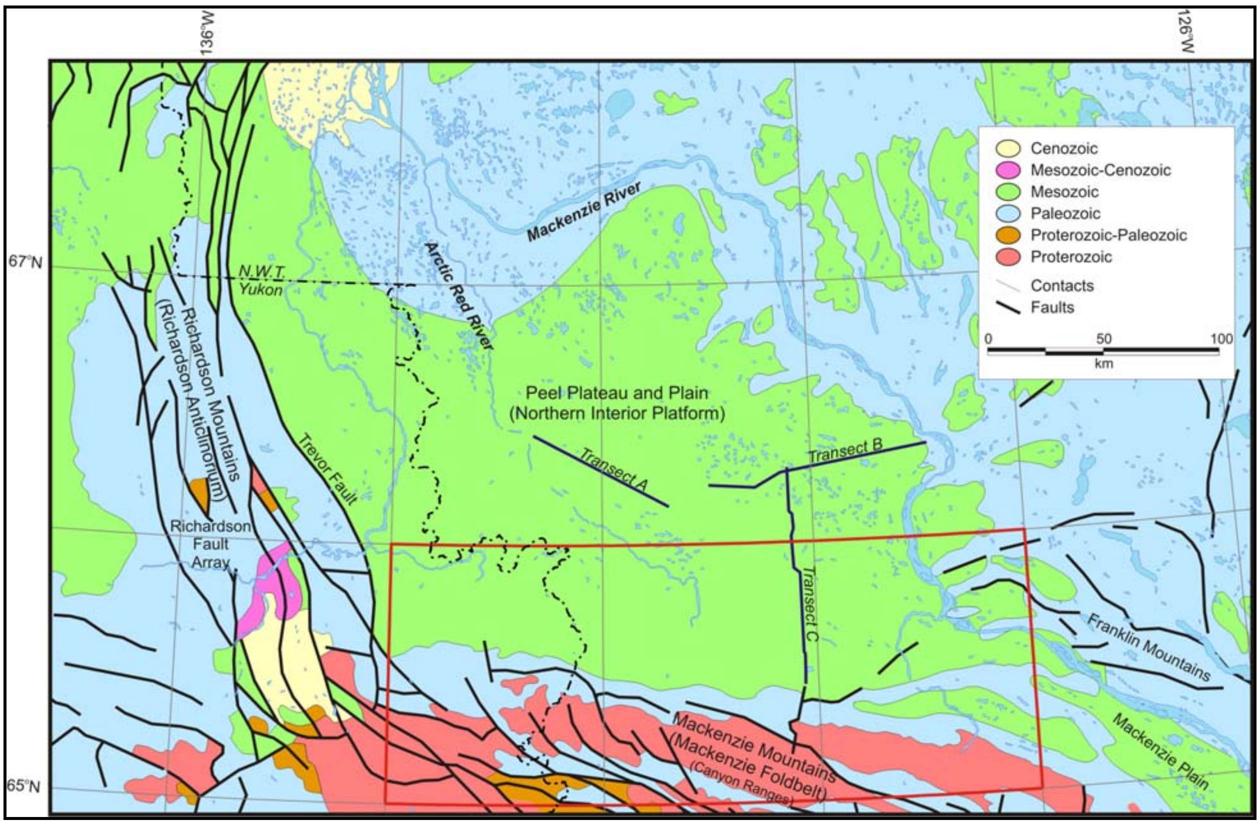


Figure 2. *Simplified geological map of Peel area and the northern Mackenzie Mountains. The red polygon highlights the extent of Figure 3. See Appendix A and Pierce and Jones (2009) for transects A through C. Geology after Wheeler et al. (1997).*

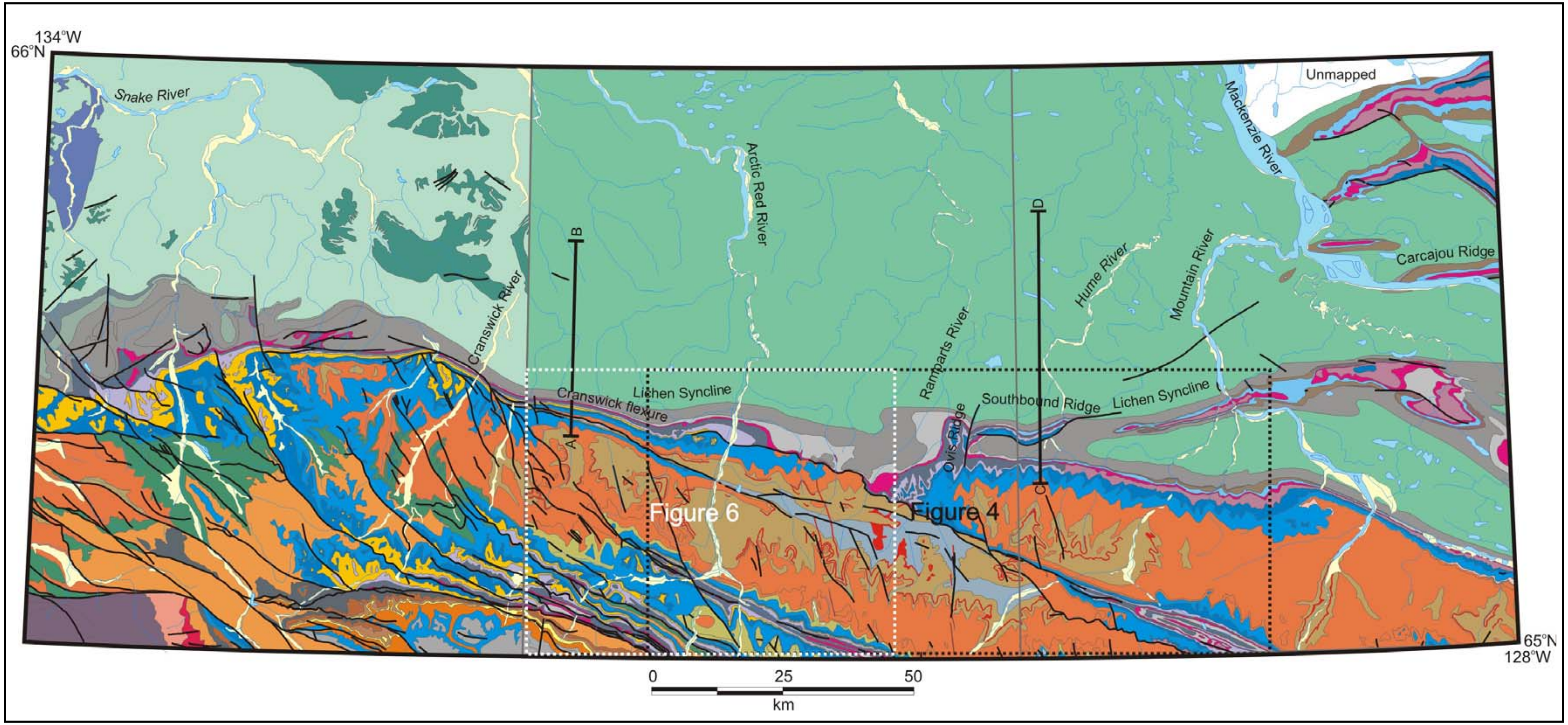


Figure 3. *Detailed geological map (and legend) of southern Peel Plateau and Plain and the northern Mackenzie Mountains, including (from east to west): Map 1453A, Sans Sault Rapids; Map 1452A, Upper Ramparts River; and Map 1529A, Snake River. Map shows the location of Figure 4 (black dotted outline), Figure 6 (white dotted outline), and Sections AB and CD (see Appendix B, Pierce and Jones, 2009). Geology after Aitken et al. (1982) and Norris (1982).*

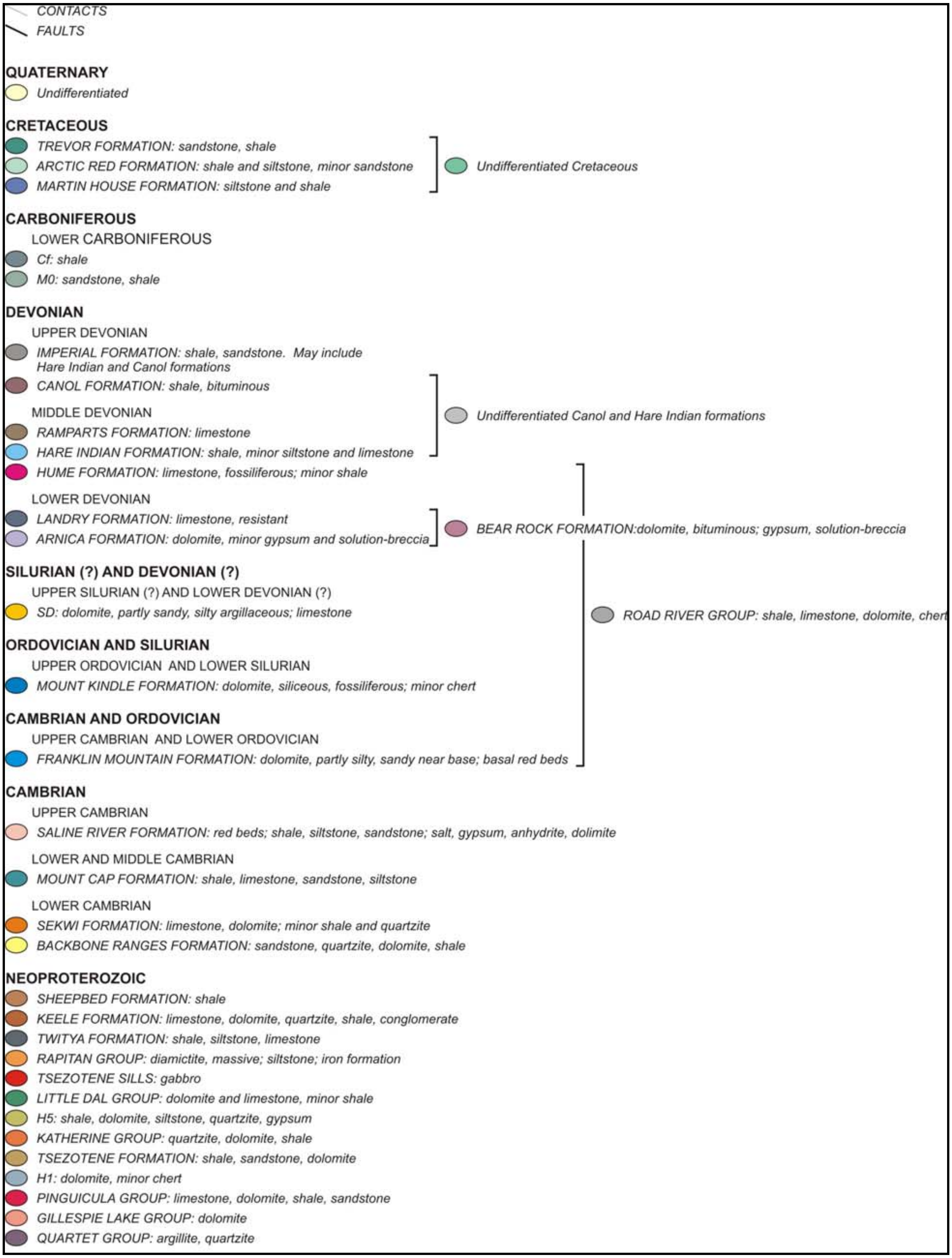


Figure 3. *Continued (legend for Figure 3 map).*

At a few localities, the Deadend Fault intersects a steep north-side-down normal fault (Figure 5). The extensional structure, termed Arctic Red fault (Lemieux et al., 2007), juxtaposes limestone of Landry Formation against dolostone of Arnica Formation; stratigraphic offset across the Arctic Red fault suggests a minimum throw of 200 m. Preliminary interpretation suggested the extensional fault to intersect the Deadend Fault (Lemieux et al., 2007) based on crosscutting relationships within the Arctic Red fault zone. On the basis of detailed mapping, the fault is re-interpreted here as an antecedent, post-Lower Devonian-pre-Laramide feature (this study). Although its exact timing remains poorly understood, it may have developed during pre-Cretaceous/post-Devonian reactivation of regional tectonic elements along the northern Franklin Mountains and northern Mackenzie Mountain front (see below; e.g., Cook and MacLean, 2004). Crosscutting relationships described by Lemieux et al. (2007) may indicate minor post-Laramide reactivation.

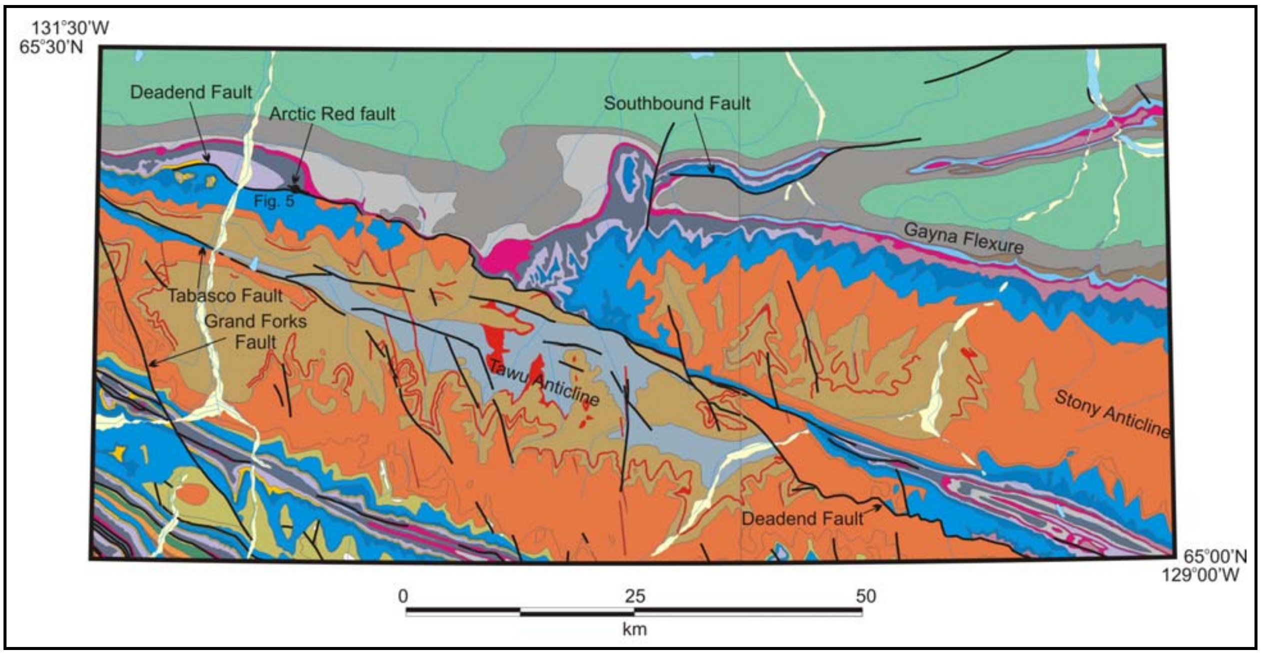


Figure 4. *Detailed geological map showing the structural elements in the northern Mackenzie Mountains. Figure shows the location of Figure 5. Geology after Aitken et al. (1982). See Figure 3 for location and legend.*

Tabasco Fault

The Tabasco Fault is a north-northeast-dipping contractional fault exposed on the northern flank of the Tawu Anticline (Figure 6). Along most of its length of about 70 km, it places Proterozoic strata of Katherine Group and Tsezotene Formation over lower Paleozoic carbonates of Arnica, Mount Kindle, and Franklin Mountain formations. Several localities were studied along the Tabasco Fault (Lemieux et al., 2007). Although generally covered by rubble or vegetation, the fault is locally well exposed (Figure 7). At one such place (Figure 7b), the fault zone is 5 m wide and marked by abundant fault breccia, slickensides, and steeply-dipping (approximately 60^{o}) discrete fault planes. The Tabasco Fault is one of the few hinterland-vergent structures exposed in the northern Mackenzie Mountains. It was interpreted by Vann et al. (1986) as a major backthrust overlying a duplex that involves largely Proterozoic strata, and was inferred to have accommodated most of the shortening at the mountain front.

Interpretation of subsurface data along the Mackenzie Mountain front at the Cranswick Flexure (Figure 3), however, revealed the occurrence of a buried foreland-vergent duplex structure on the foreland side of the Tabasco Fault that involves largely Paleozoic strata (this study; see Section AB located on Figure 3, in Appendix B). The bedding-parallel sole thrust of the duplex appears to be localized near the base of the Paleozoic succession; the hinterland-directed, bedding-parallel roof thrust occurs within the lower portion of the Cretaceous clastic succession. Jamison (1993) argued that backthrusts in active fold-and-thrust systems may be ephemeral features, and that the progressive advance of a mountain front may lead to the abandonment of major backthrusts and formation of new backthrusts, or alternatively to formation of foreland-directed thrusts. Thus, the "blind" duplex inferred near the Cranswick Flexure, unlike the Tabasco Fault, has probably accommodated substantial shortening.

Toward the hinterland, it is likely that the sole detachment of the duplex ramps down across Proterozoic rocks, linking with the "deep" detachment inferred by Aitken et al. (1982) beneath the northern Mackenzie Mountains.

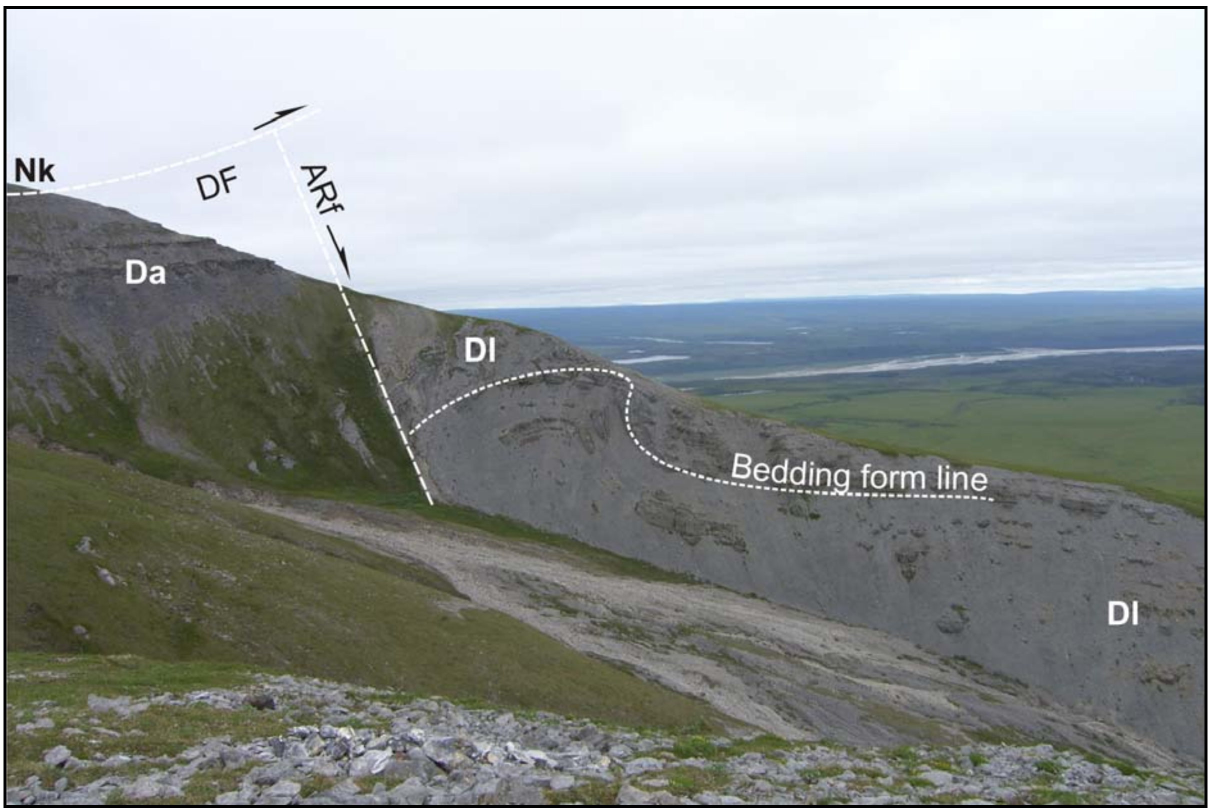


Figure 5. *Westerly view of the Deadend Fault (DF) in the vicinity of the Arctic Red River (in background) where the fault defines the front of the Mackenzie Mountains. The photograph shows the trace of the informal "Arctic Red fault" (ARf). Da = Arnica Formation; Dl = Landry Formation; Nk = Katherine Group. Field of view (middle ground) is approximately 300 m. See Figure 4 for location of photo.*

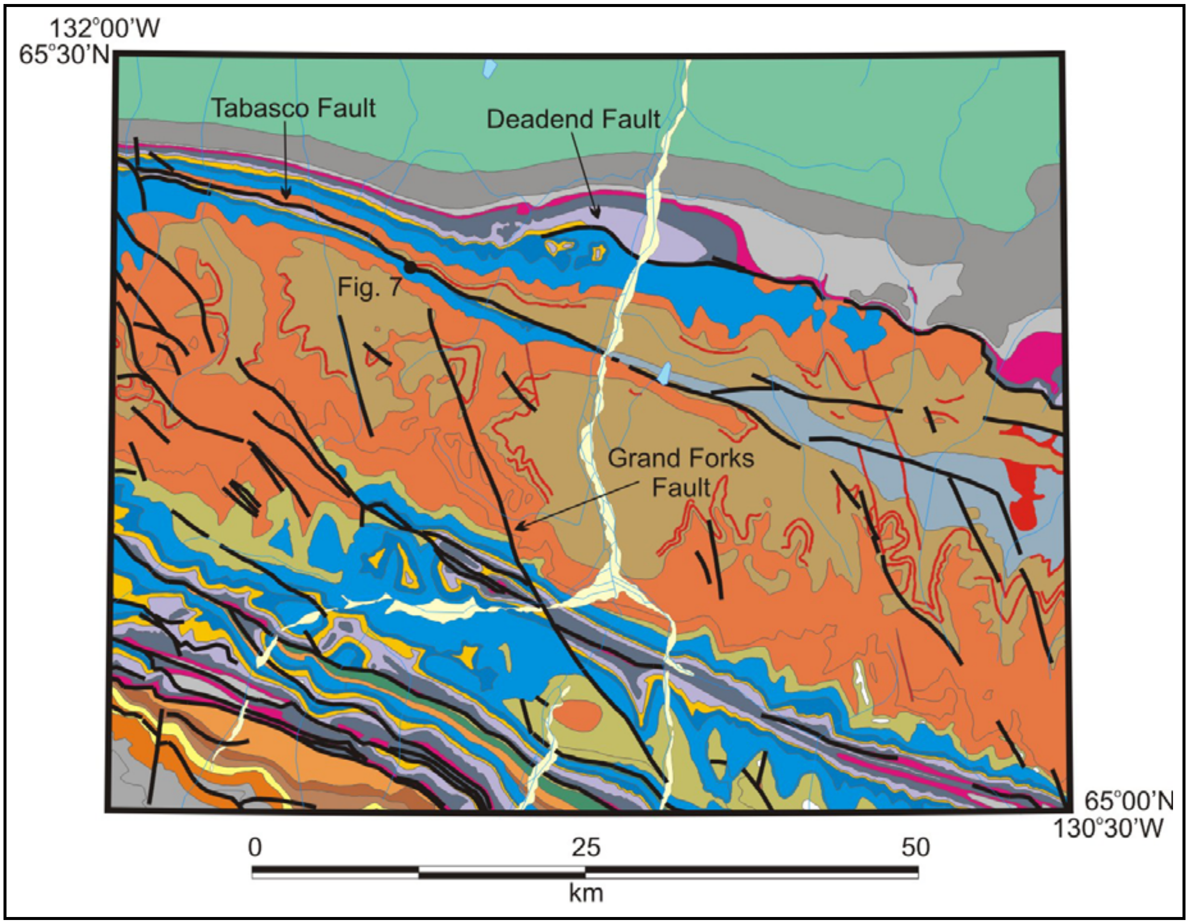


Figure 6. *Detailed geological map of the Arctic Red River area of the northern Mackenzie Mountains. Tabasco and Deadend faults are discussed in the text. Figure shows the location of Figure 7. Geology after Aitken et al. (1982). See Figure 3 for location and legend.*

Flyaway Creek Section

Flyaway Creek, located 8 km east of the Cranswick River, exposes a semi-continuous section from carbonate strata of the Ordovician-Silurian Mount Kindle Formation to Cretaceous clastic rocks of Martin House Formation (Figure 8). The structurally complex section exposed on the valley-side bluffs and contiguous ridges for over 6 km features several generations of extensional and contractional faults (Norris, 1982). Detailed mapping along Flyaway Creek (Lemieux et al., 2007) recorded moderate- to steeply dipping normal faults and hinterland-vergent thrust faults (lower portion of Figure 8), as well as abundant bedding-parallel, reverse slip planes. In several places contractional faults repeat portions of the stratigraphic succession.

Along the ridge, the southernmost portion of the section exposes two normal faults cutting across Lower Paleozoic carbonate rocks (see lower portion of Figure 8). Stratigraphic offset across the faults suggest a maximum throw of a few hundred metres. At the north end of the ridge, a thrust fault brings dolostone of Peel Formation (labeled “SD” on lower portion of Figure 8) over limestone of Landry Formation. This hinterland-directed thrust, unnamed on Norris’ Map 1529A (1982), is likely the western termination of the Tabasco Fault.

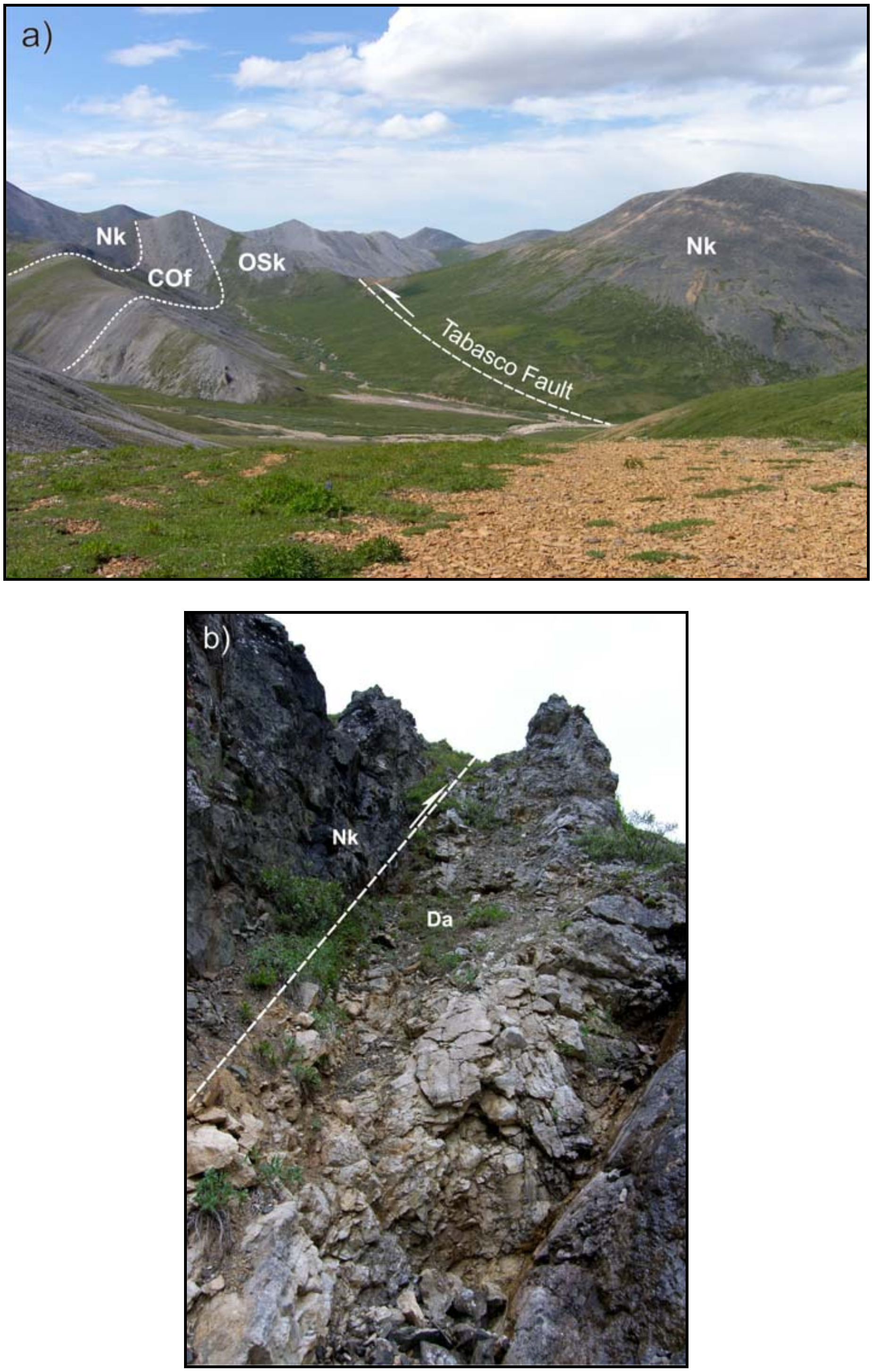


Figure 7. *a) View to the northwest of the Tabasco Fault, one of the few hinterland-vergent structures exposed in the northern Mackenzie Mountains. Fine dotted lines highlight stratigraphic contacts. Nk = Katherine Gp; COf = Franklin Mountain Fm; OSk = Mount Kindle Fm. Field of view in valley is approximately 400 m. See Figure 6 for location of photo; b) Close-up of the Tabasco fault zone showing the 5 m wide fault zone marked by abundant fault breccia and steeply-dipping discrete fault planes. Da = Arnica Formation; Nk = Katherine Group. View to the east. Horizontal field of view is approximately 5 m.*

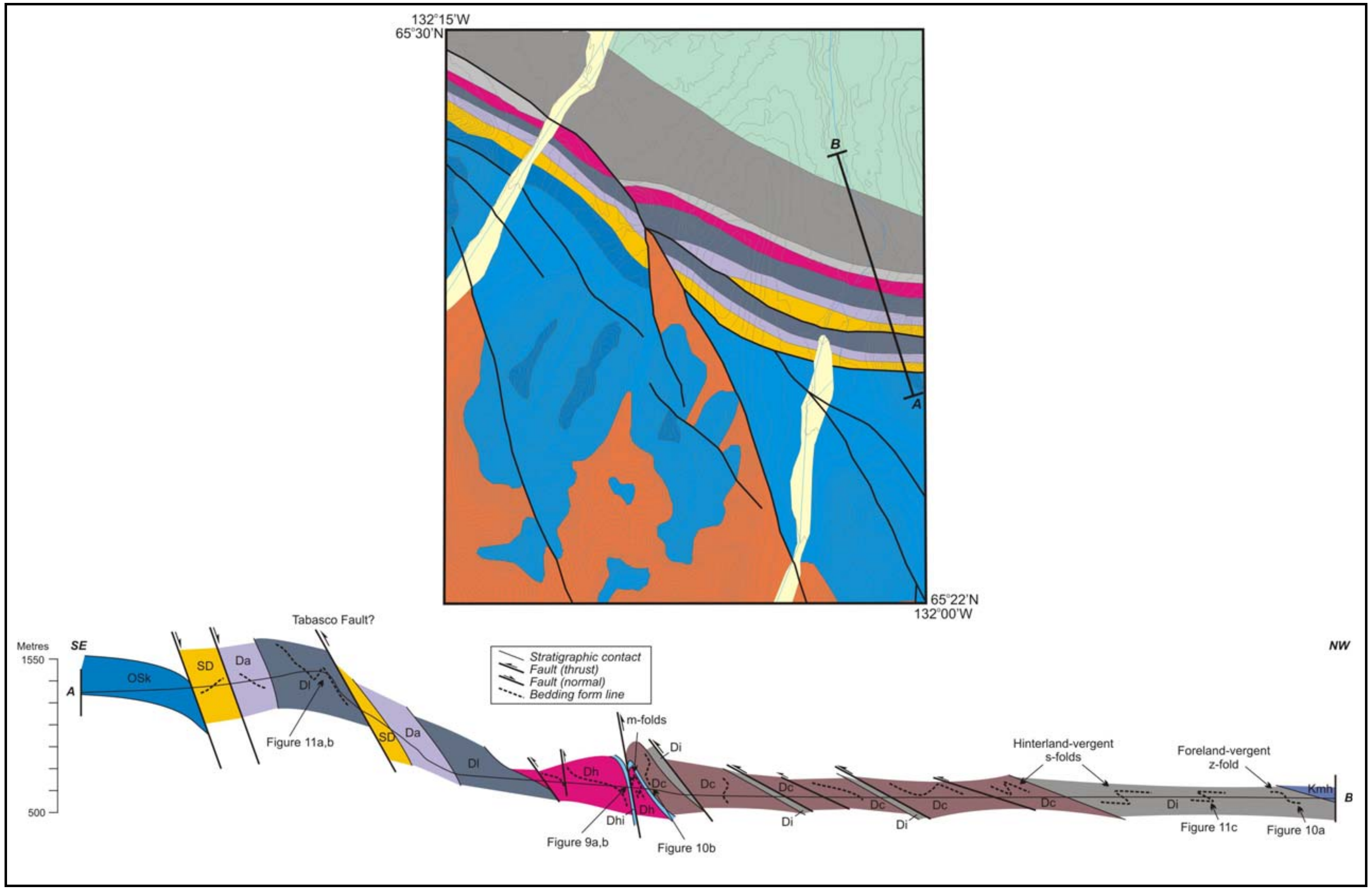


Figure 8. *Upper: Geological map of the Flyaway Creek area, showing the line of section A-B. Geology after Norris (1982). Here, Imperial Formation (in dark grey) includes Canol Formation (as shown on Map 1529A of Norris, 1982). Lower: Diagrammatic cross-section showing the structural relationships along the section mapped at Flyaway Creek. In this section, Canol Formation has been mapped separately. The structurally complex section features several generations of extensional and contractional faulting. Detailed mapping recorded moderate to steeply dipping normal faults and hinterland-vergent thrust faults. Vertical exaggeration is approximately 3:1. See Figure 3 for legend.*

The northern segment of the section displays many moderate and steeply dipping, hinterland-vergent thrust faults. The best exposed fault (Figure 9) places limestone of Hume Formation above strata of Bluefish Member (Hare Indian Formation); extremely fissile, black and bituminous shale of Bluefish Member likely acted as the detachment horizon. Here, the immediate hangingwall is marked by tight upright folds (Figure 9b), suggested by variable facing directions. To the north, several faults place competent, shaly intervals of Canol Formation above less competent, thin (less than 50 m thick) horizons of Imperial Formation. Canol Formation, dominated by grey to black, hard and siliceous shale, has distinctive blocky fractures. Incompetent, fissile shale at the base of Canol Formation, however, appears to have provided a detachment surface for these faults. Displacement along these faults is difficult to estimate as they are mostly bedding-parallel, but are likely in the order of hundreds of metres.

Two phases of folding have been recognized along the section. The earliest (?) phase is characterized by foreland-vergent, outcrop scale kink-like structures (Figure 10). The folds are open, have amplitudes and half-wavelengths of a few metres, and resemble foreland dipping monoclines (Figure 10a); these are common structures in thrust fronts (e.g., Morley, 1986). In some cases, the kink folds have been reoriented by later deformation (Figure 10b). The second, most prominent phase of folding is marked by hinterland-directed, mesoscopic folds ranging from open and moderately inclined to isoclinal and recumbent (Figure 11). Along the ridge, in the footwall of the Tabasco Fault (?), chevron-like folds are developed within resistant limestone of Landry Formation with the largest folds having amplitudes and half-wavelengths of a few tens of metres (Figures 11a, b). The south-dipping axial surface of some folds (e.g., Figure 11b) suggests some degree of reorientation. The folds become isoclinal, recumbent, and smaller in less competent lithologies, such as in Imperial Formation, with amplitudes and half-wavelengths of less than a metre (Figure 11c). Alternatively, the fold in Figure 11c could represent an overturned limb of a tight recumbent syncline.

In summary, detailed fieldwork along Flyaway Creek has demonstrated that a structurally thickened succession (> 250 m) of Canol Formation shale is present locally in the subsurface of the frontal Mackenzie Mountains. This has important implications for petroleum exploration as organic-rich Canol Formation has excellent source rock potential throughout the study area (Gal et al., 2007; Chapter 10, this volume).

Pre-Laramide structural elements

The ca. 780 Ma Tsezotene sills form an array of gabbro sheets within the core of the Tawu and Stony anticlines near the front of the Mackenzie Mountains in the Arctic Red River area (Figure 12a; Aitken et al., 1982; Ootes et al., 2008). The sills range in thickness from 10 m to 50 m. They are generally bedding concordant and confined to Proterozoic Tsezotene Formation. Aitken et al. (1982) also mapped one sill intruding the contact between Tsezotene Formation and underlying map unit H1. Gabbroic dykes up to 60 m wide and similar to the Tsezotene sills are rare but were observed to intrude strata of Little Dal Group, Katherine Group, Tsezotene Formation, and map unit H1 (Figure 12b). The dykes commonly strike north-northwest (N340^{o} to N355^{o}) and have steep dips. They possibly intruded along antecedent and regionally extensive fault systems of pre-Rapitan age (pre-Windermere Supergroup; Aitken and Cook, 1974; Aitken et al., 1982) or, alternatively, accompanied faulting of the Mackenzie Mountains Supergroup (Ootes et al., 2008).

Figure 9. *a) View to west of the thrust fault at Flyaway Creek. Solid line shows the fault plane. The dotted line highlights the approximate contact between Hume Formation (in the shade) and black shale of Bluefish Member (Hare Indian Formation). The interval between the black shale and Hume Formation in the immediate hangingwall of fault is rubble-covered. Backpacks (circled) in the foreground for scale. b) View to east of the fault zone at Flyaway Creek showing tight folding within the fault zone. Solid line is main fault plane; dashed line is a splay of the main fault. Dotted line is a bedding form line. Dh = Hume Fm; Dbf = Bluefish Mbr; Dhi = Hare Indian Fm. Horizontal field of view is approximately 6 m. See Figure 8 for location of both photographs.*

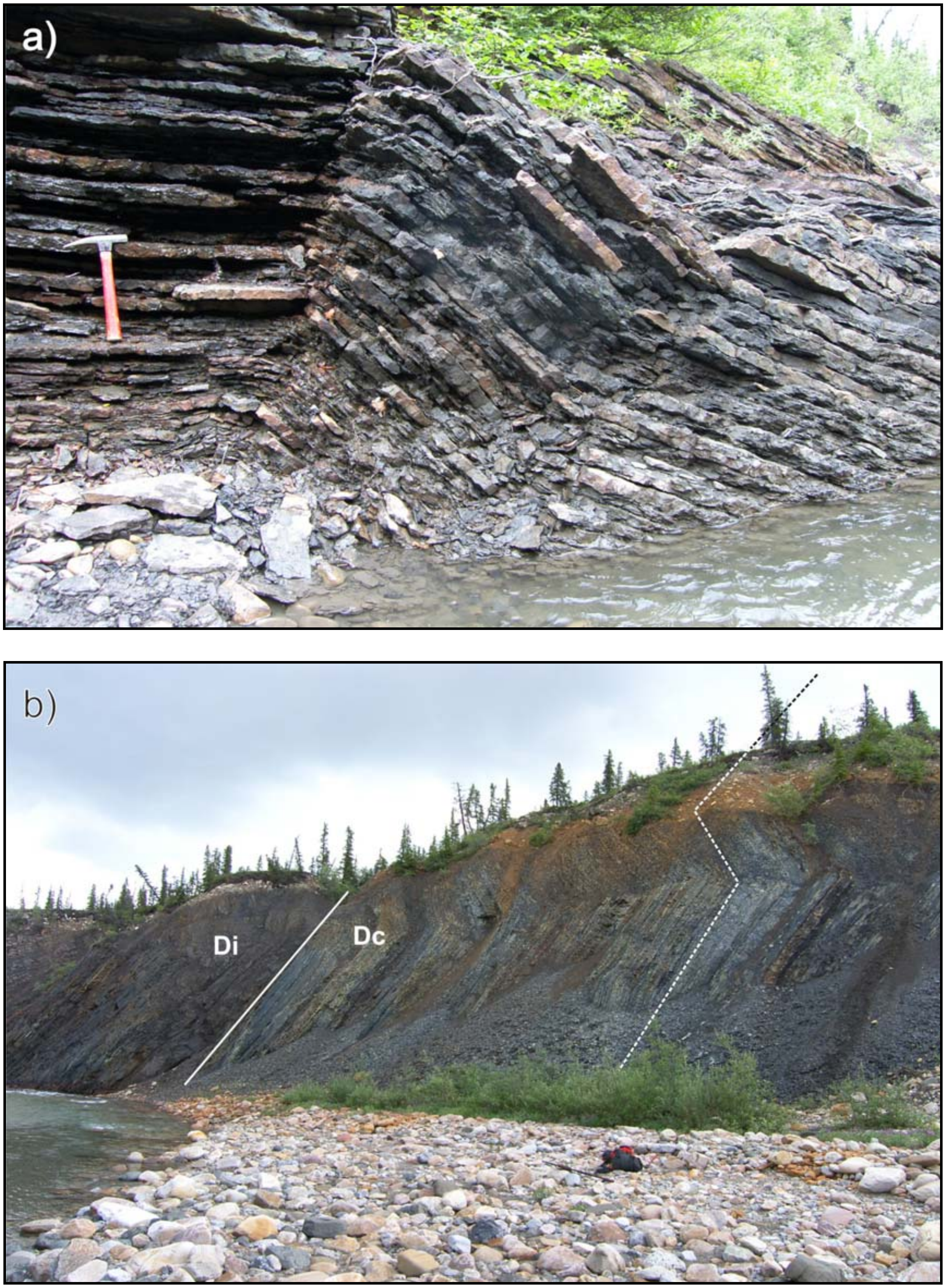


Figure 10. *a) View to west of foreland-directed, kink-like fold in Imperial Formation. Folding is akin to a frontal monocline. b) View to east of foreland-directed fold at Flyaway Creek; the steeply dipping beds suggest they have been reoriented. Dashed line highlights a bedding form line within Canol Formation (Dc). Solid line shows the approximate contact between Canol and Imperial (Di) formations. Backpack in the foreground for scale. See Figure 8 for location of both photographs.*

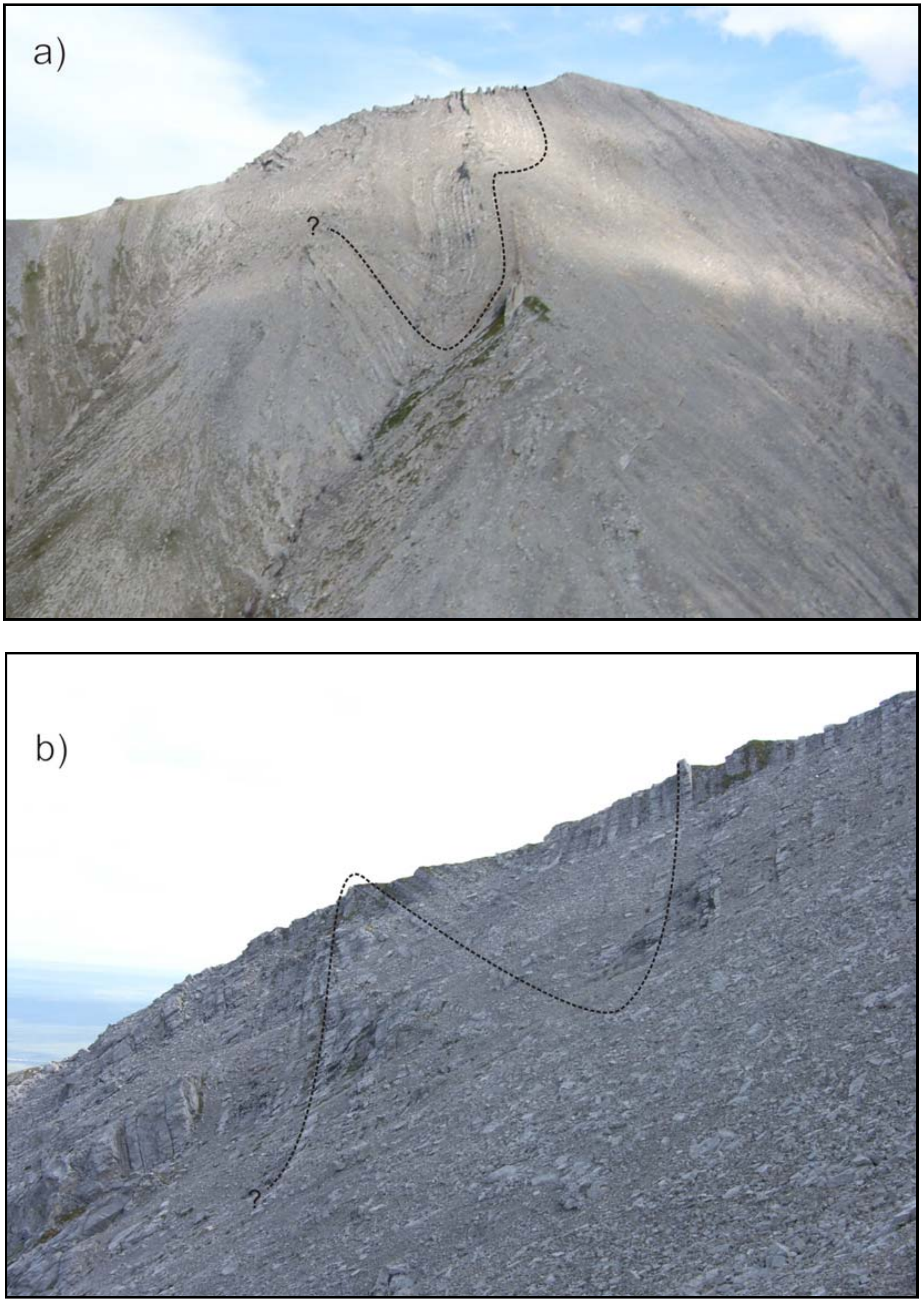


Figure 11. *a) Deformation in Landry Formation at the Mackenzie Mountain front. View is to the east. Dashed line corresponds to a bedding form line. Field of view is approximately 500 m; b) Hinterland-directed folding in Landry Formation at the Mackenzie Mountain front. The orientation of the axial surface, which dips to the south, suggests some degree of reorientation. View is to the east. Dashed line corresponds to a bedding form line. Field of view is approximately 100 m.*

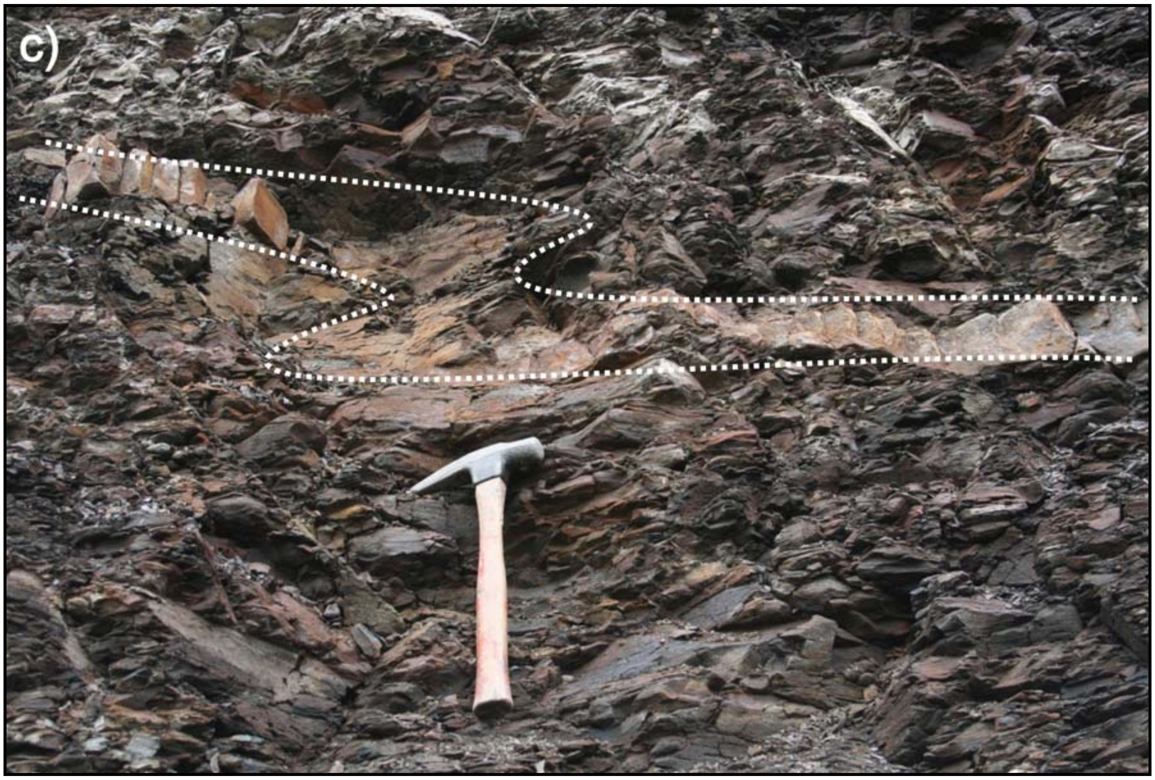


Figure 11. *Continued. c) View to east of tight hinterland-directed fold in Imperial Formation. Alternatively, the fold may represent an overturned limb of a tight recumbent syncline. The dotted lines highlight a resistant sandstone bed within the shale. See Figure 8 for location of photograph.*

Although weakly deformed in places by late Neoproterozoic and (or) Phanerozoic deformation, the sills are typically sub-horizontal or gently tilted. They are characterized by well-developed columnar jointing (Figure 12c), and two prominent joint sets are recognized cross-cutting the sills. One commonly strikes between N050^{o} and N110^{o}, and the second one between N320^{o} and N010^{o} (Figure 12d).

Structural elements of the Northern Franklin Mountains and Mackenzie Plain

Imperial Anticline

The Imperial anticline is an arcuate, northwest- to west-trending regional structure lying between the Mackenzie and Franklin mountains (Figure 13). The anticline, which extends as far west as Hume River, mimics the regional curvature of the northern Franklin Mountains. Although of greater structural relief, the Imperial anticline is similar in style to Franklin Mountain structures. The anticline is a north-vergent asymmetric fold, with a shallow-dipping south limb and a steep-dipping north limb (Figures 14a, b). Abrupt changes in the structural asymmetry occur locally (Figure 14c). Its geometry is commonly delineated by resistant limestone of Ramparts Formation; however, much of the structure is obscured by vegetation. At one locality, the forelimb of the Imperial anticline displays a section of interbedded laminated dolostone, anhydritic dolostone and gypsum beds conformably overlain by a tongue of dolostone and limestone of Arnica Formation (Figure 14d). The incomplete, approximately 55 m thick section of interbedded dolostone and gypsum has been assigned here to Early Devonian Fort Norman Formation (subsurface equivalent of the Bear Rock facies; Meijer Drees, 1993) on the basis of lithology and overall lack of breccia (Chapter 6, this volume). From a structural perspective, and although largely bedded and undeformed here, the occurrence of gypsum along the flank of the Imperial anticline is of interest and suggests that the lithology has played a role in the development of the structure.

At surface, the core of the Imperial anticline exposes no strata older than Ordovician-Silurian Mount Kindle Formation. A single well drilled on the Imperial anticline (Petro-Canada Sammons H-55, see Figure 15), however, encountered Proterozoic strata more than 2000 m above the regional level, implying the involvement of basement rocks in the development of the anticline.

On the basis of subsurface data, Cook and MacLean (1999) interpreted the Imperial anticline as a fault-bend fold resulting from the propagation toward the foreland of a wedge of Proterozoic strata over a “bedding-parallel” thrust ramp. They hypothesized that thrusting was facilitated by the presence, at shallow levels, of Saline River Formation evaporites. This assumption by Cook and MacLean (1999) has significant implications for petroleum potential, as the proposed geometry allows for structural traps involving sub-Saline River Formation siliciclastic intervals (i.e., Cambrian Mount Clark and Mount Cap formations). Mount Clark Formation is a known reservoir in the Colville Hills area, approximately 200 km to the northeast of Peel Plain (Chapter 3; this volume). Alternatively, Taborda and Spratt (2008) interpreted the Imperial anticline as a wedge defining a triangle zone developed above a ramp within Neoproterozoic and Lower Paleozoic strata. This proposed tectonic wedge, composed of imbricated Proterozoic to Cretaceous strata, was inferred to define the northern Mackenzie Mountain front. Implicit in the model of Taborda and Spratt (2008) is the occurrence of Lower and Middle Devonian strata (which include several reservoir and source rocks) beneath the sole thrust of the wedge, a geometry allowing the potential development of a structural trap.

Whirlpool Transfer Zone

The Whirlpool fault, as mapped by Aitken et al. (1982), is a southeast-directed thrust fault that lies along the northwestern edge of the Mackenzie Plain and Franklin Mountains in the Mountain River area, west of the Mackenzie River (Figure 13). It has been mapped as a single structure for approximately 30 km northeastward between West Mountain anticline and Southbound Ridge, along the northern flank of the Lichen Syncline (Map 1453A of Aitken et al., 1982). It marks an area where the dominant structures of the northern Franklin Mountains swing to the west near Carcajou Ridge, and then southwest near Mountain River before joining with those at the front of the Mackenzie Mountains. Aitken et al. (1982) interpreted the area along the Whirlpool fault as a Laramide-aged wrench-dominated zone linking the western termination of the Franklin Mountains to the Mackenzie Mountain front. Although the fault is shown to juxtapose a sliver of Imperial Formation strata over Cretaceous sediments along Mountain River (Map 1453A of Aitken et al., 1982), reconnaissance work revealed no exposures of the fault.

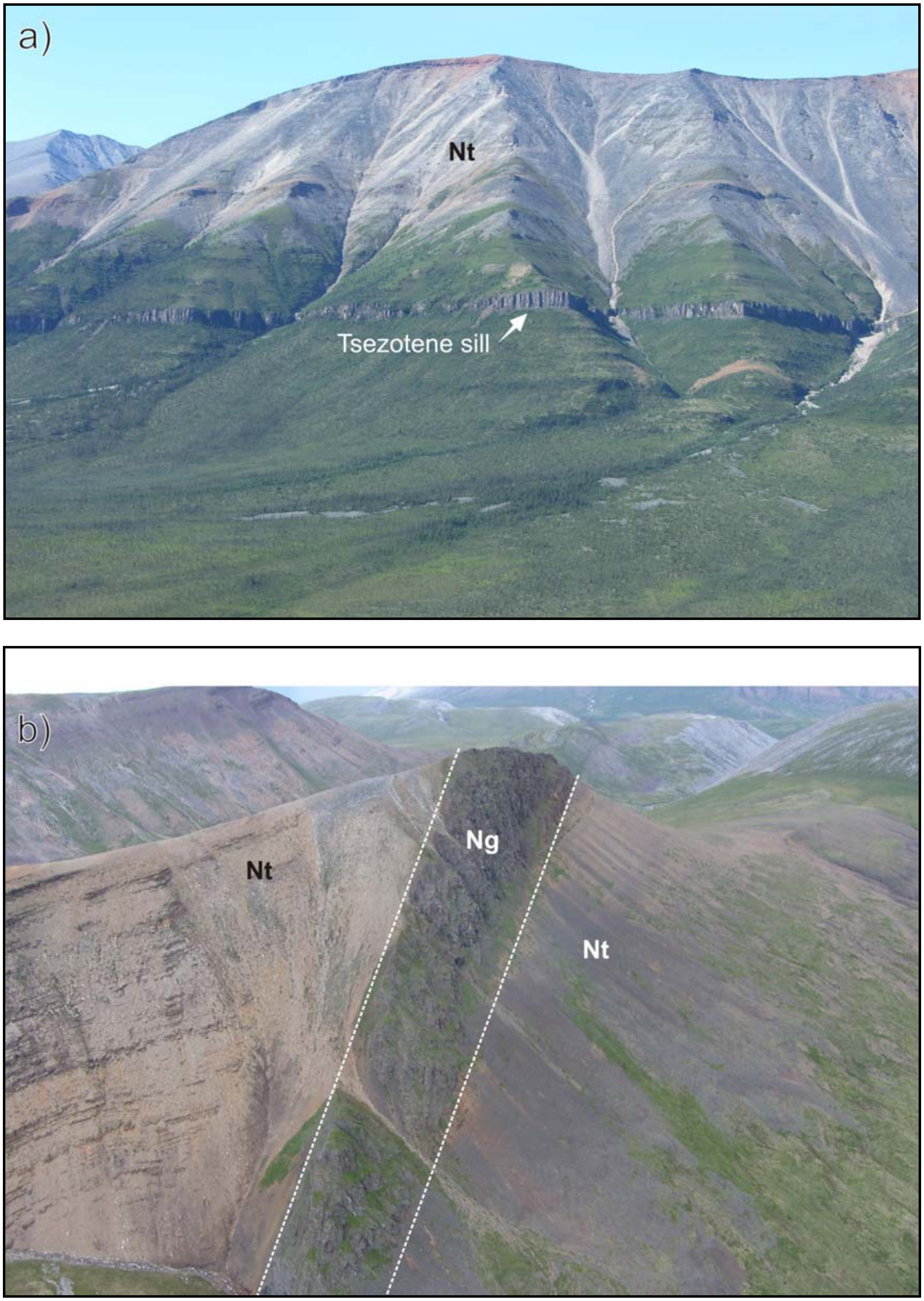
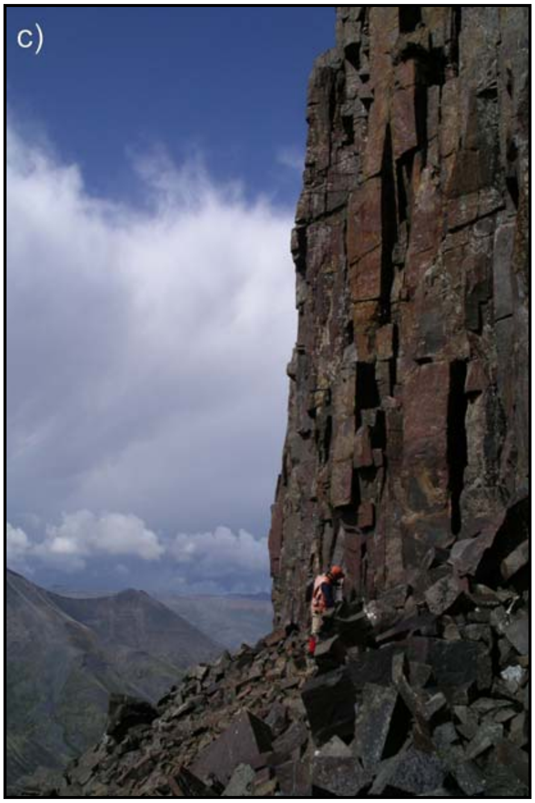


Figure 12. *a) View to the southwest of a gabbro sill intruding Tsezotene Formation (Nt). The sill is approximately 50 m thick; b) View to the northwest of a gabbro dyke (Ng) intruding the Tsezotene Formation (Nt). Here, the orientation of the dyke is 345/81^{o} NE. The dyke is approximately 60 m thick.*



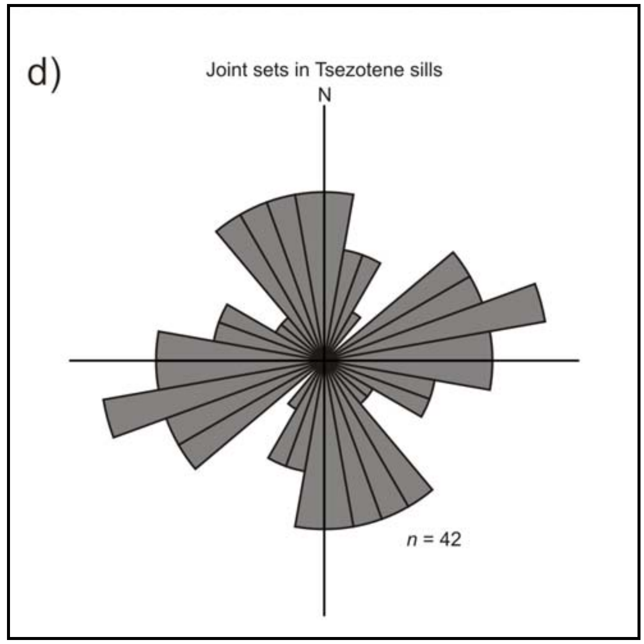


Figure 12. *Continued. c) Well-developed columnar jointing in the Tsezotene sills. The prominent joint sets strike east to northeast, and north to northwest; d) Rose diagram showing all joint orientation measured within the Tsezotene sills at five different localities in the Arctic Red River area. Circular scale is in percent, n = 42.*

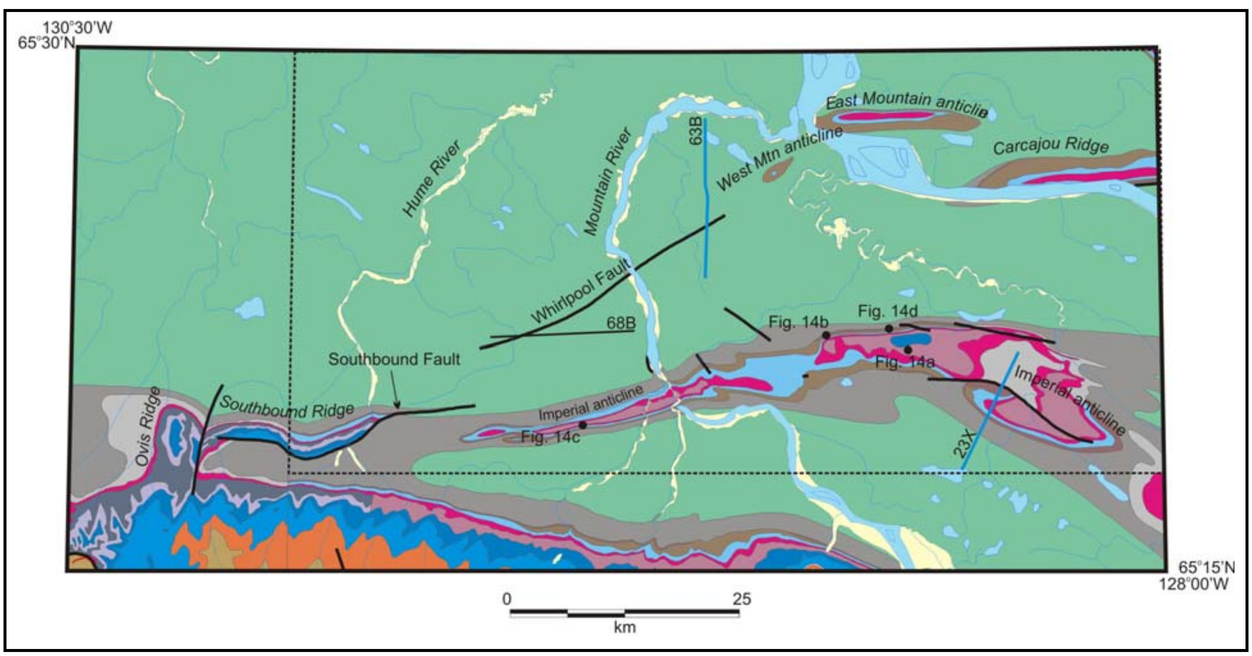


Figure 13. *Detailed geological map showing the structural elements in the northern Franklin Mountains. The dashed polygon shows the extent of Figure 17. The location of the photos in Figure 14 is shown. Geology after Aitken et al. (1982).*

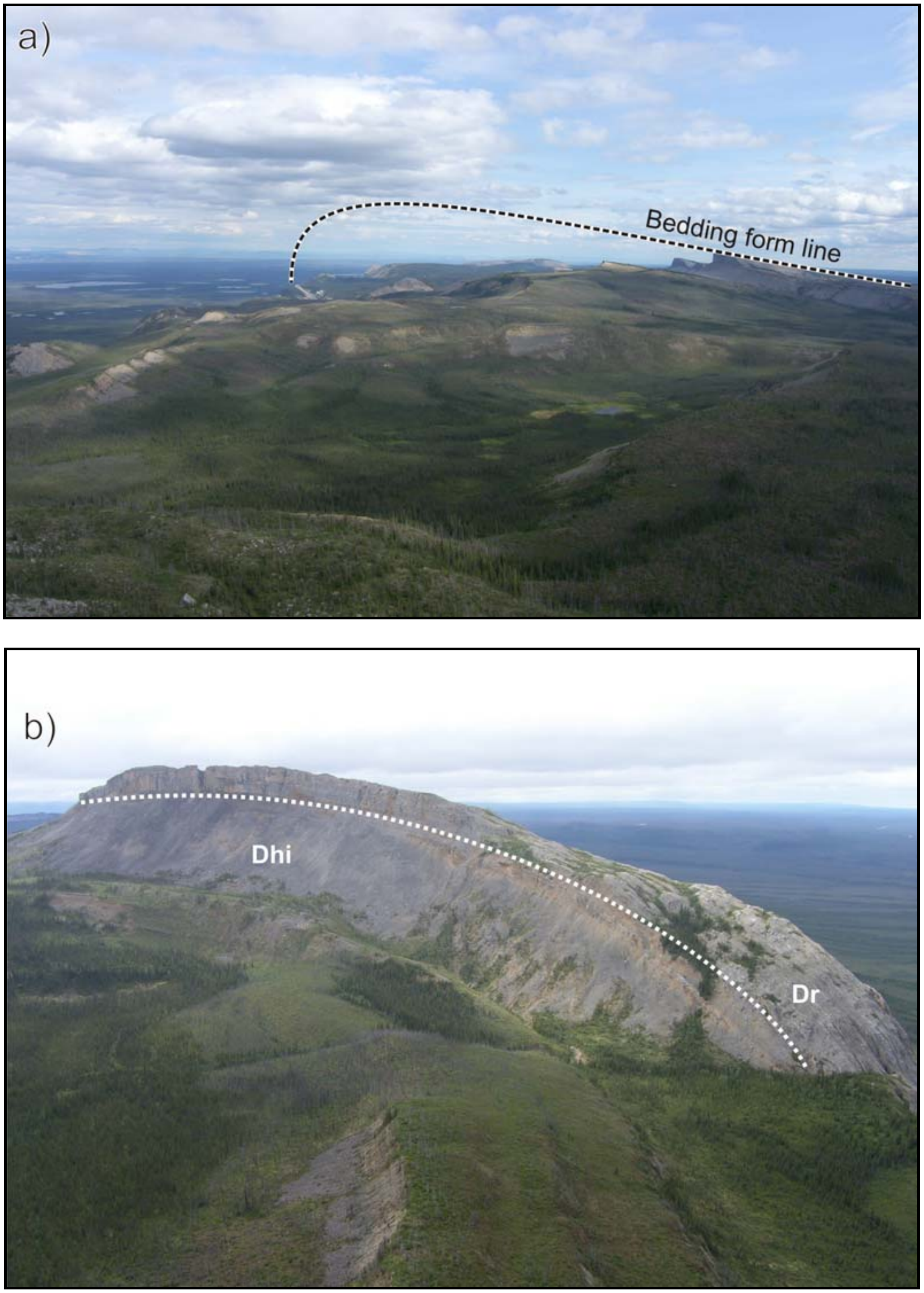


Figure 14. *a) Imperial anticline as viewed to the northeast from Stratigrapher Cliffs, approximately parallel to the axis of the anticline. The dashed line corresponds to a bedding form line. The anticline is largely a north-vergent asymmetric structure, with a shallow-dipping south limb and a steep-dipping north limb. Field of view in the middle ground is approximately 4 km; b) Photograph of the north limb of the Imperial anticline at Stratigrapher Cliffs. The dashed line shows the approximate contact between Ramparts (Dr) and Hare Indian (Dhi) formations. Direction of view (to the west) is approximately parallel to the axis of the anticline. Field of view in the middle ground is approximately 3 km.*

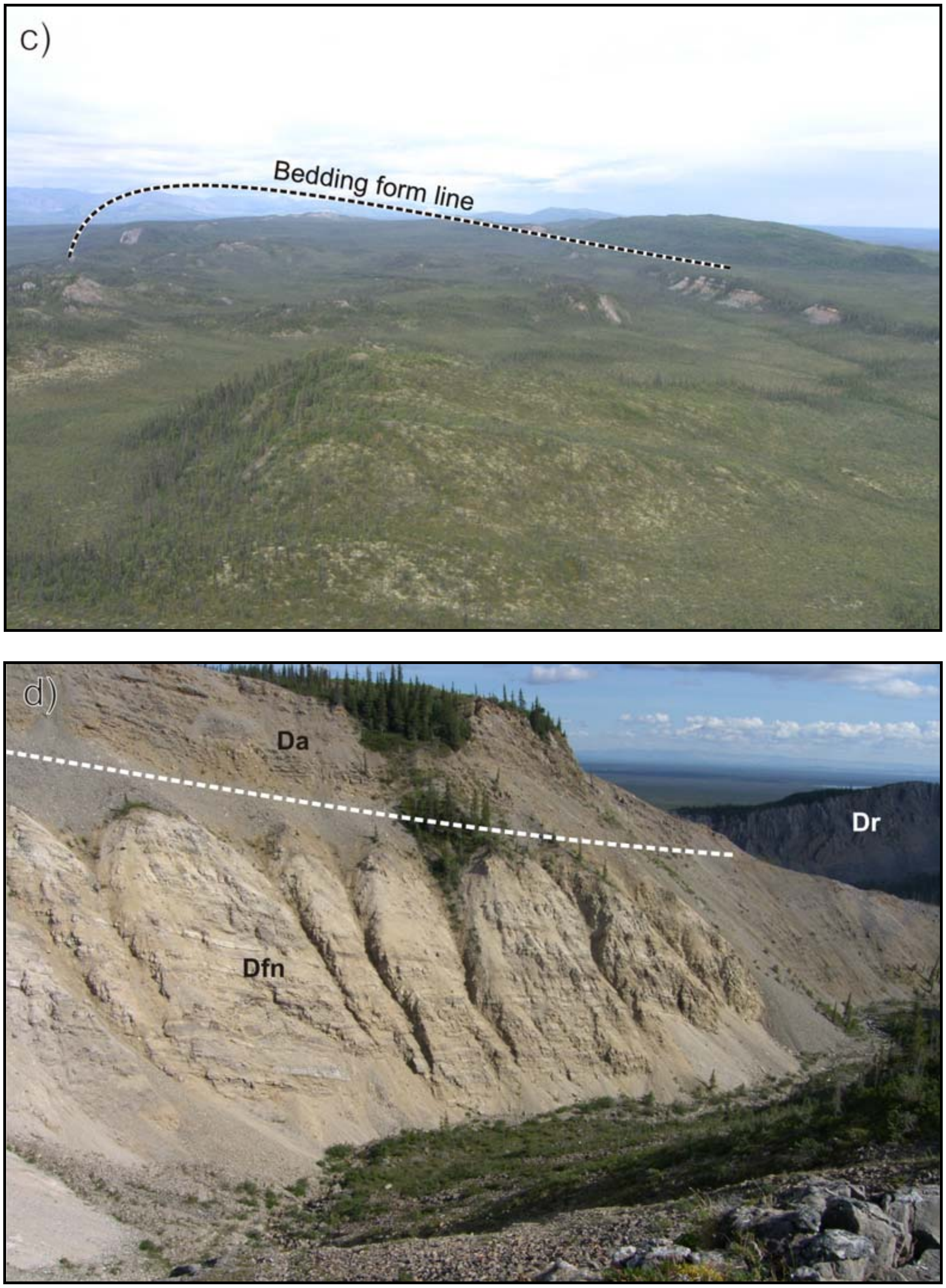


Figure 14. *Continued. c) The western termination of the Imperial anticline as viewed to the west, approximately parallel to the axis of the anticline. Here, the anticline is marked by an abrupt change in the structure asymmetry with a gently dipping north limb and subvertical south limb. The dashed line corresponds to a bedding form line. Field of view in the middle ground is approximately 2 km; d) North limb of the Imperial anticline. The section is marked by interbedded laminated dolostone, anhydritic dolostone and gypsum beds of Fort Norman Fm (Dfn), conformably overlain by a tongue of dolostone and limestone of Arnica Fm (Da). Dr = Ramparts Fm. This incomplete section of Fort Norman Fm is approximately 55 m thick. See Figure 13 for location of photos.*

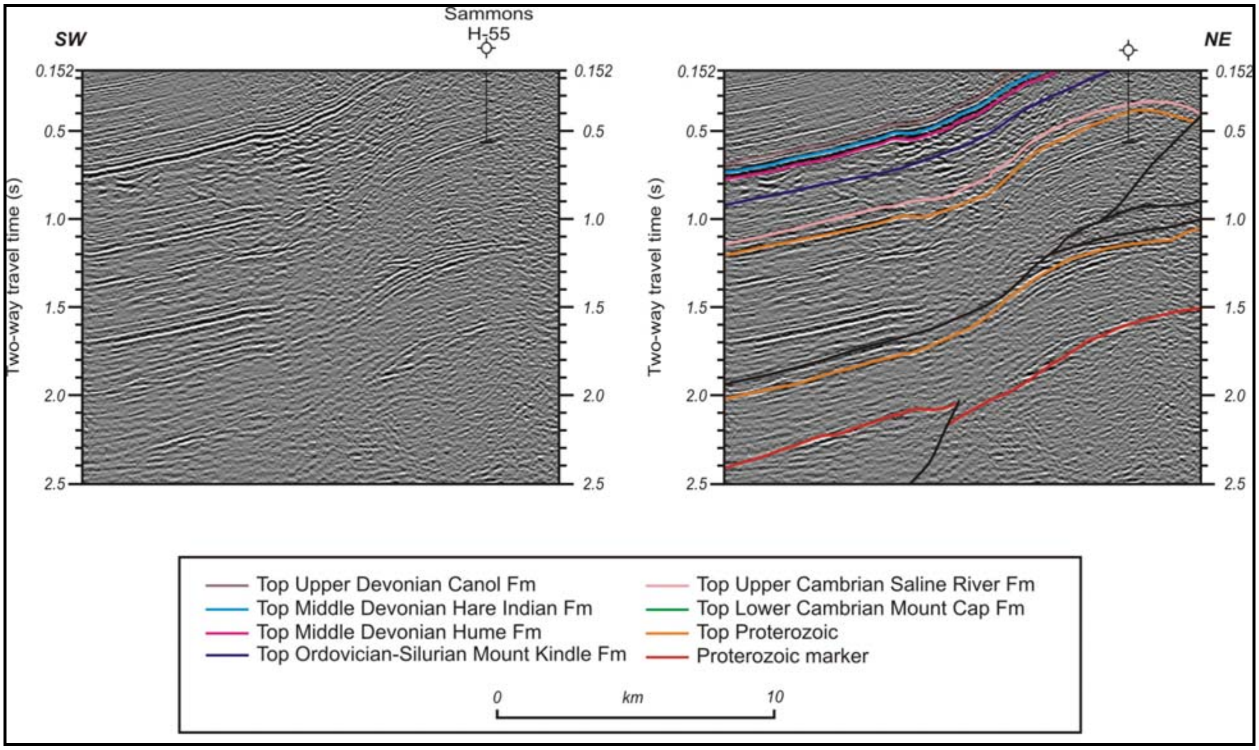


Figure 15. *Uninterpreted and interpreted portion of 1982 Petro-Canada line 23X across the Imperial anticline. The Petro-Canada Sammons H-55A well drilled on the Imperial anticline encountered Proterozoic strata more than 2000 m above the regional level, implying the involvement of basement rocks in the development of the anticline. Vertical axis is two-way travel time (seconds). Interpretation after B.C. MacLean, GSC-Calgary. See Figure 13 for location of seismic line.*

Integration of fieldwork and seismic data along the western termination of the Franklin Mountains and the northern Mackenzie Mountain front (Lemieux and MacLean, 2008) revealed the occurrence of a relatively narrow zone marked by an array of *en échelon* northwest- and southeast-directed thrust faults that root into a detachment situated near the base of the Paleozoic succession (Figure 16). Northeast-striking steep reverse faults, locally delineating pop-up structures, and northeast-trending fault-propagation folds have been interpreted. Data suggest that this tectonic corridor, termed *Whirlpool transfer zone* (Lemieux and MacLean, 2008), extends from Carcajou Ridge to Southbound Ridge (Figure 17). The dominance of northeast/southwest-oriented structures along the Whirlpool transfer zone is, therefore, in marked contrast with those in adjacent areas.

Aitken et al. (1982) attributed the development of the transfer zone to the westward disappearance of Saline River evaporites from beneath the northern Franklin Mountains. This interpretation is supported by subsurface data, which indicate that Saline River evaporites occur beneath much of the northern Franklin Mountains and Mackenzie Plain, and eastern Peel Plain, but pinch-out near the Mackenzie River, north of the Mackenzie Mountain front (Dixon and Stasiuk, 1998). Analysis of subsurface structures suggests left-lateral transpressive deformation associated with the zero edge of Saline River evaporites (Figure 18; Lemieux and MacLean, 2008).

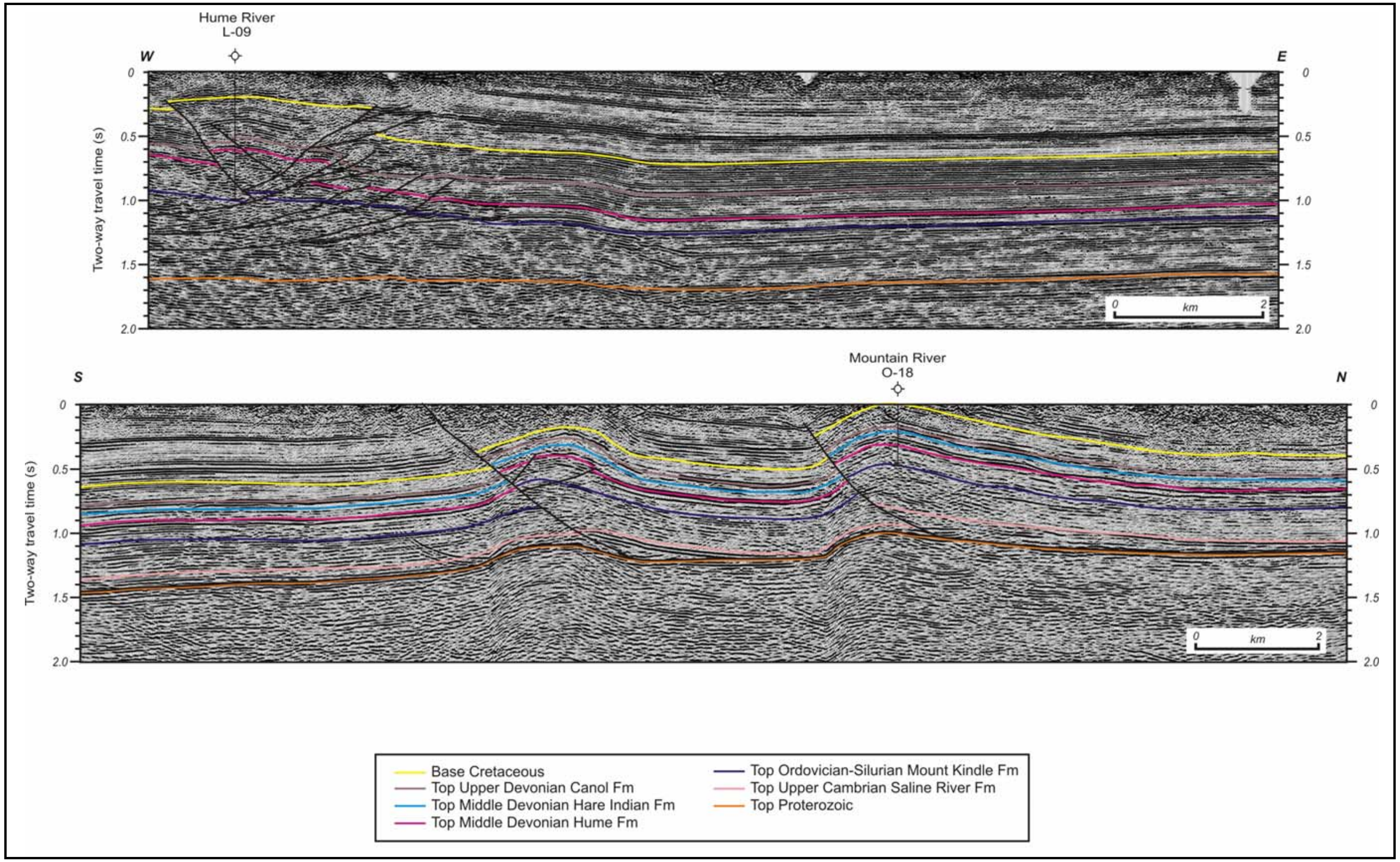


Figure 16. *Interpreted versions of 1989 Chevron Canada lines 68B (upper panel) and 63B (lower panel). Integration of fieldwork and seismic data revealed the occurrence of a relatively narrow zone marked by an array of northwest- and southeast-directed thrust faults that root into a detachment situated near the base of the Paleozoic succession. Northeast- and southwest-striking steep reverse faults, locally delineating pop-up structures, and northeast-trending fault-propagation folds have been interpreted. See Figure 13 for location of lines. Vertical axis is two-way travel time (s).*

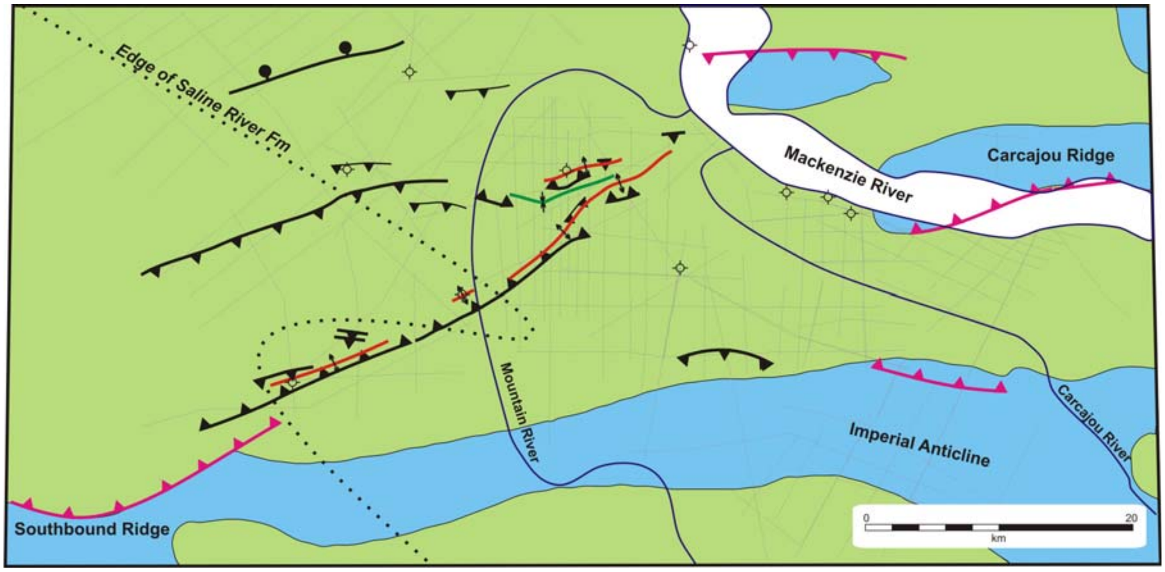


Figure 17. *Map showing the extent of subsurface structures interpreted at the top of Devonian Hume Formation along the Whirlpool transfer zone. The area is marked by northwest- and southeast-vergent thrust faults and northeast-trending folds. Geology shown as in Figure 2, see Figure 13 for location of map. Green and red lines represent axial traces of synclines and anticlines, respectively. Structures shown in magenta outcrop at surface. Seismic track lines are shown in light grey. Fine dotted line shows the approximate western depositional edge of Cambrian Saline River Formation.*

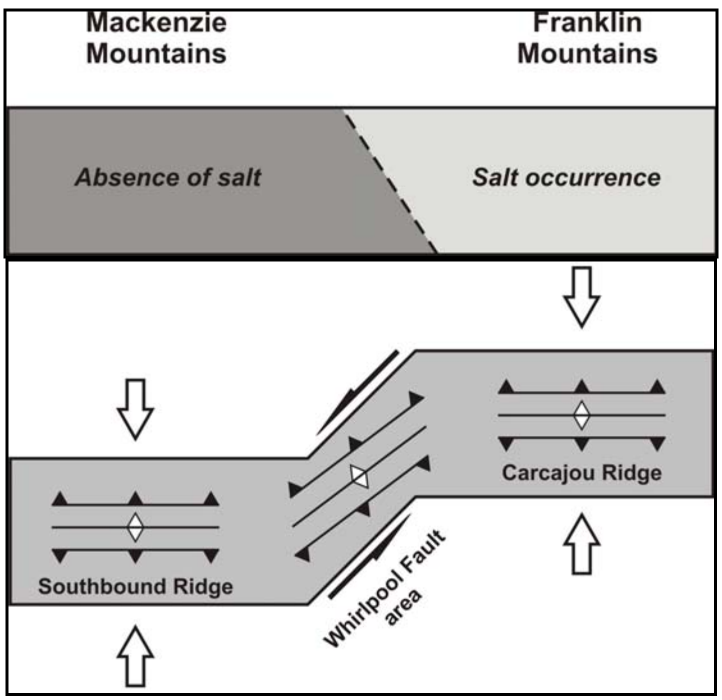


Figure 18. *Map view diagram illustrating a potential scenario for the development of left-lateral transpressive deformation between the Mackenzie and Franklin mountains. Upper diagram: initial pre-Laramide configuration; lower diagram: syn- to post-deformation configuration, showing left-lateral transpressive deformation along the Whirlpool Fault area. Modified after Sanderson and Marchini (1984).*

East of the evaporite zero edge, the Franklin Mountains sheet moved northward above a weak basal detachment. To the west where Saline River Formation is absent, the Mackenzie Mountain front and Peel Plateau and Plain sheet were “pinned” to their substratum. The trend of the Whirlpool transfer zone also suggests its development may have been influenced by northeast-striking antecedent faults described above (Lemieux and MacLean, 2008).

Southbound Fault

The Southbound Fault, a structure of Franklin Mountain type, defines the mountain front at Southbound Ridge, a structurally complex area where structural elements of the northern Franklin Mountains meet those of the northern Mackenzie Mountains (Figure 13; Map 1453A of Aitken et al., 1982). The Southbound Fault is a listric, hinterland-vergent contractional structure exposed on the southern flank of Southbound Ridge. The fault surface has a moderate dip of 45^o to 55^o at surface, flattening at depth near the base of the Phanerozoic succession (Section CD, Appendix B). Where exposed, the fault commonly juxtaposes Franklin Mountain Formation strata above Imperial Formation clastic rocks (Figure 19a). Several localities were studied on Southbound Ridge and along Hume River (Lemieux et al., 2007). At one of these, an approximately 6 m thick horse of fossiliferous Mount Kindle Formation carbonate was found within the fault zone (Figure 19b). Map relationships surrounding the Southbound Fault suggest it is a reverse fault; however, asymmetric structures at outcrop scale (Figure 19c) suggest the last motion on the fault was normal, likely the result of post-Laramide relaxation. Aitken et al. (1982) interpreted the fault to have developed within evaporites and shale of Saline River Formation. Analysis of subsurface data (e.g., Pugh, 1983; Dixon and Stasiuk, 1998; Cook and MacLean, 1999), however, indicate that the regional erosional edge of Cambrian strata (Mount Clark to Saline River interval) lies east of Southbound Ridge. As such, the fault may have developed within basal strata (basal red beds?) of Franklin Mountain Formation.

The Southbound Fault is inferred here to represent the western termination of the Whirlpool transfer zone. On Map 1453A of Aitken et al. (1982), the Southbound Fault is shown as a west-striking thrust distinct from the Whirlpool Fault. On their figure 24, however, Aitken et al. (1982) show the Southbound Fault as a curvilinear feature with its northeastern segment merging with the Whirlpool fault, an interpretation that is supported by re-examination of seismic data along the Whirlpool transfer zone (e.g., Figure 17; Lemieux and MacLean, 2008).

Structural Style of Peel Plateau and Plain

Peel Plain is largely underlain by flat-lying and relatively undeformed Cretaceous sandstone and shale, but Devonian strata are locally exposed at the surface in structural uplifts near the Mackenzie River or along the front of the deformed belt. Peel Plateau, an erosional remnant underlain by Cretaceous sediments, owes its physiographic expression to resistant sandstone of Trevor Formation. The thick succession of Proterozoic and Paleozoic carbonate and clastic strata underlying the Cretaceous rocks forms uplifted outcrops in the mountain flexure of the Mackenzie Mountains.

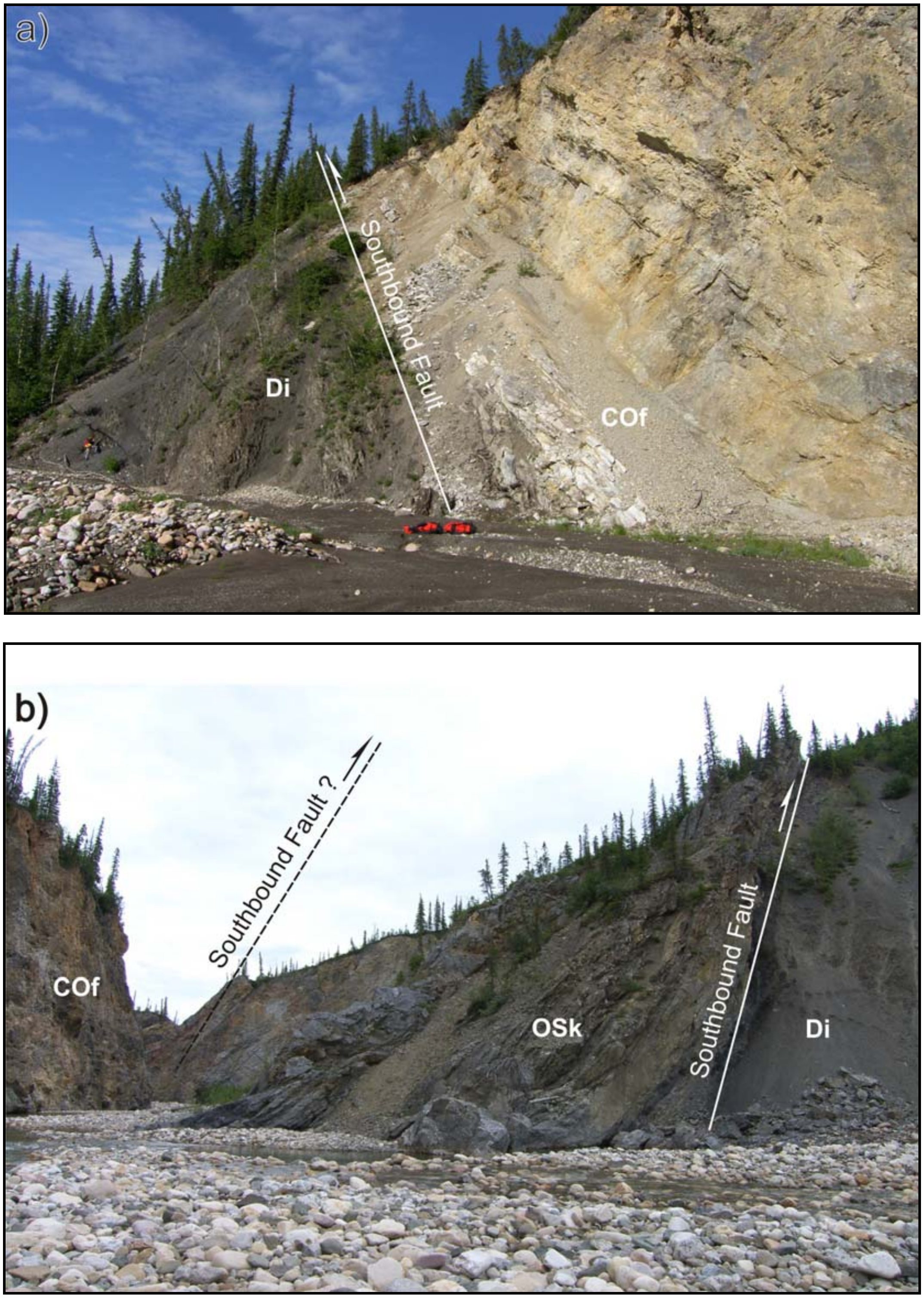


Figure 19. *a) View to the west of the Southbound Fault. Backpacks in the foreground for scale; b) View to the east of the Southbound Fault. The photograph shows a horse of Mount Kindle Formation rocks within the fault zone. The northernmost fault (dashed line) is assumed and probably represents a splay of the main fault. COf = Franklin Mountain Formation; OSk = Mount Kindle Formation; Di = Imperial Formation. Horizontal field of view is approximately 15 m.*

Figure 19. *Continued. c) Asymmetric structures in the Imperial Formation within the fault zone shown in b). These structure suggest the last motion on the fault was normal, likely the result of post-Laramide relaxation. Lens cap for scale. View to the east.*

Although Peel area is underlain by largely undeformed Phanerozoic strata, faults and folds of regional extent have been interpreted from seismic reflection data or mapped at surface. Lichen Syncline (Figure 3), a gentle structure of Laramide origin, extends for more than 200 km across the study area near the mountain front. Aitken et al. (1982) mapped thrust faults with several metres of displacement breaking through Cretaceous strata. Interpretation of seismic data across Peel Plateau and Plain has also indicated steep normal and reverse faults offsetting Paleozoic units (e.g., Transects A, C in Appendix A; see also Cook and MacLean, 2004). Although some of the contractional faults may be of Laramide origin, Cook and MacLean (2004) interpreted most of the extensional faults to have developed at various time during the Phanerozoic.

Trevor Fault marks the boundary between Richardson Mountains and the western flank of Peel Plateau and Plain (Figure 2). The fault has been interpreted as: a) an antecedent strike-slip fault reactivated as a dip-slip structure during the Laramide orogen (Norris, 1985, 1997); b) a foreland-directed thrust fault rooting into Proterozoic sediments (Hall and Cook, 1998); and (c) a major east-vergent blind thrust defining the base of an intercutaneous wedge at the leading edge of the Richardson Anticlinorium (Taborda and Spratt; 2008). Clearly, the nature of the Trevor Fault remains elusive, and will require the comprehensive analysis that is beyond the scope of this chapter.

PALEOGEOGRAPHY AND TECTONICS

Proterozoic structures of the Interior Platform and Mackenzie Fold Belt were the product of a series of complex extensional, basin-forming episodes punctuated by contractional orogenic events (Cook and MacLean, 2004; Thorkelson et al., 2005) and have been instrumental in the development of Phanerozoic structural elements (e.g., Cook and MacLean, 2004). Within the Canyon Ranges of northern Mackenzie Mountains (Figure 2), well developed north and north-northwest trending faults of inferred late Paleoproterozoic age and attributed to the Racklan orogeny have been shown by Aitken and Cook (1974) to have had a profound effect on the development of younger Laramide structures. Similarly, Cook and MacLean (2004) have demonstrated that the development of the Imperial anticline, a major feature in Peel area, was influenced largely by the Precambrian structural framework.

The early Paleozoic architecture of the northwestern North American margin consisted of a series of north- to northwest-trending depocentres and positive elements, parallel to the Cordillera and segmented by northeast-trending, high-angle linear features (figure 1 in Cecile et al., 1997; Dixon and Stasiuk, 1998). The Mackenzie Arch (Williams, 1987), a northwest-trending paleotopographic high, separated Cambrian depocentres of the Interior Platform from the Selwyn Basin to the west (Chapter 3, this volume). East of the arch, the Mackenzie Trough, a narrow graben- to half-graben-feature, accumulated Cambrian siliciclastics, carbonates, and evaporites. Mackenzie Arch lay on trend with the Peel Arch (Williams, 1987), a subsurface element that separated the Interior Platform from the Richardson Trough (Fritz et al., 1992). The Mackenzie-Peel Arch remained active episodically throughout the early Paleozoic (Williams, 1990), as manifested by several regional unconformities throughout the early Paleozoic sedimentary record (see Chapters 4 and 5, this volume). The north-northwest trending Richardson Trough (Gabrielse, 1967; Norris, 1985) has been interpreted as an aulacogen (Pugh, 1983) that opened into the Franklinian margin to the north (Churkin, 1969; Cecile et al., 1997). This elongate basin was initiated in the late Cambrian and accumulated sediment into the Middle Devonian. Mackenzie Platform (Fritz et al., 1992) was a region of Cambrian to Devonian shallow-water deposition east of Richardson Trough. Rift-related sedimentation within a shelf environment continued until the Middle Devonian (Pugh, 1983). A major change in tectonic regime occurred during uppermost Middle to Late Devonian and Early Carboniferous time in the Mackenzie Platform and Richardson Trough (Morrow and Geldsetzer, 1988). Onset of uplift and orogeny created sourcelands east, west and north of Peel area from which thick, siliciclastic dominated deposits were derived (Gordey et al., 1992).

Late Paleozoic and early Mesozoic paleogeography in Peel area is poorly understood due to the absence of strata of the upper Carboniferous, Permian, Triassic, and Jurassic systems. This profound unconformity records pre-Cretaceous (pre-Aptian) regional uplift and/or tilting of tectonic elements, such as the Keele Arch (Cook, 1975), as well as deep erosion of late Paleozoic and early Mesozoic strata. The result is that along the northern Franklin Mountains and northern Mackenzie Mountain front, Aptian and younger sediments overlie Upper Devonian strata (e.g., Figure 3). The absence of Imperial and Canol formations strata near Carcajou Ridge (e.g., see East Mountain and West Mountain anticlines, Figure 13), suggests that incipient movement along the Whirlpool transfer zone pre-dated deposition of Cretaceous strata and thus, may have been contemporaneous with uplift of the Keele Arch.

The most important tectonic event recorded in the subject region was the Laramide Orogeny, which deformed the sedimentary cover, creating the Mackenzie and Franklin Mountains, and formed many of the structures exposed at the mountain front in Peel area. On the basis of stratigraphic and structural relationships preserved in the sedimentary record (Aitken et al., 1982) timing of deformation in most of the northern Mackenzie Fold Belt has been constrained as latest Cretaceous or Paleocene.

The northern Mackenzie Mountains consist mostly of uplifted Proterozoic and Paleozoic clastic and carbonate strata (Figures 2, 3). They are characterized by west- to northwest-trending, broad, flat-topped and regionally continuous anticlines (up to 32 km across and over 200 km long) commonly exposing Proterozoic Katherine Group (or older) strata, with tight and narrow intervening synclines underlain by recessive Devonian strata (Figure 3; Aitken et al., 1982). The fold bundles display a left-lateral *en échelon* array, in which individual folds overlap along strike and step to the left (Figure 3). The concentric, parallel geometry of the folds and the involvement of Proterozoic strata (Figure 4) have been interpreted to suggest the presence of a deep detachment beneath the northern Mackenzie Mountains (Aitken et al., 1982). Shortening within the northern Mackenzie Mountains was largely accommodated by regional folding (e.g., Aitken et al., 1982); between Ramparts and Cranswick rivers, however, the Deadend and Tabasco faults and associated structures, accommodated much of the shortening near the mountain front.

North and east of the Mackenzie Mountains, the northern Franklin Mountains and Mackenzie Plain form an extension of the Mackenzie Fold Belt bordering the Interior Plains. The Mackenzie Plain is underlain by a westward-thickening wedge of Cretaceous-Tertiary strata overlying a broad asymmetric syncline of Lower Paleozoic strata, and marked by a gently dipping eastern limb and a more steeply dipping western limb surfacing at the Mackenzie Mountain front. The Franklin Mountains, on the other hand, form a series of curvilinear low ranges and ridges cored by Lower Paleozoic carbonates. Along the Franklin Mountains, the dominant structural grain typically trends northwest-southeast; structures swing sharply to the west and southwest near the Mackenzie River and Carcajou Ridge (Figures 2, 3). At their northern termination, structures of the Franklin Mountains meet with those of the Mackenzie Mountain front near Ovis and Southbound ridges, producing unusual structural relationships (Aitken et al., 1982). Deformation involves no strata older than Cambrian Saline River Formation, which led Cook and Aitken (1973) to suggest that structures of northern Franklin Mountains developed above a detachment in shale and evaporite of Saline River Formation. The Franklin Mountains are characterized by drape folding and display evidence for both high-angle reverse faults and shallow thrusts. They also display reversal of fold asymmetry and direction of faulting from range to range, but also within single ranges (Cook, 1983). Such structural relationships are commonly observed in thin-skinned fold-and-thrust belts (e.g., Davis and Engelder, 1985) and controlled by the presence of a weak detachment (e.g., Saline River evaporites) at the base of the deformation wedge. Modelling also predicts that the presence of a weak detachment allows folding and thrusting across a wider belt, "…giving the impression in map-view that the mountain belt has been projected far outward" (Davis and Engelder, 1985, p. 71), an analogy that well describes the expression of the Franklin Mountains.

The marked contrast in style between "deeper" structures of the Mackenzie Mountains and thin-skinned tectonics of the Franklin Mountains and Mackenzie Plain has been attributed to a migration of the detachment surface from a deep structural level beneath the hinterland to a shallower one toward the foreland (Aitken et al., 1982). The concentric, broad regional anticlines and narrow intervening synclines marking the Mackenzie Mountains is typical of "dejective" fold style (e.g., Dahlstrom, 1969) and indicate the presence of a deep structural detachment. Aitken et al. (1982) postulated that the detachment occurred beneath unnamed map unit H1, which lies below Neoproterozoic Tsezotene Formation. West of Southbound Ridge, Aitken et al. (1982) interpreted the main detachment to emerge as a single structure near the front of the Mackenzie Mountain monocline, just north of the Cranswick Flexure. Although our interpretation differs slightly from that proposed by Aitken et al. (1982; see Section AB, Appendix B), it is consistent, in a general sense, with the presence of a foreland-vergent thrust system at the mountain front. In contrast, the "ejective" fold style (e.g., Dahlstrom, 1969) of the Franklin Mountains, marked by broad synclines with narrow intervening ridges, implies the occurrence of a detachment surface at a much shallower structural depth than beneath the Mackenzie Mountains; shale and evaporite of Saline River Formation were recognized early on as an ideal detachment level (e.g., Cook and Aitken, 1973).

In the vicinity of the Imperial anticline, Cook and MacLean (1999) have proposed an interpretation in which the regional detachment rises up from deep "basement" rocks to the base of the Phanerozoic succession via two ramps. Beneath the Stony Anticline, the regional detachment ramps up across deformed, pre-Mackenzie Mountains Supergroup rocks to a level near the base of map unit H1, consistent with the interpretation of Aitken et al. (1982). As it progresses toward the foreland, the detachment rises up again, reaching weak shale and evaporite of Saline River Formation, forming the Imperial anticline. In the absence of adequate subsurface control the tectonic translation of the regional detachment along the mountain front, from deep to shallow levels, is difficult to infer. It is clear, however, that the transition from deep to shallow detachment levels occurs at the pronounced swing of the northern Franklin Mountain structures, coinciding with the regional depositional edge of Saline River salt. Here, the Whirlpool transfer zone, whose orientation and geometry was dictated by, among other factors, deep-seated northeast-trending faults (e.g., Cecile et al., 1997), likely acted as a "wrench" zone between the Franklin Mountains sheet as it moved northward relative to the Mackenzie Mountain sheet (Figure 18).

Shortening across the entire Mackenzie Fold Belt has been estimated to range from 45 km to 55 km (Gordey, 1981; Cecile et al., 1982), but Vann et al. (1986) inferred as much as 80 km of shortening. Aitken et al. (1982, their figure 23) estimated that shortening across the western Outer Fold Belt (i.e., frontal Mackenzie Mountains west of Southbound Ridge), inferred to be entirely due to folding, approximated 7.4 km. By contrast, shortening across the central Outer Fold Belt (i.e., frontal Mackenzie Mountains east of Southbound Ridge) together with the northern Franklin Mountains, approximated 12.5 km. The discrepancy was interpreted, in part, to reflect a progressive westward decrease of shortening across the belt (Aitken et al., 1982). It has been shown here, however, that blind and (or) discrete contractional structures along the front of the Mackenzie Mountains west of Southbound Ridge (i.e., western Outer Fold Belt of Aitken et al., 1982) have likely accommodated substantial shortening and provide part of the solution to balance shortening across the Mackenzie Mountain front.

In summary, Peel area is marked by three subregions of contrasting structural styles in which subtle variations in the stratigraphic succession have dictated the style of structural deformation and level of the main detachment.

CONCLUSIONS

Peel area includes segments of the Northern Interior Platform, Mackenzie Fold Belt, and Richardson Anticlinorium. For the most part, Peel area is underlain by largely undeformed Phanerozoic strata bordered to the west by the Richardson Anticlinorium which forms a narrow and linear range of low mountains. The Mackenzie Fold Belt, flanking Peel area to the south, is marked by east- to northeast and west- to southwest-directed broad box folds and thrust faults, and associated oblique-slip faults. The Mackenzie Mountains occupy the innermost portion of Mackenzie Fold Belt and are dominated by fold bundles and associated strike-slip transfer faults. By contrast, the outermost part of Mackenzie Fold Belt, namely the Franklin Mountains, is marked by a series of narrow and isolated, linear to arcuate ridges. The marked contrast in style between the Mackenzie and Franklin mountains has been attributed to a migration of the detachment surface from a deep structural level beneath the hinterland to a shallower one toward the foreland. Instrumental in the development of the contrasting structural style was the regional depositional edge of Cambrian Saline River evaporites.

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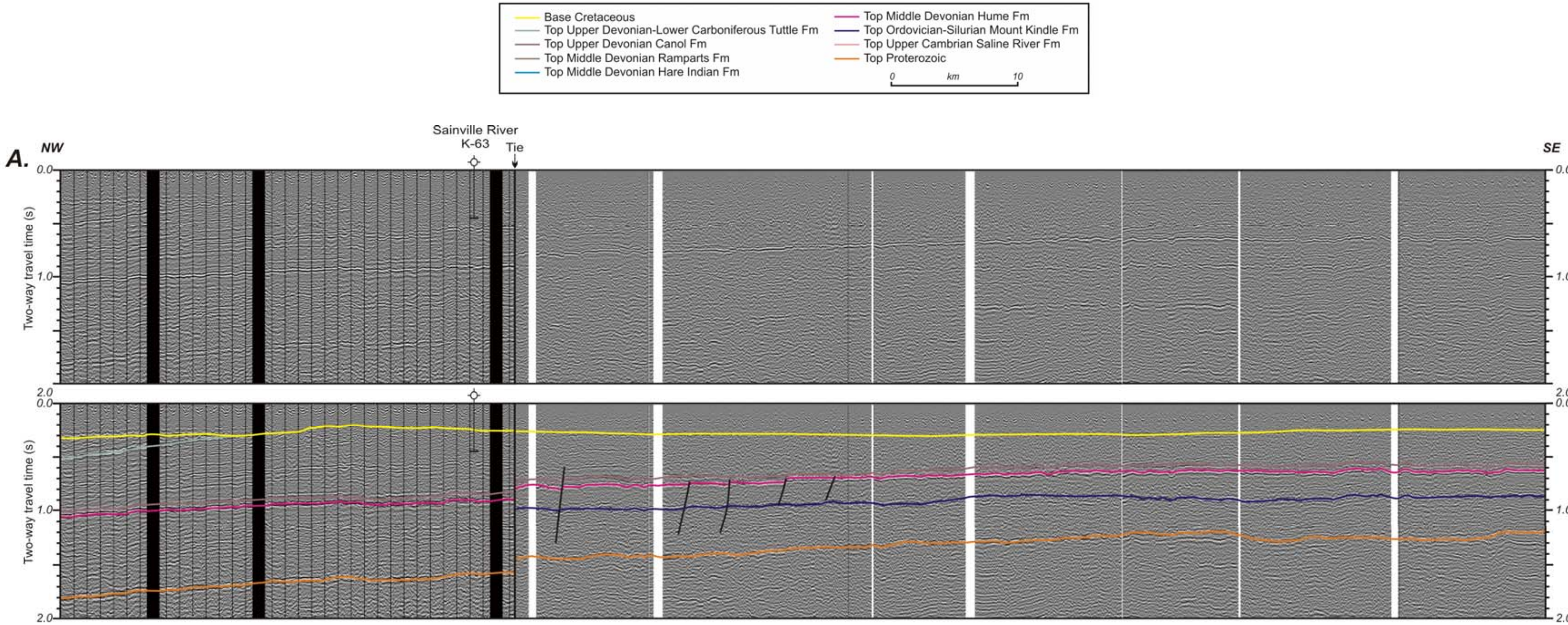
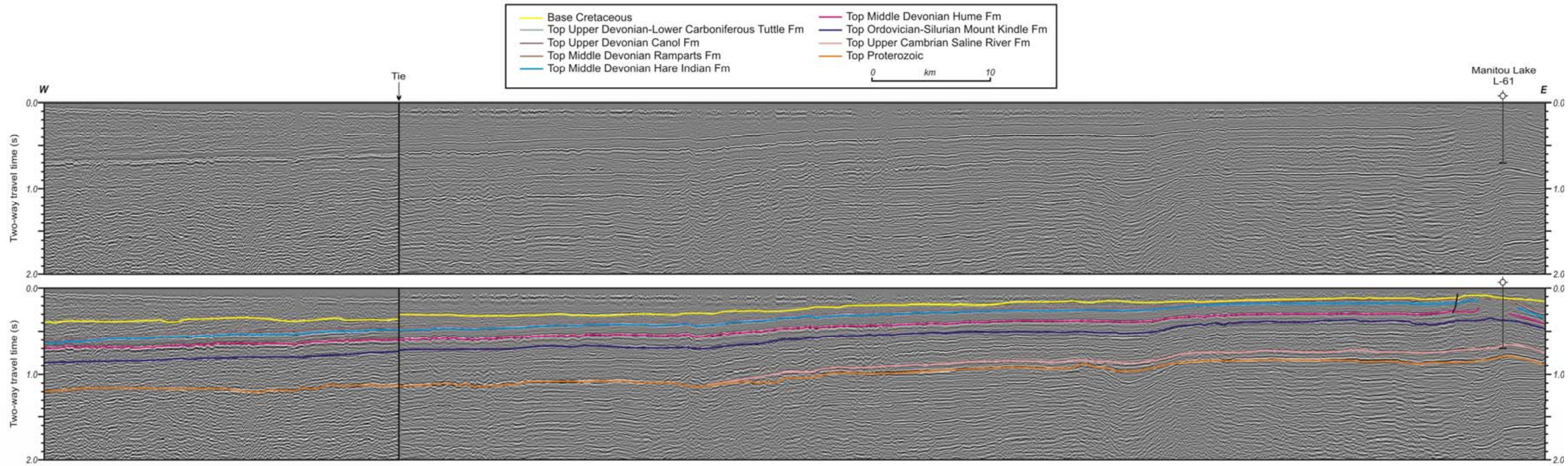
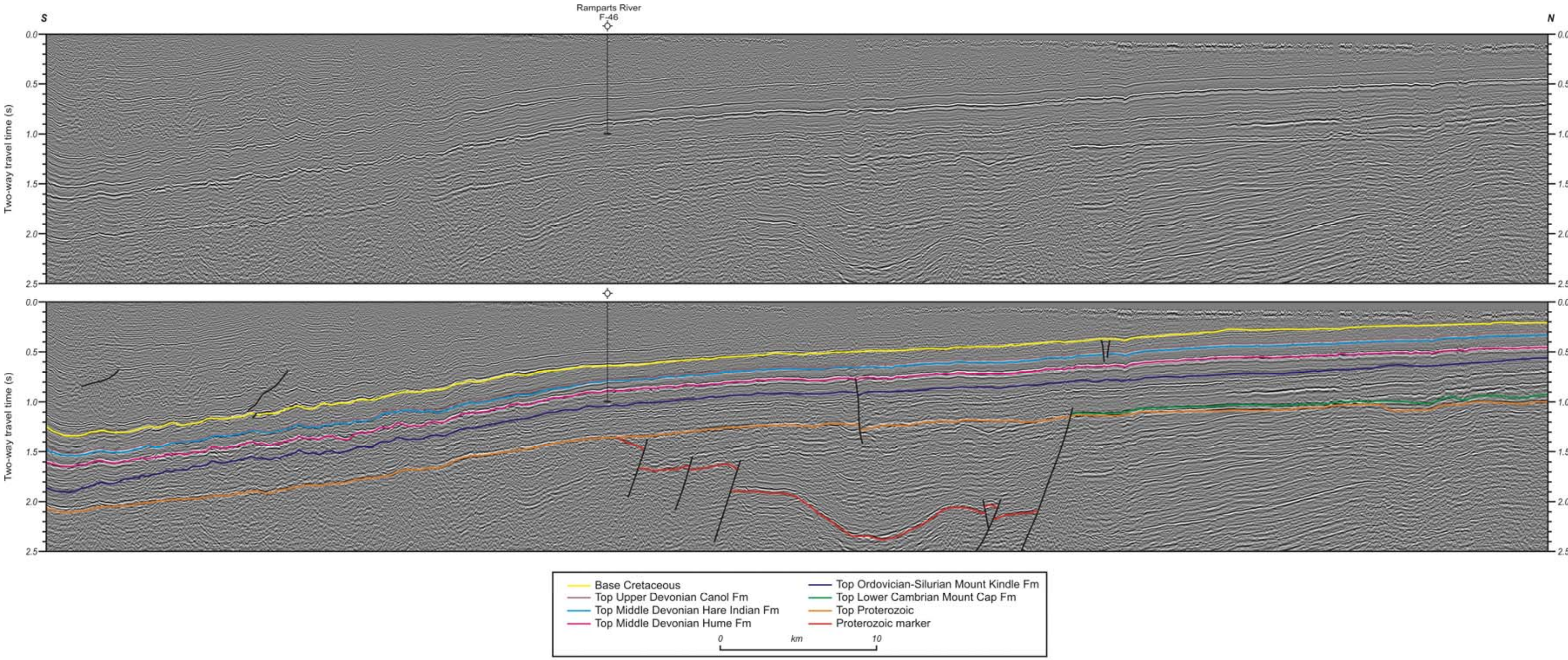
APPENDIX A



Transect A. *1969 Atlantic Refining Company line 18. Interpretation of seismic data across Peel Plateau and Plain indicates steep normal and reverse faults offsetting Paleozoic units. Although some of the contractional faults may be of Laramide origin, most of the extensional faults have been interpreted to have developed at various time during the Phanerozoic (see text for discussion). Tuttle Formation mapped as M0 on Figure 3. See Figure 2 for location of transect.*

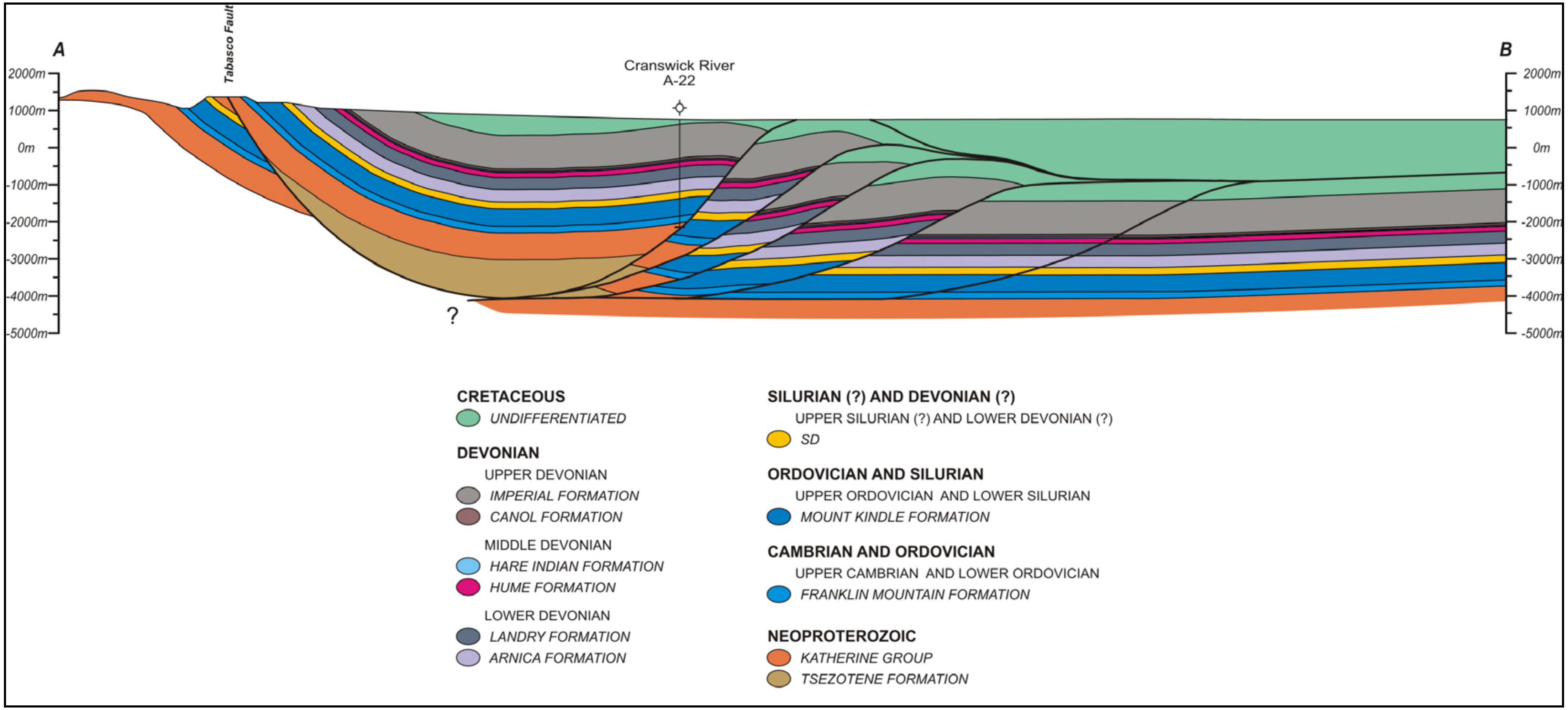


Transect B. *1969 Atlantic Refining Company line 19. This transect illustrates the largely undeformed Phanerozoic succession underlying Peel Plateau and Plain area. See Figure 2 for location of transect.*

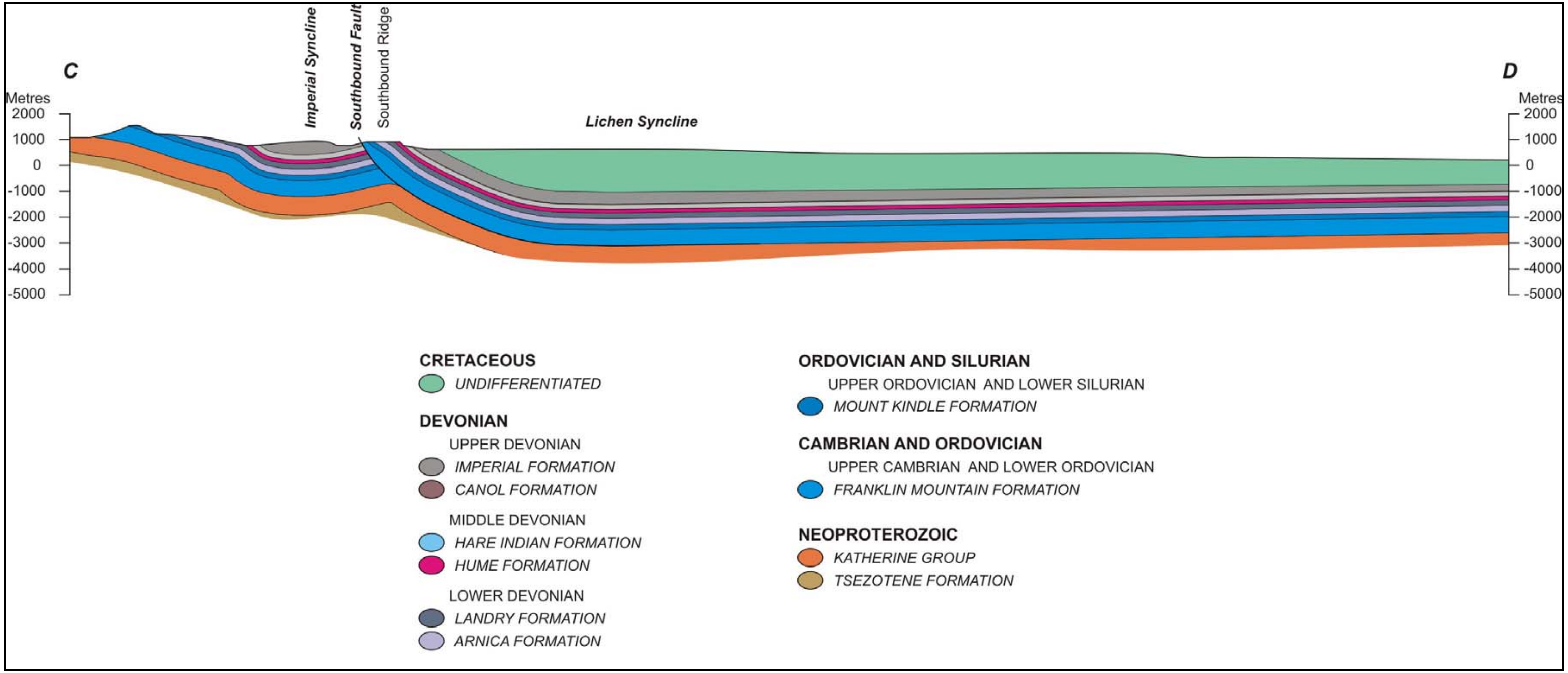


Transect C. *1985 Sigma Explorations (1978) Ltd. line 21. Interpretation of seismic data indicates steep normal faults offsetting Paleozoic unit. The south end of the line is marked by the Lichen Syncline, a gentle structure of Laramide origin that extends for more than 200 km near the mountain front. See Figure 2 for location of transect.*

APPENDIX B



Section AB. *Section through Tabasco Fault and the front of the Mackenzie Mountains near Cranswick River based on surface mapping, and geophysical and well data. This section illustrates the interpreted buried foreland-vergent duplex structure on the foreland side of the Tabasco Fault. The bedding-parallel sole thrust of the duplex appears to be localized near the base of the Paleozoic succession; the hinterland-directed, bedding-parallel roof thrust occurs within the lower portion of the Cretaceous clastic succession. No vertical exaggeration. See Figure 3 for location of section.*



Section CD. *Section through the front of the Mackenzie Mountains at Southbound Ridge based on surface mapping and geophysical data. This section illustrates the Southbound Fault, a listric hinterland-vergent contractional structure exposed on the southern flank of Southbound Ridge. The fault has a moderate dip at surface, flattening at depth; the fault may have developed within basal strata of Franklin Mountain Formation. No vertical exaggeration. See Figure 3 for location of section.*

Chapter 3 – Cambrian Strata and Basal Cambrian Clastics Play

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ABSTRACT

Cambrian strata in Peel area include Mount Clark, Mount Cap, and Saline River formations. The succession is present only in southeastern Peel area and along the northern Mackenzie Mountains since it pinches out westward against the Cambrian Mackenzie-Peel Arch. This study describes Cambrian strata from three outcrop sections and six wells. Red-weathering quartz sandstone above the sub-Cambrian unconformity is tentatively assigned to Mount Clark Formation. Mount Cap Formation consists of sandstone, shale, and dolostone. Saline River Formation is poorly exposed and consists of red- and green-weathering shale, siltstone, and minor sandstone. The succession represents an overall shallow marine to evaporitic basin setting within Mackenzie Depocentre. The Basal Cambrian Clastics play includes all pools and prospects hosted in sandstones of Cambrian Mount Clark and Mount Cap formations. No data on potential reservoir characteristics are available from these formations in Peel area, but one outcrop sample of Mount Cap sandstone southeast of Peel area yielded 4.4 % porosity and 0.03 millidarcies permeability. Potential source rocks in Peel area in Mount Clark/Mount Cap and Saline River formations are not thick and generally yielded less than 0.5% total organic carbon. Evidence for a Paleozoic (Cambrian to Ordovician) source of oil comes from new solvent extraction analysis of oil-stained Devonian outcrop samples. Top seal to a Mount Clark/Mount Cap Formation potential reservoir would likely be shale and dolostone of Mount Cap or lower Saline River Formation; fault seals are also possible. Possible traps include updip depositional pinch-outs against paleotopographic highs, intraformational facies changes from sand to shale, and intraformational diagenetic changes affecting porosity. Timing of petroleum generation, migration, and possible accumulation in Peel area is not well constrained due to limited data.

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INTRODUCTION

Cambrian strata in Peel area consists of Mount Clark, Mount Cap, and Saline River formations that lie unconformably above Proterozoic rocks and unconformably to conformably below uppermost Cambrian to Silurian Ronning Group (Figure 1). Mount Clark (mainly sandstone) and Mount Cap (sandstone, dolostone, limestone, and shale) formations are collectively referred to as basal Cambrian siliciclastics, which constitute a conceptual petroleum play in Peel area (Hannigan et al., 2006). These formations are overlain by evaporites and siliciclastics of Saline River Formation.

Stratigraphic relationships of Cambrian strata were controlled by a complex epicontinental marine setting north of latitude 60°N, as understood from field relationships, isopach thicknesses, cross-sections, and gravity data (Meijer Drees, 1974; Williams, 1987; Pugh, 1993; Dixon, 1997; Dixon and Stasiuk, 1998). In Peel area, Mackenzie and Peel arches were positive features (Figure 2) that trended northwest (Gabrielse, 1967; Gabrielse et al., 1973; Williams, 1987) and bordered the western margin of the Laurentian craton. Two separate depositional realms existed from Early to Middle Cambrian in which Mackenzie Arch separated depocentres of the Mackenzie Platform, such as Mackenzie Plain Depocentre, from the eastern side of Richardson Trough (Figure 2; Cecile et al., 1997). The arches either had thin sedimentary cover or underwent repeated phases of uplift and erosion during the Cambrian (Dixon and Stasiuk, 1998).

The Cambrian succession is present only in southeastern Peel area and in outcrop along the northern Mackenzie Mountains south of Peel area (Sans Sault Rapids map area, 106 H; Aitken et al., 1982). This study describes Cambrian strata from three outcrop sections and six wells (Figure 3). Sections LP-01 at Powell Creek and LP-24 at Fan Creek (Figures 4a, b) were measured and the section at Imperial Canyon (Figure 3) was studied briefly during reconnaissance work.

PREVIOUS WORK

In Peel area, Cambrian units were mapped in Sans Sault Rapids map area (106 H; Aitken et al., 1982). Cambrian outcrops were studied north and east of the Peel area (Balkwill, 1971; Cook and Aitken, 1971) and in the Mackenzie Mountains (Aitken et al., 1973; Laudon, 1950). Subsurface studies (Tassonyi, 1969; Pugh 1983, 1993; Meijer Drees, 1986; Williams, 1987) provided a stratigraphic framework for more detailed cross-sections and correlations by Dixon (1997) and Dixon and Stasiuk (1998). A study of Mount Clark and Mount Cap formations and tectono-stratigraphic evolution across Mackenzie Plain (17 measured sections) was completed by Serié (2008) and Serié et al. (2009). Pugh (1983) described Cambrian cuttings and core for six wells in Peel area (Table 1) and additional wells in the northern Interior Plains. Dixon (1997) listed cored intervals for wells containing Cambrian strata in the northern Interior Plains.

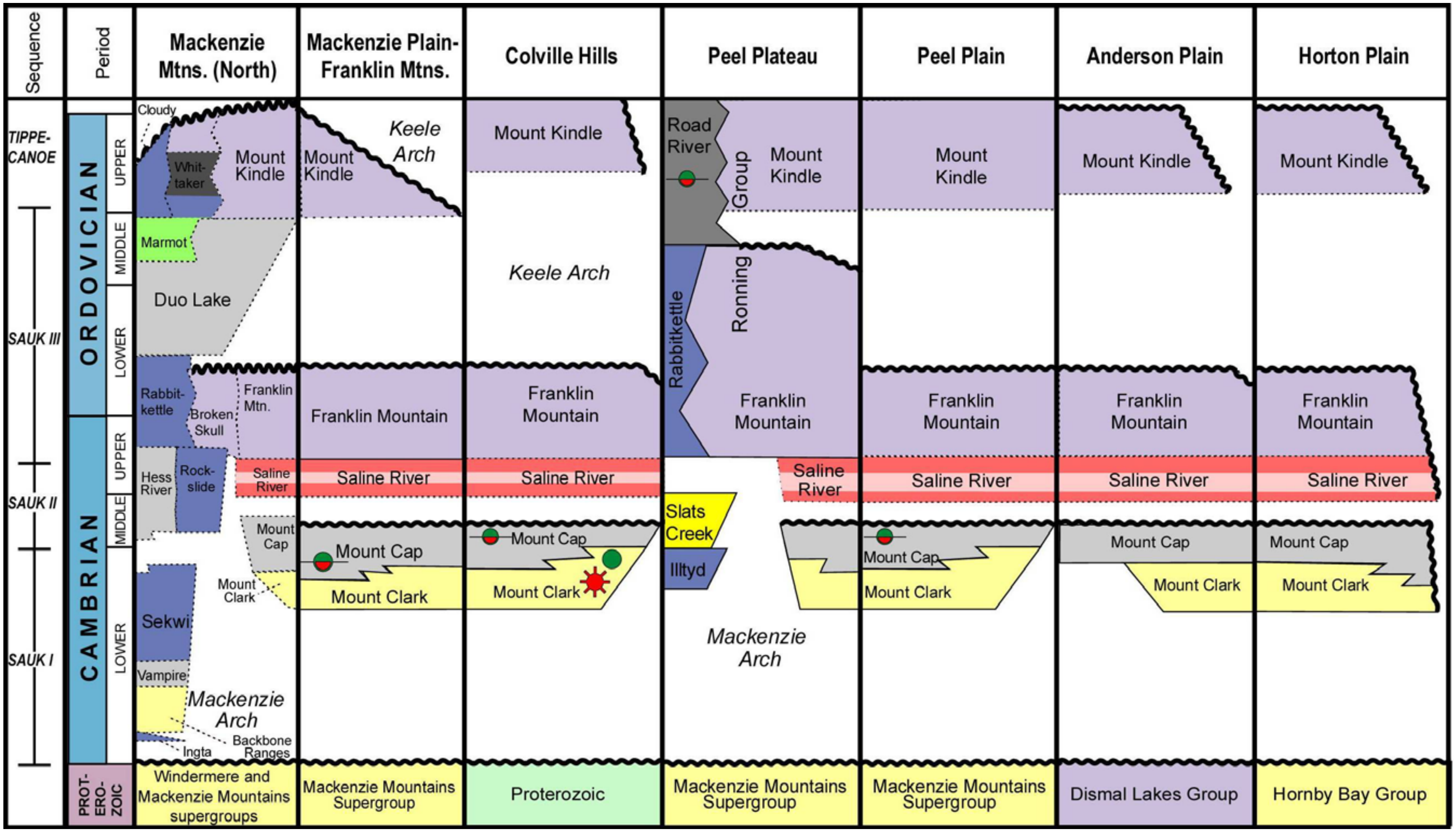

Figure 1. *Stratigraphic chart for the Interior Plains Region. Mackenzie Mountains north stratigraphy after Aitken et al. (1973), Pugh (1983), Morrow (1991), and Gordey and Anderson (1993); Mackenzie Plain-Franklin Mountains stratigraphy after Pugh (1983), Morrow (1991), and Dixon and Stasiuk (1998); Colville Hills after Pugh (1983, 1993) and Dixon and Stasiuk (1998); Peel Plateau and Peel Plain after Pugh (1993), Morrow (1991, 1999), Dixon and Stasiuk (1998), and Cook and MacLean (2004); Anderson and Horton Plains after Pugh (1983, 1993), Morrow (1991, 1999), Dixon and Stasiuk (1998), and Cook and MacLean (2004).*

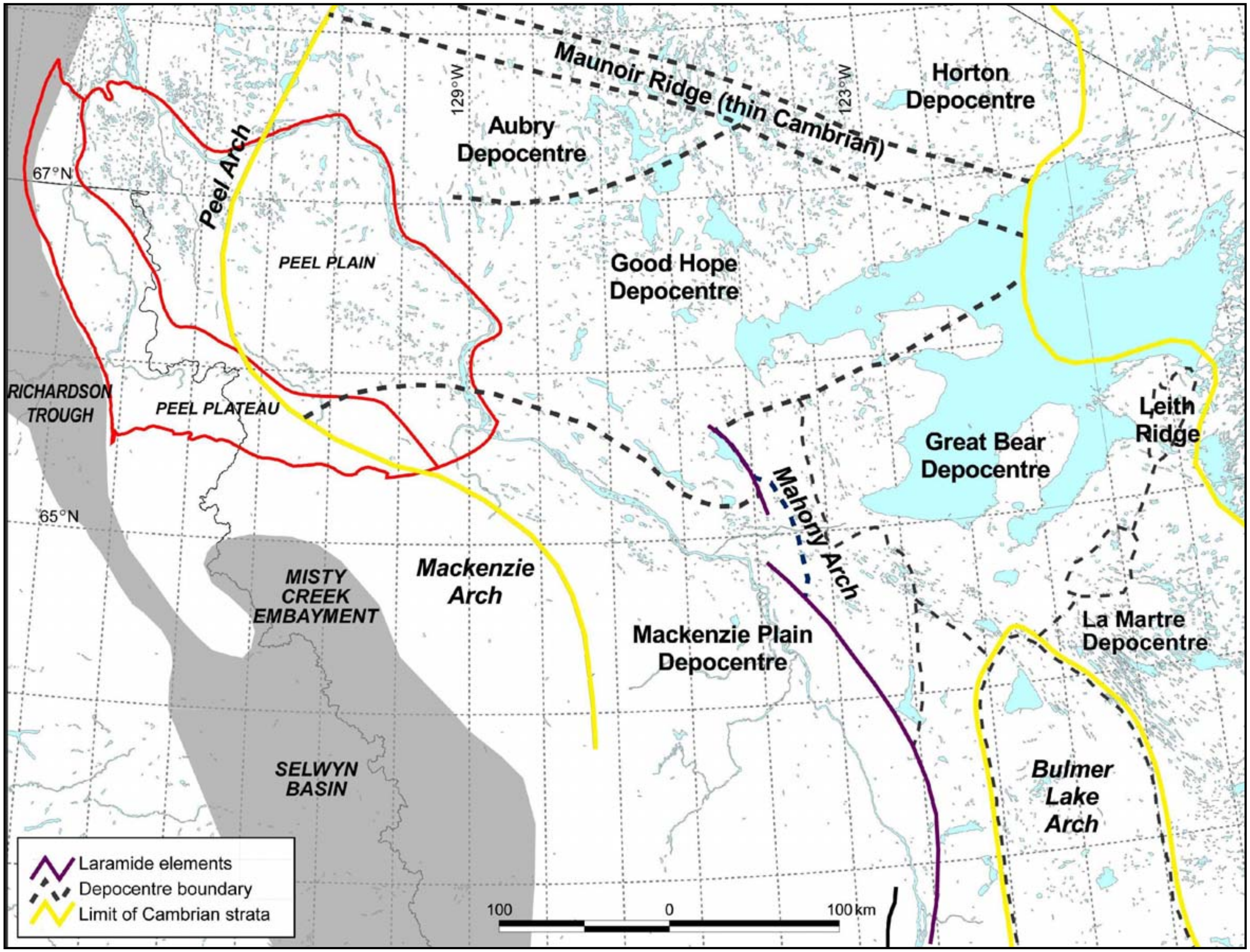

Figure 2. *Cambrian paleogeographic elements in Peel and adjacent areas (after Dixon and Stasiuk, 1998 and Morrow, 1999).*

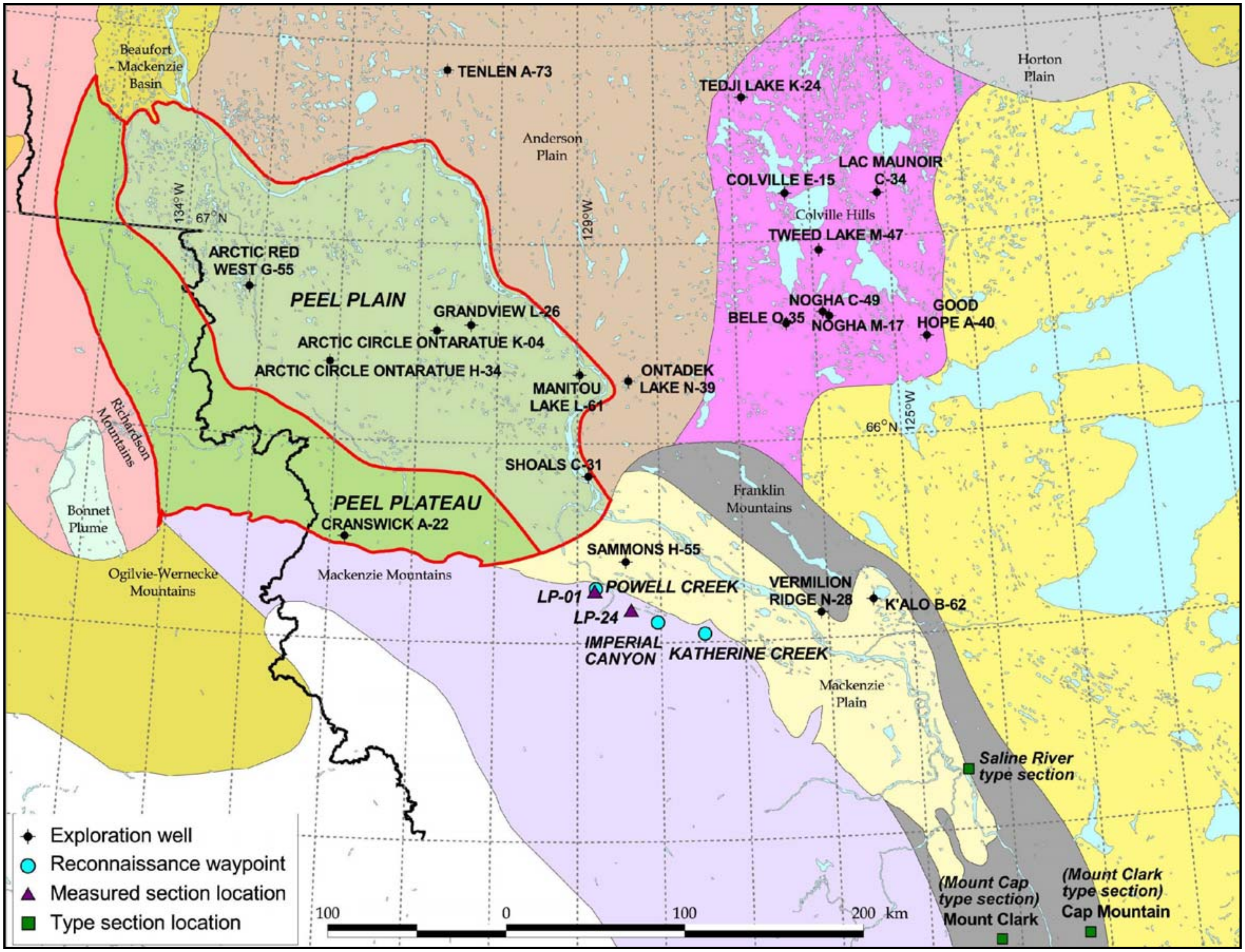

Figure 3. *Location map of Peel area showing exploratory wells and outcrop sections and stations (exploration areas after Mossop et al., 2004).*

Figure 4a. *View southwest to exposure opposite of measured section on Powell Creek (LP-01).*

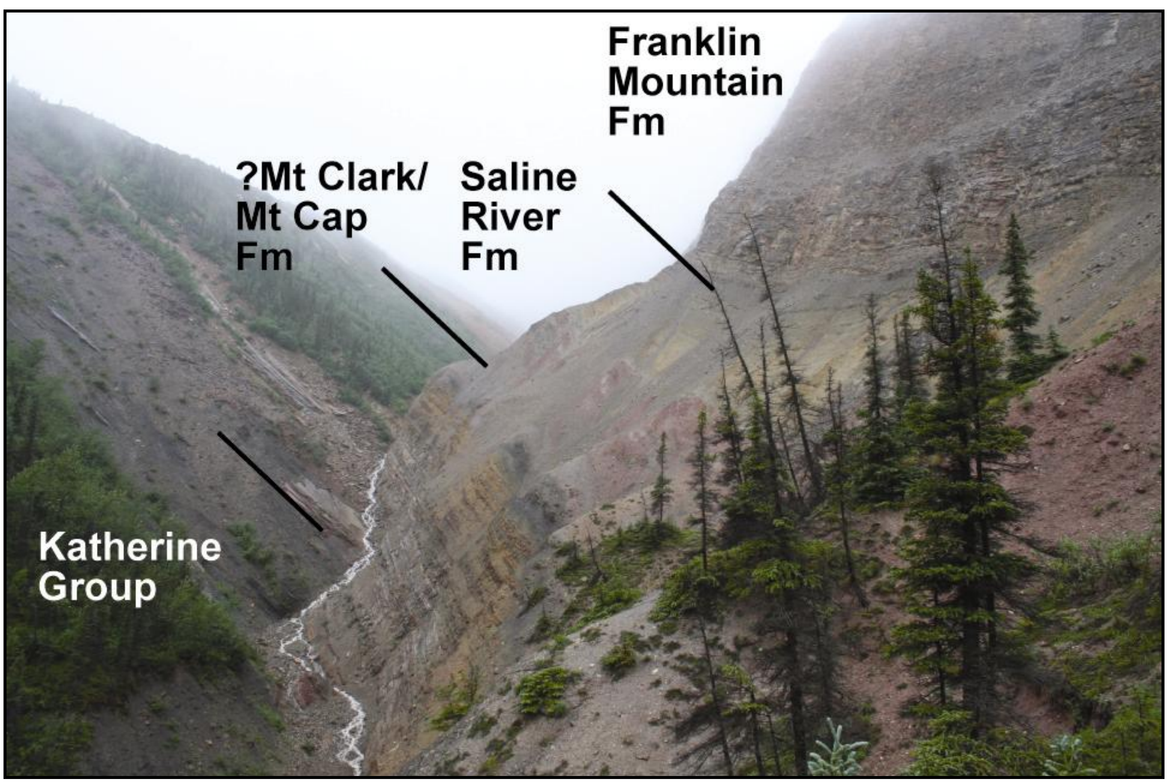

Figure 4b. *View west to Fan Creek (LP-24) section in gully west of main canyon.*

Short Well Name	KB/RT (m)	Saline River (m)	Mount Cap (m)	Mount Clark (m)	Pre-cambrian (m)	Total Depth (m)	Subsurface Material	Description
Shoals C-31	87.6	1831.8				1981.2	cuttings	Shale and dolomite (upper clastic member), halite (salt member; Pugh, 1983)
Grandview L-26	164.9	2004.1	2203.7		2240.3	2395.6	cuttings	Shale, dolomite, siltstone, sandstone (upper clastic member), halite (salt member; Pugh, 1983)
Manitou Lake L-61	131.7	1633.1				1724.3	core	Pink halite, green and red shale interbeds; minor dolostone (this study)
Arctic Circle Ontaratue K-04	103.8	2420.4			2518.6	2728.0	cuttings	Shale, siltstone, trace anhydrite (Pugh, 1983)
Arctic Circle Ontaratue H-34	141.7	2883.4	2899.4		2923.0	4075.2	cuttings	Orthoquartzite, siltstone and shale (Pugh, 1983)
Arctic Red West G-55	44.6		3285.7	3300.7		3322.3	cuttings	Shale and orthoquartzite, siltstone (Pugh, 1983)

Table 1. *Formation tops and lithologies of Cambrian formations in Peel area wells. Tops after Hogue and Gal (2008). KB=kelly bushing; RT=rotary table.*

MOUNT CLARK FORMATION

Mount Clark Formation was defined by Williams (1923). It was originally assigned to Macdougal Group (along with Mount Cap and Saline River formations) but Aitken et al. (1973) deemed the term obsolete. Mount Clark Formation is defined as a basal Cambrian sandstone unit. Aitken et al. (1973) described the unit as very thick-bedded to massive, fine- and very fine-grained quartzite with granule- and pebble-sized clasts in the basal 8 m, prominent cross-bedding in the lower 30 m, and abundance of vertical *Skolithos* burrows in the basal 92 m. Old Fort Island Formation has been applied to stratigraphic equivalents of the Interior Plains (Norris, 1965; Balkwill, 1971) but the name Mount Clark Formation has publication precedence (Bell, 1959; Dixon and Stasiuk, 1998).

Type Section and Origin of Name

The type section of Mount Clark Formation, designated by Williams (1923), is on the northeast-facing scarp of Cap Mountain in the Franklin Mountains (63.433ºN, 123.235ºW). Aitken et al. (1973) and Serié et al. (2009) measured and described the type section. The formation is named after Mount Clark in Fort Norman (96 C) map area (Figure 3; Cook and Aitken, 1977).

Lithology and Log Response

In Section LP-24 (Figure 4b), the basal 50 cm of red-weathering quartz sandstone with green shale chips (Figure 5) is tentatively assigned to Mount Clark Formation. Dixon (1997) described the formation in the subsurface as containing pebbly facies at the base, with cross-bedded, coarse-grained quartz arenite in the basal portion and fine-grained, bioturbated sandstone in the upper portion. Pugh (1993) described additional lithologies including minor conglomerate, shale, and siltstone. The gamma log response may be blocky overall, but shale interbeds within the formation yield variable log responses (Figure 6).

Figure 5. *Sharp contact (at hammer base) between upper "red beds" of Katherine Group and ?Mount Clark quartz sandstone.*

Contacts

Throughout the Interior Plains, Mount Clark Formation unconformably overlies Proterozoic or Archean rocks (Gilbert, 1973; Williams, 1987). Its top boundary is marked by a lithologic change to glauconitic sandstone, shale, or dolostone of Mount Cap Formation and is conformable (Aitken et al., 1973; Pugh, 1993).

In this present study, Mount Clark/Mount Cap formations at Section LP-24 (Figure 5), Section LP-01 (Figure 7), and Imperial Canyon section unconformably overlie Proterozoic rocks. This sub-Cambrian unconformity is remarkably subtle (erosional and down-cutting, but non-angular; representing a hiatus of at least 250 million years), marked by an abrupt change from fine-grained, well cemented sandstone or "red beds" of the Proterozoic upper Katherine Group to fine- or medium-grained, bioturbated sandstone of the Mount Clark/Mount Cap formations. The sub-Cambrian unconformity that underlies the Cambrian succession is interpreted seismically as a regional angular unconformity (Cook and MacLean, 2004).

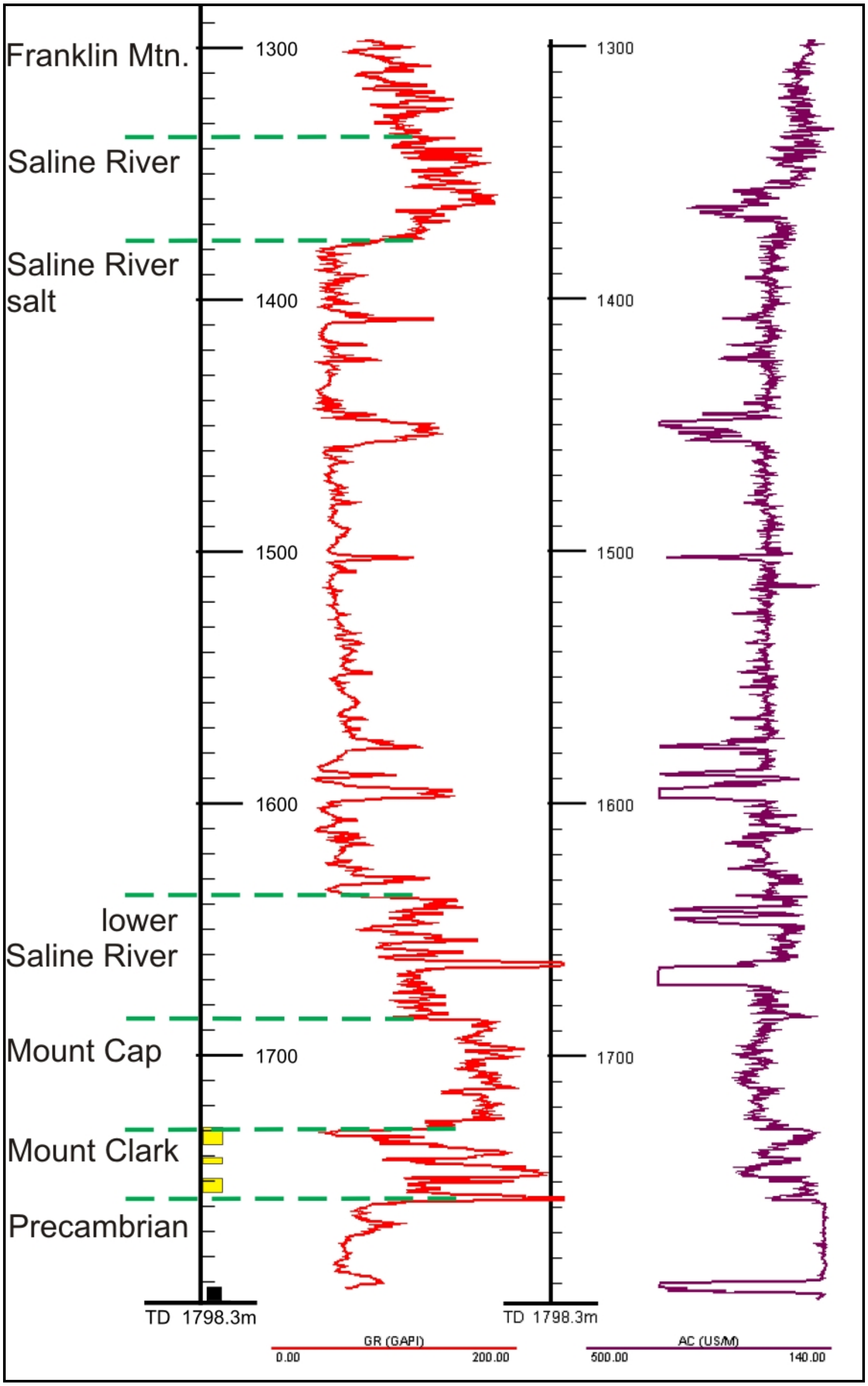

Figure 6. *Log response (gamma ray in red and sonic in purple) of the Cambrian succession from Ontadek N-39 well. Probable sandstone in Mount Clark Formation is indicated by the yellow boxes.*

Figure 7. *Geologist at sub-Cambrian unconformity, Powell Creek (Section LP-01), separating upper Katherine Group sandstone (left of geologist) from Mount Cap Formation sandstone.*

Distribution and Thickness

Regionally, Mount Clark Formation is more than 200 m thick at the type section (Aitken et al., 1973) with a maximum thickness of 88.4 m in the subsurface (Good Hope A-40 well, North Great Bear Plains). Mount Clark and Mount Cap formations are distributed widely but discontinuously in the Interior Plains and are penetrated by only three wells in Peel area: Ontaratue H-34, Grandview L-26, and possibly Arctic Red West G-55 (Table 1, Figure 3). Both formations are limited to outcrop in southeastern Sans Sault Rapids (106 H) map area (Figure 3). Mount Clark Formation is likely present in the basal part of Section LP-24 (50 cm thick; Mount Cap Formation is 39.4 m thick).

MOUNT CAP FORMATION

Mount Cap Formation was defined by Williams (1922). It is predominantly shale with beds of sandstone, dolostone, and limestone (Bell, 1959; Douglas and Norris, 1963) in a series of shale-to-carbonate and/or sandstone cycles (Dixon and Stasiuk, 1998).

Type Section and Origin of Name

The type section of Mount Cap Formation, designated by Williams (1922) on the north flank of Mount Clark in the Franklin Mountains (63.435ºN, 124.231ºW), was described by Aitken et al., (1973). The formation is named after Cap Mountain in Wrigley (95 O) map area (Figure3; Gabrielse et al., 1973).

Lithology and Log Response

In the present area of study, Mount Cap Formation consists of interbedded sandstone, shale, and dolostone. Sandstone beds are brown- and orange-weathering quartz arenite and/or green and glauconitic, ranging from fine- to coarse-grained, and commonly bioturbated (Figure 8a). Shale is dark grey to green. Dolostone beds at the Imperial Canyon section contain stromatolites and are interbedded with black shale (Figure 8b). In the subsurface, Pugh (1983) described orthoquartzite, siltstone, and shale from cuttings (Table 1). Lithologic variation in the subsurface yields no characteristic log response, although higher gamma readings typically distinguish Mount Cap Formation from upper Mount Clark sandstone (Figure 6).

Contacts

Locally, where Mount Cap Formation does not conformably overlie Mount Clark Formation, it may overlap Mount Clark Formation to rest unconformably on Proterozoic rocks. The upper contact with Saline River Formation is problematic, but has been interpreted as a regional unconformity (Aitken et al., 1973, 1982; Dixon and Stasiuk, 1998).

As described above for Mount Clark Formation, the lower boundary of Mount Cap Formation is the sub-Cambrian unconformity. The upper boundary with Saline River Formation is typically covered (Section LP-24), but is marked by a change to anhydritic sandstone and shale at Powell Creek and Imperial Canyon (Figure 8b) sections.

Figure 8a. *Quartz sandstone of Mount Cap Formation contains abundant horizontal burrows (bed at hammer head), interbedded with glauconitic-rich sandstone beds, Section LP-24.*

Figure 8b. *Stromatolitic dolostone and interbedded black shale at Imperial Canyon section (Saline River Formation in background).*

Distribution and Thickness

Mount Cap Formation is 212 m thick (incomplete thickness due to cover) at its type section and is up to 896 m thick in K'Alo B-62 well in Mackenzie Plain (Figure 3). In this study, Mount Cap Formation was identified at Powell Creek Section (19.5 m thick) where it was previously mapped as Saline River Formation. Mount Cap Formation is 28.5 m thick at Imperial Canyon Section and is limited in outcrop to southeastern Sans Sault Rapids (106 H) map sheet.

SALINE RIVER FORMATION

Saline River Formation was defined by Williams (1923). It consists of red, silty, and sandy mudstone, red and green shale and siltstone, pink to grey gypsum, grey, microcrystalline dolostone, and gypsiferous breccia containing redbed fragments (Aitken et al., 1982). It was divided into three members by Meijer Drees (1975) and adopted by Dixon and Stasiuk (1998) as: Lower clastic member, Evaporite member, and Upper clastic member. It has been left undivided at the margins of Mackenzie Platform where the middle member was not recognized (Pugh, 1983; Meijer Drees, 1986).

Type Section and Origin of Name

The type section of Saline River Formation, designated by Williams (1923) on the north side of Saline River, upstream from the confluence of the Saline and Mackenzie rivers (64.30ºN, 124.47ºW; Figure 3), was described by Aitken et al. (1973). The formation is named after the Saline River in Fort Norman (96 C) map area (Cook and Aitken, 1977).

Lithology and Log Response

In the present area of study, Saline River Formation was not studied in detail and is poorly exposed at all sections. It is primarily shale and siltstone, with minor sandstone, which weather light red and light greenish-grey. Anhydrite (gypsum at surface exposures) layers and salt casts are common. Core of Saline River Formation (1697.7-1716.3 m in Manitou Lake L-61 well, Figure 3) contains pink halite, red and green shale interbeds, and minor grey dolostone. Meijer Drees (1975) divided the formation into Lower and Upper clastic members (interbedded shale, dolostone, and anhydrite) and Evaporitic member (or Evaporite member *sensu* Dixon and Stasiuk, 1998) that contains mainly halite with interbeds of shale, dolostone, and anhydrite. Saline River Formation has a distinctive serrated gamma log response (Figure 6); the Evaporite member, where present, is readily identified by a number of mechanical logs including caliper measurements.

Contacts

The base of Saline River Formation is likely unconformable, and its upper boundary has been described as gradational and conformable with Franklin Mountain Formation at the type section (Aitken et al., 1973) but also as abrupt, marked by a brecciated dolostone bed at Tenlen A-73 well (Figure 3; Dixon and Stasiuk, 1998). At Section LP-24, the upper contact of Saline River Formation with Franklin Mountain Formation is abrupt and erosional, marked by a change from green siltstone and shale to a downcutting, quartz sandstone and dolostone conglomerate bed at the base of Franklin Mountain Formation (Figure 9).

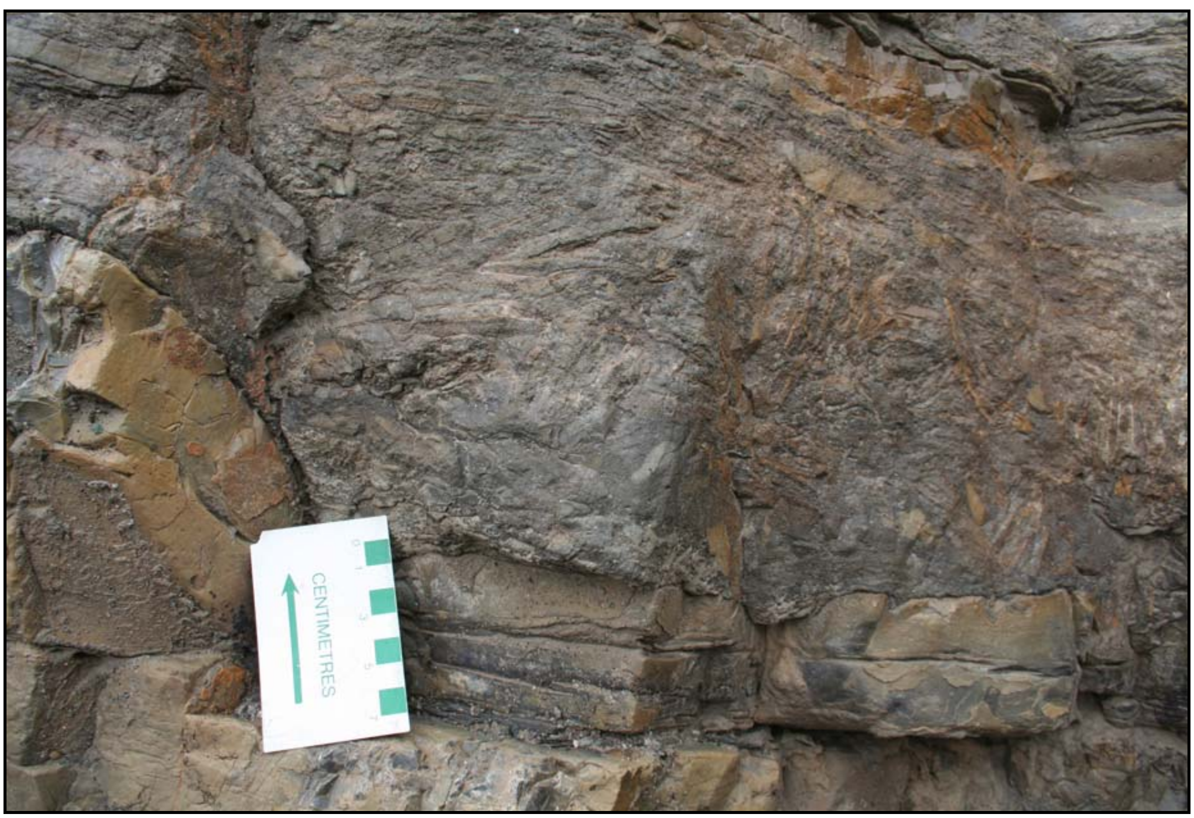

Figure 9. *Top of the Saline River Formation at Section LP-24 is an erosional unconformity.*

Distribution and Thickness

Saline River Formation is only 39 m thick at the type section (incomplete thickness because the base is not exposed) and up to 888 m in the Vermilion Ridge No. 1 well, Mackenzie Plain (Figure 3). Great thicknesses of Saline River Formation, however, are likely due to tectonic thickening or flowage in the Evaporite member. Saline River Formation was penetrated in four wells in Peel area: Shoals C-31, Manitou Lake L-61, Ontaratue K-04, and Ontaratue H-34 (Table 1, Figure 3). In outcrop, it is 23 m thick at Section LP-01 and 84 m thick at LP-24; it was not measured in the cliff section at Imperial Canyon.

All three Cambrian formations pinch out westward toward the Cambrian Mackenzie Arch. The present dataset does not add any new information to existing isopach maps by Dixon and Stasiuk (1998).

PALEONTOLOGY AND AGE

The relative age of Cambrian strata is broadly constrained by trilobite zones known only from Mount Cap Formation. There are no age diagnostic fossils from Mount Clark Formation, only *Skolithos* and *Teichichnus* burrows and *Lingula* and *Olenellus* macrofossils (Hamblin, 1990). An Early to Middle Cambrian age (*Bonnia-Olenellus* to *Glossopleura* zones, Dyeran to Delamaran stages) is known for Mount Cap Formation [Determinations by Fritz in Braun et al., 1970 (Shell Keele River L-04); Barss et al., 1971 (Imperial Vermilion Ridge No.1); Aitken et al., 1973, and Barnes et al., 1974 (Mobil Colville E-15); North American stages after Palmer, 1998]. Fossils with Burgess Shale-type preservation were reported from Mount Cap Formation in wells of Colville Hills (Butterfield, 1994) and from outcrop in the northern Mackenzie Mountains associated with Middle Cambrian trilobites (Butterfield and Nicholas, 1996). Fossils have not been discovered in Saline River Formation. The extent of sub-Saline River Formation erosion is unknown, but based on its stratigraphic position it may be as old as Middle Cambrian, or entirely Late Cambrian in age (Figure 1).

FACIES DISTRIBUTIONS AND STRATIGRAPHIC CORRELATION

Cambrian facies are limited to eastern Peel area, east of Mackenzie-Peel Arch. Mount Clark Formation was reported in Arctic Red West G-55 well (Osadetz et al., 2005), but lithologies described in the well report (i.e., shale, quartzite, sandstone) are not diagnostic and may instead be Mount Cap Formation. Distribution of Mount Clark sandstone, where present, or of Mount Cap Formation is discontinuous due to the configuration of epicontinental Cambrian basins bordered by arches and local paleogeographic depressions on the Proterozoic surface (Figure 2).

Correlation of three sections in the northern Mackenzie Mountains (Figure 10) shows the sub-Cambrian unconformity which represents the base of the cratonic Sauk Sequence (Sloss, 1963). This sequence boundary has a downcutting relationship at Imperial Canyon and Section LP-24, and is merged with a transgressive surface, representing overall transgression onto the craton. The lowermost beds at these two sections are interpreted as channel fills, with high angle cross-beds and absence of bioturbation, which may suggest a fluvial origin. These basal deposits are absent at Section LP-01, where Mount Cap Formation is interpreted as a transgressive systems tract containing largely shallow marine facies, including bioturbated sandstone beds. The upper part of Mount Cap Formation which contains thin beds of limestone, shale, and stromatolitic dolostone is interpreted as a highstand systems tract above a flooding surface.

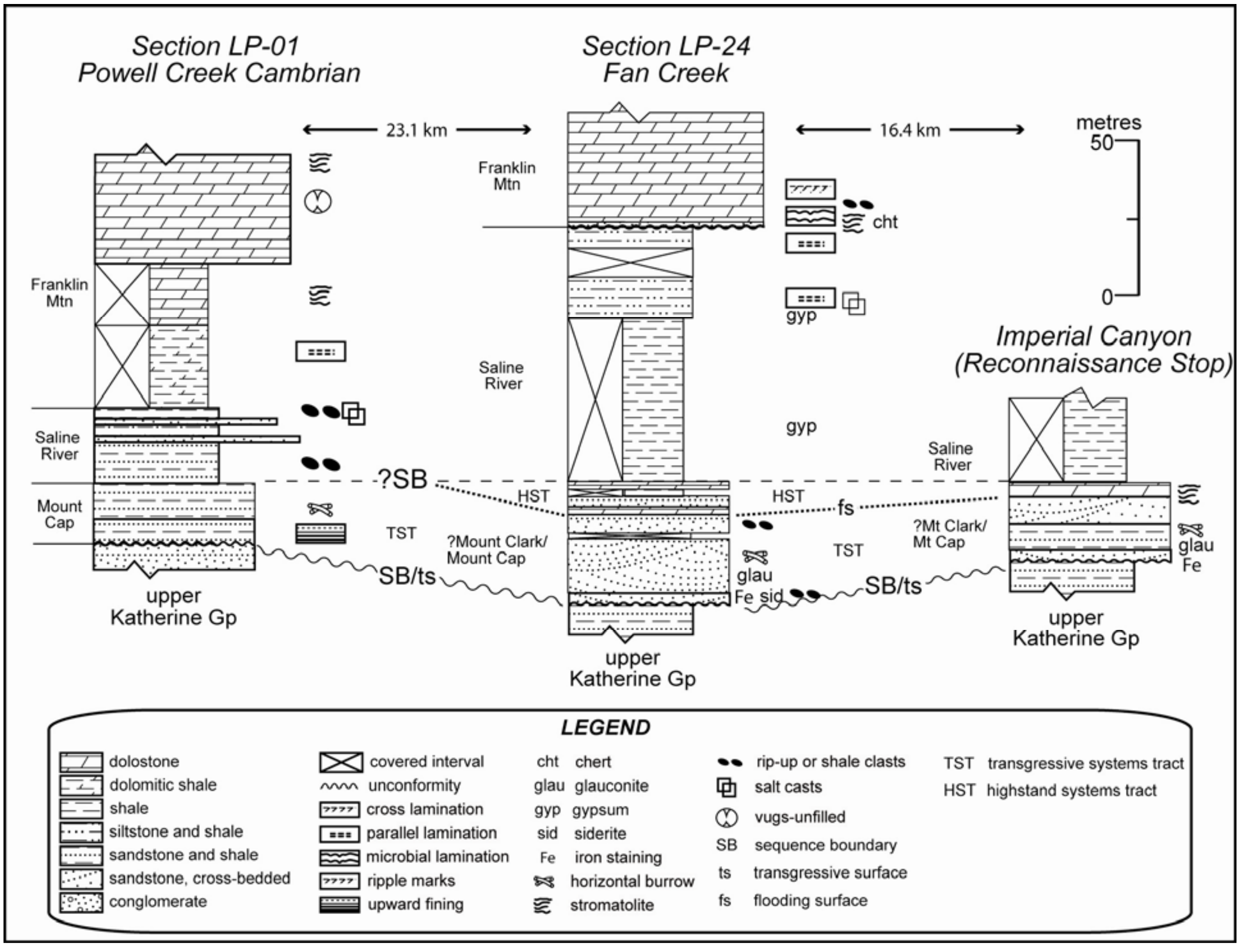

Figure 10. *Correlation of three Cambrian sections south of Peel area (see Figure 3 for section locations.*

Correlations within the Cambrian of northern Interior Plains were established by Dixon (1997) and Dixon and Stasiuk (1998) who proposed a sequence stratigraphic framework. They identified shale-to-sandstone or dolostone cycles within upper Mount Cap Formation that could be correlated between wells. They also interpreted the base of Saline River Formation as a sequence boundary, often quite subtle in its expression, and a marked change to restricted marine deposition. In our present outcrop study, the lower contact of Saline River Formation was not clearly exposed. Dixon and Stasiuk (1998) identified a carbonate interval at the base of the Lower clastic member that was correlatable throughout the subsurface and interpreted the base of these beds as an unconformity. Meijer Drees (1975, 1986) suggested a sub-Saline River unconformity at the basin margin and a transitional relationship between Mount Cap and Saline River formations within depocentres. Serié (2008) correlated the Mount Clark and Mount Cap succession across Mackenzie Plain and illustrated the complexity of thickness and facies changes due to localized extension and subsidence.

DISCUSSION AND DEPOSITIONAL HISTORY

Depositional patterns and architecture of subsurface Cambrian units across the Interior Plains define an intracratonic basin containing several depocentres, bounded by positive elements and opening to the southwest onto a continental shelf (Dixon and Stasiuk, 1998). In Peel area, Cambrian deposition was influenced by an irregular surface of the sub-Cambrian unconformity and uplifted Mackenzie Arch, separating Cambrian depocentres of the Interior Platform from Selwyn Basin (Gabrielse, 1967; Figure 2).

Mount Clark sandstones may represent fluvial (Macauley, 1987; Serié, 2008) and shallow marine deposits, the latter based on the presence of bioturbation and marine fossils (Hamblin, 1990). An overall shallow marine setting is suggested for Mount Cap Formation based on extensive bioturbation, carbonate lithologies, and shelly material (Dixon and Stasiuk, 1998); across Mackenzie Plain, however, a range of deposits from estuarine to turbidite fan complexes occur (Serié, 2008). A subtidal to evaporitic basin setting is suggested for the lower two members of Saline River Formation, and an open-marine shelf setting with periods of evaporite deposition is suggested for the Upper clastic member (Dixon and Stasiuk, 1998).

Cambrian strata exposed immediately south of Peel area record early Cambrian basal sandstone (?Mount Clark Formation), overlain by shallow marine deposits of Mount Cap Formation which represents continuous transgression. This relative sea level rise was part of the global Cambrian transgression (Sauk I sequence of Palmer, 1981), but was also influenced by local subsidence such as development of Misty Creek Embayment in late Early Cambrian (Cecile, 1982). Mount Cap Formation forms part of Sauk II Sequence; it is not certain if Saline River Formation is also part of Sauk II, it may also form part of Sauk III together with Franklin Mountain Formation (Figure 1).

By Middle Cambrian time, deposition of carbonate with less siliciclastic input may suggest inundation of arches. A Middle Cambrian connection of Mackenzie and Good Hope depocentres to basins to the west (Richardson Trough and Selwyn Basin; Figure 2) via flooding of Peel Arch was suggested by Pugh (1993). Correlation by Dixon and Stasiuk (1998) and facies and thickness trends do not support such a connection. Deposition of Saline River Formation facies in restricted and hypersaline settings was associated with renewed uplift of arches (Pugh, 1993), although the timing of this is poorly constrained.

Distribution of basal Cambrian siliciclastics across Peel area is poorly constrained due to sparse well data. Outcrop extends as far west as Powell Creek (Figure 3) where facies pinch out against Mackenzie Arch or were removed by subsequent erosion during reactivation of the arch.

BASAL CAMBRIAN CLASTICS PLAY

Play Definition

The play includes all pools and prospects hosted in sandstones of Cambrian Mount Clark and Mount Cap formations. Oolitic dolostones of Mount Cap Formation are another possible reservoir (Meding, 1998). The play must be considered conceptual within Peel area, as no discoveries have been made.

The play is, however, established with discoveries in Colville Hills, approximately 200 km north of Norman Wells and 150 km northeast of Fort Good Hope (Figure 3). Three gas and/or condensate pools were discovered in the 1970s and 1980s, with additional recent discoveries of gas (e.g., Nogha C-49, M-17; Table 2) and oil (Maunoir C-34; Figure 3). In addition, the Canadian Gas Potential Committee (2005) has estimated a total endowment for this play (discovered and undiscovered gas) of 247 x 109 m^3 (8.7 Tcf) in Colville Hills region. Given the probable restricted occurrence of potential reservoir rocks in Peel area, only a small portion (if any) of this endowment should be ascribed to Peel area.

Discovery Well(s) (Year)	Gas in Place[2] ($x10^6$ m^3)	Reference
Tedji Lake K-24 (1974)	1019 (36 Bcf)	Canadian Gas Potential Committee, 2005
Tweed Lake M-47 (1985)	5408 (191 Bcf)	Canadian Gas Potential Committee, 2005
Bele O-35 (1986)	4786 (169 Bcf)	Canadian Gas Potential Committee, 2005
Nogha C-49, M-17 (2003)	1161 (41 Bcf)	MGM Energy Corp., 2008
All Discoveries	24551 (867 Bcf)	Canadian Gas Potential Committee , 2005

Table 2. *Estimated gas resources of discoveries in Colville Hills. Bcf = billions of cubic feet.*

Previous workers have shown the play area restricted to a region just east of Peel area (e.g., Canadian Gas Potential Committee, 2005; Gal, 2007). However, distribution of Mount Clark Formation is poorly known due to sparse well penetrations, and it may extend further west, perhaps to the crest of Mackenzie Arch (Aitken et al., 1973; Pugh, 1983). The basal Cambrian sandstone is generally confined to paleogeographic depressions on the pre-Cambrian surface, which may be isolated and dispersed throughout Peel area. The Arctic Red West G-55 well reportedly intersected Mount Clark Formation (Osadetz et al., 2005), and Gal (2007) showed possible Mount Clark Formation encountered in Ontaratue K-04 well. Based on lithologies in well history reports and log responses in these wells, however, there is more resemblance to Mount Cap Formation. Due to the lack of subsurface information in Peel area, the play area boundary is placed at Mackenzie Arch in southwest Peel area, and follows the zero edge (as interpreted by Pugh, 1983) of Mount Cap subcrop northward to the Mackenzie River (Figure 10 in Chapter 10, this volume).

Mount Cap Formation probably extends to Mackenzie Arch. Mount Cap subcrop through the eastern third of the Peel area is mainly carbonate, with fine siliciclastics dominating in the west (Pugh, 1983). Mount Cap Formation is intersected in the Arctic Red West G-55, Ontaratue H-34, and Grandview L-26 wells (Table 1).

Potential Reservoir Rocks

Potential reservoir rocks are quartz sandstones of Cambrian Mount Clark and Mount Cap formations, although oolitic dolostone in Mount Cap Formation may also be considered a potential reservoir rock (Meding, 1998). Proterozoic arenitic sandstones of Katherine Group unconformably underlie Mount Clark Formation and younger units throughout much of Peel area, and have been considered potential reservoir rocks. A separate Proterozoic petroleum system may have existed where dark shales also occur in the upper Proterozoic section. Katherine Group sandstones are generally tight, completely quartz cemented and texturally closer to quartzite, and hence are poor potential reservoir rocks (Tassonyi, 1969; Figure 11).

Lithological logging by Canadian Stratigraphic Services (2000) Ltd. from cuttings at the base of the Cranswick A-22 well identified Cambrian fine-grained quartz sandstone/quartzite with some streaks of poor porosity, but this is likely Katherine Group. This is supported by the well history report description of the basal 6 m (from 2263 m) as very fine- to fine-grained, white to light grey, pyritic, dense, tight quartzite with minor dolomite (Cannon, 1972). The possible Mount Clark Formation in the Ontaratue K-04 well might also be Proterozoic Katherine Group. Well history reports describe "quartzites" so it is expected these lithologies are tight, regardless of which unit is assigned. The Canadian Stratigraphic log of Grandview L-26 well indicates probable Mount Cap Formation dominated by dolomite with only rare streaks of poorly porous sandstone; the basal dolostone in this well is possibly Proterozoic. Reported Mount Clark Formation in Arctic Red West G-55 (Osadetz et al., 2005) does not have the log character of quartz sandstone, and the well history report describes multi-coloured shales, pale quartzite, and red siliceous sandstone. From this description, the unit is likely Mount Cap Formation or the basal "red bed" unit of Franklin Mountain Formation.

The Sammons H-55 well (Figure 3), southeast of Peel area on Imperial anticline, was drilled with 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 is well cemented with silica and hence lacks porosity. The operator picked this as Proterozoic Katherine Group, lying below Saline River Formation. Katherine Group quartz sandstones outcropping along the front of the Mackenzie Mountains, at the southern edge of Peel area, are generally without porosity. Sparse well intersections, notably Sammons H-55 well just southeast of Peel area, likewise encountered tight, quartz cemented to recrystallized Katherine Group sediments. Katherine Group examined in this study is not deemed a viable reservoir rock; however, Proterozoic quartz sandstones below the sub-Cambrian outcrop may be considered potential reservoir rock in adjacent regions to merit an extension of the conceptual play boundaries. Hu (in press) compiled porosity data from Proterozoic cores in wells of Colville Hills area, with results up to 11.7% in Tweed Lake C-12 well.

There are no reported porosity and permeability measurements from core in Mount Clark and Mount Cap formations in Peel area. An outcrop sample taken during the current study at Section LP-24 southeast of Peel area yielded 4.4 % porosity (0.03 millidarcies permeability) in glauconitic Mount Cap Formation sandstone (Figure 12). ?Mount Clark quartz sandstone from the same area is tight with quartz overgrowths (Figure 13).

For three Colville Hills discoveries, Janicki (2004) estimated average pay zone porosity of 10 to 14% (8% cut-off). Reservoir permeability at the Colville Hills discoveries, as reported by Janicki (2004) is variable: 0.04 mD from core measurements at Bele pool, and 112 mD estimated from drill stem tests at Tedji Lake. In the Peel area, well logs suggest zero, or only minor porosity in: Cranswick A-22, Arctic Red West G-55, Ontaratue H-34, and Ontaratue K-04 wells. Well cuttings indicate only very minor occurrences of porosity. Hu (in press) compiled measured porosity data from cores of several wells in Colville Hills area, with values up to 19.4% in Mount Clark Formation in Colville D-45 well, 23.9% in Tweed Lake A-67 well, and 21.1% in Stopover K-44 well.

Gross thicknesses of potential reservoir sandstones are likely less than 15 m. At Section LP-24 southeast of Peel area, 40 m of undifferentiated Mount Clark/Mount Cap quartzose and glauconitic sandstone with lesser shale and dolostone was measured (Pyle and Gal, 2007). At Section LP-01, 19.5 m of quartz sandstone and shale occur. Pay thickness in the three original Colville Hills discoveries range from 1.0 to 7.5 m (Janicki, 2004).

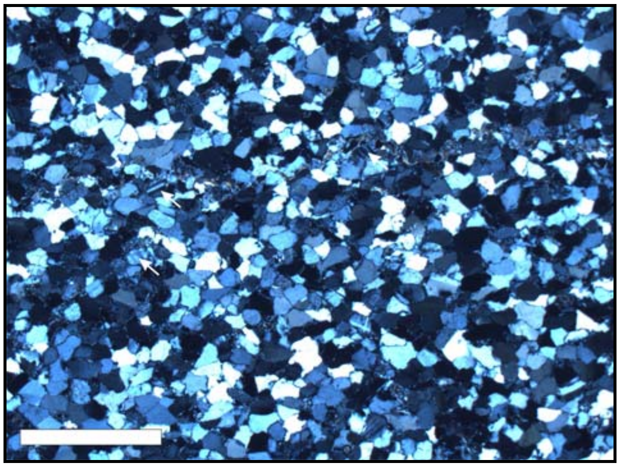

Figure 11. *Sample 06LP 24-08, Katherine Group quartz sandstone/quartzite, Section LP-24. Note tightly packed and embayed quartz grains, with a few feldspars grains (some indicated by white arrows) and chert; essentially no porosity. Crossed polarized light, scale bar is 1 mm.*

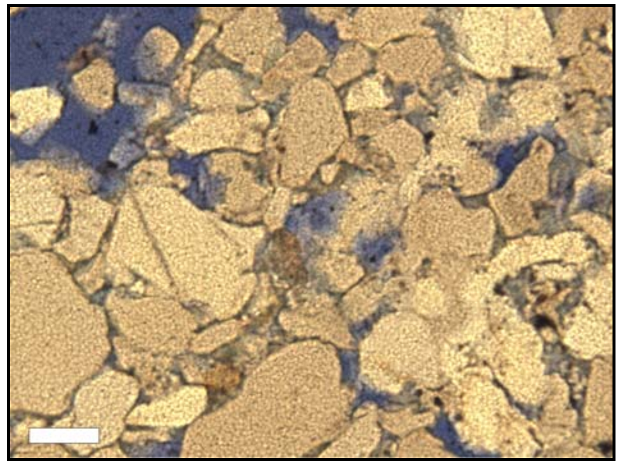

Figure 12. *Sample 06LP 21-14, Mount Cap Formation glauconitic quartz sandstone, Section LP-24. Note poorly sorted, subangular to subrounded, slightly embayed quartz grains, greenish glauconite matrix/cement. Blue epoxy indicates porosity. Plane polarized light, scale bar is 0.1 mm.*

Source Rocks

Potential source rocks for the basal Cambrian play are present, but limited in thickness and richness. Shale in Mount Cap (Figure 14) and Saline River formations is commonly red or green; black shale does not represent a large proportion of either formation. Other possible source rocks may occur in the Proterozoic section such as a black shale unit below upper Katherine Group quartzite/quartz sandstone.

A number of analyses have been made of lower Paleozoic potential source rocks from well cuttings and outcrop samples in Peel area. Pyle et al. (2006a) compiled Rock-Eval, total organic carbon (TOC), and vitrinite reflectance data. Based on TOC, source rock potential of Saline River, Mount Cap, Mount Clark, and Proterozoic formations in the study area is generally poor, with most samples yielding less than 0.5% TOC. Regionally, however, there are thin, rich (1.5 to 6% TOC) organic layers within Mount Clark/Mount Cap Formation (Wielens et al., 1990; Dixon and Stasiuk, 1998). A sample from the top of Mount Cap Formation in the Colville E-15 well at 1415 m yielded 2.9% TOC (Geochem Laboratories and AGAT Consultants, 1977). Mount Clark/Mount Cap Formation samples from the Ontaratue H-34 and K-04 wells yielded TOC values as high as 0.83% (Macauley, 1987) although most were less than 0.5%. Samples collected closer to the study area included one with 0.22% TOC from Saline River Formation; and 0.03, 0.10, and 0.39% TOC from Mount Cap Formation, at Imperial Canyon southeast of Peel area (Pyle et al., 2006b). Other samples collected from Mount Cap Formation outcrop at Section LP-24 yielded 0.21% and 0.16% TOC (Gal et al., 2007).

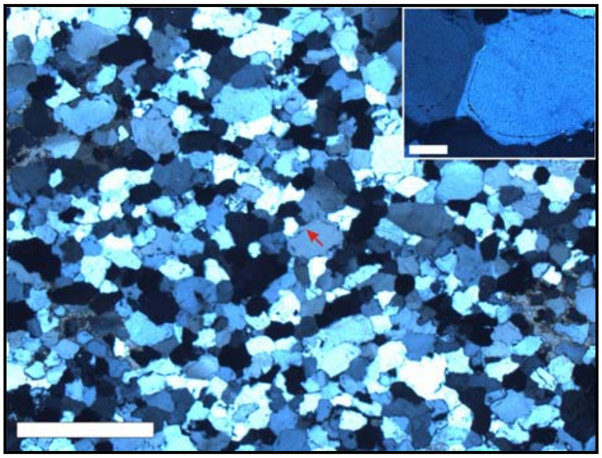

Figure 13. *Sample 06LP 21-15, ?Mount Clark Formation quartz sandstone, Section LP-24. Note highly embayed and sutured grain boundaries, and quartz overgrowths (example at red arrow, and inset); essentially no porosity. Cross polarized light, scale bar in main picture is 1 mm, inset is 0.1 mm.*

Figure 14. *Interbedded dolostone and shale, Mount Cap Formation, Imperial Canyon. Hammer for scale.*

Most lean samples have hydrogen and oxygen indices typical of Type III kerogen. Geochem Laboratories and AGAT Consultants (1977) noted Mount Cap Formation source rocks were comprised mainly of oil-prone amorphous-herbaceous type organic matter; although this assessment is unlikely since there was no source of terrestrial herbaceous organic matter during the lower Paleozoic. Most of the Mount Cap samples from Colville Hills wells analysed by Macauley (1987) had hydrogen and oxygen indices typical of Type II kerogen. The Mount Clark/Mount Cap succession contains thin beds of rich oil-prone Type I organic matter alginites (Dixon and Stasiuk, 1998). Such sources, although commonly thin, are often prolific and known to be effective elsewhere such as in the Williston Basin (Osadetz and Snowdon, 1995; Osadetz et al. 1992; 1995; Stasiuk and Osadetz, 1993), the mid-Continent region (Longman and Palmer, 1987; Jacobson et al., 1988) and other lower Paleozoic successions globally (Hoffmann et al., 1987; Foster et al., 1989).

Proterozoic formations are other possible source rocks. Samples collected in 2006 from Katherine Group at Section LP-24 yielded 0.45% TOC, just southeast of Peel area (Gal et al., 2007). Most samples analyzed have TOC values of less than 0.4% up to a maximum of 1.4% TOC (Snowdon and Williams, 1986). However, intriguing results of 2.26% TOC were reported by Feinstein et al. (1988) from Proterozoic shale in the Ontaratue H-34 well at 3384 m, which is similar to findings by Geochem Laboratories and AGAT Consultants (1977) who reported 2.42% TOC at 3384 m and 2.56% at 3415 m. Macauley (1987) reported a sample of Proterozoic material yielding 5.97% TOC from the Ontadek N-39 well just east of Peel area. Rock-Eval analyses indicated high maturity, although Macauley (1987) suspected the sample was bituminous and the Rock-Eval results were not clearly representative of source rock kerogen potential. Other studies reported maximum values from this well of only 0.17% TOC (Geochem Laboratories and AGAT Consultants, 1977). Petroliferous sediments were reported in the upper 30 m of Katherine Group in McDougall Canyon, southeast of Peel area (Tassonyi, 1969).

The available data on the maturity of potential source rocks for this play indicates that the Proterozoic and Mount Cap formations are currently overmature in Peel area (Geochem Laboratories and AGAT Consultants, 1977; Macauley, 1987; Feinstein et al., 1988; Dixon et al., 2007). In the Colville Hills, Cambrian source rocks are marginally mature to mature in the north and that maturity increases southward (Dixon and Stasiuk, 1998).

There are also local indications for an active petroleum system in lower Paleozoic rocks. Oil-stained samples collected at Powell Creek in 2007 (Devonian Ramparts Formation), and Katherine Creek (southeast of Peel area; Figure 3) in 2008 (Devonian Imperial Formation), were extracted and analyzed. Some were inferred to have compositional traits indicative of an early Paleozoic source, most likely in the Cambrian to Ordovician succession (K. Osadetz, pers. comm., 2008). The composition of these oil stains is similar to Colville Hills crude oil compositions.

In summary, thin intervals of the Cambrian succession are rich in oil-prone source rocks in Peel area. Currently these sources are thermally overmature and within the dry gas window. Proterozoic shale source rocks have thermal maturity attributes similar to Cambrian strata. Oil stains from potential lower Paleozoic petroleum source rocks are not precisely tied to specific source rocks at a given stratigraphic level, and it is uncertain if the oil stains were generated in Mount Clark and Mount Cap formations or in overlying Saline River and Franklin Mountain formations.

Seal and Overburden Rocks

Immediate top seal to a Mount Clark/Mount Cap Formation potential reservoir would likely be shale, dolostone, anhydrite, and salt of Mount Cap or lower Saline River formations. The evaporite member in the middle part of the Saline River Formation is up to 70 m thick in Peel area (at the Grandview L-26 well). Farther southeast in Peel area, adjacent to Franklin Mountains, there is evidence for tectonic thickening of the salt (e.g., Cook and MacLean, 2004). The salt zero (depositional) edge (Figure 7 in Dixon and Stasiuk, 1998) lies between the Ontaratue K-04 and Ontaratue H-34 wells in eastern Peel area. Fault seals are also possible, as well as lateral seals against Proterozoic shale.

The top of Saline River Formation in Peel area varies from about 1500 m below sea level in eastern Peel area to over 3200 m below sea level at the Arctic Red West G-55 well. Cambrian clastic rocks attained maximum burials deeper than this because there has been considerable erosion inferred (Chapter 10, this volume). There are major unconformities at the base of Delorme Group and base of Cretaceous, and significant erosion of Cretaceous strata is inferred in eastern Peel area. Thus there is sufficient thickness in, and burial by, overburden rocks to suggest early oil and later dry gas generation for a Cambrian clastic play. The shale and dolostone top seal, with overlying salt, is similar to the setting in Colville Hills.

Traps

A variety of conceptual trap types in Cambrian clastic rocks are proposed, including updip pinch-outs against paleotopographic highs, intraformational facies changes from sand to shale, and diagenetic changes affecting porosity (e.g., changes in quartz cementation). Structural traps such as faulted anticlines (Early Tertiary age thrust-faulted anticlines; Dixon et al., 2007) may be important in southeast Peel area along the Franklin Mountains trend, and along the front ranges of the Mackenzie Mountains. Differential compaction drape structures over pre-existing basement highs also may be possible. Kodiak Energy Inc. has interpreted a basal Cambrian sand lying in an updip trapping position against a Proterozoic uplift from recent seismic data in Little Chicago area in northeastern Peel area (Kodiak Energy Inc., 2008).

Areas of closure may be expected to be rather sizeable for linear, updip pinch-outs along Proterozoic highs, or in large structures along the Mackenzie Mountains front (Chapter 10, this volume). Lemieux et al. (2008) outlined structural closures from 1 km by 3 km to 4 km by 16 km in the northern Franklin Mountains southeast of Peel area, and closures as large as 20 km by 30 km in the Colville Hills.

Timing of Generation, Migration, Accumulation

In the Colville Hills area, Cambrian clastic gas reservoirs are bitumen stained, indicating early oil generation and migration, followed by later flushing of the reservoir rocks by gas and condensate (Dixon et al., 2007). Early oil may have been generated in the higher maturity southern part of the Colville Hills, then migrated north and west (Dixon et al., 2007). The oil show in the Maunoir C-34 well (235 bbl/day; MGM Energy Corp., 2008) may be a preserved example of early hydrocarbons that escaped later flushing.

Oil stained rocks at Powell Creek and Katherine Creek have chemical characteristics that suggest a Mount Cap Formation source, so it is likely that some oil was generated from Cambrian source rocks. Hydrocarbons generated in the Peel area also may have migrated eastward up along the regional dip, toward the Keele Arch. Stratigraphic traps (such as localized pinch-outs against paleotopographic highs) may have impeded some of this eastward migration.

Timing of petroleum generation, migration, and possible accumulation in Peel area is not well constrained (Chapter 10, this volume). Most likely, Cambrian sources were buried to sufficient depths for oil generation in late Paleozoic time under Imperial Formation siliciclastics. Migration at this time would predate the creation of Laramide structural traps. Burial under Cretaceous siliciclastics in post-Albian time led to overmaturity, as indicated by limited reflectance and Rock-Eval data and possibly dry gas generation.

Hydrocarbons sourced from Proterozoic rocks may have been generated before the Cambrian (and likely breached during pre-Cambrian erosion), or during the Cambrian (and thus would have had to survive other periods of uplift and erosion).

Qualitative evaluation, risks, best parts of play (fairways)

There are significant play level exploration risks for the Cambrian clastics play in Peel area. There are not enough well penetrations of Cambrian strata to confidently infer that Mount Clark or Mount Cap quartz sandstones occur in eastern Peel area. Beyond this, there are play level risks of adequate potential reservoir rock (development and/or preservation of porosity), adequate source rock (sufficient quality and rock volume), and possibly communication with source rock (Hannigan et al., 2006). Analyses of oil-stained Devonian rocks (Chapter 10, this volume) indicating the existence of a petroleum system with source rocks inferred to occur in the lower

Paleozoic succession reduce play level risks associated with source rock occurrence. These data do not reduce the prospect level petroleum systems risks. These include prospect level migration and timing risks, which may be high if basal sandstones are confined to isolated paleotopographic depressions in Peel area. Prospect level risks on trap, seal, timing and preservation are also important and difficult to infer. A competent top seal is vital.

Timing of petroleum generation, and subsequent migration, is not well understood for this interval. Protracted diagenesis of Proterozoic rocks below the sub-Cambrian unconformity may significantly increase migration risks associated with petroleum systems having Proterozoic source rocks. 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 potential reservoirs and increased prospect level preservation risks.

Gal (2007) ranked this play’s potential as low or low to moderate within the Ramparts River and Wetlands study area, which included the southeastern part of Peel area. This inferred low petroleum potential is confirmed here. Colville Hills area to the east, where petroleum accumulations are identified, has higher potential for discoveries in this stratigraphic interval (e.g., Gal, 2005). At the play level, mature source rocks are more clearly identified, and reservoir-quality porosities are more common. At the prospect level, structural closures are readily apparent.

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Chapter 4 – Cambrian-Ordovician to Silurian Strata and Lower Paleozoic (Ronning Group) Platform Play

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ABSTRACT

Cambrian-Ordovician to Silurian Franklin Mountain and Mount Kindle formations (Ronning Group) are widespread in Peel area. These formations consist mainly of platform carbonate rocks deposited on Mackenzie-Peel Shelf and are correlative with deeper water formations of Road River Group to the west and southwest (Richardson Trough and Misty Creek Embayment). Ronning Group was studied at 16 new outcrop sections along the northern Mackenzie Mountains and is penetrated by 36 wells in Peel Plateau and Plain. The succession typically lies unconformably on the Proterozoic upper Katherine Group (in proximity to Mackenzie-Peel Arch); elsewhere the lower contact is conformable or unconformable on the Cambrian Saline River Formation. It is regionally bound by a sub-Delorme Group or sub-Bear Rock Formation unconformity. The succession represents peritidal to subtidal deposits of the Sauk III and Tippecanoe Sequences. The Lower Paleozoic Platform play is a conceptual play in Peel area that consists of all pools and prospects hosted in porous dolostones of Franklin Mountain and Mount Kindle formations, and possibly quartz sandstones in basal Franklin Mountain Formation. Potential reservoir intervals may be on the order of tens of metres thick. Franklin Mountain outcrop samples yielded a range of 1.7% to 9.4% porosity and a range of 0.02 to 1.07 millidarcies (mD) permeability; in the subsurface weighted average porosities up to 6.7% were reported. Mount Kindle dolostone samples from outcrop yielded a range of 1.5% to 9.7% porosity and a range of 0.005 to 1.51 mD permeability; in the subsurface weighted average porosities up to 6.7% and permeabilities to 21 mD were reported. Potential source rocks are Road River Group (outcrop samples yielded up to 6.14% total organic carbon), which is overmature and likely dry gas generating. A variety of stratigraphic (e.g., interfingering facies at the platform edge) and structural traps (faulted anticlines in southern Peel area) are possible. Exploration risks for this play include distribution of potential reservoirs, communication with source rocks, formation of closures, viability of top and lateral seals over time to preserve hydrocarbons, and timing of trap formation relative to hydrocarbon migration.

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INTRODUCTION

Cambrian-Ordovician to Silurian strata consist of mainly platform carbonate of Ronning Group (Franklin Mountain and Mount Kindle formations) and correlative deeper water formations of Road River Group (Figure 1). Franklin Mountain Formation lies conformably or unconformably above Saline River Formation or unconformably on Proterozoic rocks in proximity to Mackenzie-Peel Arch (Figure 2). Mount Kindle Formation unconformably overlies Franklin Mountain Formation and is unconformably overlain by either Delorme Group or Bear Rock Formation. The Lower Paleozoic succession generally represents a passive continental margin phase along the western Laurentian margin.

Broad carbonate platforms developed from the latest Cambrian to Silurian on Mackenzie-Peel Shelf (A.W. Norris, 1985; Morrow and Geldsetzer, 1988) or Mackenzie Platform (Fritz et al., 1991). Phases of extensional tectonism created basins, troughs, and embayments westward of the carbonate platform (Cecile et al., 1997; Figure 2) such as the north-northwest trending Richardson Trough (Gabrielse, 1967; D.K. Norris, 1985). The trough has been interpreted as an aulacogen (Pugh, 1983) that was initiated in the late Cambrian, opening into the margin to the north (Churkin, 1969; Cecile et al., 1997). Along the southwestern margin of the Mackenzie-Peel Shelf, the Misty Creek Embayment (Cecile, 1982) developed in the early Cambrian and opened southward into Selwyn Basin (Gabrielse, 1967). These basins to the south and west accumulated deeper water facies equivalents to Ronning Group (Morrow, 1999). Mackenzie Arch, a northwest-trending paleotopographic high (Gabrielse, 1967; Gabrielse et al., 1973) lies on trend with a subsurface feature to the north called Peel Arch (Williams, 1987). Mackenzie Arch is the eastern boundary of Misty Creek Embayment and Peel Arch is the eastern boundary of Richardson Trough (Figure 1). These arches remained active episodically throughout the Paleozoic.

Franklin Mountain and Mount Kindle formations are mainly dolostone in Peel area and the northern Mackenzie Mountains. A basal Franklin Mountain “red bed unit” occurs along the Mackenzie Arch (Aitken et al., 1973) and a basal sandstone is known from Mount Kindle Formation south in the Great Slave Lake area called Little Doctor member (Meijer Drees, 1975a). Porous dolostone of Ronning Group constitutes a conceptual petroleum play in Peel area called the Lower Paleozoic platform play. Ronning Group strata are continuous across Peel Plateau and Plain and outcrop along the northern Mackenzie Mountains. This chapter describes the succession from 16 outcrop sections and 36 wells (Figure 3, Table 1).

PREVIOUS WORK

In Peel area, Franklin Mountain and Mount Kindle formations and Road River Group have been mapped in Upper Ramparts River (106 G) and Sans Sault Rapids (106 H; Aitken et al., 1982), Snake River (106 F; Norris, 1982a), and Wind River (106 E; Norris, 1982b) map areas. The Road River Group was also mapped in the Trail River (106 L; Norris, 1981a) and Fort McPherson (106 M; Norris, 1981b) map areas. Lithologic and stratigraphic descriptions of Ronning Group in the Franklin and Mackenzie mountains were given by Douglas and Norris (1963), Macqueen (1969, 1970), Aitken and Cook (1974), Aitken et al. (1982), Norford and Macqueen (1975), Williams (1996), and Morrow (1999). Descriptions of Road River Group (initially defined as a formation by Jackson and Lenz, 1962) were given by Cecile (1982), Fritz

(1985), and Morrow (1999). Ronning Group in the subsurface of the Interior Plains has been described by Tassonyi (1969), Meijer Drees (1975a, 1975b), Pugh (1983, 1993), and Williams (1996).

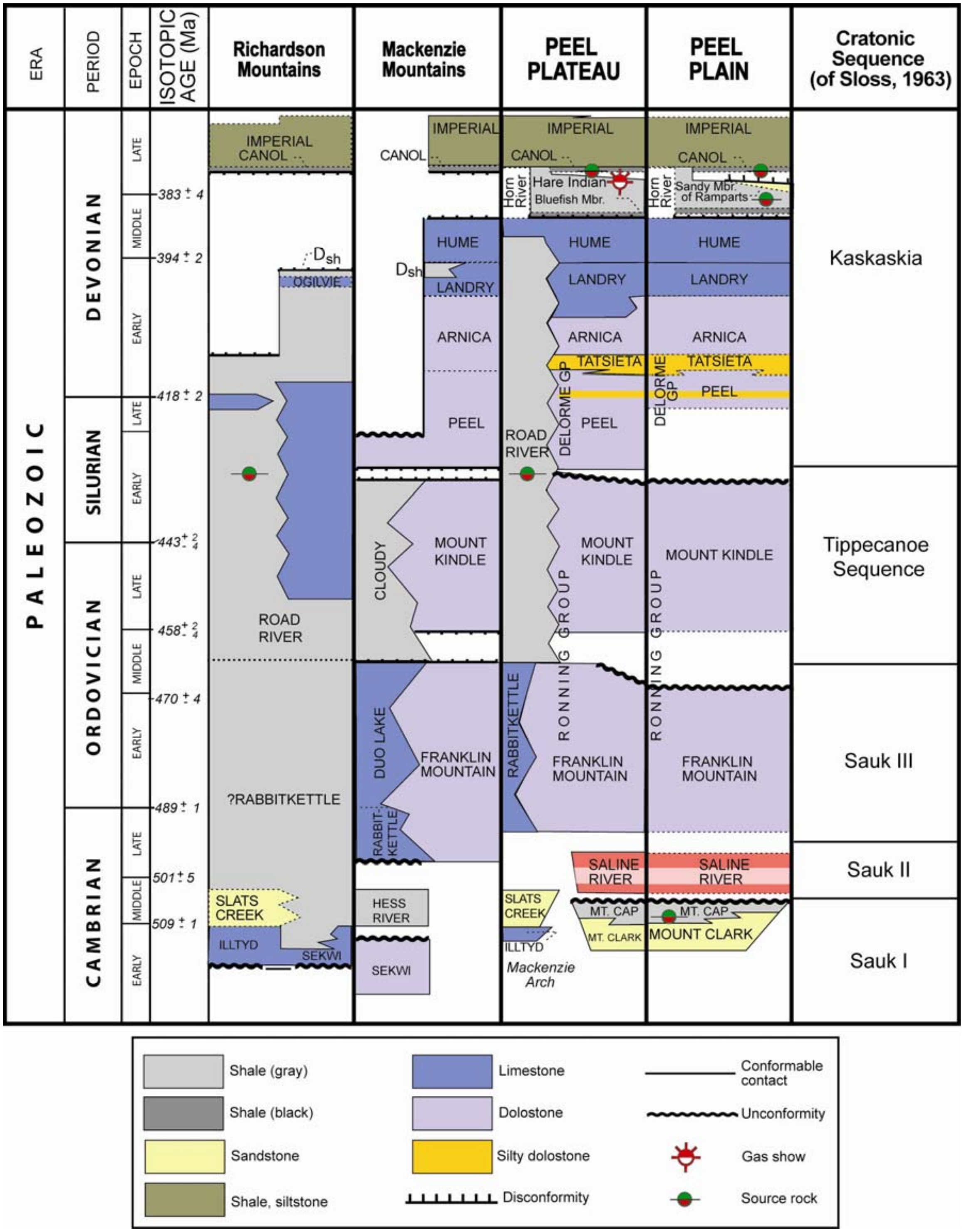


Figure 1. *Table of formations for Peel area and adjacent parts of the Cordillera showing stratigraphic position of the Ronning Group. Timescale after Okulitch (2004); stratigraphic data after Norris (1983, 1997) and Jones and Gal (2007).*

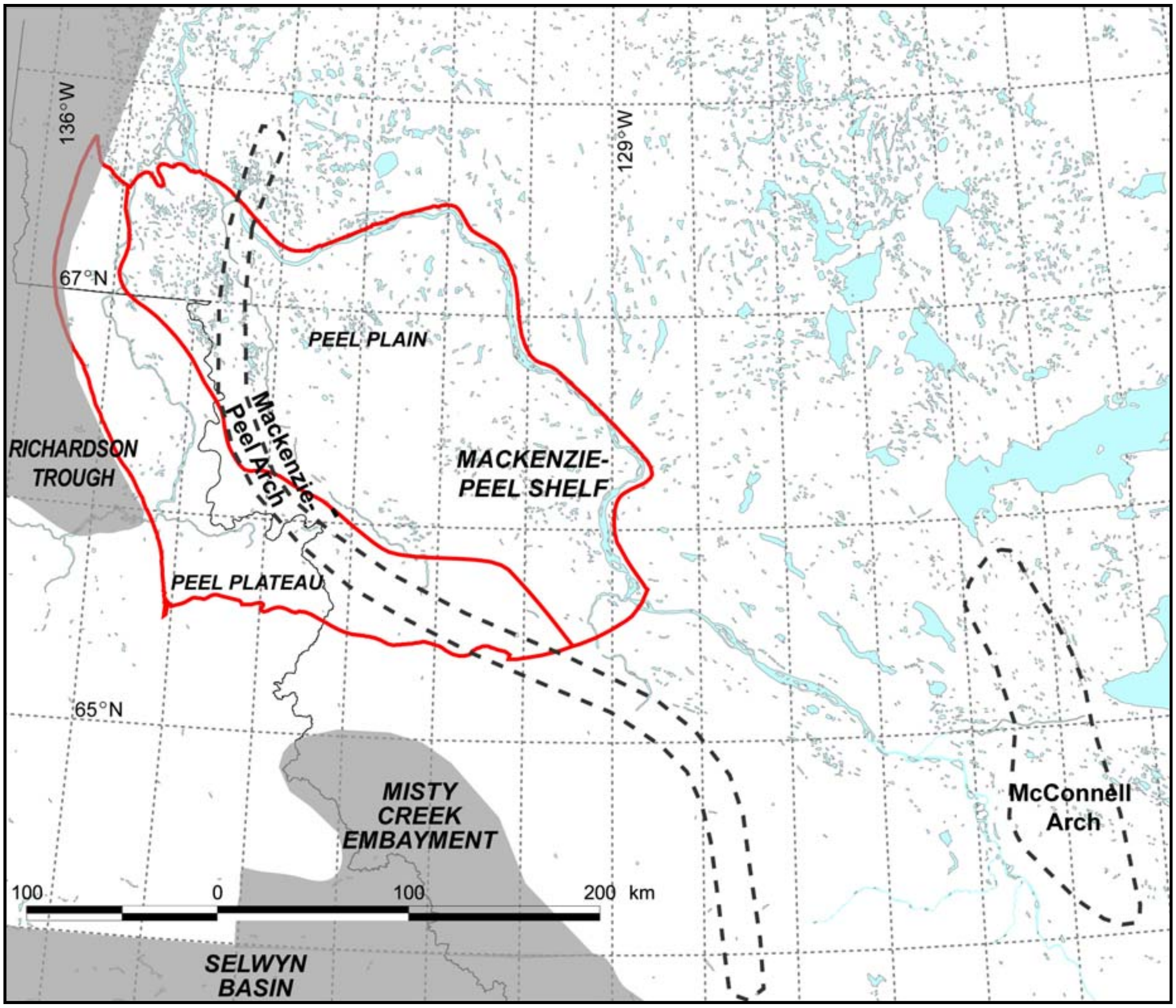


Figure 2. *Late Cambrian to Silurian paleogeography of Peel area and adjacent areas (modified from Williams, 1996 and Morrow, 1999).*

RONNING GROUP

Ronning Group was established by Hume and Link (1945). The term was deemed obsolete by Macqueen (1970) but was applied by Pugh (1983) who reviewed the usage of the term. Pugh (1983), however, included Peel Formation in Ronning Group and also extended the term westward to rocks in the Yukon Block. Morrow (1999) retained the use of Ronning Group for just Franklin Mountain and Mount Kindle formations and proposed a new formation (Bouvette) for equivalent rocks in the Yukon.

Franklin Mountain Formation was defined by Williams (1922, 1923) as calcareous shale and limestone lying below Mount Kindle Formation. Douglas and Norris (1963) described a thicker succession at the type section as containing brown, green, and red shale, sandstone, and dolostone in the lower one-third and pale grey dolostone with minor chert lenses in the upper two-thirds. Norford and Macqueen (1975) re-described the type section as containing three mappable units: 1) lower cyclic member consists of cycles of fine crystalline dolostone with argillaceous dolostone; 2) middle rhythmic member consists of finely crystalline, commonly oolitic, dolostone that alternates regularly with silty dolostone; and 3) cherty upper member consists of fine to coarse crystalline dolostone with abundant chert. A fourth “porous” dolomite unit was mapped by Pugh (1983) after it was identified in Tenlen Lake A-73 well by Mackenzie (1974). A basal Franklin Mountain “red beds unit” was reported by Aitken et al. (1973) along Mackenzie Arch.

Mount Kindle Formation was named by Williams (1922) and defined as massive to thick-bedded, medium grey, fine to medium crystalline, sugary, finely vuggy dolostone in which the basal portion is rich in corals (Douglas and Norris, 1963). Macqueen (1970) described the formation in the northern Franklin and eastern Mackenzie Mountains as medium to dark brownish grey, finely to medium crystalline dolostone. Norford and Macqueen (1975) redescribed the formation as consisting of three informal members: 1) a basal recessive unit of argillaceous dolostone; 2) a middle resistant unit of biostromal, vuggy, thin- to thick-bedded dolostone; and 3) an upper recessive unit of thin-bedded, microcrystalline dolostone.

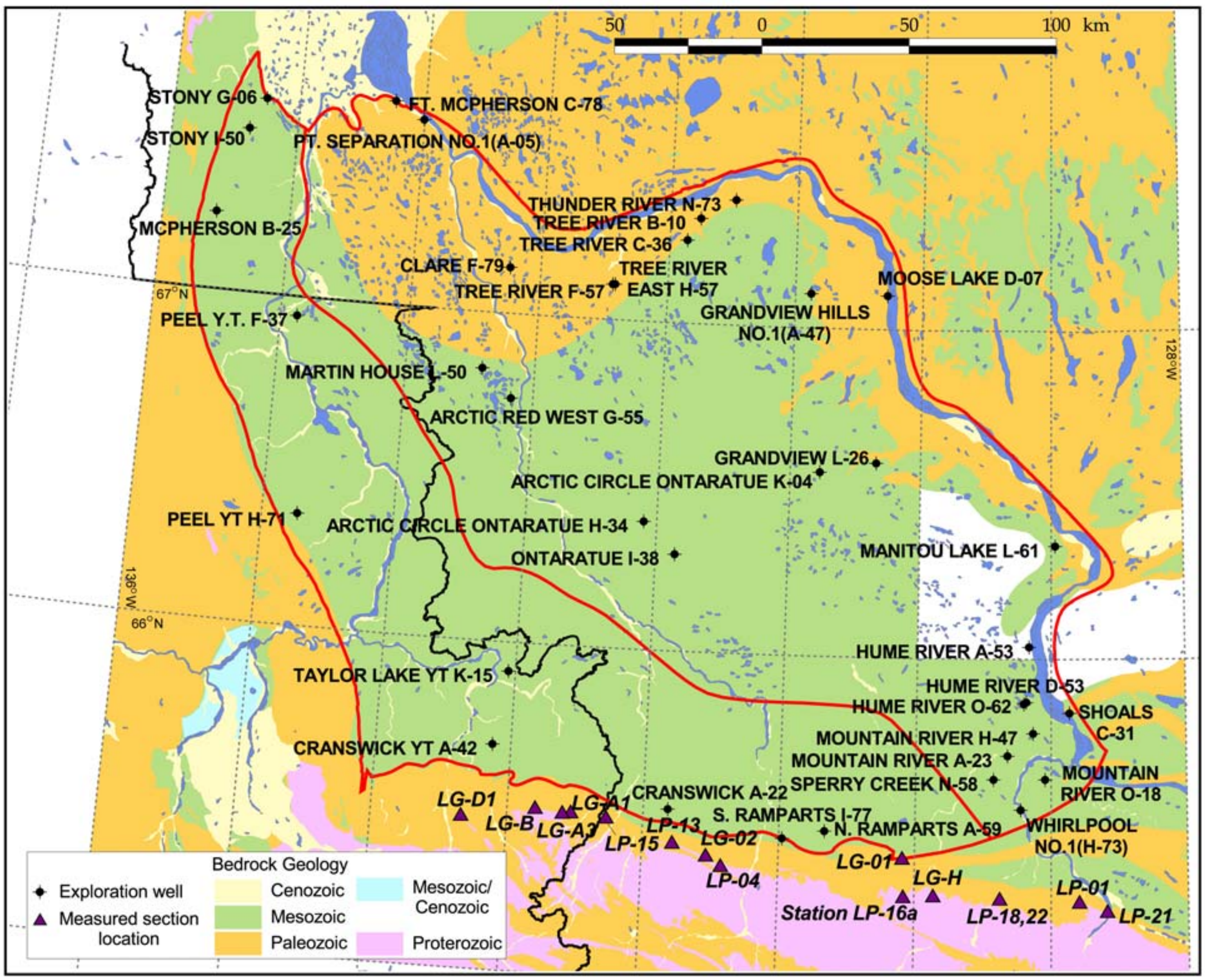


Figure 3. *Geological map of Peel area showing locations of outcrop sections and stations and exploratory wells that penetrate the Ronning Group.*

Unique Well Identifier (UWI)	Short Well Name	KB/RT	Mount Kindle	Franklin Mtn	Saline River	Mount Cap	Mount Clark	Pre-cambrian	Total Depth
300A596530130300	N. Ramparts A-59	580.5	2849.9	2983.4					3205.0
300I776530130450	S. Ramparts I-77	595.6	1363.1	1539.2					1621.8
300A226540131450	Cranswick A-22	768.4	1993.4	2164.1				2843.8	2869.1
300O186540129000	Mountain River O-18	115.0	946.0						1120.0
300H736540129000	Whirlpool No. 1 (H-73)	105.5		1654.4					1955.9
300N586540129150	Sperry Creek N-58	160.7	1838.0	1988.5					2160.0
300A236550129150	Mountain R. A-23	115.5	1410.0						1553.6
300H476550129000	Mountain River H-47	93.9	890.0						1044.5
300C316600128450	Shoals C-31	87.6	1047.3	1216.2	1831.8				1981.2
300D536600129001	Hume River D-53	88.4	1246.6						1267.7
300O626600129000	Hume R. O-62	86.9	1264.0						1402.1
300A536610129000	Hume R. A-53	62.8	996.7						1158.2
300L616630128450	Manitou Lake L-61	131.7	762.6	944.3	1633.1				1724.3
300I386620131450	Ontaratue I-38	144.5	1808.7	2076.3					2287.5
300L266640130150	Grandview L-26	164.9	1010.7	1230.5	2004.1	2203.7		2240.3	2395.6
300K046640130450	Arctic Circle Ontaratue K-04	103.8	1218.9	1437.4	2420.4			2518.6	2728.0
300H346630132000	Arctic Circle Ontaratue H-34	141.7	1836.4	2139.7	2883.4	2899.4		2923.0	4075.2
300G556650133000	Arctic Red West G-55	44.6	2064.1	2507.0		3285.7	3300.7		3322.3
300L506650133150	Martin House L-50	88.0	2285.2						2407.9
300B256720135301	McPherson B-25	492.3	3774.7	3993.6					4136.1
300I506730135150	Stony I-50	321.9	2706.6	2993.7					3343.0
300A056740134000	Pt. Separation No. 1 (A-05)	18.9	2286.0						2445.4
300C786740134000	Ft. McPherson C-78	19.8	2636.2	3009.3					3068.1
300G066740135150	Stony G-06	56.7	2324.7						2529.8
300F576710132150	Tree River F-57	93.0	1657.5						1979.2
300H576710132150	Tree River East H-57	108.2	1708.4						1981.2
300F796710133000	Clare F-79	108.7	2121.2	2484.9					2525.6
300D076710130150	Moose Lake D-07	54.0	780.0	846.5					900.0
300A476710130450	Grandview Hills No. 1 (A-47)	369.5	1205.2	1434.7					1998.0
300B106720131451	Tree River B-10	188.1		1163.0					1294.0
300C366720131451	Tree River C-36	135.0	1591.0						1878.0
300N736730131151	Thunder River N-73	124.1		1061.0					1146.0
300A426550133001	Cranswick Y.T. A-42	620.1	3350.1	3582.0					4267.2
300K156600133000	Taylor Lake Y.T. K-15	468.8	2315.9						2378.7
300H716630134300	Peel Y.T. H-71	513.0	2783.1	3004.1					3419.6
300F376700134450	Peel Y.T. F-37	54.6	3327.2						3368.0

Table 1. *Formation tops (in metres) of wells that penetrate Ronning Group in Peel area. NWT tops after Hogue and Gal (2008) and Yukon tops after Fraser and Hogue (2007). KB=Kelly bushing; RT=rotary table.*

Type Sections and Origin of Names

The type section of both Franklin Mountain and Mount Kindle formations is at Mount Kindle (Williams, 1922). Norford and Macqueen (1975) re-described the type section (63.35ºN, 123.20ºW) on the northeast face of Mount Kindle. Mount Kindle Formation is named after Mount Kindle in the Franklin Mountains, Northwest Territories and Franklin Mountain Formation is named after the Franklin Mountains.

Lithology and Log Response

Lithologic descriptions from outcrops of Franklin Mountain and Mount Kindle are summarized in Norford and Macqueen (1975), Pugh (1983), Williams (1996), and Morrow (1999), with the latter reference being the most applicable to strata in the northern Mackenzie Mountains. Williams (1996) reviewed subsurface lithologies of Ronning Group which include mostly light grey to brown dolostone, microcrystalline to rarely coarse crystalline, silty dolostone with bedded chert or chert nodules, and minor quartz sand and silt partings. Members are not as easily recognizable across the northern Mackenzie Mountains and become indistinct westward (such as at Section LG-B, Figure 3).

Franklin Mountain Formation

Lithological descriptions are based on complete sections of Franklin Mountain Formation measured at LG-H, LP-04/12, LG-A3, and LG-B (which is section 44 of Morrow, 1999; Figure 4), and incomplete sections or stations (LP-01, LP-13, LP-18, LP-21, LP-24, and Station LP-16a; see section descriptions in Pierce and Jones, 2009). Subunits of Franklin Mountain Formation are more difficult to discern west of the type area (toward Misty Creek Embayment), although the basal clastic unit, cyclic unit, and cherty unit are mappable in eastern Peel area.

A basal clastic unit (“red bed unit”) above the Proterozoic Katherine Group is present at Sections LG-H, LP-04, and Station 16a and best exposed at the latter (Figure 5). This unit contains red-weathering, thin- to medium-bedded, quartz sandstone with ripple marks and red (and lesser green) shale (Figures 6a, b). Sedimentary structures include ripple marks, mudcracks, scoured beds, and flaser bedding.

The lower cyclic unit is characterized by containing mainly light grey- to yellowish, light grey-weathering, fine crystalline, dolomudstone that contains algal lamination and stromatolites (Figure 7). Rare, coarse crystalline, vuggy weathering dolostone occurs in this lower unit (Figure 8). Well developed alternations of yellowish-weathering dolomudstone and dark grey, argillaceous dolomudstone are well exposed at Section LG-H (Figure 9). Sedimentary structures include fine planar and algal lamination, scoured beds containing laminated rip-up clasts (Figure 10), and red-weathering, subaerial exposure surfaces (Figure 11). Abundant silicified oncolites occur in western sections (Figure 12). A float horizon at 90.5 m above section base at Section LG-H contains massive barite and oxidized sulphides (Figure 13).

The middle unit refers to the interval containing alternations of brown grey-weathering, burrow mottled dolostone and light grey-weathering, laminated dolostone. Bedding varies from thin to thick. Vuggy weathering, sucrosic dolostone is common. The term rhythmic member for these intervals is not applicable because it was originally defined as metre-scale alternations of oolite or packstone to fine crystalline, silty dolostone capped by flat-pebble conglomerate (Norford and Macqueen, 1975).

The cherty unit includes dolostone in the upper part of the formation that weathers medium grey and contains white and black chert nodules and bedded chert. The dolostone is more silty overall than the lower units with common vuggy surface weathering, sucrosic beds. Sedimentary structures include planar to cross-lamination, intraclast breccia beds, and burrow mottling (Figure 14).

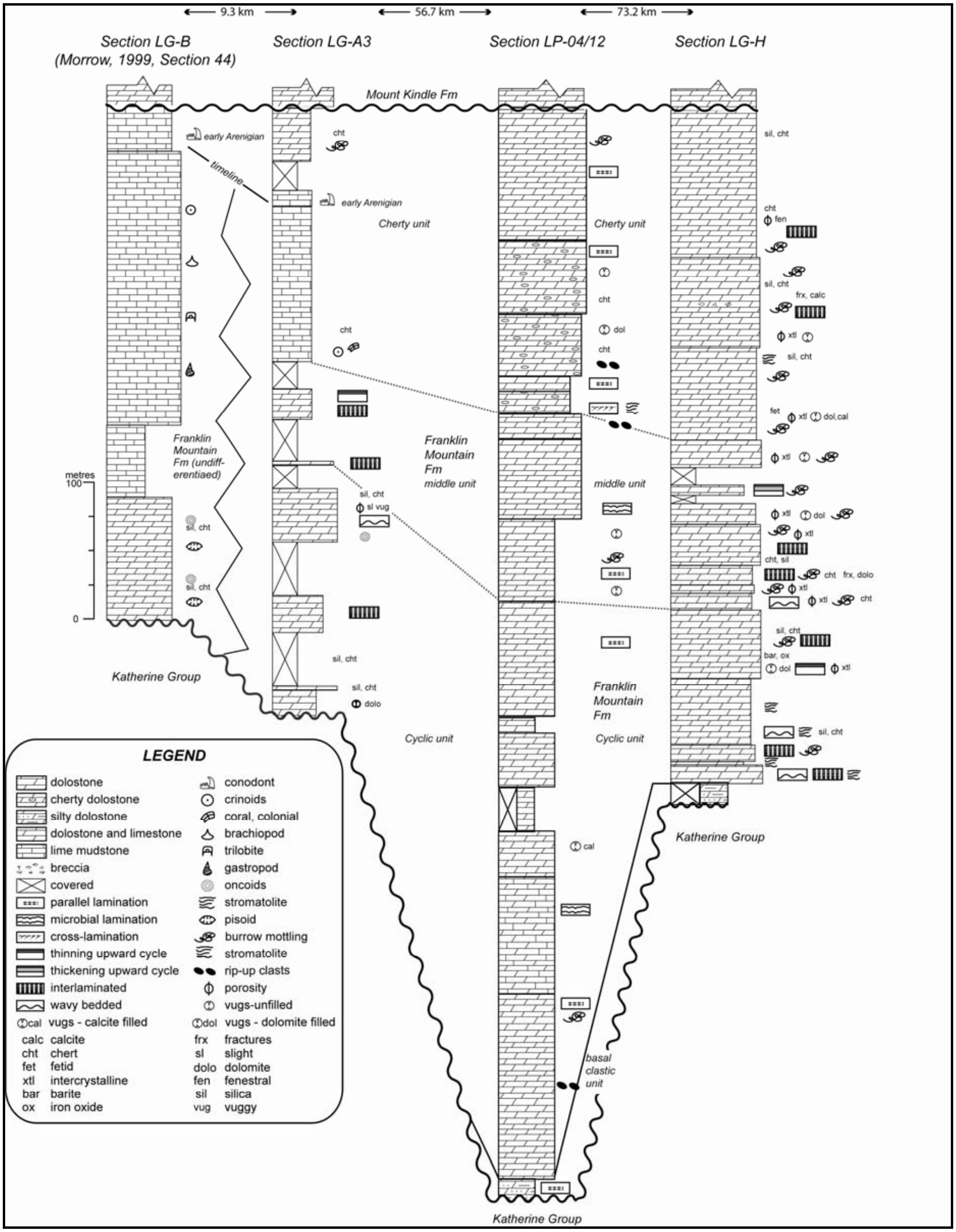


Figure 4. *Lithostratigraphic correlation of Franklin Mountain Formation sections across the northern Mackenzie Mountains (see Figure 3 for section locations).*

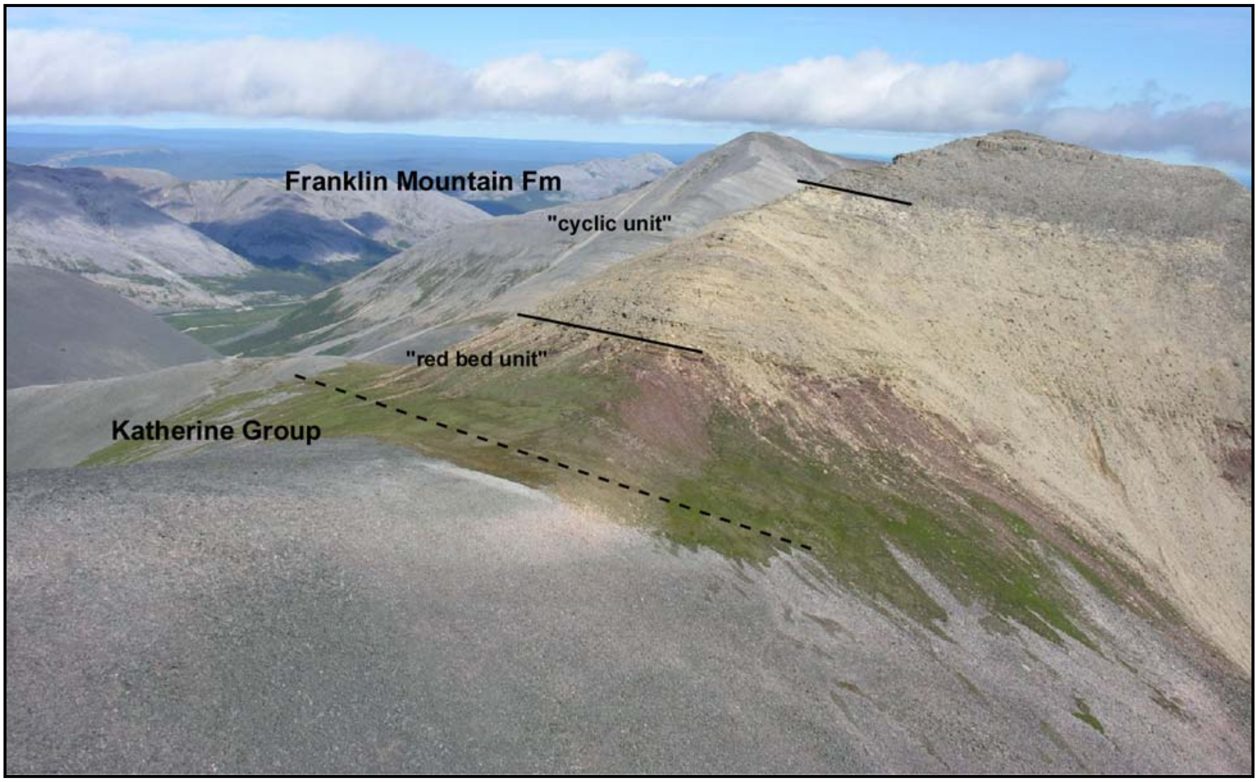


Figure 5. *View northwest of Station LP-16a, showing prominent basal clastic or "red bed unit" of Franklin Mountain Formation.*

Figure 6a. *Ripple marks in quartz sandstone, basal clastic unit, Franklin Mountain Formation, Station 16a (hammer is 38 cm long for scale).*

Figure 6b. *Quartz sandstone with scoured bases (at hammer head), interbedded with shale, basal clastic unit, Franklin Mountain Formation, Station 16a (hammer is 38 cm long for scale).*

Figure 7. *Stromatolitic dolomudstone, Section LG-H, Franklin Mountain Formation (hammer is 38 cm long for scale).*

Figure 8. *Vuggy surface weathering of dolostone, lower Franklin Mountain Formation, Section LP-04 (scale bar in cm).*

Figure 9. *Couplets of yellowish weathering dolomudstone capped by thin, darker grey weathering, argillaceous and limy dolomudstone, Franklin Mountain Formation, Section LG-H (hammer for scale is 38 cm long).*

Figure 10. Rip up clasts in lower Franklin Mountain Formation, Station LP-16a (hammer is 38 cm long for scale).

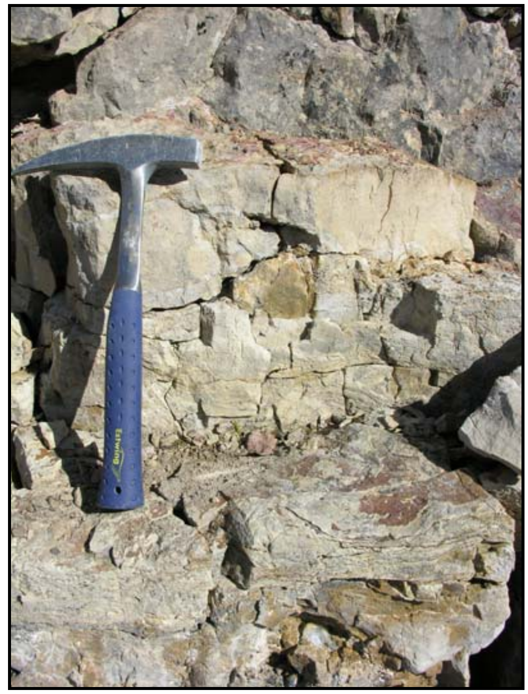


Figure 11. Irregular, red-weathering, subaerial exposure surfaces (at base and top of hammer), lower Franklin Mountain Formation, Station LP-16a (hammer is 38 cm long for scale).

Figure 12. Silicified oncolites in Section LG-B (Section 44 of Morrow, 1999), lower Franklin Mountain Formation (scale bar in cm).

Figure 13. Arrows indicate massive barite and oxidized rubble (after iron sulphides?), apparently stratiform, Franklin Mountain Formation, Section LG-H (hammer is 38 cm long for scale).

Figure 14. *Cherty, siliceous, burrow mottled dolostone of Franklin Mountain Formation, Section LP-04. Hammer head is 18 cm long.*

Franklin Mountain Formation changes facies westward from dolostone to limestone between sections LP-04 and LG-A3. Section LG-A3 has mainly limestone in the upper part, and further west to Section LG-B (Section 44 of Morrow), the formation is almost entirely limestone (Figure 4).

In the subsurface, core of Franklin Mountain Formation was studied in the following wells: Arctic Red West G-55, Clare F-79, Peel YT H-71, Stony I-50, and Whirlpool No. 1 H-73 (Table 1). In the intervals studied, the primary lithology is dolostone, light grey to brownish grey, finely to medium crystalline and rarely coarse crystalline. Mottling, algal lamination, and rare bioclasts occur in Stony I-50 core. In the most outboard well, Peel YT H-71, dolostone is more limy and argillaceous, with floating chert grains and rare bioclasts (core descriptions in Pierce and Jones, 2009).

Mount Kindle Formation

Lithological descriptions are based on complete sections of Mount Kindle Formation measured at sections LP-21, LG-H, LP-04/12, LG-02, LP-13, LG-A1, LG-A3, LG-B (Figure 15) and additional sections (LP-18, LP-15, LP-22, LG-01, LG-A4, LG-D1, and LG-H; descriptions in Pierce and Jones, 2009). Mount Kindle Formation is readily distinguished from Franklin Mountain Formation by a change to medium to darker grey- and brown-weathering, and overall increase in chert and silicified fossils. It is typically more resistant overall compared to underlying Franklin Mountain Formation and overlying orange-weathering, silty carbonates of the Delorme Group (Figure 16).

Norford and Macqueen (1975) divided Mount Kindle Formation dolostone into basal and upper recessive units separated by a middle resistant unit; however, this subdivision is difficult to recognize in Peel area. In some sections (e.g., LP-04), recessive, flaggy weathering, less fossiliferous, lower and upper units occur in which bedding is thin to medium compared to medium and thick for the rest of the formation. Otherwise, the formation is homogenous across the study area and has an overall stripy or banded weathering appearance in ridge sections (Figure 16).

Dolostone is typically fine crystalline, and weathers brownish-grey to medium grey. Burrow mottled dolostone (Figure 17) occurs in alternations with laminated dolomudstone (Figure 18). Bedding ranges from medium and thick to massive and gives the formation a more resistant nature compared to underlying Franklin Mountain Formation. Chert is common throughout the formation, although it becomes less abundant in outboard sections (LG-B, Figure 15). Some intervals contain up to 40% bedded and nodular, white and black chert (Figure 19). Brecciated layers may represent storm deposits. Some intervals contain dolomitic limestone interbeds.

Silicified fossils (colonial corals, cephalopods, and stromatolites) are common in the formation. Sedimentary structures include planar lamination, algal lamination, burrow mottling, scoured bed bases, and mudcracks (e.g., upper unit of Section LP-04).

Mount Kindle dolostone has some fenestral porosity and slightly vuggy intervals, in which some vugs are filled by quartz or calcite and/or dolomite (e.g., Sections LG-A1, LG-02; Figure 15). Some medium crystalline sucrosic dolostone intervals occur (e.g., Section LP-04).

In the subsurface, core of Mount Kindle Formation was studied in the following wells: Cranswick A-22, Mountain River H-47, Mountain River O-18, Point Separation No. 1 A-05, and Stony I-50 (Table 1; descriptions in Pierce and Jones, 2009). Core from the western and northern part of the study area contains a mix of dolostone and fossiliferous limestone (Cranswick A-22), algal lamination, and burrow mottling (Point Separation No. 1 A-05). Lime mudstone to packstone occurs in Stony I-50.

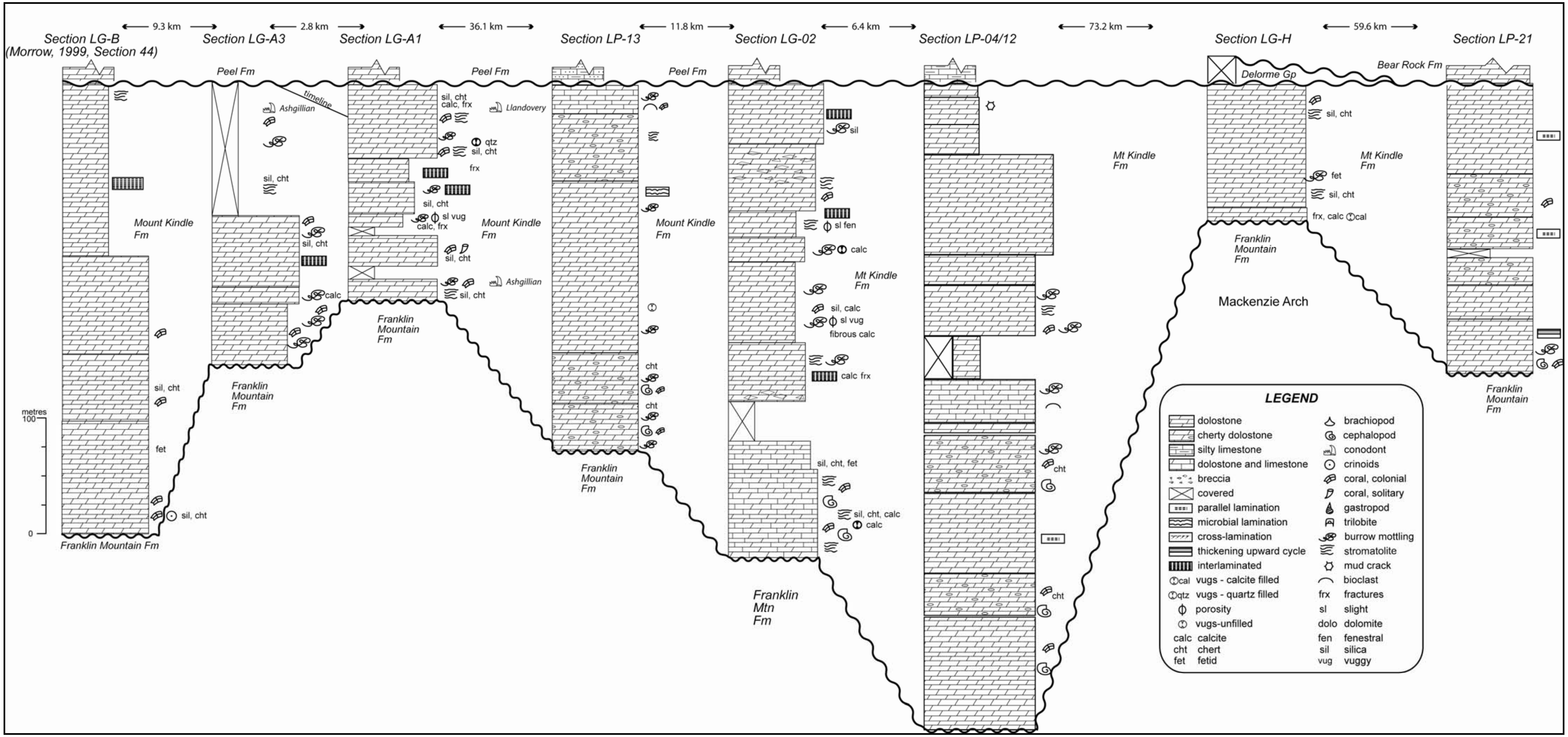


Figure 15. *Lithostratigraphic correlation of Mount Kindle Formation across the northern Mackenzie Mountains (see Figure 3 for Section locations).*

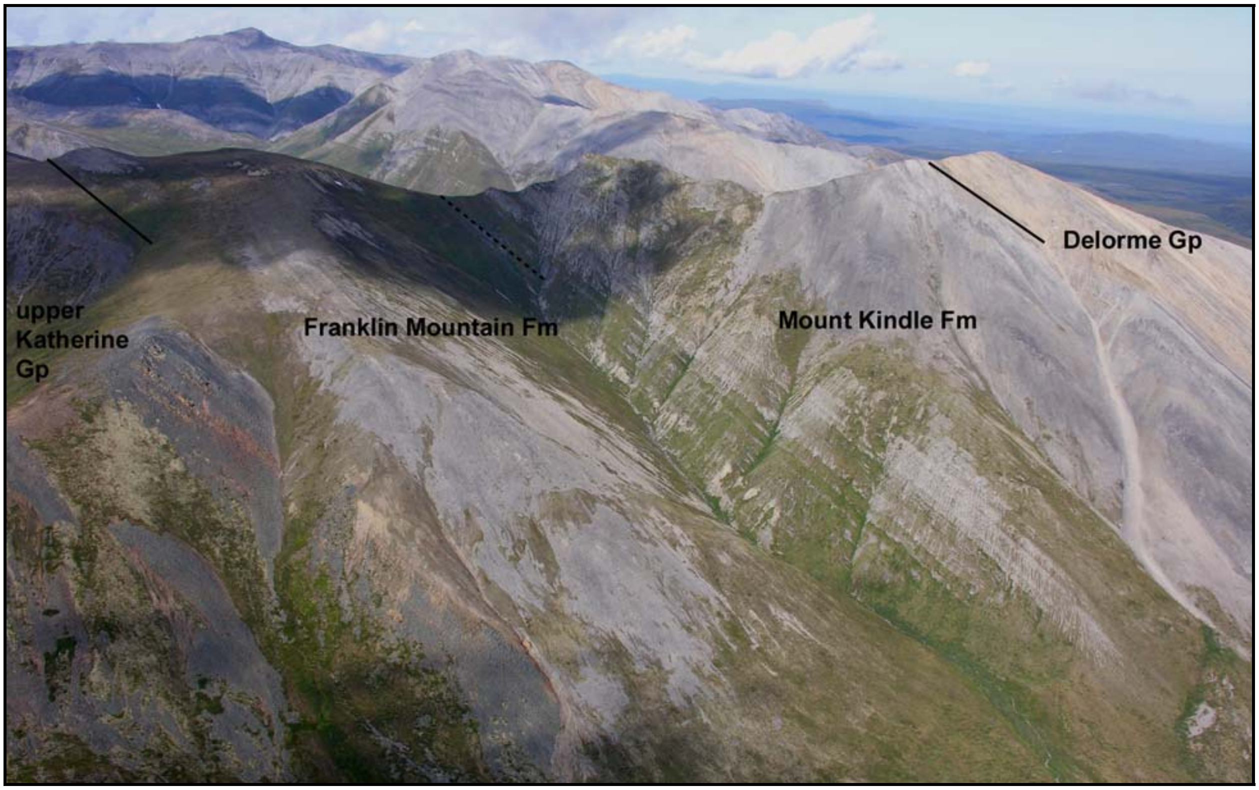


Figure 16. *View of exposure west of Section LG-B, showing more resistant and darker weathering Mount Kindle Formation compared to underlying Franklin Mountain Formation (total Ronning Group thickness is greater than 600 m here), although contact (dashed line) is not well exposed. The upper part of Mount Kindle Formation is here noticeably more recessive than the lower part.*

Figure 17. *Burrow mottled dolostone in middle unit of Mount Kindle Formation, Section LP-18 (hammer head is 18 cm for scale).*

Figure 18. *Laminated dolomudstone in middle unit of Mount Kindle Formation, Section LG-A1 (scale bar in cm and inches).*

Figure 19. *Bedded and nodular chert in middle unit of Mount Kindle Formation, Section LP-18 (hammer is 38 cm long for scale).*

Contacts and Log Responses

Franklin Mountain Formation rests unconformably on Proterozoic upper Katherine Group across most of the northern Mackenzie Mountains (Mackenzie Arch; Figure 4). It rests unconformably on Saline River Formation at LP-24 (Figure 20) but elsewhere across Mackenzie-Peel Shelf, this contact is interpreted as conformable (Morrow, 1999). The sub-Cambrian unconformity beneath Saline River, Mount Clark/Mount Cap formations merges with the sub-Franklin Mountain unconformity from east to the southwest across Mackenzie-Peel Shelf (Aitken et al., 1973).

The upper contact of Franklin Mountain Formation with Mount Kindle Formation is a regional unconformity which may diminish in magnitude from east to west as a correlative conformity in Snake River area (Williams, 1988 based on Lenz, 1972). This contact relationship was generally obscured by scree in most ridge sections but was well exposed as a downcutting, erosional surface at Gayna River (Figure 21). The upper contact of Mount Kindle Formation is the regional sub-Delorme unconformity (Figure 22), or sub-Bear Rock unconformity (Figure 15).

Generally the Franklin Mountain-Saline River contact is easily picked on well logs throughout Peel area, based on the increased gamma response at the top of Saline River Formation, and associated slower sonic travel times.

Figure 20. *Base of Franklin Mountain Formation at Section LP-24 is an erosional unconformity, with a basal breccia downcutting into Saline River Formation (scale bar in cm).*

Figure 21. *Erosional contact (white dashed line) between Franklin Mountain and Mount Kindle formations, Section LP-18 (hammer is 38 cm long for scale).*

Figure 22. *Reddish stained dolostone, possibly indicating subaerial exposure, at contact of Delorme Group (left) and Mount Kindle Formation (right), Section LG-A3 (hammer head is 18 cm long for scale).*

Morrow (1999) illustrated the log response of thin, argillaceous interbeds in the lower cyclic member and correlated the top of the rhythmic member between Cranswick A-22, Atlantic et al. Ontarature H-34, and Arctic Red West G-55 wells at the transition to cherty beds (figure 11 in Morrow 1999). The slightly more argillaceous cyclic member is illustrated in the log response from the Ontaratue H-34 well (Figure 23). The division between upper cherty member and the middle unit in subsurface is generally taken to be represented by a gamma kick (e.g., Pugh, 1983; Figure 23) although in surface sections the cause of this gamma kick is not readily apparent.

The upper contact of Franklin Mountain Formation is often difficult to pick, although it is marked in some locations by a pronounced gamma ray log excursion and low-velocity excursion on the sonic log (Morrow, 1999).

The upper contact of Mount Kindle Formation is generally well defined on the basis of gamma and sonic logs, where it is overlain by shalier Delorme Group. Within Mount Kindle Formation, the division into upper and lower recessive, and middle resistant units (Norford and Macqueen,

1975) is seen in some logs (Figure 23). This relationship is not seen throughout Peel area however, and more commonly the log response indicates an upper shaly and lower clean unit (Figure 24), or a more homogenous clean carbonate.

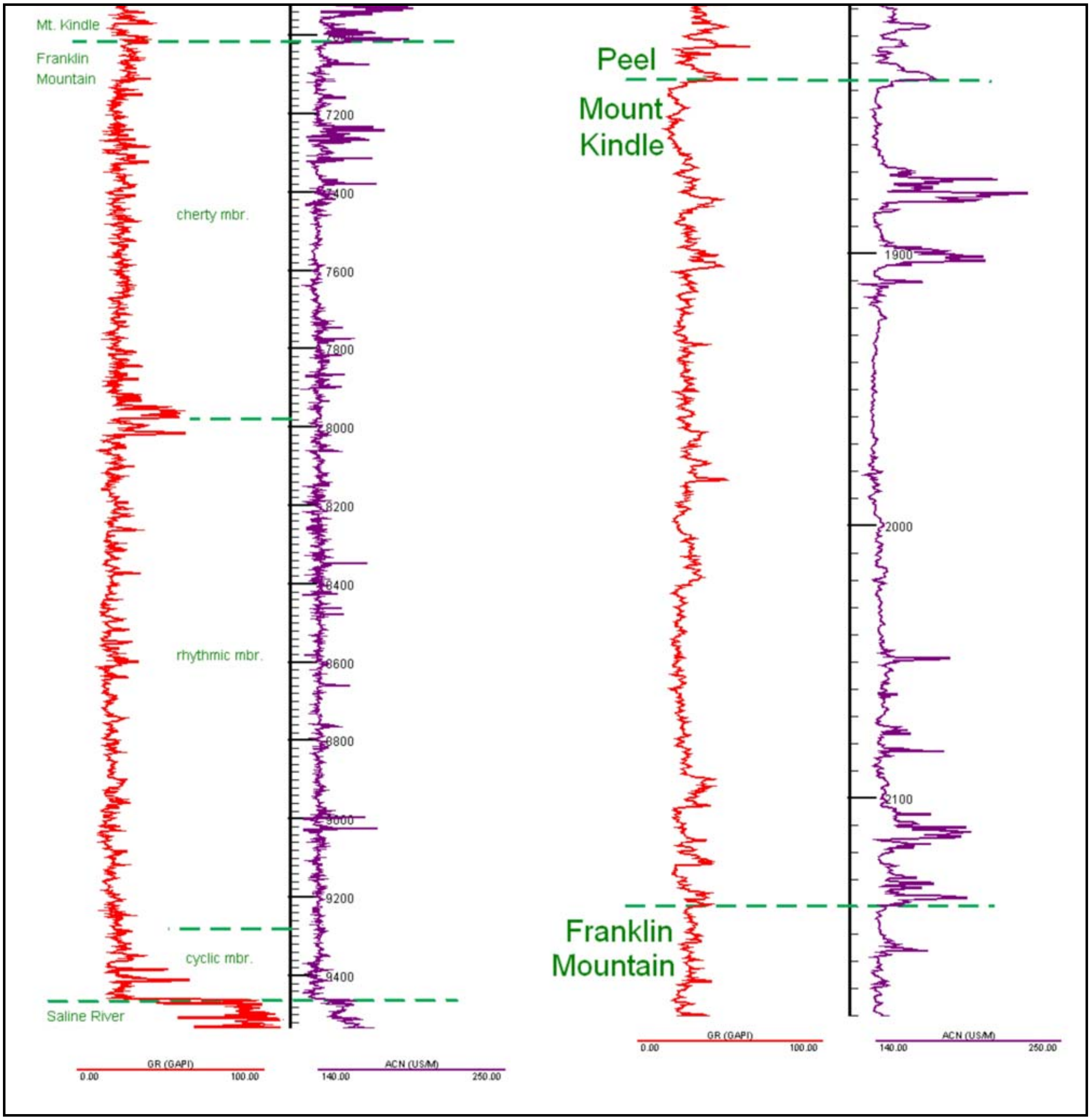


Figure 23. *Gamma (red) and sonic interval transit time (purple) logs from Ronning Group in Ontaratue H-34 well. On the left, Franklin Mountain Formation logs illustrate the higher gamma response in the lower cyclic member, and the pronounced gamma kick at the base of the upper, cherty member. On the right, logs from Mount Kindle Formation indicate upper and lower, relatively more shaly units analogous to outcrops described by Norford and Macqueen (1975). Well depths in m, log scales (gamma in API units, sonic in microseconds per m) shown at base of figures.*

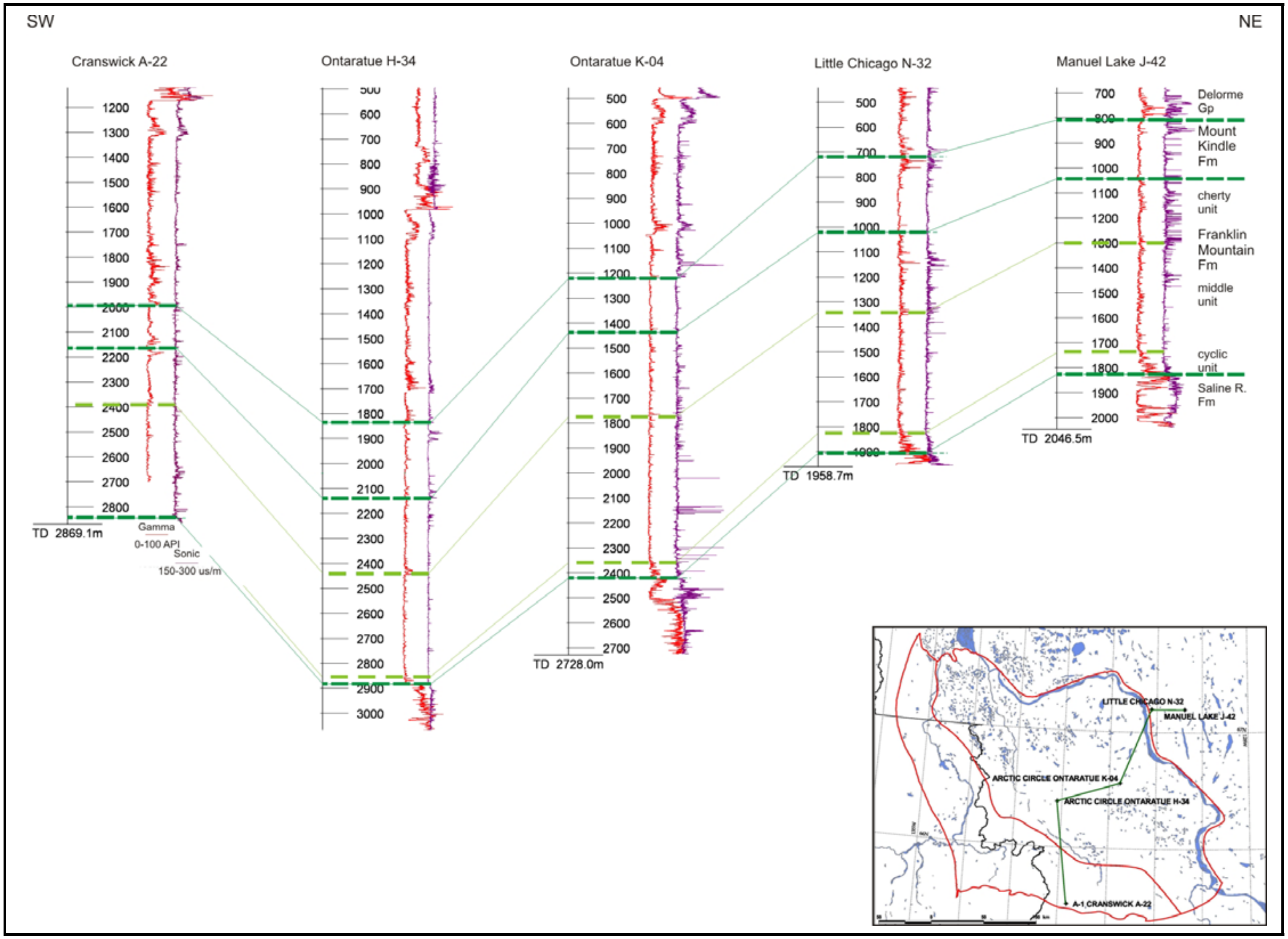


Figure 24. *Southwest to northeast structural cross-section of Ronning Group based on well logs across Peel area. Gamma (red) and sonic (purple) log curves are shown for each well. Formation tops for Mount Kindle and Franklin Mountain formations and correlations between wells in dark green lines (bold dashed and fine solid, respectively). Subunits of Franklin Mountain Formation are delineated by light green lines. Well depths in metres, log units (API units for gamma, microseconds per metre travel time for sonic) and scales are shown below the A-22 well, inset at lower right gives cross-section location.*

Distribution and Thickness

Ronning Group is distributed widely across Peel area and the Interior Plains (Meijer Drees, 1975b; Tassonyi, 1969). In outcrop, completely measured Franklin Mountain Formation ranges from 375.5 m (Section LG-B/Section 44 of Morrow, 1999) to 797.0 m thick (Section LP-04; Figure 4). The basal clastic unit of Franklin Mountain Formation is 32 m thick at Station 16a, and poorly exposed at Section LG-H and LP-04 (Figure 4). This unit was also mapped at Section U-2 of Aitken et al. (1973) as 87 m thick. Franklin Mountain Formation was completely penetrated in five Peel area wells (Table 1, Figure 3) and ranges in thickness from 615.6 m (Shoals C-31) to 983 m thick (Arctic Circle Ontaratue K-04; Figure 25). Thickening trends of Franklin Mountain Formation are poorly understood, although Pugh (1983) interpreted it to thin to the west and southwest, and thicken northeast from 700 m along the Mackenzie Mountains Front to more than 1000 m beneath Peel Plateau. This differs from the isopach map in Figure 25 in which the thickest Franklin Mountain Formation forms a north-trending keel just east of the crest of the Mackenzie-Peel Arch, and thins toward the platform edge in the west and southwest, and toward the McConnell Arch to the southeast.

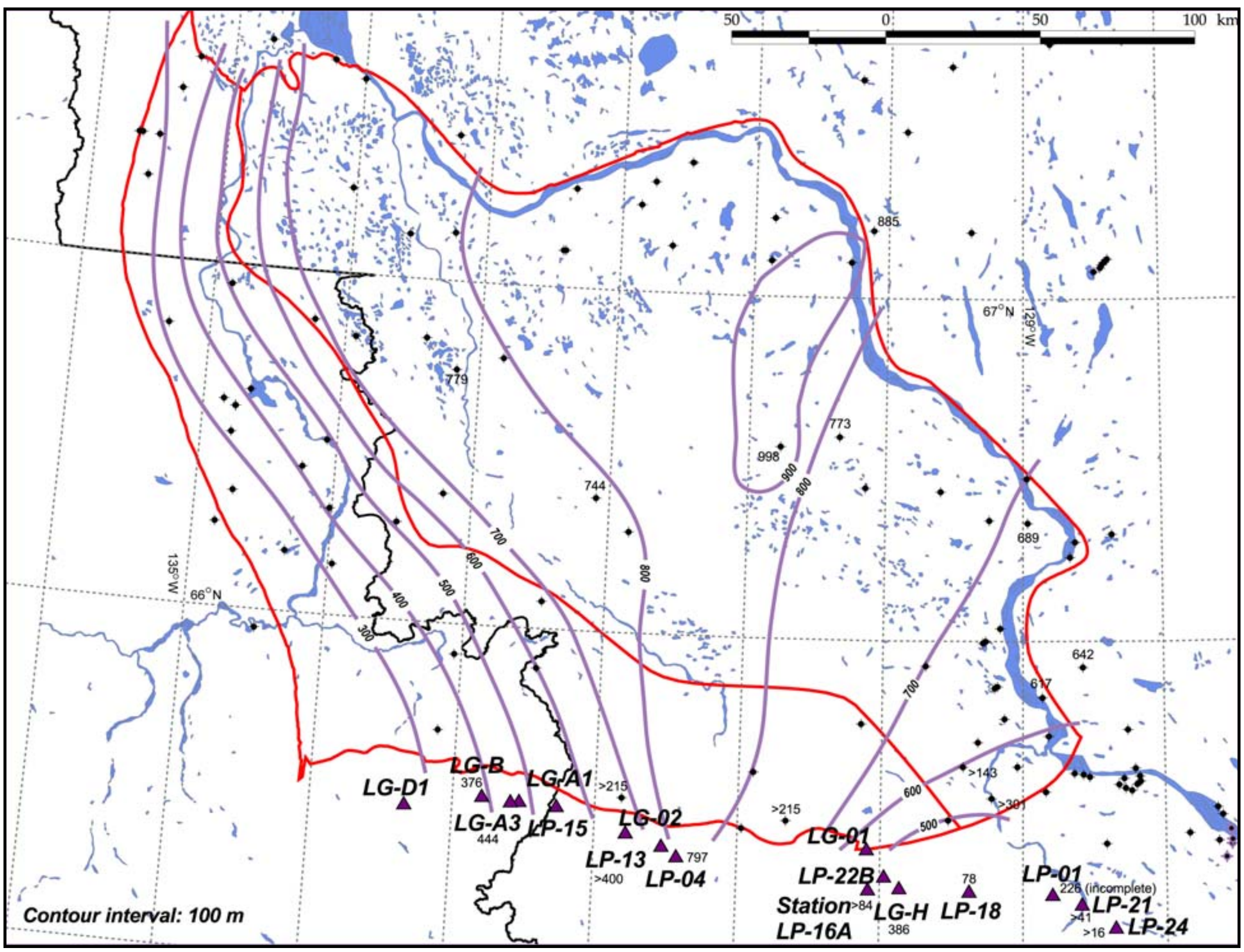


Figure 25. *Isopach map of Franklin Mountain Formation.*

Mount Kindle Formation ranges from 94.5 m (Section LG-H) to 436.0 m thick (Section LP-04). The formation was completely penetrated in 19 wells (Table 1, Figure 3) and ranges in thickness from 66.5 m (Moose Lake D-07) to 442.9 m thick (Arctic Red West G-55; Figure 26). Trends from new outcrop measurements show that the formation, together with Franklin Mountain Formation, thins toward the platform edge, perhaps indicating a structural high.

A structure contour map of the top of Mount Kindle Formation illustrates the general west and southwestward sedimentary and tectonic dip of the basin (Figure 27). The dip steepens considerably toward the Richardson Trough. Tectonic uplifts near the Mackenzie Mountains front are also evident, as is a trough in northeast Peel area which likely reflects subsidence at the upper Mackenzie Delta.

Regionally, at the type section, Franklin Mountain Formation was estimated to be 310 m thick by Norford and Macqueen (1975). In the subsurface, Franklin Mountain thicknesses range from an erosionally thinned 25 m in South Great Slave Plain (Cli Lake M-05 well; Figure 28) to 998 m in Peel Plain (Ontaratue K-04). At the type section of the Mount Kindle Formation, it is 262 m thick (Norford and Macqueen, 1975). In the subsurface, thicknesses range from 10 m to 15 m where eroded in Great Slave Plain (Redknife H-28 and Trail River P-13 wells; Figure 28) to 442.9 m thick in the Arctic Red West G-55 well.

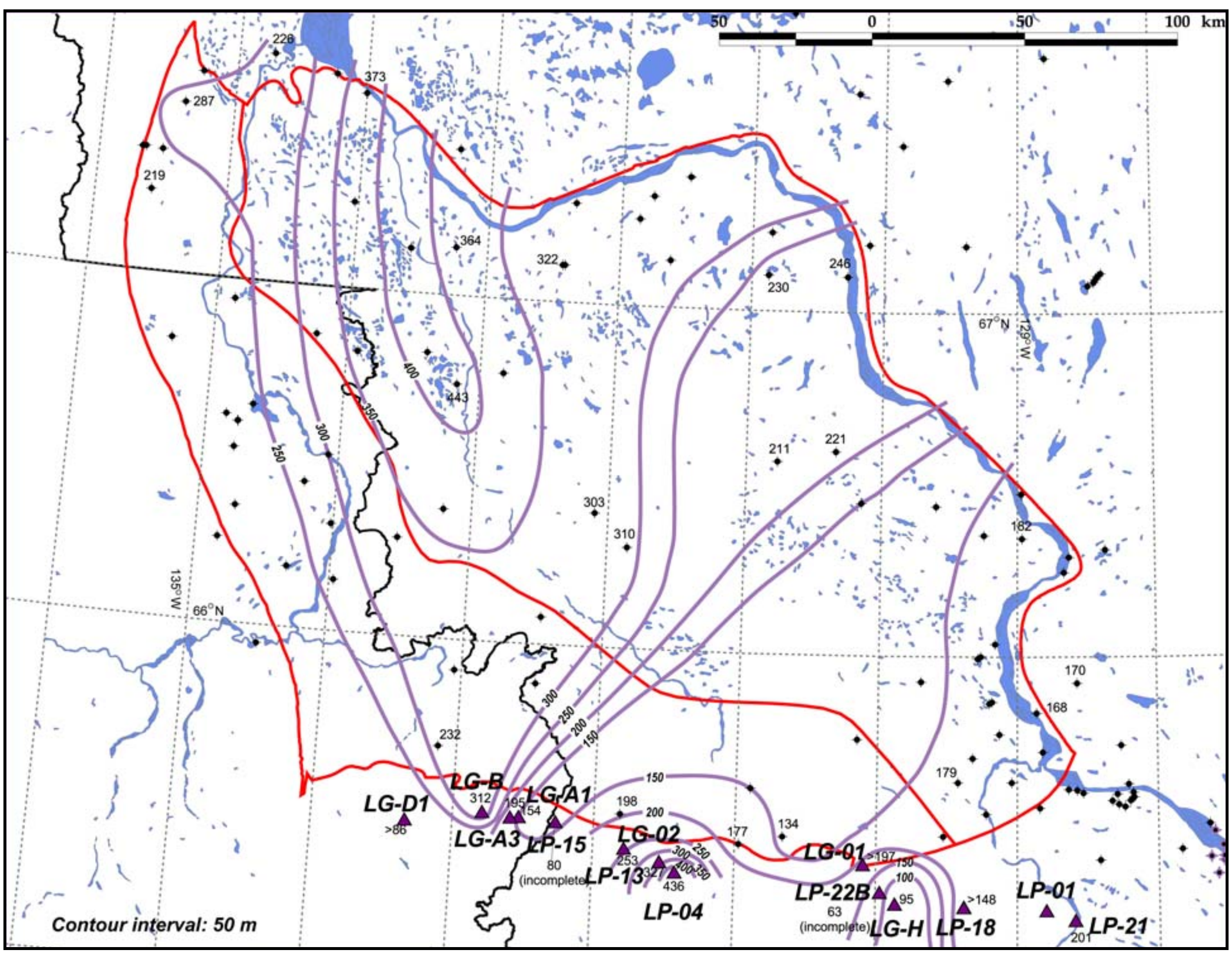


***Figure 26.** Isopach map of Mount Kindle Formation.*

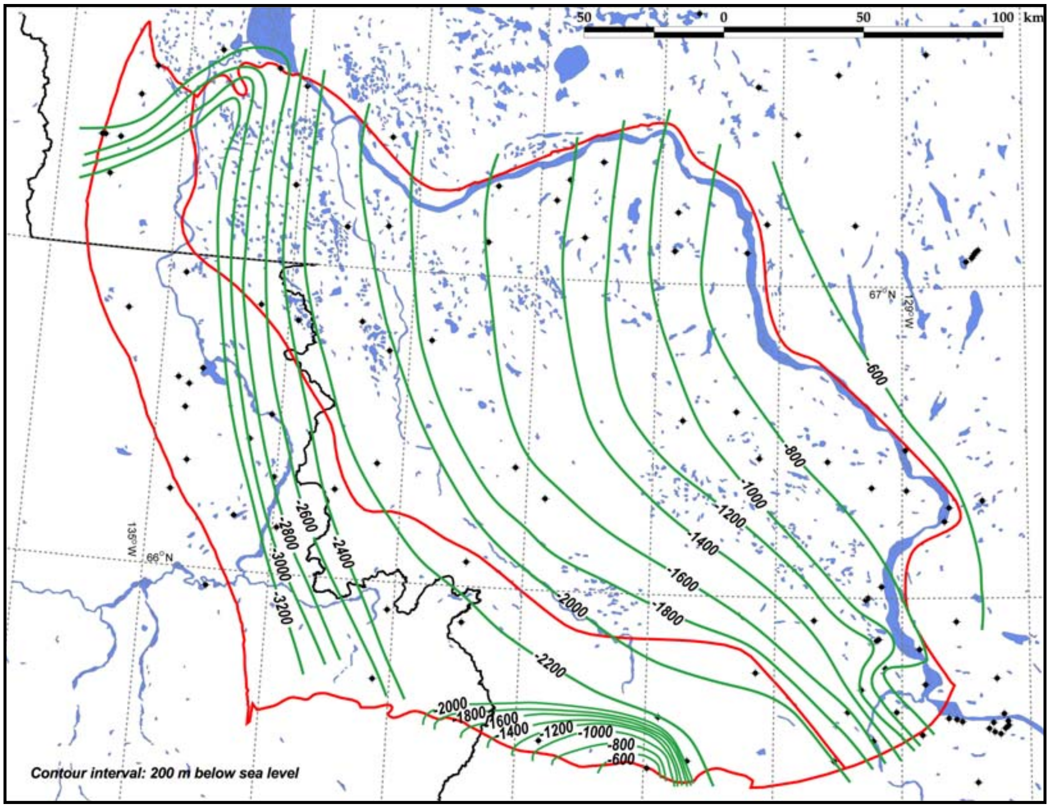


Figure 27. *Structure contour map of Mount Kindle Formation.*

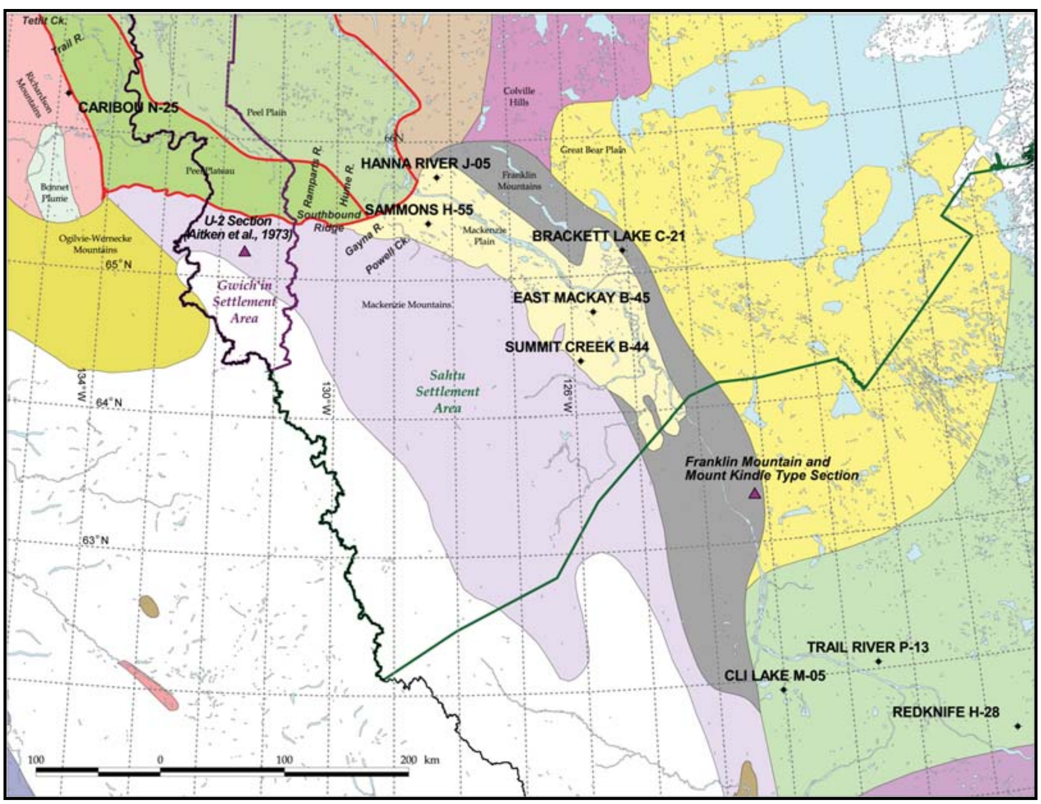


Figure 28. *Regional index map showing positions of wells, sections, settlement areas, and geographic locations mentioned in the text.*

Paleontology and Age

Franklin Mountain Formation lies in possibly the latest Cambrian based on *Cedaria-Crepicephalus* Zone fossils reported from basal "red beds" by Aitken et al. (1973). An Early Ordovician age was reported based on conodonts from Aquitaine Brackett Lake C-21 well east of Peel area by Norford and Macqueen (1975), an Early to Middle Ordovician age was based on conodonts reported from transitional facies by Cecile (1982) and an Early Ordovician age was suggested by trilobite identifications from Section 44 of Morrow (1999).

In this present study, conodonts from near the top of Franklin Mountain Formation (Sections LG-B and LG-A3) yielded *Paroistodus proteus* and *Paracordylodus gracilis* indicative of an Arenigian, Early Ordovician age (Table 2; McCracken, 2008). The lower age of Franklin Mountain Formation was not refined from our collections.

Sample	Section	Formation	Metreage	Easting	Northing	Age or Zone	CAI
07LG-4-A	LG-A1	Mount Kindle	9 m above base	132d32.040m	65d29.683m	Late Ordovician, Ashgillian, *A. ordovicicus* Zone	1.5
07LG-4-B	LG-A1	Mount Kindle	top of formation	--	--	Early Silurian, ?Llandovery	3
07LG-6-B	LG-B	Franklin Mountain	20 m below top	132d47.183	65d29.967m	Late Early Ordovician, early Arenigian	2
07LG-10-B	LG-A3	Franklin Mountain	375 m above base	132d35.698m	65d29.513m	Late Early Ordovician, early Arenigian	2
07LG-10-C	LG-A3	Mount Kindle	50 cm below top	132d35.698m	65d29.513m	Late Ordovician, Ashgillian, *A. ordovicicus* Zone	3
DDA-LP-05-H1	Trail River	Road River	reconnaissance	135d30.342m	66d24.783m	Middle to Late Ordovician	4
DDA-LP-05-H2	Trail River	Road River	reconnaissance	135d30.243m	66d24.810m	Silurian (*petula* Zone—Wenlock and younger, to Emsian)	4
DDA-LP-05-S2	106F	Franklin Mountain	top of formation	132d52.207m	65d29.700m	Middle Ordovician	4
DDA-LP-05-S5	106F	Mount Kindle	top of formation	133d00.259m	65d29.733m	Middle Ordovician-Devonian	5

Table 2. *List of productive conodont samples and their colour alteration indices (CAI) from Ronning and Road River groups, northern Mackenzie Mountains. Eastings and northings expressed as degrees (d) and minutes (m).*

Age determinations from macrofossils (silicified orthocone cephalopods, stromatoporoids, and corals of the *Bighornia-Thaerodonta* fauna) in the Mount Kindle Formation south of its type section (Norford and Macqueen, 1975; Cecile, 1982) and from Section 44 of Morrow (1999) indicate a Late Ordovician to Early Silurian or younger age. A Silurian age was based on macrofossils in the upper part of the Mount Kindle Formation from Stony I-50 well (Norford et al., 1971).

In this present study, conodonts from the base of Mount Kindle Formation (Section LG-A1) are assigned to the *Amorphognathus ordovicicus* Zone (Late Ordovician, Ashgillian) and from the top of the formation, a probable Silurian (Llandovery) age is based on species of *Oulodus*, *Ozarkodina*, and *Panderodus gracilis* (Table 2; Figure 15; McCracken, 2008).

In summary, Franklin Mountain Formation most likely spans from latest Cambrian to late Early Ordovician age in Peel area, and possibly into the Middle Ordovician in Misty Creek Embayment. Mount Kindle Formation is late Ordovician to early Silurian in age.

ROAD RIVER GROUP

At the southwestward limit of Mackenzie Platform, Franklin Mountain and Mount Kindle formations interfinger with Rabbitkettle, Duo Lake, and Cloudy formations of Misty Creek Embayment (Figure 2; Cecile, 1982, 2000). The Lower Paleozoic platform succession also shales out westward to Road River Group (including Rabbitkettle Formation) of Richardson Trough (Figures 1, 2). A brief description of these rocks is included here, although no detailed study was undertaken in these remote basinal locations due to logistical constraints. Some reconnaissance conodont and total organic carbon (TOC) samples were taken within Road River Group of the Richardson Mountains.

Jackson and Lenz (1962) initially defined "Road River Formation" for a succession of graptolitic shale, argillaceous limestone, chert, dolostone, siltstone, and sandstone. Fritz (1985) redefined Road River as a "Group" based on the proposal by Cecile (1982) to include all basinal strata from Slats Creek to Canol Formation. Morrow (1999) maintained the name Road River Group for units in Richardson Trough and Misty Creek Embayment and included the formally defined Rabbitkettle Formation, three informal formations (Loucheux, Dempster, and Vittrekwa) above Rabbitkettle, and one informal unit (unit Csh) below Rabbitkettle Formation (Cecile et al., 1982). Unit Csh of Cecile et al. (1982) is equivalent to unit CDr0 of Norris (1981a) and is a black or rusty brown shale, siltstone and sandstone unit that has a gradational lower contact with Slats Creek Formation. Norris' map-units CDr1 corresponds to the Loucheux (OS1 of Cecile et al., 1982), CDr3 is the Dempster (Sd of Cecile et al., 1982), and CDr4 corresponds to Vittrekwa strata (SDv of Cecile et al., 1982).

Origin of Name and Type Section

The type section (with faulted base) of Road River Formation is on Tetlit Creek (66.73ºN, 135.77ºW), a tributary of the Road River on the east flank of the southern Richardson Mountains. Road River Group is named after the Road River on the east flank of the southern Richardson Mountains, Yukon.

Lithology

Road River Group in Richardson Trough contains black, graptolitic shale, limestone, chert, and debris flow conglomerates in a succession up to 3133 m thick at Rock River in the Richardson Mountains (Norford, 1964). Rabbitkettle Formation in Richardson Trough was described as yellow- to grey-weathering, dark grey to black, argillaceous lime mudstone that alternates rhythmically with shaly lime mudstone and contains chert nodules (Cecile et al., 1982). Rabbitkettle Formation corresponds to the basal member of the type "Road River Formation", as defined by Norford (1964) and is correlative with Franklin Mountain Formation. Upper Road River strata in Richardson Trough were divided by Cecile et al. (1982) into the informal Loucheux, Dempster, and Vittrekwa formations. The former two units are partly correlative with Mount Kindle Formation. Loucheux strata consist of black, graptolitic, silicified shale, orange- to yellow-weathering limestone, black chert, and resedimented carbonate breccia (Figure 29; Cecile et al., 1982). Dempster strata consist of buff- to orange-weathering argillite and argillaceous dolostone (Cecile et al., 1982) or light orange- and yellow-weathering, calcareous shale, argillaceous lime mudstone, silty dolostone, and granule conglomerate (Morrow, 1999).

Figure 29. *Type section of Road River Group (Loucheux formation), north side of Tetlit Creek, Richardson Mountains, containing black shale, siltstone, chert, silty dolostone, and discontinuous debris-flow breccia beds (geologists for scale).*

In Misty Creek Embayment, Cecile (1982) proposed that Rabbitkettle Formation, the underlying Hess River Formation, and overlying Duo Lake and Cloudy formations be assigned to Road River Group. Rabbitkettle and Duo Lake (in part) formations are correlative with Franklin Mountain Formation and Duo Lake (in part) and Cloudy formations are equivalent to Mount Kindle Formation (Figure 1). Rabbitkettle Formation consists mainly of silty limestone interbedded with calcareous shale, with some slope facies preserved near the platform to basin transition. Duo Lake Formation consists of silty limestone, graptolitic shale, and chert. Cloudy Formation consists of limestone, shale, and chert. Marmot Formation volcanics were deposited contemporaneously with Duo Lake and Cloudy Formations (Cecile, 1982).

Contacts and Log Response

Road River Group sharply overlies either Illtyd Formation or Slats Creek Formation with a disconformable to conformable contact (Fritz, 1985; 1996). The upper contact with Canol Formation is debatable and was described as unconformable (Perry et al., 1974), conformable (Pugh, 1983; Williams, 1983), or both (A.W. Norris, 1985). In Misty Creek Embayment, the upper boundary of Cambrian Hess River Formation is gradational with Rabbitkettle Formation within the basin, and disconformable with tongues of transitional or platformal facies of Franklin Mountain Formation. The upper boundary of Rabbitkettle Formation is gradational with Duo

Lake Formation. Cloudy Formation conformable overlies Duo Lake Formation and is unconformably overlain by Delorme Group (Cecile, 1982).

The Lower Paleozoic part of Road River Group is not penetrated by wells in Peel area. Log response and correlation between Franklin Mountain and Mount Kindle formations and Road River Group in Ontaratue H-34 well in Peel Plain and Caribou YT N-25 well of Richardson Trough (Figure 28) were illustrated by figure 19 in Morrow (1999).

Distribution and Thickness

Cambrian to Devonian Road River Group is greater than 3 km thick in both Richardson Trough (3133 m thick at Rock River, Richardson Mountains; Norford, 1964) and Misty Creek Embayment (3000+ m at Section 9 of Cecile, 1982). In Misty Creek Embayment, Rabbitkettle Formation is up to 750 m; Franklin Mountain Formation and its transitional facies are up to 530 m thick; Mount Kindle and its transitional facies are up to 570 m thick; Duo Lake Formation is up to 415 m thick; and Cloudy Formation is up to 470 m thick (isopach maps in Cecile, 1982). In the Richardson Mountains, Rabbitkettle Formation is up to 2000 m thick; Loucheux formation is up to 525 m thick (577 m in Caribou YT N-25 well); and Dempster formation is up to 150 m thick (524 m in Caribou YT N-25 well; Cecile et al., 1982; Morrow, 1999;).

Paleontology and Age

Road River Group has an age range of Late Cambrian to Middle Devonian (Norford, 1996). Rabbitkettle Formation is coeval with Franklin Mountain Formation (Upper Cambrian to Lower Ordovician; Cecile, 2000), although precise ages from Peel area and Richardson Trough are poorly known (early Early Ordovician, *tenuis* Zone; Morrow, 1999). South of 64°N the formation yielded Early to Middle Ordovician conodonts (Pohler and Orchard, 1990).

Duo Lake Formation ranges in age from late Tremadocian to late Early Silurian (*Adelograptus* cf. *A. tenellus* Zone to *Pendeograptus fruticosus* Zone; Jackson and Norford, 2004), and is therefore equivalent to upper Franklin Mountain Formation and Mount Kindle Formation. Cloudy Formation is Late Ordovician to Early Silurian based on *Monograptus* and is correlative with Mount Kindle Formation (Cecile, 1982).

Loucheux formation of upper Road River Group ranges in age from early Middle Ordovician (*Paraglossograptus tentaculatus* Zone) into latest Llandovery (*Cyrtograptus sakmaricus-C. laqueus* Zone; Morrow, 1999). Dempster formation has no age diagnostic fossils and is interpreted as being deposited during development of the sub-Delorme Group unconformity (Figure 19 in Morrow, 1999). Biozones in Road River strata of Richardson Trough (Rock River and Tetlit Creek sections) range from Darriwilian as indicated by *Paracordylodus horridus* to Llandovery *Pterospathodus amorphognathoides-P. celloni* Zone (McCracken, 1991a, b). More detailed work is necessary to further refine correlations between Ronning Group and their deeper water equivalents in Misty Creek Embayment and Richardson Trough.

FACIES DISTRIBUTIONS AND STRATIGRAPHIC CORRELATION

Ronning Group is extensive across Peel Plateau and Plain and the northern front of the Mackenzie Mountains. Some internal cycles are evident but the homogenous nature of the formations, lack of prominent internal bounding surfaces, and lack of biostratigraphic control preclude a meaningful sequence stratigraphic approach.

Two major sequence boundaries define Franklin Mountain Formation. It lies on the sub-Cambrian unconformity at most sections in proximity to Mackenzie-Peel Arch (except where it overlies the Saline River Formation such as at Sections LP-01 and LP-24) and is everywhere unconformably overlain by Mount Kindle Formation. The basal clastic unit or "red bed" unit is present near Cambrian Mackenzie-Peel Arch (Figure 30). The zone of medium to coarse crystalline dolomite within the lower 250 m of Franklin Mountain Formation outcrop sections (Figure 30; from sections LP-04, LP-13, LG-02 shown in Figure 3) may not be stratigraphically controlled because additional vuggy dolostone occurs in other intervals in wells (discussed further in *Reservoir Rocks* section below).

Lithostratigraphic correlation of Franklin Mountain Formation from east to west across the northern Mackenzie Mountains (Figure 4) is challenging because subunits become less distinct westward. Yellow-weathering dolomudstone of the cyclic member may be correlated, although this unit changes facies westward to more grey weathering dolostone and limestone that contain abundant oncoid and pisoids (Section LG-B, Section 44 of Morrow, 1999). The upper cherty unit becomes less siliceous westward. The formation contains more limestone and limy dolostone (as in the Peel YT H-71 well) toward the platform edge, some of which contains floating chert grains and scoured beds which may represent grain flow deposits in deeper water settings.

Franklin Mountain Formation platform carbonates form most of Sauk III Sequence and represent widespread transgression (Cecile and Norford, 1993). In general, the formation deepens upward from the lower Cyclic to middle unit. Despite extensive sampling for conodonts, the only productive samples were those from the uppermost part of the formation where more neritic environments prevail (Sections LG-A3, LG-B; Table 2).

Within Peel Plain, Franklin Mountain Formation is thickest in the northeast (Figures 25, 30). It thins to the west from Section LP-04 (797 m thick) to Section LG-B (375.5 m thick; Figures 4, 25) toward the platform edge.

Mount Kindle Formation is also bound by two major unconformities. On Mackenzie-Peel Shelf, a late Ordovician unconformity that separates Franklin Mountain and Mount Kindle formations is the base of Tippecanoe Sequence (Cecile and Norford, 1993). Mount Kindle Formation is truncated by either a sub-Delorme or sub-Bear Rock unconformity, or a merger of these surfaces which may be the "sub-Devonian" unconformity. Detailed internal correlation of the formation is not possible (Figure 15); although similar to Franklin Mountain Formation, Mount Kindle shows deepening upward trends from its thinner bedded basal part, to more burrow mottled, thick-bedded dolostone containing neritic faunas. There is also a deepening trend from east to west, and chert decreases in western sections of the formation.

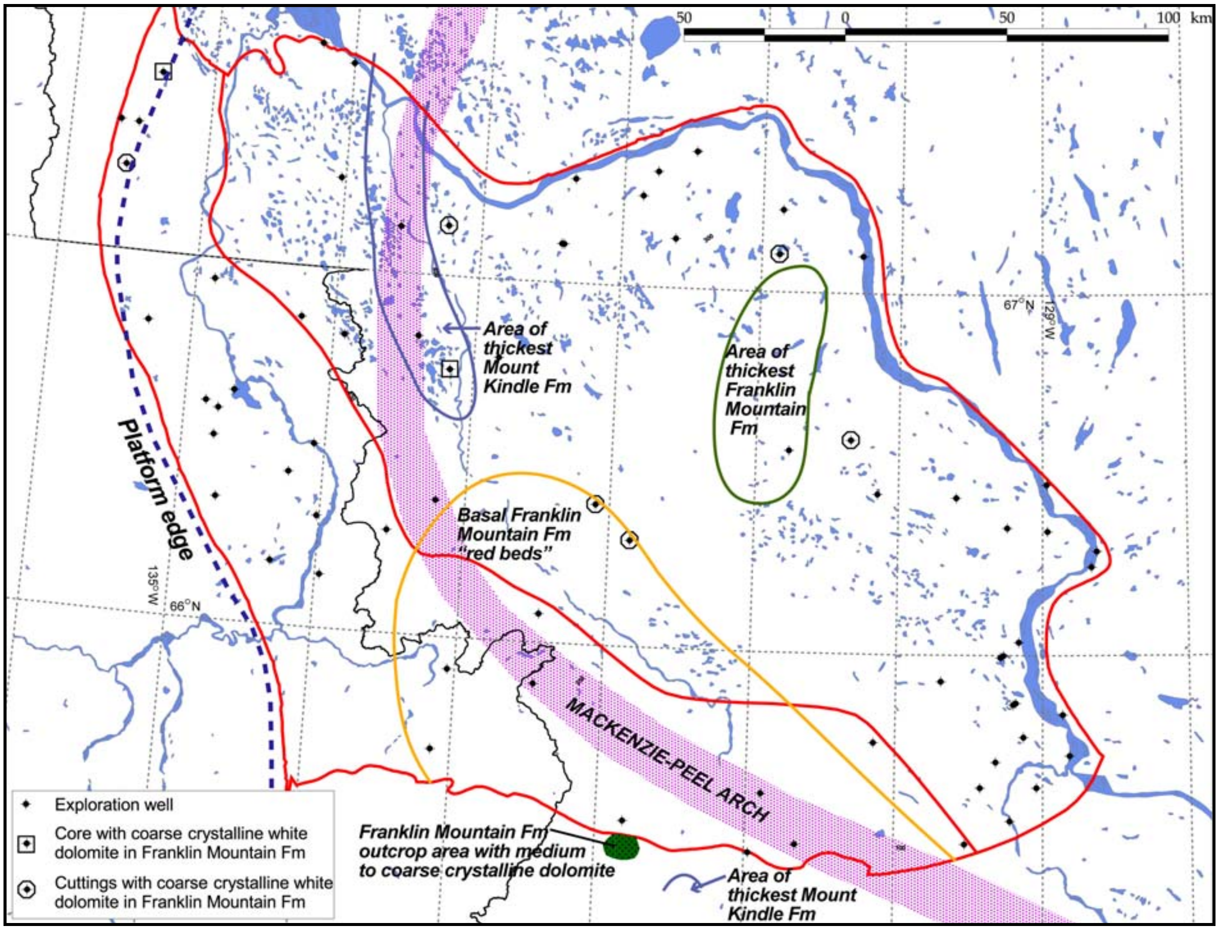


Figure 30. *Facies map of Ronning Group in Peel area.*

Mount Kindle Formation represents renewed transgression following sub-Mount Kindle erosion. Highstand deposits may be interpreted at Section LP-04/12 where the formation thins upward and contains mudcracks. The greatest thicknesses of the formation occur at this section near the southern part of the Cambrian Mackenzie-Peel Arch, and also in the northwest in the area of the arch. The variable thicknesses of Mount Kindle Formation seen in a northeast to southwest cross-section across Peel Plain (Figure 24) and from measured sections across the northern Mackenzie Mountains from east to west (Figure 15) may be explained by either erosion, or deposition on an irregular Franklin Mountain surface. Subaerial exposure and erosion (Figure 22) is documented at the sub-Delorme unconformity. The thickness trends associated with the arch suggest an underlying basement control, with thinner areas of Mount Kindle possibly deposited over high areas of Franklin Mountain Formation.

DISCUSSION AND DEPOSITIONAL HISTORY

Franklin Mountain Formation (latest Cambrian to late Early Ordovician) was deposited in peritidal and subtidal settings (Morrow, 1999) and contains transitional facies in deeper water settings toward Richardson Trough, and along the northeastern and northwestern margins of Misty Creek Embayment where it interfingers with Rabbitkettle Formation (Cecile, 1982). Ripple-marks and flaser bedding in the basal clastic "red bed" unit suggest high-energy to tidal settings. Aitken et al. (1973) reported the trace fossil *Arthrophycus* (a burrow/trackway, possibly of an arthropod) in half of their localities containing this unit. The basal clastic unit likely represents a marginal marine setting around Mackenzie Arch which bounded the western edge of the Saline River evaporitic basin.

Peritidal indicators in lower Franklin Mountain Formation include rip-up clasts, stromatolites and algal laminations, exposure surfaces, oncoid and pisoids. The latter two features are common even in western sections (Section LG-02; Sections 44 and 27 of Morrow, 1999), which indicates the depositional setting for lower Franklin Mountain remained shallow across a wide region.

Following this initial transgression, continued deepening is suggested for the middle part of Franklin Mountain Formation based on subtidal features such as burrow mottling (Sections LG-H, LP-04) and occurrence of macrofossils such as crinoids, brachiopods, gastropods, and trilobites toward the platform edge (Section LG-B). Some of the upper part of the formation may represent highstand deposits and a return to more peritidal conditions (e.g., rip-up clasts at Section LP-04/12).

Mount Kindle Formation was deposited in an open-marine shelf setting, based on the occurrence of corals, stromatoporoids, and cephalopods. Peritidal deposition is indicated by interlaminated beds and stromatolites in the upper part, although these alternate with cherty intervals that may represent deeper water conditions. In the area of the Misty Creek Embayment, Mount Kindle transitional facies overlie deeper water formations of Road River Group and consist of thin-bedded limestone and dolostone and dolostone mounds (Cecile, 1982). Morrow (1999) noted shaly limestone in wells near Richardson Trough suggesting deeper water deposition westward.

Following a period of erosion at the base of the Tippecanoe Sequence, renewed transgression is marked by Mount Kindle Formation deposition. The extent of this basal hiatus remains poorly constrained. Conodonts of late Early Ordovician age occur near the top of the Franklin Mountain Formation (Section LG-A3). Conodonts of Ashgillian age were recovered from near the base of Section LG-A1 and from near the top of Section LG-A3. The whole Mount Kindle Formation therefore spans the late Late Ordovician to Silurian which suggests a hiatus spanning the entire Middle Ordovician. This unconformity presumably decreases in magnitude westward (Cecile and Norford, 1993), although Morrow (1999) described the Franklin Mountain-Mount Kindle boundary as sharp near Richardson Trough in the Snake River map area.

The upper contact of Mount Kindle Formation is well defined, represented by varying degrees of erosion (either the sub-Delorme unconformity, or sub-Bear Rock unconformity). Conodonts from near the top of the formation yielded a late Ordovician age (Section LG-A3) and an early Silurian age (Section LG-A1), suggesting lower Silurian strata may be removed by erosion at the former section.

Road River Group is interpreted to represent continental margin to slope and basin environments that contain turbidites and pelagic to hemipelagic sediments. A carbonate ramp to basin transition from the Mackenzie-Peel Shelf to Richardson Trough is suggested during deposition of Franklin Mountain to Rabbitkettle formations, whereas a more pronounced slope is suggested by debris flow deposits of Loucheux formation. Loucheux formation is early Middle Ordovician to later Early Silurian in age, and therefore partly time equivalent to Mount Kindle Formation. A

Middle Ordovician age for the lower part of the formation suggests it spans time represented by the sub-Mount Kindle unconformity on Mackenzie-Peel Shelf (figure 19 in Morrow, 1999). Abundant debris flow beds such as at the type section on Tetlit Creek, were likely sourced during highstand shedding and erosion of upper cherty Franklin Mountain Formation to the east. Dempster formation is interpreted as being deposited during development of the sub-Delorme Group unconformity (figure 19 in Morrow, 1999) but has no age diagnostic fossils. This formation represents a shallower water environment within Richardson Trough because it contains abundant bioturbation and a higher silt content indicative of lowstand (Morrow, 1999).

In summary, a long-lived carbonate platform setting (Mackenzie-Peel Shelf) was initiated in the latest Cambrian to early Ordovician (Sauk III sequence) following transgression of the Saline River evaporitic basin. Peritidal conditions dominated across Peel area through the Early Ordovician and shifted, with continued transgression, to deeper subtidal conditions by the late Early Ordovician. Thickness variations of Franklin Mountain Formation across Peel area, although poorly constrained by sparse well coverage, indicate the formation is thickest in a depocentre in north-central Peel Plain, east of Mackenzie-Peel Arch. The formation thins toward the platform edge but its deeper water facies equivalents are up to 2000 m thick (Rabbitkettle Formation in Richardson Trough). Mount Kindle Formation represents subtidal to peritidal deposition in the late Ordovician to early Silurian, following a period of non-deposition or erosion across Mackenzie-Peel Shelf (base of the Tippecanoe Sequence). Mount Kindle Formation is thickest in northwest Peel area and thick in the region just south of the Mackenzie-Peel arch. Thickness variations suggest phases of renewed subsidence to accommodate platform carbonate deposition, along a “passive” margin that underwent periods of rifting during the Early Paleozoic (Cecile et al., 1997). Mount Kindle also thins westward toward the platform edge, although this is poorly constrained, and is equivalent to a thicker (500+ m) package of transitional and basinal strata of Richardson Trough and Misty Creek Embayment.

LOWER PALEOZOIC PLATFORM PLAY

This play includes all pools and prospects hosted in vuggy, fractured, and otherwise porous dolostones of Franklin Mountain and Mount Kindle formations. Quartz sandstones in basal Franklin Mountain Formation are another possible reservoir. A basal sandstone member of Mount Kindle Formation has been reported southwest of Peel area (Meijer Drees, 1975a) but is not known within Peel area.

The play is conceptual within Peel area, as no discoveries have been made. Minor gas and oil shows have been found in drill stem tests (DST). This play is also conceptual through much of the Interior Plains and Northern Foreland of the NWT (Pyle, 2008). A discovery of oil in Franklin Mountain Formation in the East Mackay B-45 well in Mackenzie Plain (Figure 28) is a rather atypical occurrence in that the oil is sourced from Cretaceous Slater River Formation that directly overlies fractured Franklin Mountain Formation dolostone (Feinstein et al., 1988a). The distribution of juxtaposed Cretaceous source and Cambro-Ordovician reservoir rocks is not well understood in Mackenzie corridor (Pyle, 2008).

Franklin Mountain and Mount Kindle formations are widespread in the subsurface of Peel area, and thus the play can be considered to extend virtually throughout the entire area, limited only by areas of shallow subcrop and outcrop. The western limit of the play area coincides with the Mackenzie-Peel platform edge, which is close to the western boundary of Peel area.

Few quantitative estimates of the Lower Paleozoic Platform Play endowment have been published. In an unpublished report, Drummond (2008) made a quantitative assessment of the Lower Paleozoic Platform Play in the Sahtu and Gwich'in Settlement Areas of the NWT, which includes Peel area. Osadetz et al. (2005) estimated that their Paleozoic Carbonate Platform Play, within Peel Plain of Yukon (which includes strata of Hume Formation and older, and thus is much broader than the Lower Paleozoic Platform Play discussed here) had a mean play potential of 272 $x10^6m^3$ gas in place (less than 10 Bcf) distributed in one pool. This low potential resource reflects the geological risks and lack of historical drilling success. Another defined Paleozoic carbonate play in Osadetz et al. (2005), the Paleozoic Carbonate Margin Play (which also includes Hume Formation and older Lower Paleozoic carbonate reservoirs), lies in Peel Plateau of Yukon between the eastern limit of thrusting and Trevor Fault. The play had predicted results of seven gas pools with a mean potential of 4.46 billion cubic metres of gas in-place. In addition, two publications by the National Energy Board (2000 a, b) contain quantitative petroleum resource assessments for Peel Plain and Plateau in Yukon.

There have been a number of indications of hydrocarbons in Lower Paleozoic platform rocks in and near Peel area: Peel Y.T. H-71 well (Figure 3) had gas to surface on a drill stem test (DST) of the interval 2726 m to 2893 m (basal Peel Formation equivalent and upper Mount Kindle Formation) with an estimated flow rate of 1841 m^3 (65,000 ft^3) per day and recovery of water and gassy drilling mud. The Peel Y.T. F-37 well (Figure 3) tested mud, gassy salt water, and gassy, muddy salt water from basal Peel Formation and upper Mount Kindle Formation at 3319 m to total depth (TD) at 3368 m. Taylor Lake Y.T. K-15 well (Figure 3) recovered gassy salt water from Peel and Mount Kindle formations from the interval 2252.5 m to TD at 2378.7 m.

Just east of Peel area, oil-cut salt water was recovered from the top of Mount Kindle Formation (823 m) on a DST in Hanna River J-05 well (Figure 28).

Other indications of hydrocarbons in the succession include oil staining in a number of wells: Shoals C-31 (Franklin Mountain Formation from 1232 m to 1238 m), Hume River A-53 (Mount Kindle Formation), Tree River C-36 (1538 m to 1628 m, basal part of Peel Formation and Mount Kindle Formation), Cranswick YT A-42 (3426 m to 3429 m, Mount Kindle Formation), and in the Sammons H-55 well (just southeast of Peel area in Mount Kindle Formation from 435 m to 445 m). Bitumen was noted in Franklin Mountain and/or Mount Kindle formations in stylolites, vugs, and/or fractures in the following wells: Cranswick A-22, Stony I-50, Ontaratue I-38, and Arctic Red West G-55. A gas anomaly was recorded while drilling through Mount Kindle Formation in Sperry Creek N-58 well at 1889 m to 1896 m.

Reservoir Rocks

While Franklin Mountain and Mount Kindle formations are distributed throughout Peel area and have a combined thickness of more than 1 km in most places, they are dominantly composed of finely crystalline dolomudstone which is mainly poorly porous to tight. Vuggy, intercrystalline, and fracture porosity does exist over appreciable widths locally. Porosity due to dissolution related to unconformities is possible in upper parts of both Franklin Mountain and Mount Kindle formations, and evidence for karsting in Franklin Mountain Formation has been reported by Damte et al. (2003). A number of drill stem tests in these formations have recovered large volumes of formation water that suggest reasonable permeability and porosity, as do instances of lost circulation reported in a number of well history reports (e.g., Mountain River A-23 well; Figure 3).

Franklin Mountain Formation

Locally within Peel area and adjacent Mackenzie Mountains, basal Franklin Mountain Formation is composed of sandstone and shale "red beds". Sandstone outcrops are found on ridges around Hume River area and consists of angular, fine-grained quartz with carbonate cement, in thin to medium beds, interbedded with red (and lesser green) shale. Twenty-six metres of such red quartz sandstones were measured at Section LP-22 (Figure 3). Porosity is locally developed in these red bed sandstones where there is a lack of carbonate cement, or it has undergone dissolution (Figure 31).

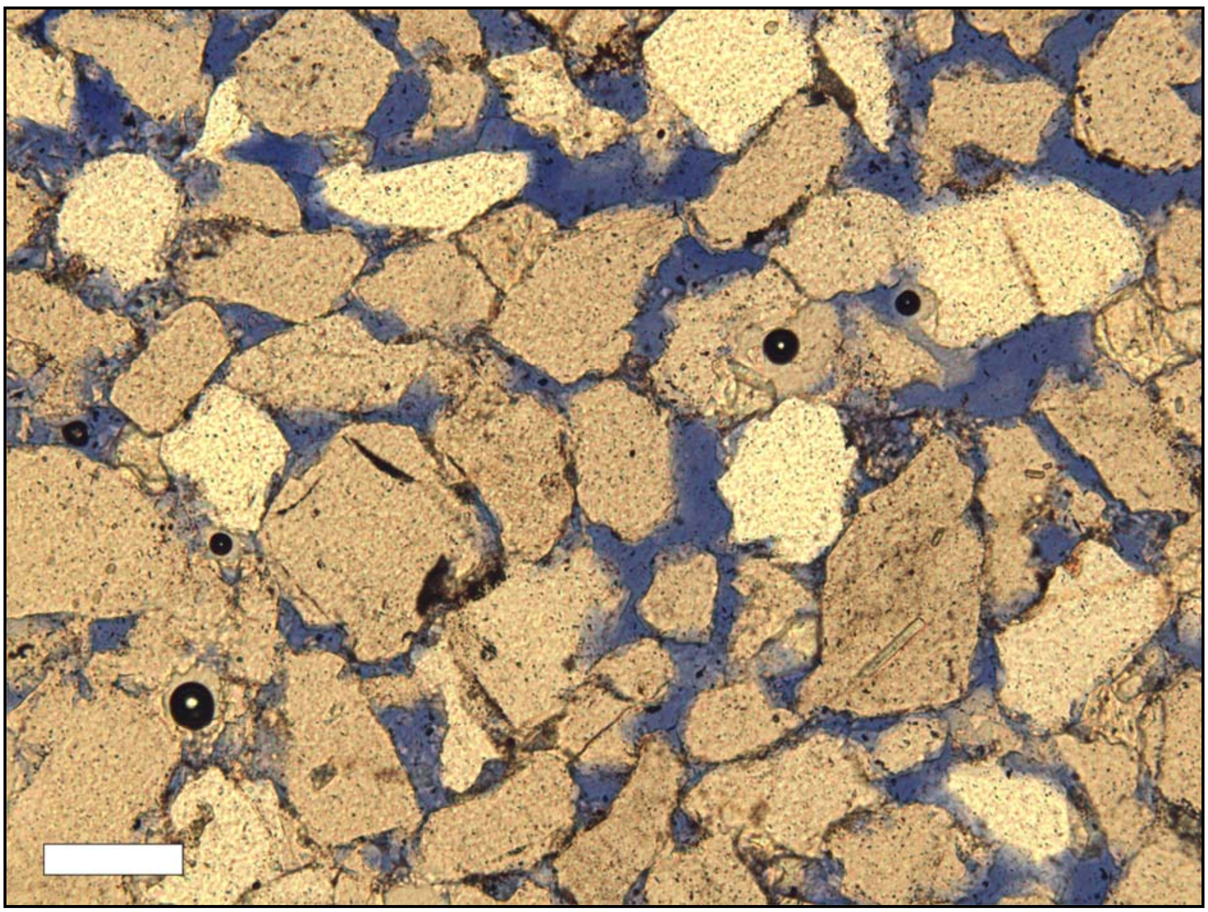


Figure 31. *Sample 06LP-16-01, basal Franklin Mountain Formation, sub-angular quartz sandstone with abundant pore space. Other samples from this area showed various amounts of carbonate, clay, or iron oxide as matrix/cement material; therefore it is assumed that this surface outcrop sample shows some dissolution. Plane polarized light. White scale bar is 0.1 mm long.*

Tassonyi (1969) and Norford and Macqueen (1975) described the upper cherty member of Franklin Mountain Formation as having potentially good reservoir characteristics. Preferential dissolution of chert would increase porosity in these rocks (Figure 32). Morrell (1995) noted porosity in dolomitic platform carbonates through Peel Plain, east of the shelf edge. Cavernous porosity related to karsting has also been noted in Franklin Mountain Formation (Damte et al., 2003).

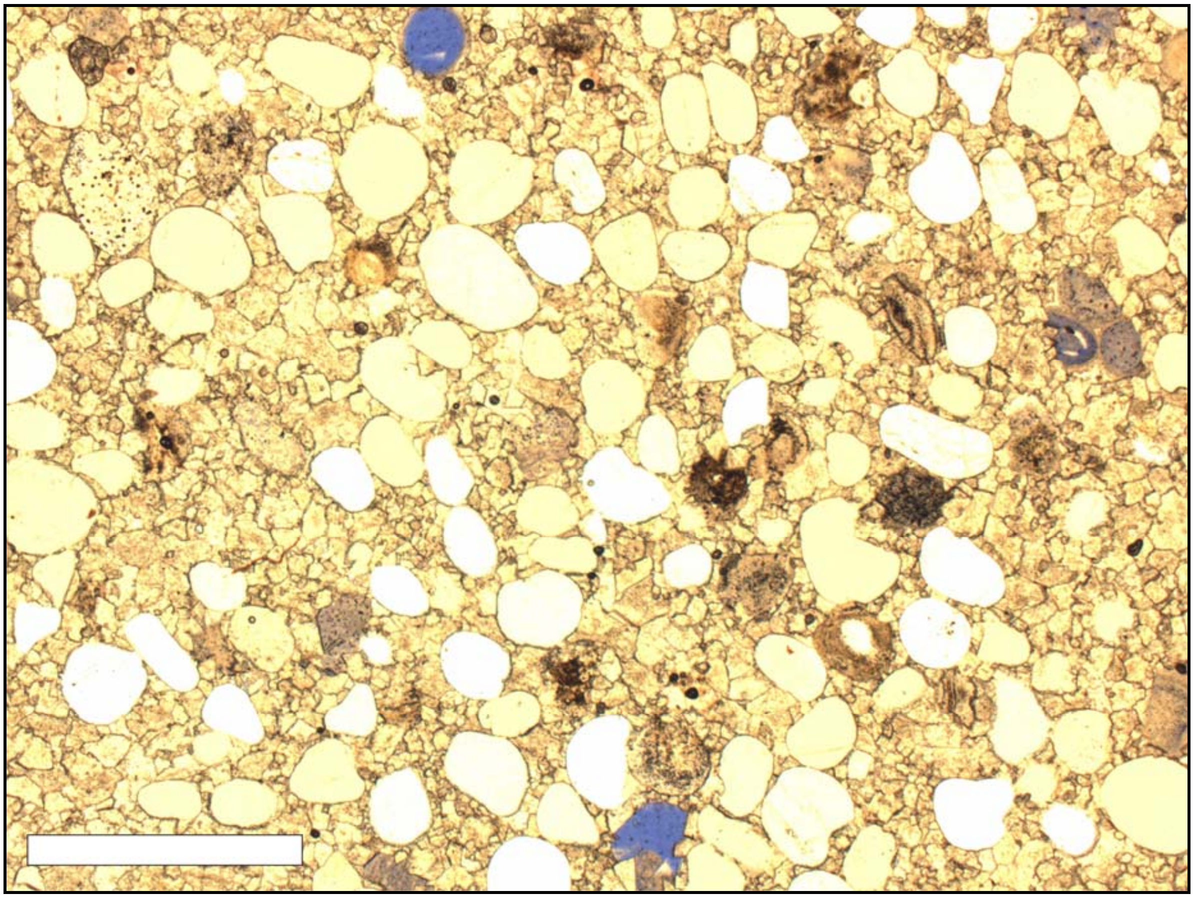


Figure 32. *Sample 06LP-13-03a, "cherty" Franklin Mountain Formation dolostone. Most of the "chert" grains are actually well rounded and sorted quartz grains in a dolomite matrix. Note some of the cloudy chert grains show partial dissolution. Plane polarized light. White scale bar is 1 mm long.*

Medium and Coarse Crystalline Vuggy Dolomite

In the course of the current study, several locations at the Mackenzie Mountains front in the area around Arctic Red River were found to have medium to coarse crystalline, vuggy, white or light grey dolomite in stratiform layers or lenses within Franklin Mountain Formation (Gal and Pyle, 2006; Figure 33). The vuggy dolomite occurs in zones 15 m to 39 m thick, in generally decimeter- or metre-scale layers with intervening finely crystalline or sucrosic dolostone beds. Occurrences at measured section locations (LP-04, LP-13, LG-02; Figure 3) were generally within about 250 m of the unconformable base of Franklin Mountain Formation (Figure 34). Samples taken from outcrop have porosities of 1.7% to 9.4%, but with low permeabilities (Table 3). Vugs are often large, with linings of dolomite, some late calcite, and locally later clay minerals (Figure 35). The coarse crystallinity and fabric-destroying texture apparent in these rocks suggests diagenetic recrystallization of dolomite.

Figure 33. *Vuggy surface weathering in medium to coarse crystalline Franklin Mountain Formation dolostone, section LG-02. Hammer for scale.*

Figure 34. *Whitish weathering band in middle background is medium to coarse crystalline and vuggy Franklin Mountain Formation dolostone, section LP-13. Dark weathering hill in background is Proterozoic Katherine Group.*

Sample	Porosity (%)	Permeability (mD)	Comments
06LP 04-02	9.4	1.07	Vuggy dolostone.
07LG 99-B	7.3	0.60	Near same site as 06LP 13-01, vuggy dolostone.
06LP 13-01	6.5	0.09	Medium-crystalline vuggy dolostone with saddle dolomite and yellowish material lining vugs.
06LP 18-07	5.2	0.05	Vuggy 30 cm bed with coarse saddle dolomite lining vugs.
06LP 10-01	4.4	0.29	Medium to coarse-crystalline vuggy dolostone.
07LG 13-D	4.0	0.32	Light grey medium to coarse-crystalline dolostone with vuggy and intercrystalline porosity.
06LP 16-02	2.3	0.13	Slightly vuggy dolostone with amphiporids.
06LP 12-01	2.1	0.02	Vuggy dolostone over 3.75 m interval.
07LG 13-C	1.7	0.02	Slightly vuggy dolostone.

Table 3. *Porosity and permeability measurements from outcrop samples of Franklin Mountain Formation. mD = millidarcies.*

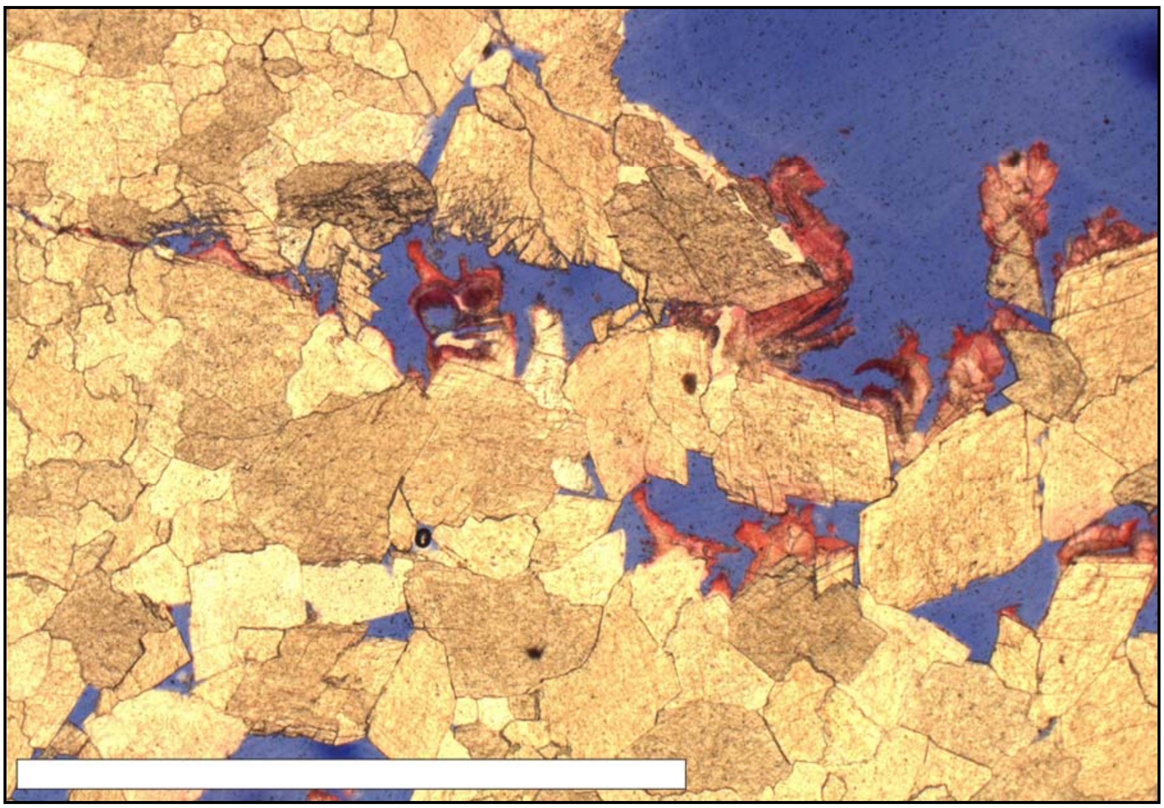


Figure 35. *Sample 06LP-10-01, coarse crystalline Franklin Mountain Formation dolostone. Note red-stained, later stage calcite partially lining vugs. Plane polarized light, white scale bar is 1 mm long.*

Reconnaissance examination of well cuttings revealed that several wells in Peel area show coarse, white, euhedral dolomite crystals in Franklin Mountain Formation samples, suggestive of open space-filling dolomite, and possibly vuggy porosity. These wells included: Stony I-50, McPherson B-25, Clare F-79, Arctic Red West G-55, Ontaratue H-34, Ontaratue I-38, Grandview Hills No.1 (A-47), and Grandview L-26.

Previous workers have also inferred zones of vuggy porosity. In Ontaratue I-38, samples from Franklin Mountain Formation were judged to have poor to good porosity mainly in vugs and fractures, as well as some intercrystalline porosity, that generally increased downhole (Ontko, 1973). The Canadian Stratigraphic Services (Canstrat) log of Grandview L-26 gave estimates from cuttings of 4% to 20% porosity over 4.6 m to 6.1 m intervals of fracture and vuggy porosity (Canadian Stratigraphic Services, 1975).

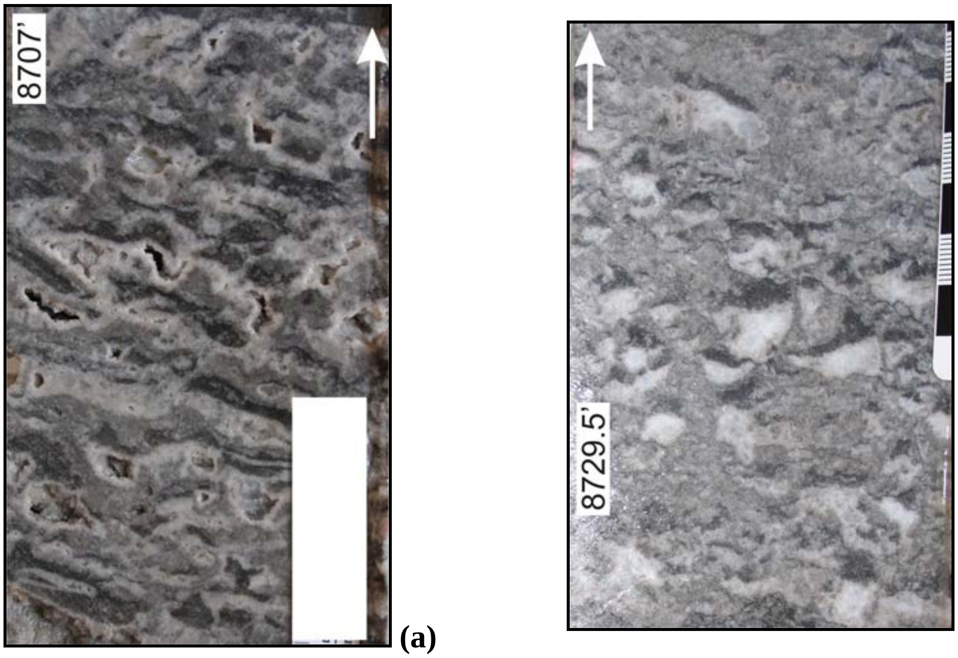
Table 4 lists intervals of significant porosity and permeability measurements on cores of Franklin Mountain Formation from wells in Peel area.

Well name	Interval (m)	Thickness (m)	Weighted average porosity (%)	Comments
Stony I-50	3085.4-3092.8	7.4	6.62	Includes 12.2% over the basal 1.4 m.
Arctic Red West G-55	2653.6-2657.1	3.5	6.73	Includes 4.2 % over 8.5 m, and 7% over 3.2 m in the upper part of the core.
	2658.6-2659.8	1.2	5.43	
Clare F-79	2520.1-2521.0	0.9	5.83	--
	2522.1-2522.8	0.7	6.52	
Grandview Hills No.1 (A-47)	1995.7-1997.1	1.4	3.90	--
	1988.6-1990.7	2.1	2.61	

Table 4. *Weighted average porosity measurements from selected core samples of Franklin Mountain Formation, compiled from well history reports.*

Of particular note are cores cut from Franklin Mountain Formation in Stony I-50 and Arctic Red West G-55, examined during the current study. These cores have intervals of coarse crystalline white dolomite, with replacement fabrics and fracture fills, and many textural features that appear similar to those in hydrothermal dolomites (e.g., Davies and Smith, 2006; Figure 36).

There does not seem to be a preferred stratigraphic horizon for these coarse vuggy dolomites within Franklin Mountain Formation, although as noted above, outcrop locations are nearer the base of the formation. From outcrop and well location occurrences, it is possible to draw poorly constrained north and/or northwest trends across Peel area where these porous rocks lie (Figure 30). Whether or not the vuggy rocks are associated with fault zones on these trends is unknown; MacLean (1999) inferred no basement faults from seismic adjacent to these locations in Peel area, and no definite faults were observed at outcrop occurrences of the coarse dolomite. In addition, without paleo-temperature data, these subsurface and surface vuggy dolomites cannot be called hydrothermal in origin, although they appear to be based on textural evidence alone. Morrow (1999) and Osadetz et al. (2005) discount the possibility of widespread hydrothermal dolomite in Peel area, at least in the lower Devonian rocks. More work will be required to determine if these occurrences are hydrothermal in nature and structurally controlled; nonetheless, vuggy porosity is present over substantial thicknesses in outcrop of Franklin Mountain Formation.



(a) (b)

Figure 36. *Cores of Franklin Mountain Formation from the Arctic Red West G-55 well: (a) subhorizontal vugs with dark-coloured geopetal texture and white saddle dolomite infill; and (b) similar to (a), vugs with grey geopetal fill followed by coarse white dolomite (compare to figure 2 in Davies and Smith, 2006). Footage of core indicated, scale bar in (a) is 5 cm, card in (b) is marked in mm and cm divisions. Note in both cases arrow points to bottom; the cores were upside down in the box and are pictured right-side-up here.*

Mount Kindle Formation

Tassonyi (1969) noted porosity in Mount Kindle Formation as a possible exploration target. Porosity is generally intercrystalline in sucrosic dolostone, and fenestral and/or vuggy dolostone. Intergranular porosity in biostromal and bioclastic layers also exists (Pyle, 2008). Dolostone with large vugs, caused by dissolution of stromatoporoids and corals and lined by dolomite and calcite, occur at Gayna River and Southbound Ridge (Figure 37).

Fenestral porosity occurs in the upper beds of Mount Kindle Formation at Powell Creek (Figure 28), and in Section LG-02 (Figure 15). The laterally continuous, medium to coarse crystalline, vuggy dolostone intervals seen in Franklin Mountain Formation (described above) were not apparent in Mount Kindle surface exposures.

Intercrystalline, vuggy, pinpoint, and fracture porosity has been noted in several well history reports. From selected Canstrat logs, estimated porosities of 6% to 12% over intervals of 3 m to 11 m are not uncommon, with most wells showing at least some minor porosity streaks. Hu (in press a) estimated porosities of 3% to 10% for the interval 1068 m to 1095 m in Thunder River N-73 well, and 3% to 5% in five thin intervals between 1210 m and 1250 m in Tree River B-10 well. Petrophysical porosity estimates from selected wells (Hu, in press b) include: 7.9% over 7.5 m (from 2739 m) in Peel Y.T. H-71 well, and 8% over 3.1 m (from 1216 m) and 7% over 4.7 m (from 1253 m) in Grandview Hills No.1 (A-47) well.

Figure 37. *Mount Kindle Formation, Gayna River. Vuggy surface weathering caused by leached stromatoporoids and other fossil fragments. Vugs are lined by quartz and/or dolomite, calcite. Hammer is 38 cm long for scale.*

Selected analyses from cored samples of Mount Kindle Formation are presented (Table 5).

Well name	Interval (m)	Thickness (m)	Weighted average porosity (%)	Comments
Mountain River O-18	1075-1082.1	7.1	6.07	Includes a weighted average of 3.3% porosity (and 21 mD permeability) over a 17 m interval, and 12.7% over 1.38 m.
	1084.4-1090.9	6.5	5.39	
Tree River F-57	1866.9-1868.1	1.2	3.69	--
Mountain River H-47	753.0-757.6	4.6	2.76	--
Cranswick A-22	2091.5-2093.6	1.8	0.81	A 30 cm section at 2094.8 m yielded 4.3% porosity.

Table 5. *Weighted average porosity measurements from selected core samples of Mount Kindle Formation, compiled from well history reports.*

Outcrop samples collected during the present study from Mount Kindle Formation were analysed for porosity and permeability (Table 6).

Sample	Porosity (%)	Permeability (mD)	Comments
07LG 7-B	9.7	1.51	Vuggy medium to coarse-crystalline dolostone.
06LP 13-05	5.1	0.05	Sucrosic dolostone, some vugs.
07LG 3-A	4.4	0.38	Sucrosic dolostone, possible fault zone.
06LP 12-06	3.8	1.90	Limestone, slightly fractured and brecciated.
06LG 09-01	3.2	0.11	Vuggy dolostone.
07LG 4-C	2.8	0.07	Sucrosic dolostone.
06LP 12-07	2.7	0.94	Medium-crystalline dolostone.
07LG 6-C	2.3	0.99	Sucrosic dolostone.
06LP 18-09	1.8	0.02	Vuggy with silicified and weathered out stromatoporoids, thick bedded, siliceous vugs.
06LP 22-02	1.5	0.005	Cherty fossiliferous dolostone.

Table 6. *Measured porosity from outcrop samples of Mount Kindle Formation collected during the current study. mD = millidarcies.*

Permeability and Reservoir Thickness

Permeabilities are variable. Outcrop samples in this study had mainly very low permeabilities (hundredths to two millidarcies). Higher permeabilities will likely be related to fracturing, which can be expected in this formation.

Gross thicknesses of potential reservoir intervals can be expected on the order of tens of metres (estimate 10 m to 40 m). Together Franklin Mountain and Mount Kindle formations range from about 800 m to over 1200 m in thickness across Peel area.

Source Rocks

From review of literature and field examination of outcrops, there are no suitable source rocks of consequence within Franklin Mountain and Mount Kindle carbonates, with the exception of sparse and very thin shale seams found locally within these units. Well south of Peel area, Meijer Drees (1975b) suggested dark grey dolostones of lower Mount Kindle Formation as the only possible source rock in this part of the section.

Some high TOC values have been reported from Ronning Group: up to 2.6% in Cranswick A-22 well (Snowdon, 1990), 1.55% in Ontaratue K-04 well, and 1.77% in Grandview Hills No.1 (A-47) well (GeoChem Laboratories and AGAT Consultants, 1977). These results were generally ascribed to contamination from cavings, or very thin shale interbeds. GeoChem Laboratories and AGAT Consultants (1977) suggested thin shale interbeds in Mount Kindle Formation may have been a good, local, and effective source.

At the western margin of Peel area, Franklin Mountain and Mount Kindle formations gradually transition into basinal equivalent black shales and limestones of Road River Group. Road River Group, which is more than 3000 m thick in Richardson Trough, contains potential, although overmature, source rocks (Figure 29).

Samples from Road River Group shale outcrops have yielded TOC values as high as 9.6% (Link and Bustin, 1989). Six samples collected from outcrop during the course of this study from 2005 to 2007, ranged from 1.58% to 6.14% TOC and averaged 3.37% (Pyle et al., 2006; Gal et al., 2007). Samples from well cuttings have yielded as much as 3.67% TOC (Caribou Y.T. N-25 well, Geological Survey of Canada, unpublished data).

GeoChem Laboratories and AGAT Consultants (1977) rated Road River Group as a very good, effective, light gas hydrocarbon generating rocks. Link et al. (1989) determined that Type I and II kerogens occurred in Road River Group, thus making it oil prone.

Road River Group shale is overmature, i.e., dry gas generating, based on conodont alteration indices (CAI; Link et al., 1989). During this study, a conodont sample from Trail River returned 4.0 CAI, which indicates overmaturity (Table 2).

Vitrinite reflectance measurements from Mount Kindle Formation in the Hume River L-09 and North Ramparts A-59 wells, and Franklin Mountain Formation in Fort McPherson C-78 well, indicate overmaturity (Feinstein et al., 1988b). Thus it is reasonable that across Peel area, sediments of this age are overmature. However, in the Arctic Red West G-55 well, reflectance indicates mature Mount Kindle (1.34% R_o) and Franklin Mountain Formation (Feinstein et al., 1988b). There are only three data points for the latter determination, so it may be considered suspect data.

In general, the source rock potential of Mount Kindle and Franklin Mountain formations is poor, but Road River Group has good source rock potential. All these units are overmature, and hence the play is gas only. Bitumen in pore space in Franklin Mountain and Mount Kindle formations may represent early oil that was cracked to gas in the reservoir. Live oil stain and oil flecked water on DSTs east of Peel area (Sammons H-55 and Hanna River J-05 wells, respectively) may reflect oil from a younger source.

Seal and Overburden Rocks

Top and lateral seals at the western platform edge may be tongues of Road River Group shale where they extend eastward over carbonates; however, the westward depositional dip at the platform margin may preclude effective top seals (Osadetz et al., 2005). Carbonate platforms dip westerly throughout Peel area (Morrell, 1995); this means that lateral seal is also poor because hydrocarbons introduced into the formations in the west, possibly from Road River source rocks, would buoyantly migrate upward and eastward along carbonate horizons and leak out at surface near the Mackenzie River. Otherwise the possible reservoirs would be buried by a thick section of dolostone and limestone, including significant thicknesses of tight dolomudstone that are within the formations themselves. Porosity developed at unconformities at the top of Franklin Mountain or Mount Kindle formations could be sealed by tight overlying units. Fault seals are also possible, especially along the Mackenzie Mountain front.

In the far eastern Peel area, Mount Kindle Formation is locally overlain by Bear Rock breccias (e.g., Section LP-21 in Figure 15), or equivalent Fort Norman Formation anhydritic dolostones in the deeper subsurface. While the shallow subsurface and outcropping breccias would make poor seals, the equivalent subsurface anhydritic rocks may be effective. This is the case in the extreme southeast corner of Peel area (e.g., Shoals C-31, Mountain River O-18 wells; Figure 3).

In eastern Peel area, top of Mount Kindle Formation is about 500 m to 600 m below sea level. This increases to well over 2000 m below sea level in western and southern Peel area (Figure 27). There are unconformities at the base and top of Mount Kindle Formation, as well as at base Cretaceous; where significant uplift and erosion may have occurred, and this may have affected seal integrity.

Traps

This is a conceptual play and a variety of traps in Lower Paleozoic platform rocks may exist including: stratigraphic pinch-outs and interfingering of porous carbonate and shale at the platform edge (notwithstanding the risky westward depositional dip mentioned above), possible buildups at platform edge sealed by shale tongues (e.g., tested by McPherson B-25 well), and intraformational diagenetic changes affecting porosity (e.g., zones of coarse crystalline vuggy dolomite discussed above). These coarse vuggy dolomite zones may also have a structural component to them. Simple structural traps such as faulted anticlines, or fault traps may be important in southern Peel area along the Mackenzie Mountains front. A large structure was tested by the Cranswick A-22 well. Unconformity related traps are possible beneath the pre-Devonian or pre-Mount Kindle unconformities (e.g., Tassonyi, 1969), and traps related to pre-Devonian faulting, folding, and drapes over basement highs are possible. Subtle structural traps related to salt solution and collapse, and/or salt flowage in underlying Saline River Formation may occur in southeastern Peel area.

Another possibility is the trapping of mega-breccia talus blocks of carbonate rock, detached from the platform margin and encased in surrounding Road River Group shale. Philips et al. (2008) outlined some of these kinds of trapping configurations in the Western Canada Sedimentary Basin.

Areas of structural closures through most of Peel Plain are expected, based on limited data, to be 1 km to 8 km long and 0.5 km to 1 km wide (Lemieux et al., 2008). Larger structures adjacent to the Mackenzie Mountain front are known, such as the Cranswick A-22 structure discussed above.

Timing of Generation, Migration, and Accumulation

In Peel area, bitumen in stylolites, vugs, fractures, and intercrystalline pores indicates that some oil has moved through these rocks. Typically only traces of bitumen are found in western Peel area wells, rather than fully plugging pore space. Road River Group shale probably generated oil, as early as Carboniferous time (Link et al., 1989). Latest Paleozoic maturation in these early Paleozoic rocks, under the clastic pile of Imperial and Tuttle formations, was also indicated by simple one-dimensional burial history models conducted during this study (see Chapter 10). The oil was probably then cracked in-situ to gas, most likely after burial by Cretaceous clastics.

Thus, oil generation predated Laramide structural traps formed in association with the Franklin or Mackenzie mountains (Link et al., 1989). Some migrating oil may have moved eastward across Peel Plain, to regions of lesser burial. Tassonyi (1969) noted that hydrocarbons produced could have migrated into more favourable Lower Devonian reservoirs, although the timing continues to be unfavourable.

The oil staining and shows in eastern Peel area and wells just to the east (Hanna River J-05 and Sammons H-55 wells; Figure 28), are perhaps due to Devonian sourced oils that migrated into lower Paleozoic platform rocks. Road River Group sourced hydrocarbons remaining in lower Paleozoic platform reservoirs would have had to be trapped and preserved a very long time, under mainly fracture-prone overburden, with several unconformities and without the benefit of an evaporite seal. Otherwise, these hydrocarbons would have had to migrate on the order of 250 km from shelf edge to eastern Peel area and Fort Norman Formation anhydrites. Meijer Drees (1975b) noted that gas could have been generated and trapped in the Paleozoic succession, sealed by Devonian evaporites, and preserved in pre-Laramide traps.

Middle and Late Devonian source rocks, which could be associated with this play, are evaluated in Chapter 6 (this volume).

Qualitative Evaluation, Risks, and Best Parts of the Play (Fairways)

The main exploration risks for this play would be the distribution of potential reservoirs, communication with source rocks, formation of closures, viability of top and lateral seals over time to preserve hydrocarbons, and timing of trap formation relative to hydrocarbon migration. The findings of the current study, specifically the identification of possible hydrothermal dolomite in Franklin Mountain Formation, offers encouragement for further study and delineation of these reservoir rocks. Chances of breached or degraded reservoirs and failed preservation, however, are relatively high.

Given the high risks associated with the geometry of the potential for platform margin stratigraphic traps (as outlined by Osadetz et al., 2005), perhaps the best chances for hydrocarbons in this interval in Peel area are associated with Devonian source rocks and Laramide structural traps. Considering a purely Lower Paleozoic petroleum system, the most likely situation may be that of Road River Group source rock oil generation and migration into porosity traps in central Peel area, with sealing under Devonian carbonates or evaporites. In-situ cracking of oil to gas, and renewed migration, may have occurred. Long-distance migration may be problematic, given the abundance of tight lithologies in this part of the section.

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 Peel Plateau of Yukon, the far west part of current Peel 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.

Gal (2005) considered the Cambrian-Ordovician platform play to have low to moderate potential relative to other plays in his study area in the Ramparts and Hume rivers area, part of the southeastern Peel area of the current study.

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Chapter 5 – Upper Silurian-Lower Devonian Strata (Delorme Group)

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ABSTRACT

Delorme Group is part of the Silurian to Devonian assemblage in Peel area that includes silty carbonate rocks of Peel and Tatsieta formations. These rocks were measured at 12 outcrop sections from east to west across the northern Mackenzie Mountains and are penetrated by 33 wells in Peel area. Peel and Tatsieta formations have type sections in the subsurface (Peel Y.T. F-37 and Grandview Hills No.1 (A-47) wells, respectively); a surface reference section (200 m thick) is herein proposed in Upper Ramparts River map area (NTS 106 H). Delorme Group is bound by a sub-Delorme unconformity (base of the Kaskaskia Sequence) and overlain by a transgressive surface at the base of Arnica Formation. The succession generally thickens westwards across Peel area, and shallow marine, peritidal, and supratidal settings occurred far into southwestern Peel area. Delorme Group was deposited on Mackenzie-Peel Shelf during a phase of renewed uplift of paleotopographic highs. Silty carbonate rocks of Delorme Group have limited potential as reservoir rocks for hydrocarbons (rare zones of sucrosic dolostone in Peel Formation) and no potential as source rocks.

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INTRODUCTION

Delorme Group (Delorme Assemblage of Morrow, 1991 and Meijer Drees, 1993) refers to rocks lying above Ronning Group (Cambrian to Silurian) and below Lower Devonian Arnica Formation or equivalent (Figure 1). In the present study, this succession contains Peel Formation and overlying Tatsieta Formation, although these are not everywhere differentiated from one another. Delorme Group rests on a sub-Delorme unconformity, in part continuous with the "sub-Devonian" unconformity of the continental interior, which represents the initial transgression of the Kaskaskia Sequence (Sloss, 1963).

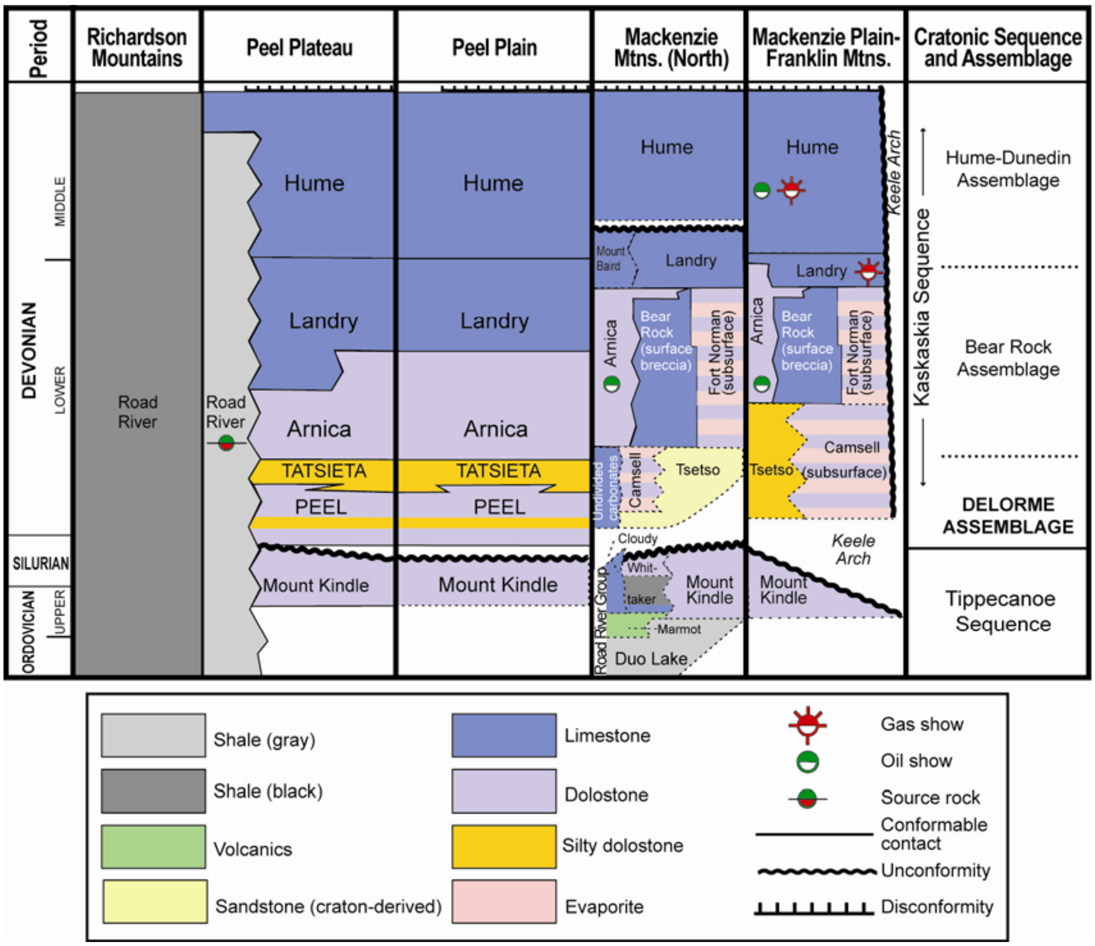

Figure 1. *Table of formations for Peel area and adjacent parts of the Cordillera showing stratigraphic position of Peel and Tatsieta formations (Delorme Group).*

Delorme Group in Peel area consists of mainly silty dolostone that weathers a distinctive yellow-orange and pale grey colour. It forms part of the platform succession that persisted on Mackenzie-Peel Shelf from latest Cambrian to Devonian time. The major paleogeographic elements that affected deposition in the Silurian to early Devonian include a transition to slope and basinal settings to the western margin of Mackenzie-Peel Shelf (Richardson Trough; Gabrielse, 1967; Norris, 1985) and its southern margin along Misty Creek Embayment (Cecile, 1982) and Selwyn Basin (Gabrielse, 1967). Paleogeographic highs such as Keele Arch (Cook, 1975) and Twitya Uplift (Cook and Aitken, 1978) may have been uplifted during the Silurian and Devonian. Block faulting such as in southern Richardson Trough (Williams, 1988) and southern Root Basin (Williams, 1989) also suggests tectonic activity in this time interval (Figure 2).

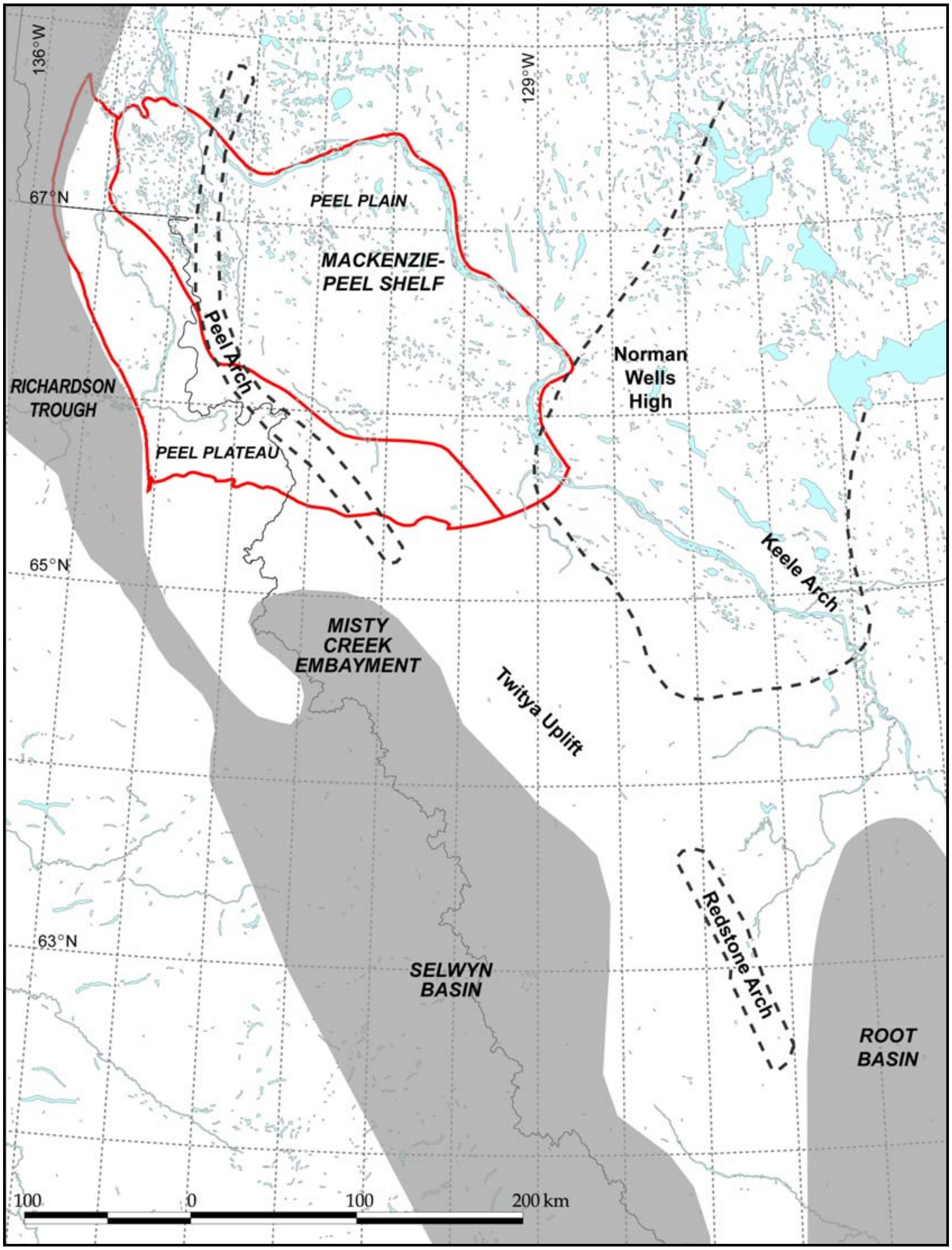

Figure 2. *Tectonic elements of Mackenzie corridor during the Late Ordovician to Middle Devonian. Basins and troughs were depocentres; arches and uplifts were areas of non-deposition or erosion. Timing of all uplifts was not necessarily coincident (after Williams, 1996).*

Delorme Group extends across Peel area from the Sans Sault Rapids (106 H; Aitken et al., 1982) to Snake River map areas (106 F; Norris, 1982). Rocks were examined at a total of 12 sections in this present study and are penetrated by a total of 33 wells in Peel area (Table 1, Figure 3). This chapter describes stratigraphy and briefly covers potential reservoir and petroleum source rocks within the succession, but Delorme Group does not constitute a conceptual petroleum play.

Unique Well Identifier (UWI)	Short Well Name	KB/RT	Tatsieta	Peel	Mount Kindle	Total Depth (m)
300A596530130300	N. Ramparts A-59	580.5		2747.8	2849.9	3205.0
300I776530130450	S. Ramparts I-77	595.6	1299.7	1341.1	1363.1	1621.8
300A226540131450	Cranswick A-22	768.4	1746.5	1795.3	1993.4	2869.1
300O186540129000	Mountain River O-18	115.0	920.0		946.0	1120.0
300D536600129001	Hume River D-53	88.4	1194.5	1197.9	1246.6	1267.7
300I386620131450	Ontaratue I-38	144.5	1573.4	1647.1	1808.7	2287.5
300L266640130150	Grandview L-26	164.9	896.1	901.0	1010.7	2395.6
300K046640130450	Arctic Circle Ontaratue K-04	103.8	986.3	1022.3	1218.9	2728.0
300O656610132150	Weldon Creek O-65	222.8	2015.3	2033.0		2214.4
300D086620133300	Sainville River D-08	203.0	2446.3	2490.2		2651.8
300H346630132000	Arctic Circle Ontaratue H-34	141.7	1591.1	1642.9	1836.4	4075.2
300G556650133000	Arctic Red West G-55	44.6	1752.0	1789.5	2064.1	3322.3
300O276650132450	Arctic Red River O-27	136.6	1642.9	1657.2		2154.0
300L506650133150	Martin House L-50	88.0	1997.7	2027.6	2285.2	2407.9
300M056720134000	Nevejo M-05	74.4	2303.5	2347.7		2378.7
300B256720135301	McPherson B-25	492.3	3445.4	3552.7	3774.7	4136.1
300I506730135150	Stony I-50	321.9	2600.5	2607.3	2706.6	3343.0
300A056740134000	Pt. Separation no. 1 (A-05)	18.9	2092.5	2112.6	2286.0	2445.4
300C786740134000	Ft. McPherson C-78	19.8	2288.4	2361.6	2636.2	3068.1
300G066740135150	Stony G-06	56.7		2081.8	2324.7	2529.8
300F576710132150	Tree River F-57	93.0	1359.4	1527.0	1657.5	1979.2
300H576710132150	Tree River East H-57	108.2	1402.1	1595.6	1708.4	1981.2
300F796710133000	Clare F-79	108.7	1845.3	1878.8	2121.2	2525.6
300D076710130150	Moose Lake D-07	54.0		723.0	780.0	900.0
300A476710130450	Grandview Hills no. 1 (A-47)	369.5	975.4	1055.8	1205.2	1998.0
300D396710131301	Ontaratue River D-39	244.5	1205.0			1250.0
300C366720131451	Tree River C-36	135.0	1464.0	1482.0	1591.0	1878.0
300A426550133001	Cranswick Y.T. A-42	620.1	3047.1	3130.0	3350.1	4267.2
300K156600133000	Taylor Lake Y.T. K-15	468.8	2057.4	2096.7	2315.9	2378.7
300M696610133450	Peel River Y.T. M-69	291.7	3080.3	3125.4		3272.6
300H716630134300	Peel Y.T. H-71	513.0	2633.5	2650.8	2783.1	3419.6
300H376640134450	Trail River Y.T. H-37	393.2	3485.1	3510.7		3721.6
300C606650133450	Arctic Red Y.T. C-60	92.0	2298.2	2329.9		2599.9
300F376700134450	Peel Y.T. F-37	54.6	2946.8	2983.1	3327.2	3368.0

Table 1. *Formation tops of wells that penetrate Delorme Group in Peel area. NWT tops after Hogue and Gal (2008) and Yukon tops after Fraser and Hogue (2007). KB=kelly bushing; RT=rotary table.*

PREVIOUS WORK

Silurian to Devonian rocks were recognized during mapping in the Mackenzie Mountains at the margin of Peel area, but not subdivided or named. These beds were identified as the "SDd" map unit on the Snake River map area (106 F; Norris, 1982), and the "SD" map unit in the Upper Ramparts River (106 G) and Sans Sault Rapids (106 H) map areas (Aitken and Cook, 1974a, 1974b).

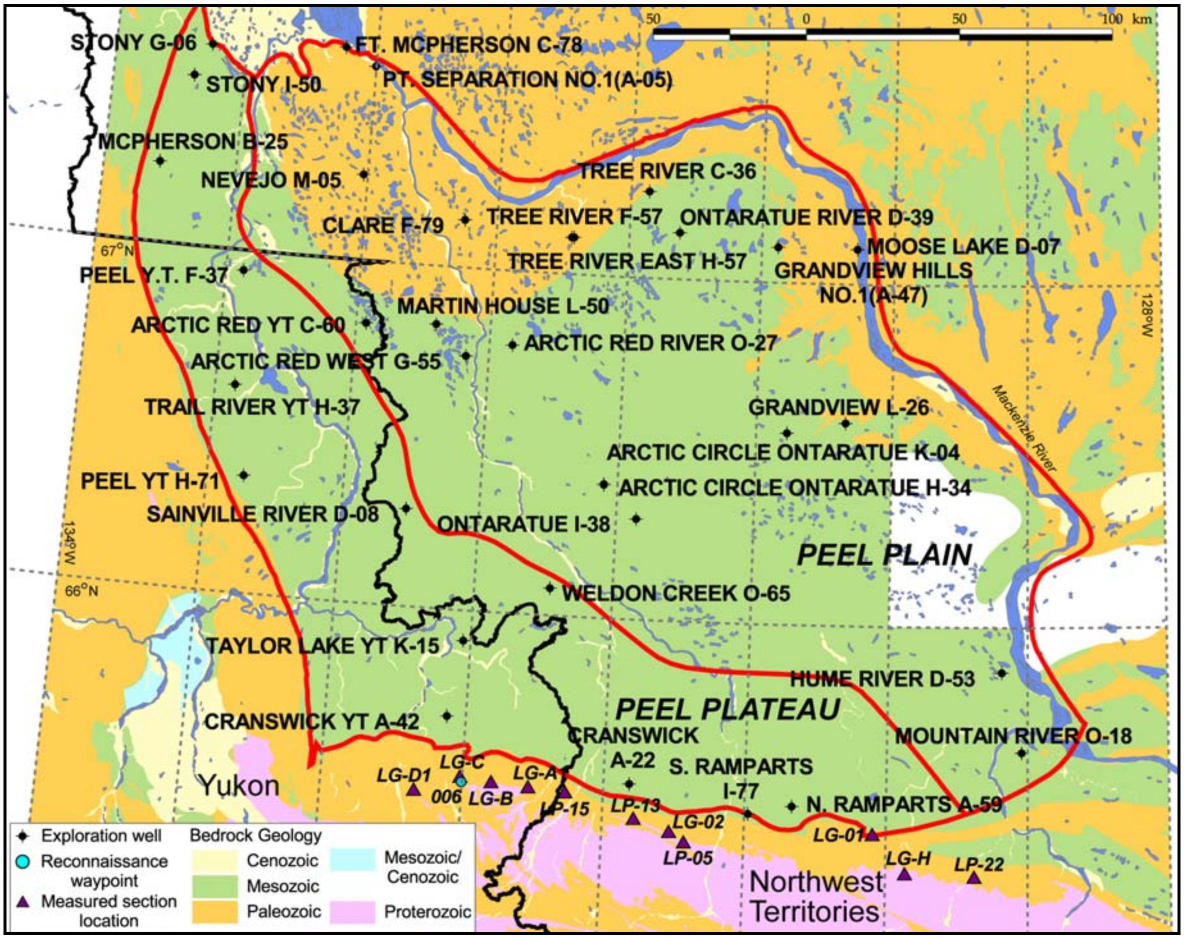

Figure 3. *Geological map of Peel area showing locations of exploratory wells and outcrop sections and stations.*

Delorme Formation was mapped by Douglas and Norris (1961) in the southern Mackenzie and Franklin mountains (95 K). Aitken et al. (1982) did not use the term Delorme Formation in the Upper Ramparts River (106 G) and Sans Sault Rapids (106 H) map areas, preferring "SD" unit. Morrow and Geldsetzer (1988) referred to a Delorme Assemblage lying between Ronning Group (Cambrian to Silurian) and below Lower Devonian Arnica Formation.

Mackenzie (1974) and Pugh (1983) described Upper Silurian to Lower Devonian rocks in the subsurface that are equivalent to Delorme Formation of the northern Mackenzie Mountains. The term Gossage Formation (Tassonyi, 1969) was superseded by division into Arnica, Landry and Delorme strata (Pugh, 1983). Pugh (1983) defined Peel Formation as being the top formation of Ronning Group and selected the Peel Y.T. F-37 well as the subsurface type section. Pugh (1983) also defined the overlying Tatsieta Formation, and considered it to be the basal Devonian formation. The subsurface type section was defined as the Grandview Hills No.1 (A-47) well, the same well from which Tassonyi (1969) described the lower limestone member of Gossage Formation. Pugh's (1983) Peel-Tatsieta relationship required the sub-Devonian unconformity to separate Tatsieta and Peel formations. Williams (1996) and Morrow (1999), however, argued that the Peel-Tatsieta contact is conformable and that Peel Formation unconformably overlies Ronning strata. Morrow (1999) described Peel and Tatsieta formations as partly facies equivalent, with a conformable and locally diachronous contact and regarded Peel Formation as part of Delorme Group instead of Ronning Group as originally interpreted by Pugh (1983).

DELORME GROUP

Delorme Group is defined in Peel area (as per Delorme Assemblage of Morrow and Geldsetzer, 1988) as the package of rocks lying above Ronning Group and below Arnica Formation (or equivalent). The Group largely comprises fine crystalline (often silty) dolostone, lesser lime mudstone, and argillaceous carbonates and some shale. Delorme Group can be subdivided in the subsurface (see Pugh, 1983) and in outcrop into a lower Peel Formation and an overlying Tatsieta Formation. Peel Formation is dominantly silty, finely crystalline dolostone, and characteristically orange-weathering in outcrop. Tatsieta Formation is dominantly lime mudstone with some greenish shale. Tatsieta Formation is chiefly recognized in outcrop by blocky, resistant, light grey-weathering limestone; in the subsurface, the formation is generally differentiated by ragged, spiky, gamma log signature due to shale interbeds.

Origin of Name, Type and Reference Sections

Delorme Group was elevated in stratigraphic rank from Delorme Formation (Douglas and Norris, 1961) by Morrow (1991). Peel Formation and Tatsieta Formation were proposed by Pugh (1983), who reviewed Silurian-Devonian strata nomenclature.

The type section of Delorme Formation is at the headwaters of Pastel Creek 62°47' N, 125°15'30" W in the Root River (95 K) map area and the formation is named after the Delorme Range of the Mackenzie Mountains, NWT (Douglas and Norris, 1961). Subsurface type sections of Peel and Tatsieta formations proposed by Pugh (1983) are Peel Y.T. F-37 well and Grandview Hills No.1 (A-47) well, respectively.

In the present study, we designate a supplementary surface reference section for Delorme Group, including both Peel and Tatsieta formations, at Section LP-13 (Figure 4), located in Upper Ramparts River map area (106 G/05; section base at 370954 E, 7257851N, NAD 83, UTM Zone 9; Figure 3). At this section, Peel Formation (100.5 m thick) consists of yellowish-orange-weathering, thin- to medium-bedded lime mudstone and dolostone. Beds are laminated with some burrow mottled beds and rare stromatolites. The lower contact of Peel Formation is obscured by scree and the upper contact with Tatsieta Formation is gradational. Tatsieta Formation (99.5 m thick) consists of light to medium grey, siliceous, silty lime mudstone with some lamination, and rare stromatolitic limestone. The upper contact with Arnica Formation is sharp but conformable. The quality of outcrop exposure at Section LP-15 (Figure 3) is slightly better than at LP-13, but Tatsieta Formation is thinner at the former section (33 m thick).

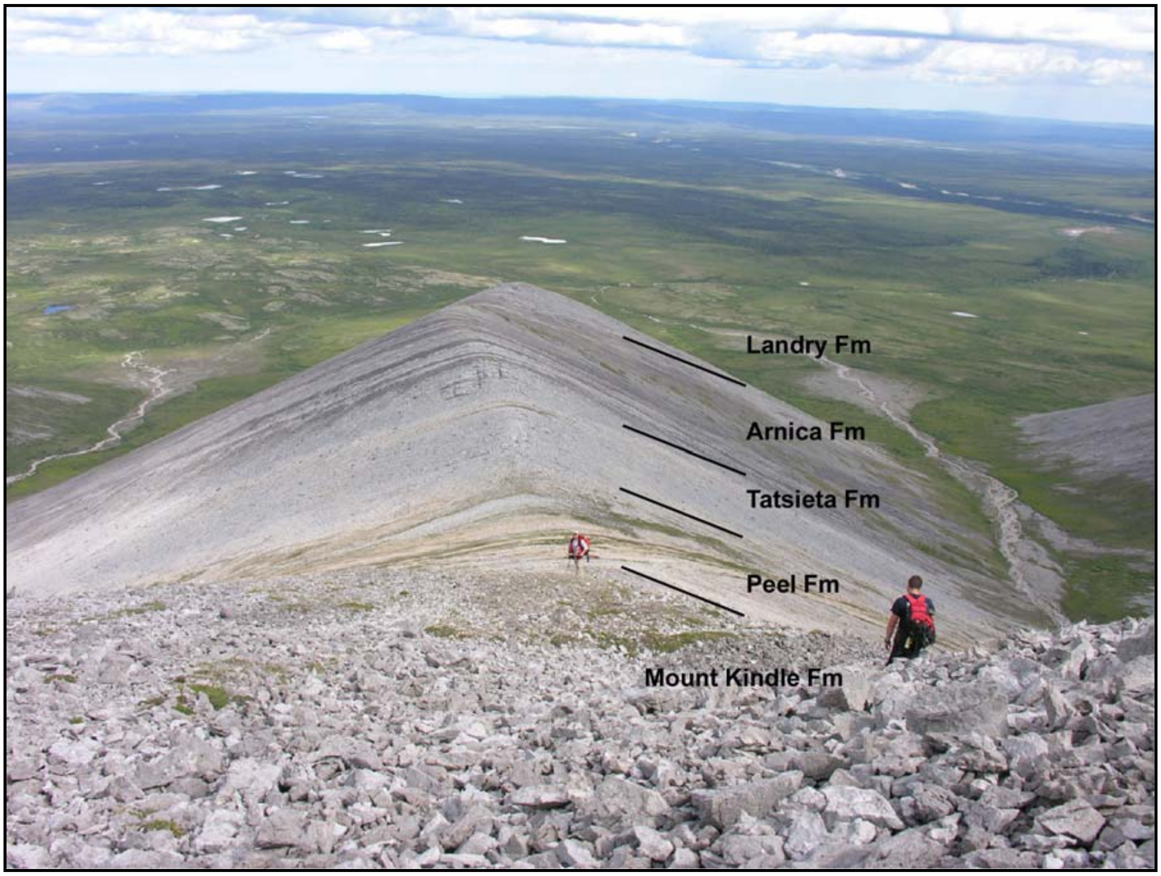

Figure 4. *View north of Section LP-13, a surface reference section for Delorme Group, from Mount Kindle Formation.*

Lithology

Peel Formation

At its type section, Peel Formation consists of pale yellowish brown and grey, slightly argillaceous and silty, finely crystalline and microcrystalline dolostone and calcareous dolostone (Pugh, 1983). In this study, cores of Peel Formation were examined from Clare F-79, Cranswick A-22, Nevejo M-05, and Point Separation No. 1 (A-05) wells (see core descriptions in Pierce and Jones, 2009; Figure 3). Peel Formation consists of light grey and buff, silty, finely crystalline dolomudstone. Bioclastic material is rare (M-05). Sedimentary structures include common fine, planar, and algal lamination with burrow mottling in some intervals (F-79, M-05). Mud clast brecciation (A-22) and rip-up clasts (M-05) occur. Thin green shale seams occur in A-22.

In the Tulita (Fort Norman) area, Williams (1996) discussed Delorme Group in the subsurface in five wells. Mackenzie (1974) described the Tenlen A-73 core and GeoChem Laboratories and AGAT Consultants (1977) described the Crossley Lakes K-60 core.

In outcrop, Peel Formation was described from 11 sections (see section descriptions in Pierce and Jones, 2009), five of which were undifferentiated Delorme Group (Sections LP-22, LG-01, LG-A1, LG-C, and LG-H; Figure 3). Peel Formation consists of grey- to orange-yellow-weathering, grey dolostone, dolomitic lime mudstone, and argillaceous dolostone, with minor shale. Carbonates are typically silty or locally sandy. Bedding is mostly thin (but ranges to thick-bedded) and typically platy to flaggy weathering. Generally, Peel Formation is recessive weathering (Figure 4). Some beds are massive. Thinning upward and shaling upward cycles (such as at Section LG-D1) are present.

Sedimentary structures include common planar and algal lamination and common burrow mottling (Figure 5). Breccia beds with scoured bases (Section LG-D1; Figure 6) in outboard sections may represent debris flow deposits or possibly tempestites of largely *in situ* breccias developed during storms. Beds with disrupted laminae grading to beds containing rip-up clasts (Section LG-B; Figure 7) may represent storm deposits. Other sedimentary structures observed include syneresis cracks, possible mud cracks and desiccation cracks, and small scale teepee structures (Section LG-C; Figure 8). Siliceous laminae, rare chert lenses, and chert clast breccia also occur.

Figure 5. *View north of Delorme Group, Section LP-05; inset of burrow mottled and silty, laminated dolostone (hammer for scale).*

Figure 6. *Disturbed clasts of finely laminated yellow weathering dolomudstone may be a debris flow bed, Section LG-D1, hammer head (18 cm) for scale.*

***Figure 7**. Dolomudstone rip-up clast breccia with some silicified lenses and bioclasts, Section LG-B, Delorme Group (scale bar in cm).*

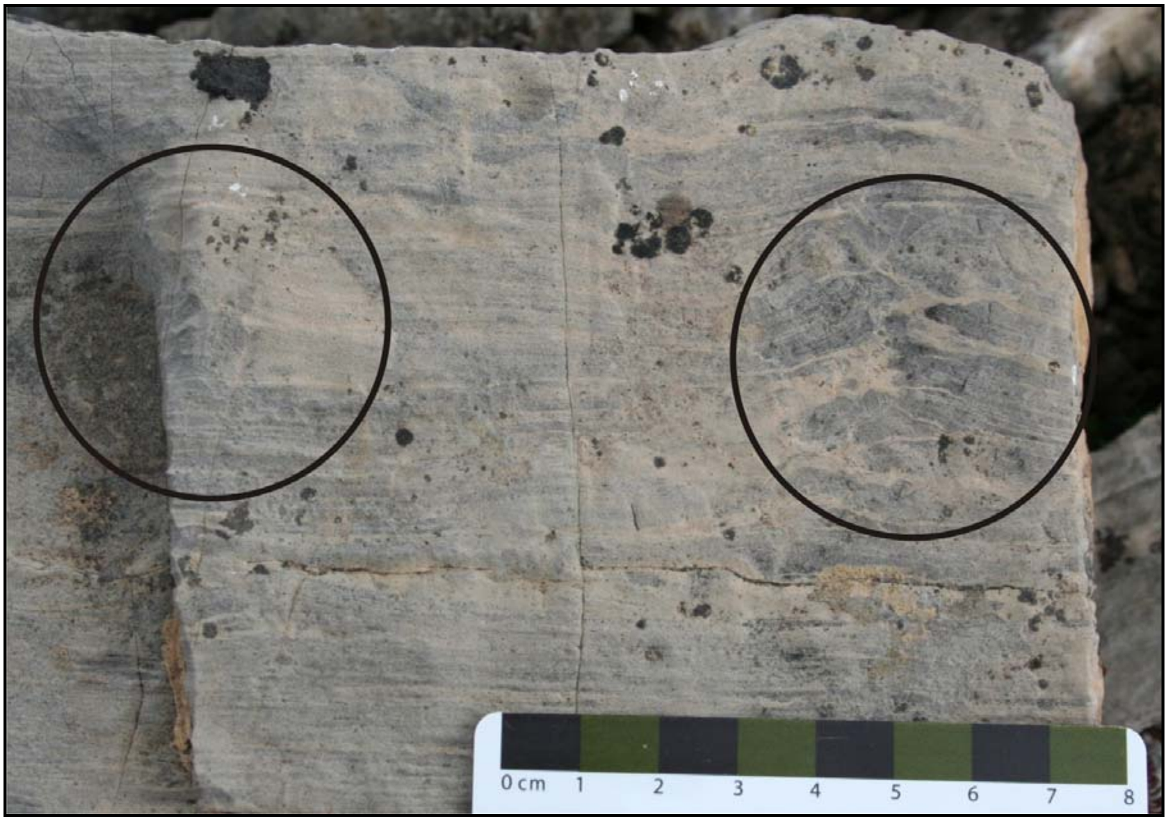

Figure 8. *Possible teepee structures (circled) in finely laminated dolomudstone, Section LG-C, Delorme Group (scale bar in cm).*

Fossils are rare in Peel Formation and include amphiporids, stromatoporoids and thin shell beds containing silicified gastropods (near the base of the formation at sections LG-B and LG-D1). Conodont samples yielded poorly, mainly with only simple cones of *Panderodus*, a long-ranging species (Middle Ordovician to Middle Devonian).

Tatsieta Formation

At its type section (Grandview Hills No. 1 (A-47)) Tatsieta Formation consists of pale buff lime mudstone, light grey silty dolostone, and pale green shale (Pugh, 1983). Pugh (1983) divided the formation into three units based on the Tree River H-57 and F-57 wells. Additional core of Tatsieta Formation is available north of Peel area in the Tenlen Lake A-73 well (Mackenzie, 1974; Pugh, 1983).

In outcrop, Tatsieta Formation was described at four measured sections (LP-05, LP-13, LP-15, and LG-02; sections described in Pierce and Jones, 2009) as a basal medium- to thick-bedded, light to dark grey lime mudstone that weathers light grey. These limestones are often resistant and bluff-forming in contrast to recessive Peel Formation. Additional lithologies are thin- to thick-bedded, light grey to brownish grey, silty, laminated lime mudstone (Figure 9), commonly interbedded with thin-bedded argillaceous limestone. Dolostone is subordinate, but limestone may be dolomitic. Some stromatolitic beds occur (Figure 10). The upper part of the formation is more thin-bedded, and may be light orange-weathering, or contain orange-weathering argillaceous interbeds. Some beds are silty or sandy, but Tatsieta Formation contains “cleaner” carbonate beds overall compared to Peel Formation. Green shale and red beds reported in subsurface descriptions are volumetrically minor components in outcrop sections, with the exception at reconnaissance Section 3 of Pyle et al. (2006).

A shallowing-upward sequence in the formation occurs at Section LP-05. Internal shallowing-upward hemicycles occur in Section LP-13 where basal limestones of each unit are thin-bedded and argillaceous and pass upward to blocky lime mudstone. Sedimentary structures are rare but include fine lamination, some peloidal textures locally, and pebble conglomerate beds with scoured, erosional bases.

Fossils are rare, generally restricted to some stromatolites. Samples taken for conodonts were barren.

Fine disseminated pyrite occurs locally. Fractures, where present, are generally calcite-filled. Siliceous limestone beds and recrystallized limestone were noted, as well as some sucrosic, medium crystalline dolostone.

Figure 9. *Silty, laminated limestone of Tatsieta Formation, Section LP-13 (hammer for scale).*

Figure 10. *Stromatolitic limestone in Tatsieta Formation, Section LG-02 (hammer head is 18cm long).*

Contacts and Log Response

In this study of outcrop sections along the northern Mackenzie Mountains, the upper and lower contacts of Delorme Group, or constituent formations, are typically poorly exposed due to the rubbly and frost-heaved nature of strata. The basal contact of undifferentiated Delorme Group, or Peel Formation with underlying Mount Kindle Formation is generally sharp, but poorly exposed in outcrop sections. The contact can be picked in most cases at the marked difference in weathering colour (light grey to orange-yellow for Delorme Group compared to darker, brown-grey of Mount Kindle Formation), and weathering style (platy, flaggy, recessive for Delorme Group compared to generally blocky with siliceous macrofossils for Mount Kindle Formation). Where the lower contact was difficult to discern, it was placed at the first substantial (greater than 50 cm thick) light grey-weathering limy or argillaceous dolomite, beyond which there are no blocky dark grey-weathering dolomudstones. Morrow (1999) described a prominent sub-Peel Formation unconformity at his Sections 19 and 30 in the northern Mackenzie Mountains in which the top of Mount Kindle Formation is irregular and karstified. At Section LG-A3 (Figure 11), the lowest bed of Peel Formation was stained red through 2 to 3 cm, suggesting iron oxidation and subaerial exposure.

The upper contact (where Peel and Tatsieta formations can be differentiated) is generally gradational, but may appear sharp. Light grey-weathering, dark grey lime mudstone interbeds (cm- to dm-scale) increase toward the top of Peel Formation within otherwise grey- or orange-weathering limy dolostone or argillaceous lime mudstone. The top of Peel Formation is generally taken as the base of the lowest substantial (> one m) light grey weathering lime mudstone bed. If no substantial light grey-weathering (and commonly medium- to thick-bedded) lime mudstone beds were encountered, no Tatsieta Formation was differentiated.

The upper contact of Tatsieta Formation with overlying Arnica Formation is everywhere sharp (Figure 12). Typically, resistant light grey-weathering medium- to thick-bedded lime mudstone of Tatsieta Formation is abruptly overlain by thin- or medium-bedded brown or brown grey weathering, sucrosic dolostone or mottled dolomudstone. The change in lithology from limestone to dolostone, and weathering colour from light grey to brownish and darker, is characteristic.

Figure 11. *Reddish stained dolostone (possibly indicating subaerial exposure) at contact of the Delorme Group (left) and Mount Kindle Formation (right), Section LG-A3 (hammer head is 18 cm long).*

Figure 12. *Contact between Tatsieta and Arnica formations (at hammer base), Section LP-13.*

Near the NWT-Yukon border, Delorme Group is not readily subdivided in surface exposures, and contacts are sharp. Characteristic weathering colours of the unit are orange-weathering at the base, a middle yellowish-grey-weathering section, and an upper orange-weathering section generally thinner than the lower zone. These upper and lower “orange zones” have been noted in industry field work reports and are reliable regional stratigraphic markers.

In the subsurface, Tatsieta Formation contains more limestone than Peel Formation but overall the formations are similar and have similar geophysical log responses (Pugh, 1983). The top of Tatsieta Formation, or Delorme Group, is picked at a marked gamma deflection below Arnica Formation, below which the gamma continues to be spiky and ragged for some distance due to thin shale interbeds in Tatsieta Formation that give local high gamma spikes (Figure 13). The contact between Tatsieta and Peel formations is difficult to pick, although Tatsieta generally has an overall higher gamma response. Sample logs from well history reports help to indicate a change from limestone with some green shale (Tatsieta Formation) to dominantly dolostone (Peel Formation). The base of Delorme Group may be difficult to pick, but generally the underlying Mount Kindle Formation has a more uniform gamma and sonic response, with less of the thin gamma spikes that characterize Peel Formation.

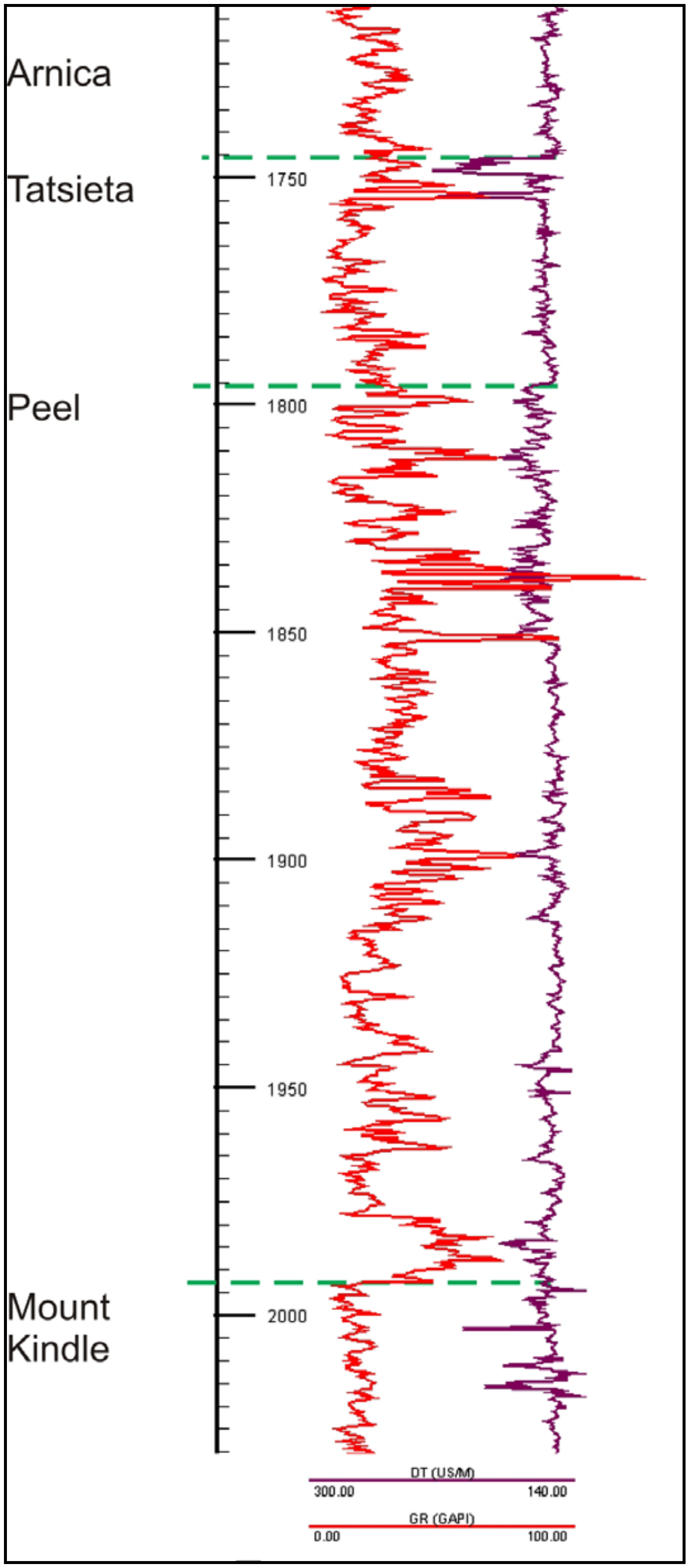

Figure 13. *Gamma (red) and sonic interval transit time (purple) logs from Delorme Group in the Cranswick A-22 well. Well depths in m, indicated at left, and formation tops indicated by green lines. Log scales (gamma in API units, sonic in microseconds per m) at base of figure.*

Distribution and Thickness

Delorme Group is widely distributed throughout Peel area, based on surface outcrops and subsurface interpretation. The eastern limit extends beyond the 130°W limit indicated by Pugh (1983). In the current study, the erosional edge of Delorme Group lies in southeast Peel area, around Mountain River, approximately on a line between Hume River L-09 and Shoals C-31 wells (Figure 14). Delorme Group rocks thicken westward and southward from 0 m to over 400 m in the Snake River area. The western limit is just beyond Peel area, where Delorme Group rocks undergo a facies change to basinal shaly rocks of Road River Group, along with the other lower Paleozoic carbonate rocks of Mackenzie-Peel Shelf.

Delorme Group is however, generally more argillaceous than formations above or below, even well east of the shelf edge. A thinning at the shelf edge is apparent in northwest Peel area, in the Stony I-50 well, where Delorme Group is only 106 m thick.

Western surface exposures of Delorme Group (approximately west of Cranswick River) cannot be reliably subdivided into Peel and Tatsieta Formations. In the east, around Hume River area, Delorme Group is 20 to 30 m thick (Figure 14), and again cannot be resolved into constituent formations.

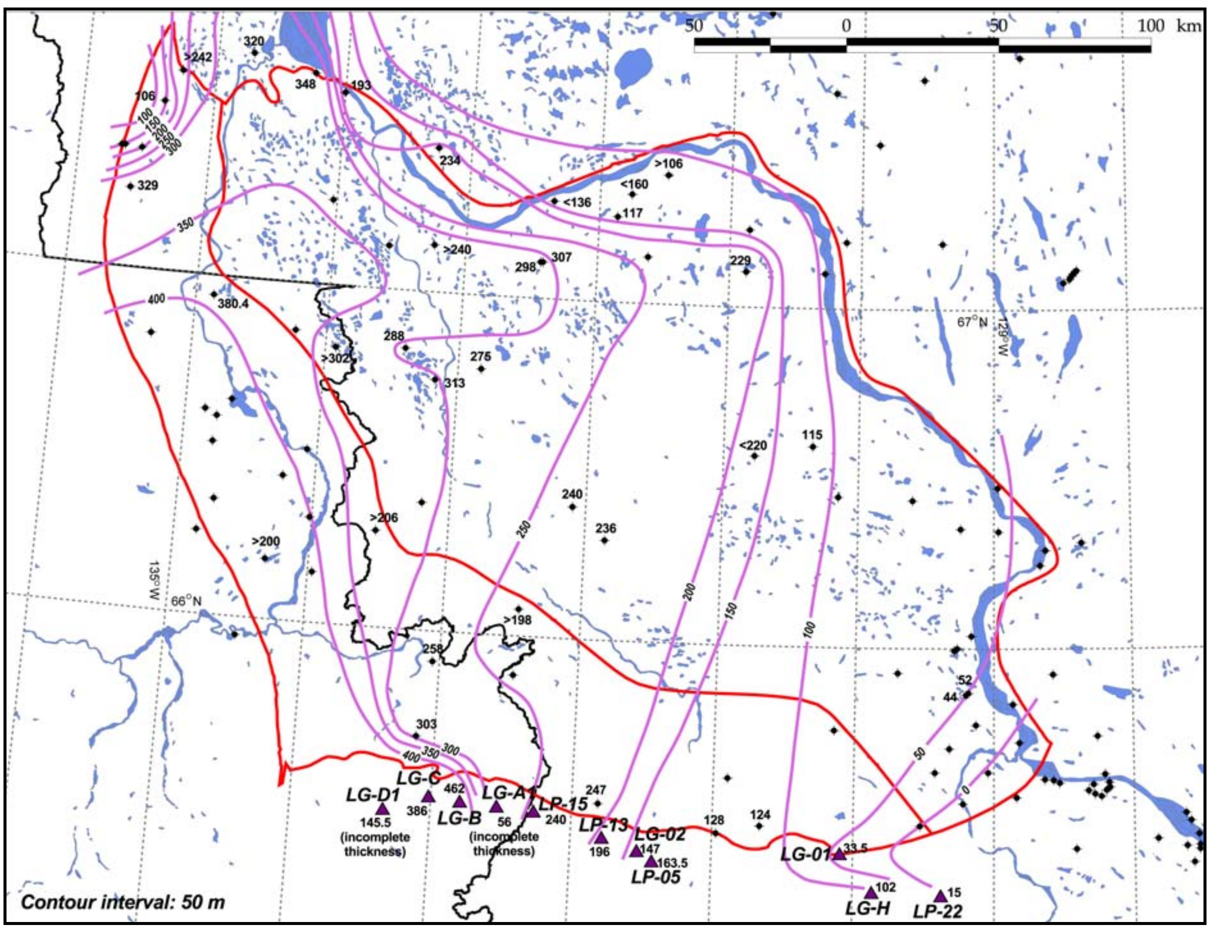

Figure 14. *Isopach map of the Delorme Group.*

Where Tatsieta Formation can be separated out in surface sections, thickness variations suggest a lens shape in which the thickest strata (111 m in Section LP-05) occurs in central Peel area, and thins to both the east and west (e.g., 33 m at Section LP-15). In the subsurface, the thickest Tatsieta Formation forms a north to northwest-trending belt through central Peel area, to the Ontaratue wells. Essentially the thickest Tatsieta occurs just inboard of its western limit, while undifferentiated Delorme Group steadily thickens to near the shelf edge (Figure 14).

Paleontology and Age

There are few fossils in Peel and Tatsieta formations, although amphiporids, brachiopods, and gastropods occur in outboard sections of Peel Formation (Sections LG-B, LG-D). Conodont samples were collected at several sections but most samples were barren. Productive samples yielded few specimens that are broad ranging but indicate a late Ordovician to Silurian age for Delorme Group at reconnaissance Section 3 (of Pyle et al., 2006) and Silurian or ?Devonian at reconnaissance Section 2 (of Pyle et al., 2006), 5 m above the base of Peel Formation. Peel Formation in Peel area is most likely post-Llandovery in age based on conodonts of this age from the underlying Mount Kindle Formation. The overlying Arnica Formation in Peel area is Emsian in age, which gives an upper age limit of Tatsieta Formation as pre-Emsian.

In the Mackenzie Mountains, an age range of Late Silurian to early Devonian (Lochkovian) was suggested for Peel Formation, dated within *eosteinhornensis* to *eurekaensis* zones (Chatterton in Morrow, 1991). An upper age limit of Tatsieta Formation is poorly constrained as pre-Emsian, based on correlative Arnica strata in the southern Mackenzie Mountains that yielded conodonts of the *serotinus* Zone (Emsian; Chatterton, 1979).

FACIES DISTRIBUTIONS AND STRATIGRAPHIC CORRELATION

In ridge sections where bedding was not obscured by scree, Delorme Group (or Peel Formation) is an overall thickening upward succession. Morrow (1999) described sections of Delorme Group in which the formations are in part facies equivalent with common lateral facies changes. In this present study, no internal marker beds or prominent surfaces were noted, with the exception of the facies containing silicified gastropods in lower Peel Formation (Figure 15a, Sections LG-B, LG-D1, and reconnaissance Section 3 from Pyle et al., 2006). Thin, argillaceous limestone beds at the top of Tatsieta Formation (Sections LP-05, LG-02; Figure 15b) may indicate deepening associated with the onset of Arnica Formation deposition.

Peel Formation contains internal cycles of alternating burrow mottled dolostone and laminated, stromatolitic dolostone. At the thickest section (Section LG-B), a range of facies is preserved: rip-up clast beds that indicate a supratidal setting, amphiporid-brachiopod packstone beds that indicate a subtidal setting, and breccia beds (Section LG-B, Unit 8) that may represent highstand shedding or storm deposits. Tatsieta Formation is differentiated from Peel Formation in containing thicker bedded, more resistant limestone beds. Shallowing upward cycles of rubbly weathering, thin-bedded lime mudstone to blocky weathering lime mudstone occur in Section LP-13, or alternations of thick lime mudstone beds and thin argillaceous laminae occur as in Section LG-02.

The persistence of peritidal to supratidal indicators (rip-up clasts, mudcracks, stromatolitic beds) across the study area, particularly in lower Peel Formation, suggests a shallow gradient from east to west. Delorme Group thickens westward (Figure 14) with a characteristic upper and lower orange-weathering zone approximately between the Cranswick A-22 and A-42 wells (Figure 16).

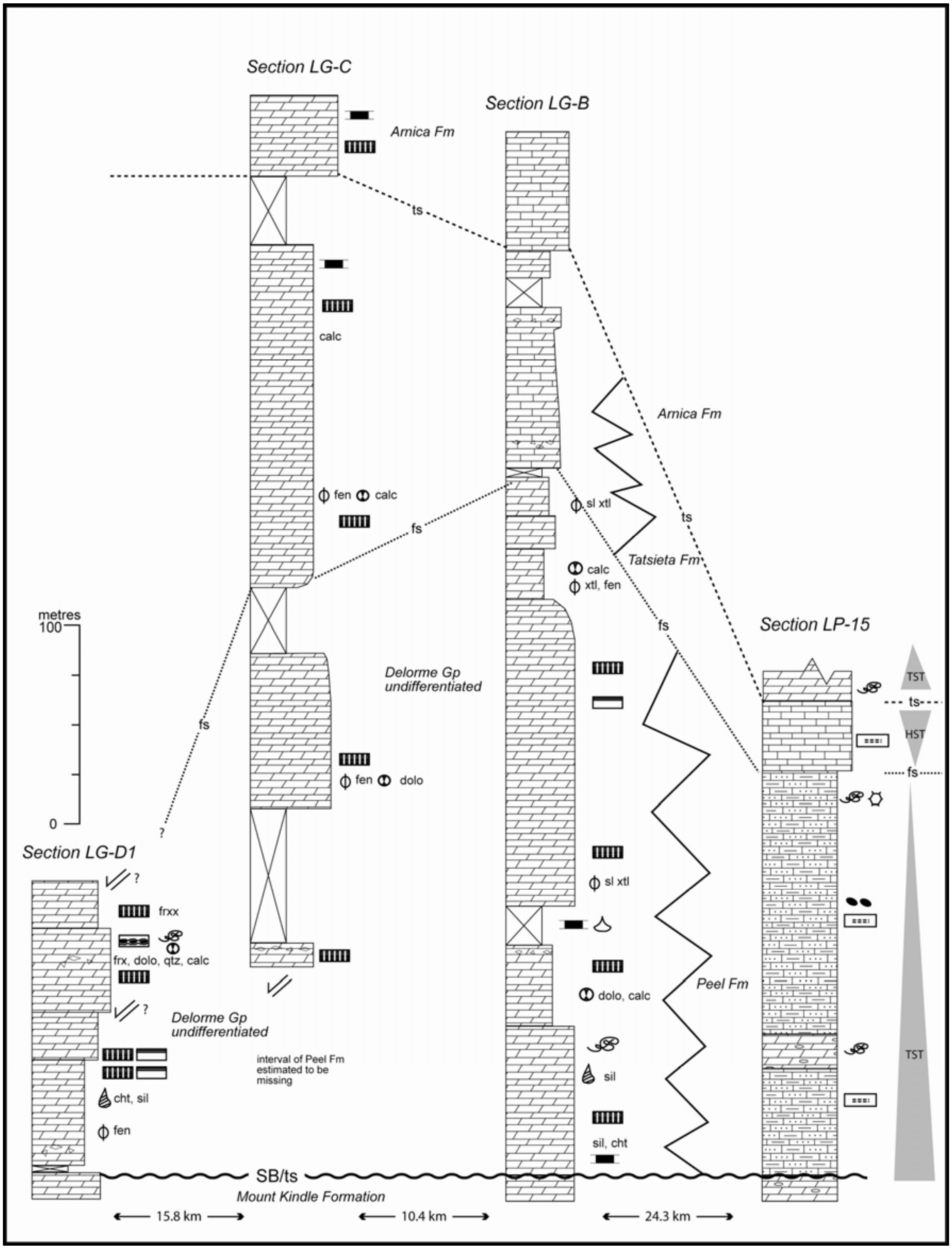

__Figure 15a.__ Correlation of sections of Delorme Group (see Figure 3 for section locations).

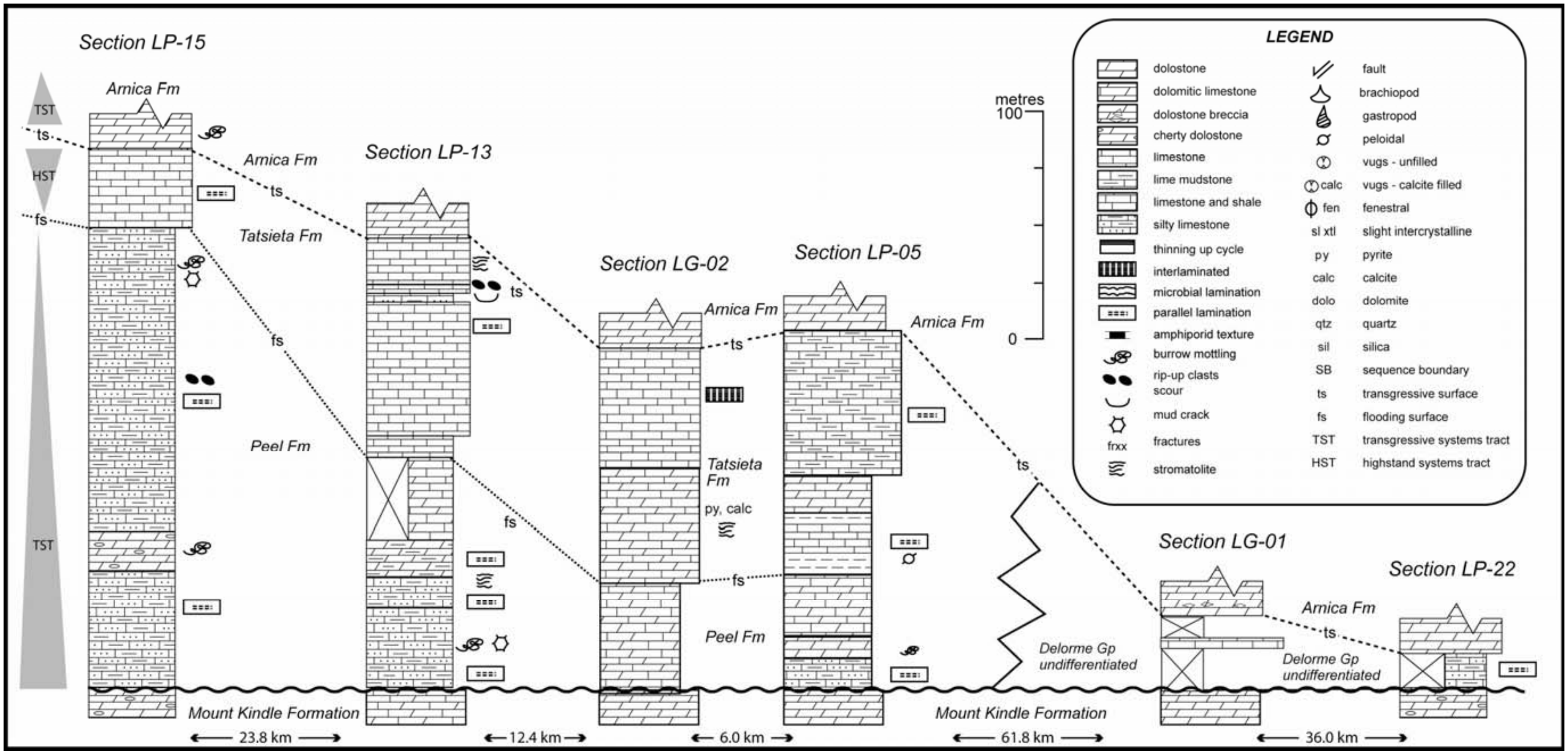

Figure 15b. *Correlation continued.*

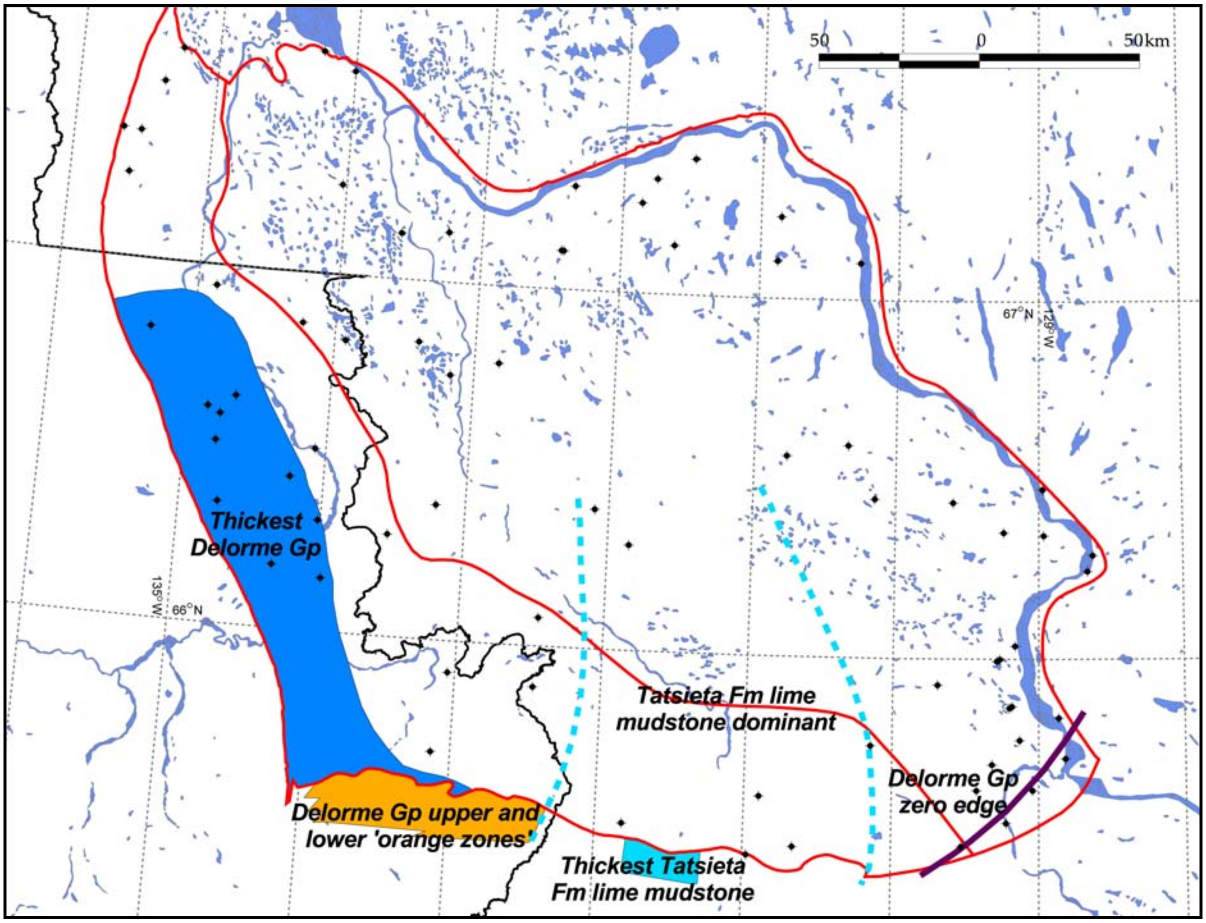

Figure 16. *Generalized facies map of Delorme Group.*

In the subsurface, gamma ray log responses are difficult to correlate except in closely spaced wells showing zones of similar characteristics, such as from Tree River East H-57 and Tree River F-57 wells.

There are prominent bounding surfaces at the base and top of Delorme Group. The basal contact of Delorme Group in Peel area is likely a transgressive surface that has merged with the sub-Delorme unconformity (Figure 15). The sub-Delorme Group basal unconformity was referred to as the regionally significant "sub-Devonian" or "sub-Kaskaskia" unconformity by Morrow (1991, 1999). Upper Silurian strata, however, also rest on this "sub-Devonian" unconformity in the Mackenzie Mountains (Morrow, 1991). The upper contact of Delorme Group, and transition to deeper water carbonates of Arnica Formation, represents marine transgression of the Kaskaskia sequence, but there is no evidence from either the surface or subsurface for regional erosion.

Within Delorme Group, internal surfaces are difficult to pick and correlate between surface measured sections and well logs. This may be because of facies equivalence of formations as proposed by Morrow (1999). The succession is broadly interpreted as a transgressive systems tract (Peel Formation, or basal part of undifferentiated Delorme Group) overlain by a highstand systems tract represented by shale and limestone of Tatsieta Formation or debris flow breccias in outboard sections (e.g., Section LG-D1, Figure 15a).

DISCUSSION AND DEPOSITIONAL HISTORY

Morrow (1999) interpreted Delorme Group as representing dominantly supratidal conditions to shallow subtidal and neritic conditions. In the present study, facies and sedimentary structures (mudcracks and possible teepee structures) in Peel Formation and undifferentiated Delorme Group suggest shallow marine to peritidal environments, as well as supratidal settings well into southwestern Peel area, far from the interpreted continental coastline. Tatsieta Formation also contains depositional features such as imbricated lime mudclasts and stromatolites indicative of a predominantly peritidal setting. A very shallow gradient must have persisted from late Silurian to early Devonian time, in which muddy carbonate bank deposits slowly prograded westward and received an influx of fine-grained terrigenous clastics. Deposition on an irregular surface or differential subsidence is suggested from facies thicknesses and distributions, particularly the "lens" shape of Tatsieta Formation limestone (Figure 16). Morrow (1999) noted the lack of internal markers as further evidence for non-uniform relative sea level change across an irregular surface.

Williams (1996) regarded the Delorme interval (Late Silurian to Earliest Devonian) as a time of tectonic activity such as uplift of Keele Arch and block faulting such as in southern Richardson Trough (Williams, 1988). Uplift in regions adjacent to Peel area may account for the supply of siliciclastic sediments common in most Delorme Group carbonates.

POTENTIAL RESERVOIR AND SOURCE ROCKS

Potential Reservoir Rocks

Peel and Tatsieta formations, although widespread in Peel area, have limited potential as reservoir rocks. Peel Formation is mainly silty and muddy dolomudstone, generally showing little porosity; however, some measured sections contain stacked dm-scale beds with intercrystalline porosity in sucrosic, fine and medium crystalline dolostones (e.g., Sample 07LG3B has 3.6% porosity and 4.13 millidarcies (mD) permeability; Sample 07LG6G has 8.1% porosity and 0.13 mD permeability; data in Pierce and Jones, 2009) interbedded with relatively non-porous dolomudstone (Figures 17, 18). Pinpoint and fenestral vuggy porosity also occur in outcrop. Vug and fracture fillings include dolomite, calcite, and quartz (Sections LG-A1, LG-B, LG-C, LG-D1; Figure 3). Morrow (1999) reported biomoldic porosity from a middle thick-bedded unit in Peel Formation in some sections in the northern Mackenzie Mountains.

Streaks of vuggy, intercrystalline, and fracture porosity from 4 to 12% have been estimated from cuttings in some wells throughout Peel area (Canadian Stratigraphic logs, e.g., Hume River D-53 and Clare F-79 wells). No core analyses of porosity and permeability have been reported in well history reports from Peel Formation. Samples collected during the current study and analysed for porosity and permeability are tabulated below (Table 2).

Where Tatsieta Formation can be differentiated, it is dominantly a light grey, lime mudstone. No outcrop samples were collected from Tatsieta Formation for porosity or source rock analyses. There is little indication of porosity from mechanical logs or descriptions of well cuttings, which generally indicate limestone and green shale interbeds beds. Core analyses of Tatsieta Formation from Tree River H-57 well included weighted averages of 1.91% porosity over 5.85 m (from

1397.2 m depth), 4.07% over 1.07 m (from 1478.4 m), and 1.19% over 1.98 m (from 1479.6 m; Hu, in press).

Figure 17. *Fifteen cm bed of sucrosic dolostone interbedded with laminated dolomudstone. Peel Formation, Section LG-B.*

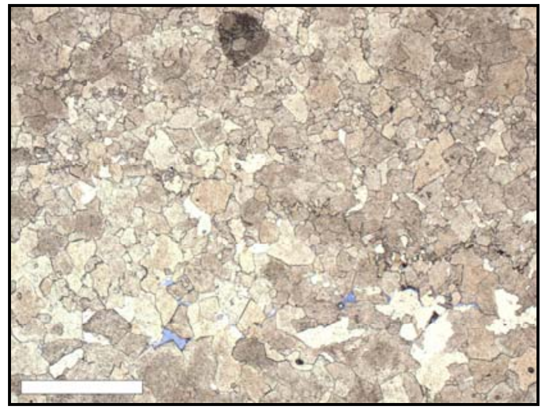

Figure 18. *Sample 2007LG-6-F, Peel Formation sucrosic dolostone with minor intercrystalline porosity. Some larger crystals have inclusion-rich cores, clear rims. Plane polarized light. White scale bar is 1 mm.*

Sample	Porosity (%)	Permeability (mD)	Comments
07LG-6-G	8.1	0.13	pelletal packstone, fenestral vugs
07LG-3-B	3.6	4.13	4 m thick sucrosic dolostone
06LP-15-06	1.8	0.32	sucrosic medium-crystalline dolostone

Table 2. *Measured porosity and permeability from outcrop samples of Peel Formation collected during current study.*

Potential Source Rocks

There are no suitable source rocks within Delorme Group. Delorme Group and particularly Tatsieta Formation are often described as silty or argillaceous, but thin green shale seams are present rather than thick sections of organic-rich shale.

A systematic study of several wells in Peel area by Geochem Laboratories and AGAT Consultants (1977) yielded average TOC values for Tatsieta Formation (0.37%, n=21), and Peel Formation (0.16%, n=62). Samples analyzed by Snowdon (1990) from Cranswick A-22 well had overall higher TOC values, with averages of 1.21% TOC (n=5) in Tatsieta Formation, and 1.71% TOC (n=20) in Peel Formation.

Rocks of Delorme Group are likely at maturity in eastern and northeastern Peel area, although strata are much thinned near their eastern limit. There is a remote possibility of Delorme reservoirs developed in lateral contact with Road River shales westward in Peel area (Richardson Trough) but these relationships were not examined in the present study.

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Chapter 6 – Lower to Upper Devonian Strata, Arnica-Landry Play, and Kee Scarp Play

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ABSTRACT

Devonian rocks beneath Imperial Formation in Peel area are divided into a Lower to Middle Devonian succession consisting of Fort Norman Formation (Bear Rock facies), Arnica Formation, Landry Formation, Mount Baird Formation, Hume Formation, and Road River Group. From east-southeast to west across Peel area, this succession records evaporitic to carbonate platform deposition, and eventually deeper basinal settings. Middle to Upper Devonian rocks are assigned to Horn River Group (Hare Indian, Ramparts, and Canol formations). These rocks record two phases of starved basin conditions (Bluefish Member of Hare Indian Formation and Canol Formation), separated by development of a siliciclastic bank upon which a carbonate bank and reef of the Ramparts Formation developed. The whole succession represents overall transgression of the Kaskaskia Sequence. Lithostratigraphic descriptions of each formation and their key bounding surfaces are based on new outcrop sections from the northern Mackenzie Mountains.

Petroleum data for two conceptual plays in Peel area, the Arnica-Landry play and the Kee Scarp play, are presented. Potential reservoir rocks in Arnica Formation include porous dolostone and carbonate breccia (Bear Rock facies), in intervals tens of metres thick with 3% to 10% porosity and permeabilities between 1-2 millidarcies (mD). Porous limestone with up to 4% to 6% porosity over metre-scale intervals are expected in Landry Formation. Few suitable source rocks occur within these carbonates, and reported shows are more likely associated with overlying Hare Indian and Canol Formation source rocks. A variety of stratigraphic and structural traps are envisioned for this play. Porous limestone in Ramparts Formation may contain intervals 10 m to 20 m or more thick with 6% to 10% porosity and permeabilities in the 1 mD range. The Charrue sandstone (Ramparts Formation) is another potential reservoir rock that has yielded 14.9% porosity in the Grandview Hills area, northeast Peel area. Middle and Upper Devonian shale of Hare Indian, Ramparts, and Canol formations are the main source rocks for the Kee Scarp play.

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Total organic carbon (TOC) values for Bluefish Member are high (average TOC = 6.68%), indicating excellent potential; the member ranges from just mature to overmature in Peel area. TOC values for Ramparts Formation are high (average TOC = 5.07%) and the potential as a source rock is excellent. The formation ranges from mature to overmature in Peel area. Outcrop samples from Peel area confirm the excellent source rock potential of Canol Formation (average TOC = 4.85%). This formation ranges from immature to post-mature in Peel area. Potential traps are likely stratigraphic for the Kee Scarp play.

INTRODUCTION

Devonian strata described here lie above Delorme Group (Silurian to lower? Devonian) and below Imperial Formation (Upper Devonian, Frasnian-Famennian). In Peel area, these rocks are divided into: 1) Lower to Middle Devonian (Arnica to Hume formations) succession consisting of, from oldest to youngest, Fort Norman Formation (Bear Rock facies), Arnica Formation, Landry Formation, Mount Baird Formation, Hume Formation, and Road River Group; and 2) Middle to Upper Devonian Horn River Group comprised of both siliciclastic rocks and carbonates lying above Hume Formation and below Imperial Formation. Formation names used in the present study are Hare Indian Formation (with basal Bluefish Member), Ramparts Formation (Kee Scarp member) and Canol Formation (Figure 1).

Devonian units have a complex distribution across Mackenzie-Peel Shelf from the vicinity of Norman Wells westward toward Richardson Trough (Figure 2). Lower to Middle Devonian rocks broadly record continued transgression from the underlying Delorme Assemblage, marking a change from evaporite deposition in the east/southeast to carbonate platform deposition, and eventually a shale-out into deeper water deposition toward the west (Morrow and Geldsetzer, 1988, 1992; Morrow, 1999). Compared with the underlying Delorme Assemblage, there was little input of terrigenous clastics or influence of tectonic uplifts (e.g., Norman Wells High and Keele Arch; Morrow, 1991). Erosion related to Keele Arch occurred such as where Bear Rock facies unconformably overlies Mount Kindle Formation, and east of Peel area in Mackenzie Plain and Franklin Mountains. Post-Hume Formation deposition in the Middle to Late Devonian represents an initial transgression and starved basin, followed by lobes of clastic deposition prograding into the basin and development of a carbonate bank/reef on top of these siliciclastic banks. The carbonate bank was uplifted and ultimately drowned in a final transgression that returned the basin to starved conditions (Yose et al., 2001).

Within the Devonian succession of Peel area, there are two conceptual plays: Arnica-Landry play and Kee Scarp play. This paper describes the stratigraphy of the Arnica-Hume succession based on 22 measured sections and stations in the northern Mackenzie Mountains, and 59 wells that penetrate these formations in Peel Plateau and Plain (Figure 3; Tables 1, 2). Petroleum data for a conceptual play called the Arnica-Landry play is described. Horn River Group was examined at 15 measured sections and stations and is penetrated by 22 wells (Figure 4, Table 3). Petroleum data for an established play in Mackenzie Plain, the Kee Scarp play, is evaluated in Peel area.

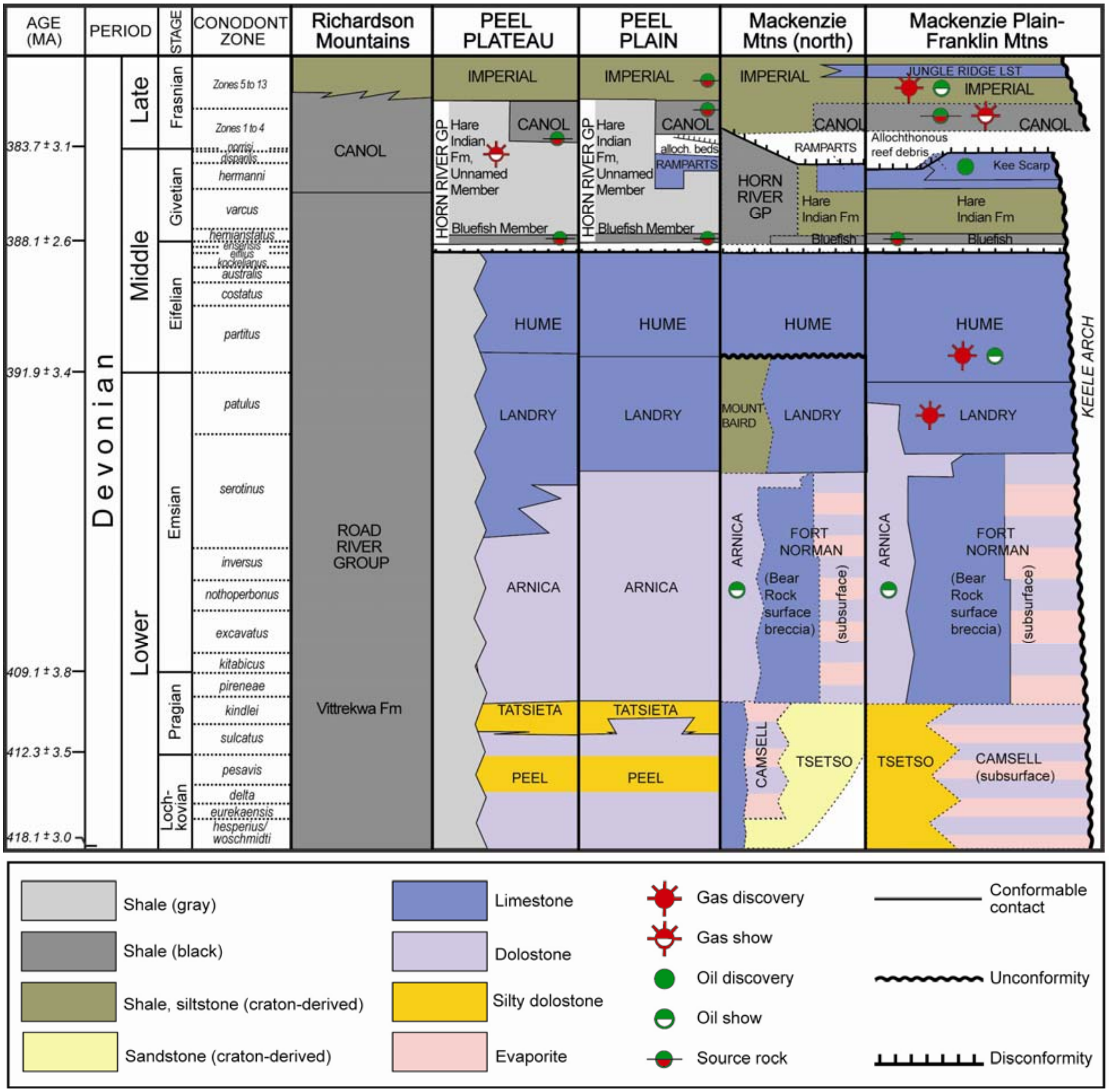

Figure 1. *Table of Devonian formations for Peel area and adjacent parts of the Cordillera. Timescale and zonation after Kaufmann (2006); stratigraphic data after Jones and Gal (2007) and Morrow et al. (2006).*

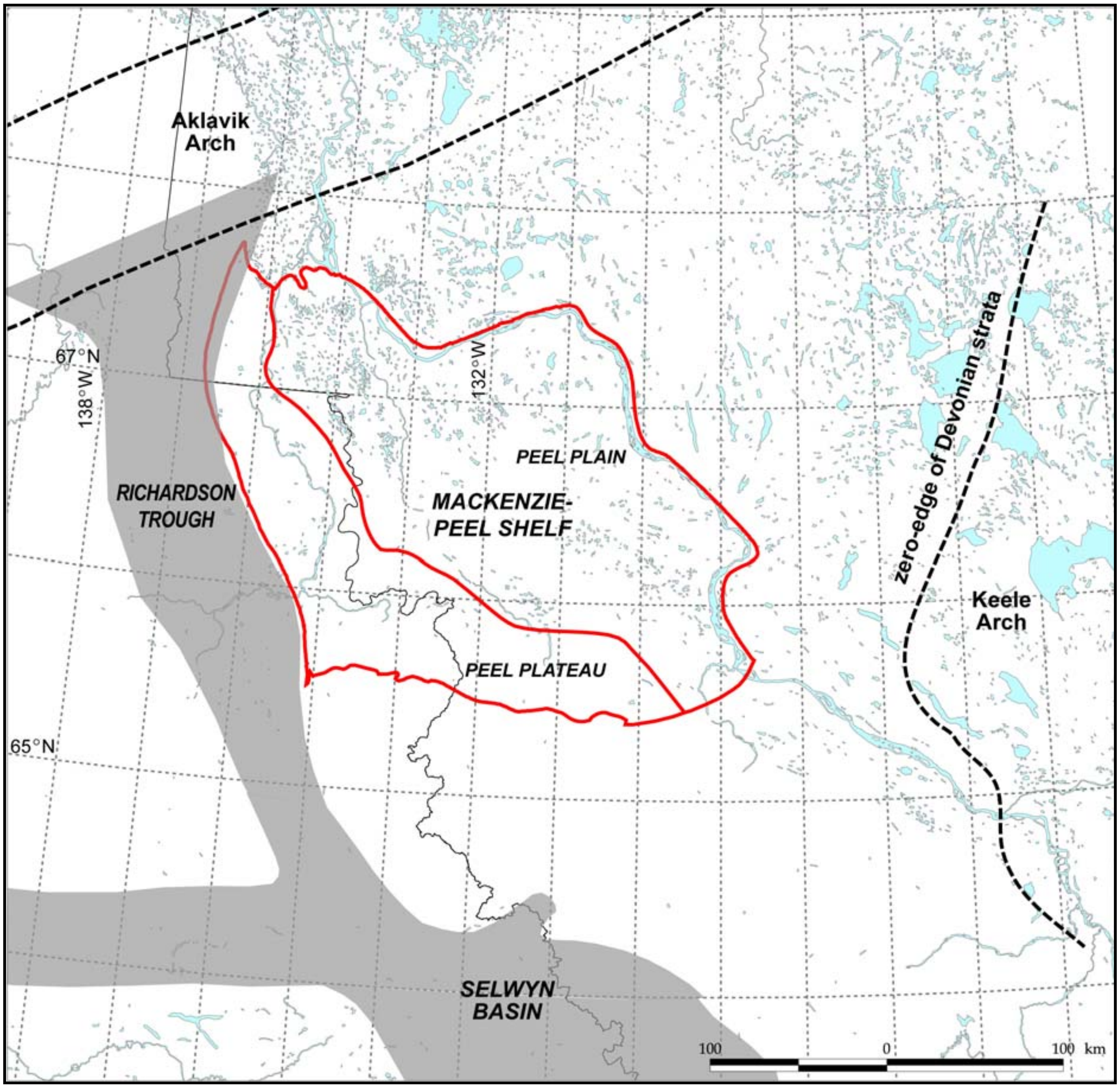

Figure 2. *Devonian paleogeography of Peel area and adjacent areas (modified from Morrow, 1999).*

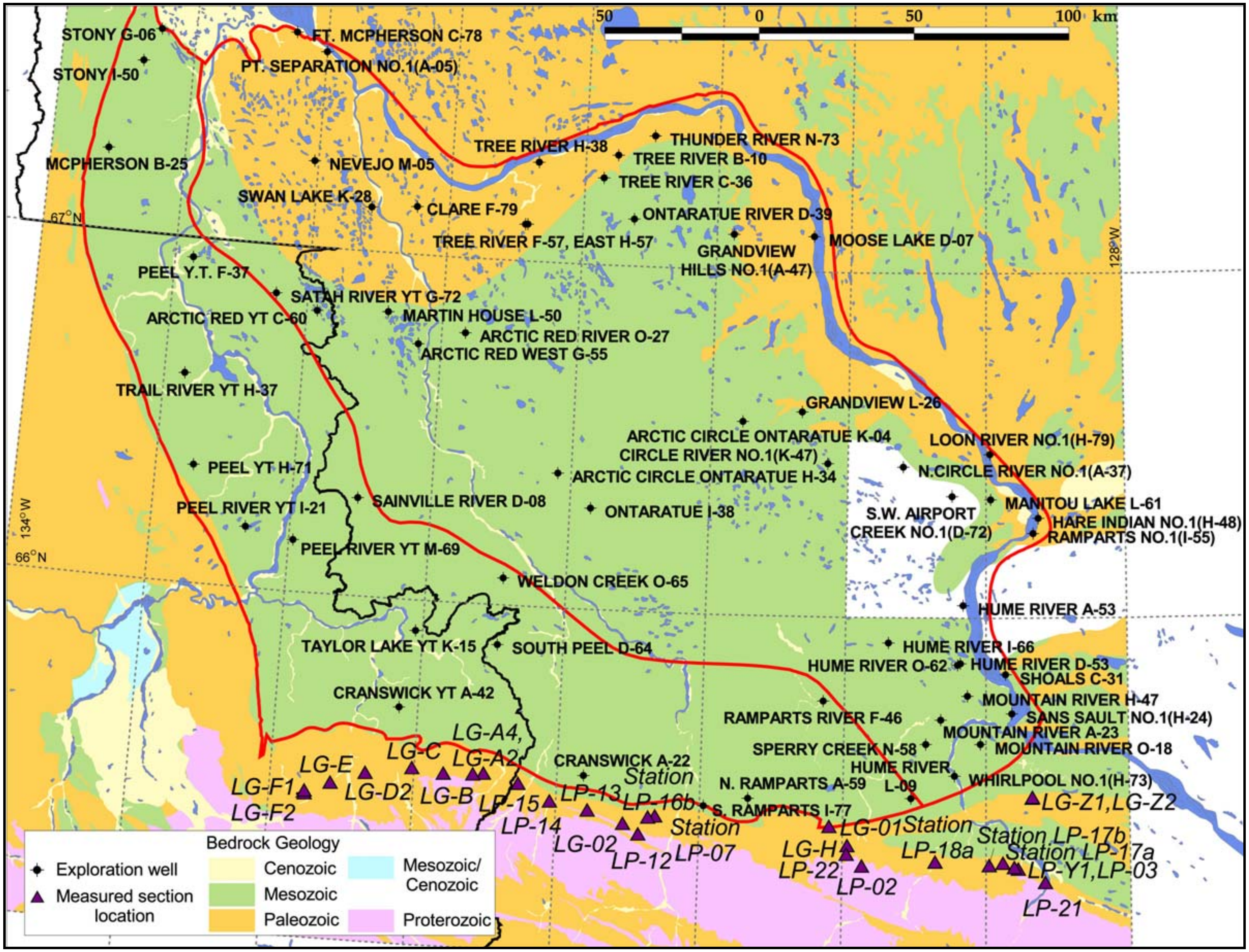

Figure 3. *Geological map of Peel area showing locations of Lower to Middle Devonian outcrop sections, field stations, and exploratory wells that penetrate Arnica to Hume formations succession.*

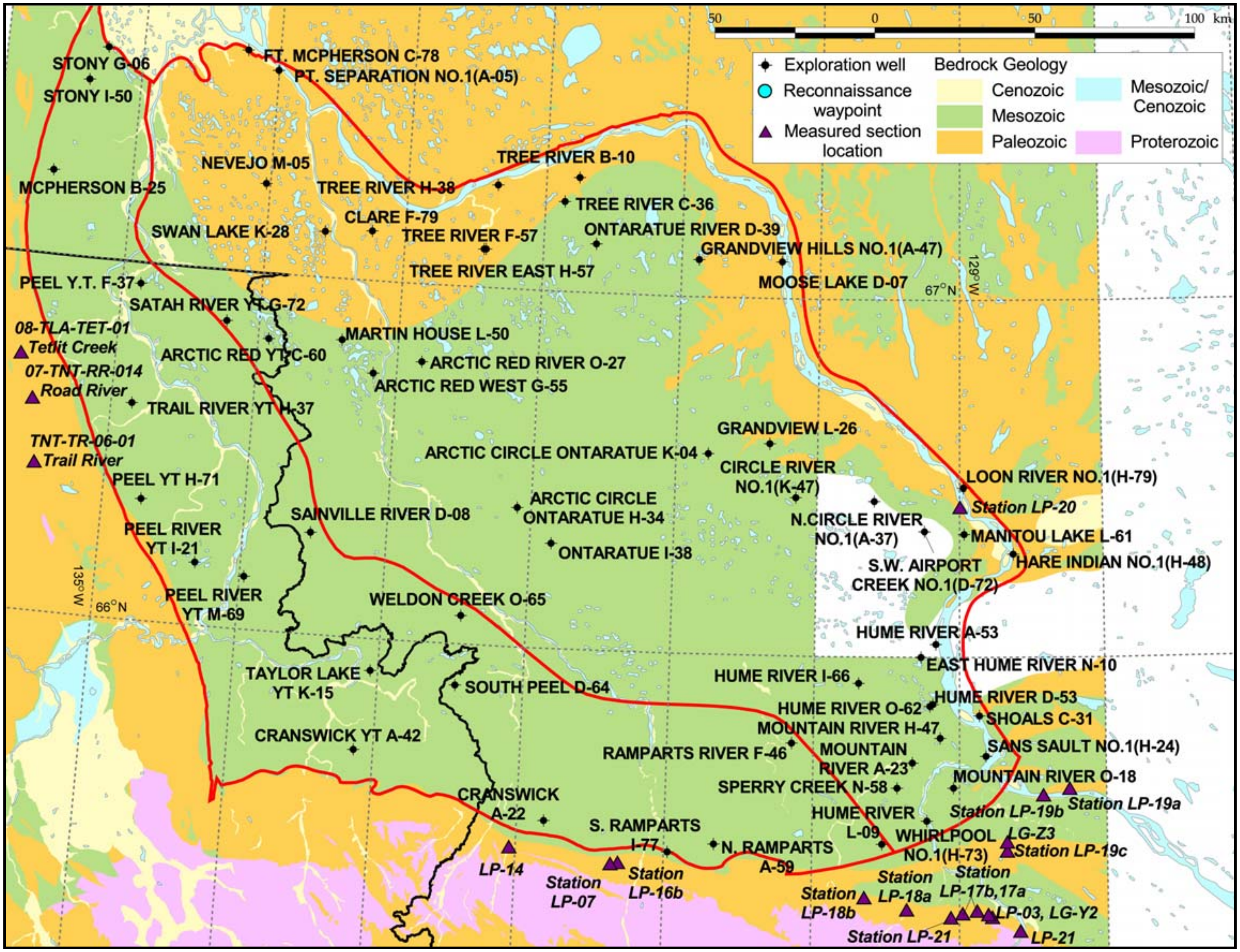

Figure 4. *Geological map of Peel area showing locations of Middle to Upper Devonian outcrop sections, field stations, and exploratory wells that penetrate the Horn River Group.*

Section or Station									Horn River Group		
	Longitude (decimal degrees W)	Latitude (decimal degrees N)	Arnica	Arnica -Bear Rock	Landry	Mount Baird	Road River	Hume	Hare Indian	Ramp-arts	Canol
LP-02 Type Hume Formation	-129.969	65.336		34.5	187.5			132.0	inc		
LP-03 Powell Creek	-128.780	65.271		273.0				136.1	165.8	46.8	16.2
LP-05 Rumbly Creek Ridge	-131.421	65.354		191.5	27.0						
LP-13 East of Morrow #27	-131.781	65.418		204.0	>6						
LP-14 Flyaway Creek	-132.045	65.438			66.5			129.0	2.0		
LP-15 West Cranswick	-132.272	65.485	>21								
LP-21 West Mountain River	-128.593	65.232		299.5				145.9	53.5	35.4	93.3
LP-22 Windy Ridge	-129.975	65.311		136.2	10.0						
LG-01 Southbound Ridge	-130.096	65.391		61.0	226.5						
LG-02 17.7 km W of ARRO camp (Upper Rumbly Creek)	-131.530	65.383		188.5	173.0						
Station LP-07 Rumbly Creek Tributary	-131.309	65.408						>15.0	35.0		>20.0
Station 16b Rumbly Creek Tributary 2	-131.359	65.404						>100.0	>5.0		
Station LP-17a Bell Creek (East arm)	-128.885	65.288						1.0	>150.0	>20.0	
Station 17b Bell Creek (West Arm)	-128.981	65.281						>5.0	>100.0	>20.0	
Station LP-21 West of Bell Creek	-129.059	65.270							1.0		
Station LP-18a Gayna Gorge	-129.358	65.291						60.2	>195.0	>30.0	
Station LP-18b Shortcut Creek	-129.646	65.325							>5.0		>10.0
Station LP-19a Carcajou Ridge (Section 4UA71*)	-128.253	65.632							40.2*	44.8*	
Station LP-19b Carcajou Rock (Section 12UA71*)	-128.433	65.613								29.3*	8.5*
Station LP-19c Imperial Anticline (Section 3UA72*)	-128.679	65.457							2.5	130.0*	
Station LP-20 Airport Creek	-128.999	66.421							15.0	15.0	>5.0
LG-A2	-132.515	65.509	229.5								
LG-A4	-132.590	65.505	364.5								
LG-B	-132.795	65.503	241.3		119.0						
LG-C	-133.019	65.512	139.5								
LG-D2	-133.340	65.490						19.0			
LG-E	-133.580	65.454				127.3	174.7				
LG-F1	-133.753	65.419	26.3								
LG-F2	-133.756	65.427	20.0								
LG-H	-129.867	65.277	92.0		40.5						
LG-Y1	-128.807	65.276		57.0				117.0			
LG-Y2	-128.807	65.279								110.4	
LG-Z1	-128.683	65.476		69.0							
LG-Z2	-128.681	65.479						30.0			
LG-Z3	-128.679	65.482								178.5	
TNT-TR-06-01 Trail River	-135.497	66.414									220
07-TNT-RR-014 Road River	-135.557	66.592									>20
08-TLA-TET-01 Tetlit Creek	-135.669	66.714									>45

Table 1. *Outcrop section and station locations and formation thicknesses (m). * indicates thicknesses measured by T. Uyeno (unpublished GSC sections).*

Unique Well Identifier (UWI)	Short Well Name	KB/RT	Hume	Landry	Arnica	Bear Rock	Fort Norman	Road River	Tatsieta	Peel	Mount Kindle	Franklin Mtn	Total Depth
300A056740134000	Pt. Separation no. 1 (A-05)	18.9	1583.7	1658.7	2006.5				2092.5	2112.6	2286.0		2445.4
300A226540131450	Cranswick A-22	768.4	1173.5	1315.8	1546.9				1746.5	1795.3	1993.4	2164.1	2869.1
300A236550129150	Mountain R. A-23	115.5	921.1	1021.7	1226.2		1346.5				1410.0		1553.6
300A376630129300	N. Circle River no. 1 (A-37)	150.8	371.9	485.9									690.7
300A426550133001	Cranswick Y.T. A-42	620.1	2159.8	2549.0	3006.2				3047.1	3130.0	3350.1	3582.0	4267.2
300A476710130450	Grandview Hills no. 1 (A-47)	369.5	479.8	571.5	844.3				975.4	1055.8	1205.2	1434.7	1998.0
300A536610129000	Hume R. A-53	62.8	589.2	682.8	864.7		965.3				996.7		1158.2
300A596530130300	N. Ramparts A-59	580.5	2174.1	2303.1						2747.8	2849.9	2983.4	3205.0
300B106720131451	Tree River B-10	188.1	577.0	660.5		1042.0						1163.0	1294.0
300B256720135301	McPherson B-25	492.3	2933.1		3041.4				3445.4	3552.7	3774.7	3993.6	4136.1
300C316600128450	Shoals C-31	87.6	695.6	807.7	882.1	919.0	999.1				1047.3	1216.2	1981.2
300C366720131451	Tree River C-36	135.0	840.5	937.0	1143.5				1464.0	1482.0	1591.0		1878.0
300C606650133450	Arctic Red Y.T. C-60	92.0	1672.1	1777.6	2174.4				2298.2	2329.9			2599.9
300C786740134000	Ft. McPherson C-78	19.8	1941.9	2019.3	2188.2				2288.4	2361.6	2636.2	3009.3	3068.1
300D076710130150	Moose Lake D-07	54.0	193.0	284.0	525.0					723.0	780.0	846.5	900.0
300D086620133300	Sainville River D-08	203.0	1735.2	1883.7	2422.2				2446.3	2490.2			2651.8
300D396710131301	Ontaratue River D-39	244.5	649.0	741.0	1115.0				1205.0				1250.0
300D536600129001	Hume River D-53	88.4	835.5	928.7	1102.8				1194.5	1197.9	1246.6		1267.7
300D646600132151	South Peel D-64	558.1	1560.6	1702.3	1935.5								1985.5
300D726630129000	S.W. Airport Creek no. 1 (D-72)	149.2	391.1	499.3	626.1								726.9
300F376700134450	Peel Y.T. F-37	54.6	2288.1	2392.7	2824.6				2946.8	2983.1	3327.2		3368.0
300F466550130000	Ramparts River F-46	215.6	1454.0										1510.0
300F576710132150	Tree River F-57	93.0	783.3	879.0	1118.6				1359.4	1527.0	1657.5		1979.2
300F796710133000	Clare F-79	108.7	1197.6	1293.7	1524.5				1845.3	1878.8	2121.2	2484.9	2525.6
300G066740135150	Stony G-06	56.7	1599.6	1664.2				1857.8		2081.8	2324.7		2529.8
300G556650133000	Arctic Red West G-55	44.6	1162.8	1269.8	1510.3				1752.0	1789.5	2064.1	2507.0	3322.3
300G726700134000	Satah River Y.T. G-72	89.6	1874.8	1978.5									2286.0
300H246550128451	Sans Sault no. 1 (H-24)	100.0	788.9	891.5	932.7								1120.0
300H346630132000	Arctic Circle Ontaratue H-34	141.7	983.6	1101.9	1332.0				1591.1	1642.9	1836.4	2139.7	4075.2
300H376640134450	Trail River Y.T. H-37	393.2	2704.8	2792.6					3485.1	3510.7			3721.6
300H386720132150	Tree River H-38	79.6	777.2	791.0	1054.6								1279.2
300H476550129000	Mountain River H-47	93.9	491.0	595.0	731.5		848.0				890.0		1044.5
300H486620128300	Hare Indian no. 1 (H-48)	45.1	164.6										169.2
300H576710132150	Tree River East H-57	108.2	804.7	903.4	1159.8				1402.1	1595.6	1708.4		1981.2
300H716630134300	Peel Y.T. H-71	513.0	1886.4	2020.8					2633.5	2650.8	2783.1	3004.1	3419.6
300H736540129000	Whirlpool no. 1 (H-73)	105.5				862.2						1654.4	1955.9
300H796630128450	Loon River no. 1 (H-79)	24.4	171.0	274.0									299.9
300I216620134150	Peel R Y.T. I-21	381.2	1451.5	1570.9									2072.6
300I386620131450	Ontaratue I-38	144.5	986.3	1100.3	1444.8				1573.4	1647.1	1808.7	2076.3	2287.5
300I506730135150	Stony I-50	321.9	2181.5	2240.9	2450.6				2600.5	2607.3	2706.6	2993.7	3343.0
300I556620128300	Ramparts no. 1 (I-55)	23.8	178.3	286.5	315.2	407.2							470.6
300I776530130450	S. Ramparts I-77	595.6	785.2	929.6	1133.9				1299.7	1341.1	1363.1	1539.2	1621.8
300K046640130450	Arctic Circle Ontaratue K-04	103.8	507.2	604.4	812.6				986.3	1022.3	1218.9	1437.4	2728.0
300K156600133000	Taylor Lake Y.T. K-15	468.8	1357.6	1524.0	1904.7				2057.4	2096.7	2315.9		2378.7
300K286710133300	Swan Lake K-28	89.6	1423.7	1516.4	1801.4								1838.2
300K476630130000	Circle River no. 1 (K-47)	89.9	405.1	513.9	741.3								810.8
300L096530129300	Hume River L-09	325.2	1569.1	1992.8	2294.8								2606.0
300L266640130150	Grandview L-26	164.9	413.9	506.0	730.9				896.1	901.0	1010.7	1230.5	2395.6
300L506650133150	Martin House L-50	88.0	1362.0	1465.7	1683.0				1997.7	2027.6	2285.2		2407.9

Unique Well Identifier (UWI)	Short Well Name	KB/RT	Hume	Landry	Arnica	Bear Rock	Fort Norman	Road River	Tatsieta	Peel	Mount Kindle	Franklin Mtn	Total Depth
300L616630128450	Manitou Lake L-61	131.7	327.7	435.3	707.1						762.6	944.3	1724.3
300M056720134000	Nevejo M-05	74.4	1696.8	1786.7	2074.8				2303.5	2347.7			2378.7
300M696610133450	Peel River Y.T. M-69	291.7	2300.0	2430.8	3035.2				3080.3	3125.4			3272.6
300N586540129150	Sperry Creek N-58	160.7	1413.0	1522.0	1687.5		1797.5				1838.0	1988.5	2160.0
300N736730131151	Thunder River N-73	124.1	501.0	585.0		952.0						1061.0	1146.0
300O186540129000	Mountain River O-18	115.0	491.0	594.0	686.0		798.0		920.0		946.0		1120.0
300O276650132450	Arctic Red River O-27	136.6	1072.6	1174.4	1396.0				1642.9	1657.2			2154.0
300O626600129000	Hume R. O-62	86.9	850.4	947.0	1123.8		1219.8				1264.0		1402.1
300O656610132150	Weldon Creek O-65	222.8	1320.7	1460.0	1676.4				2015.3	2033.0			2214.4

Table 2. *Formation tops (in metres) of wells that penetrate the Arnica to Hume formations succession in Peel area. NWT tops after Hogue and Gal (2008) and Yukon tops after Fraser and Hogue (2007). KB=Kelly bushing; RT=rotary table.*

Unique Well Identifier (UWI)	Short Well Name	KB/RT	Canol	Ramparts	Kee Scarp	Hare Indian	Bluefish Member	Hume	Bear Rock	Total Depth
300D646600132151	South Peel D-64	558.1	1494.1				1554.5	1560.6		1985.5
300A596530130300	N. Ramparts A-59	580.5	2031.8	2109.2		2122.9		2174.1		3205.0
300I776530130450	S. Ramparts I-77	595.6	670.0	759.6		765.0		785.2		1621.8
300A226540131450	Cranswick A-22	768.4	1088.1			1123.2	1161.3	1173.5		2869.1
300F466550130000	Ramparts River F-46	215.6	1247.0			1264.0	1434.0	1454.0		1510.0
300L096530129300	Hume River L-09	325.2	1265.8	1306.1		1323.7	1560.0	1569.1		2606.0
300O186540129000	Mountain River O-18	115.0			141.0	265.0	483.0	491.0		1120.0
300H736540129000	Whirlpool no. 1 (H-73)	105.5	280.5	291.2					862.2	1955.9
300N586540129150	Sperry Creek N-58	160.7	1146.0			1158.5	1395.5	1413.0		2160.0
300A236550129150	Mountain R. A-23	115.5	646.8	674.2			906.5	921.1		1553.6
300H246550128451	Sans Sault no. 1 (H-24)	100.0		429.2		593.8	780.9	788.9		1120.0
300H476550129000	Mountain River H-47	93.9		118.3		444.7	480.4	491.0		1044.5
300C316600128450	Shoals C-31	87.6		218.2		579.1	666.3	695.6	919.0	1981.2
300D536600129001	Hume River D-53	88.4	488.0	492.9		637.9	822.2	835.5		1267.7
300O626600129000	Hume R. O-62	86.9	486.5	503.5		658.4	837.9	850.4		1402.1
300N106600129150	Hume River N-10	80.1	374.8	381.1						445.0
300I666600129301	Hume River I-66	95.3	667.0	687.5		706.6				745.0
300A536610129000	Hume R. A-53	62.8	231.3	238.4		398.7	575.5	589.2		1158.2
300H486620128300	Hare Indian no. 1 (H-48)	45.1		15.2				164.6		169.2
300L616630128450	Manitou Lake L-61	131.7		100.6				327.7		1724.3
300H796630128450	Loon River no. 1 (H-79)	24.4		41.2				171.0		299.9
300D726630129000	S.W. Airport Creek no. 1 (D-72)	149.2	80.8	110.3		147.2	372.1	391.1		726.9
300A376630129300	N. Circle River no. 1 (A-37)	150.8	85.3	115.2		166.1		371.9		690.7
300I386620131450	Ontaratue I-38	144.5	887.0			932.0	981.5	986.3		2287.5
300K476630130000	Circle River no. 1 (K-47)	89.9	147.8	175.9		233.2	389.6	405.1		810.8
300L266640130150	Grandview L-26	164.9	152.4			246.9	404.8	413.9		2395.6
300K046640130450	Arctic Circle Ontaratue K-04	103.8	266.4	287.7		302.4	496.5	507.2		2728.0
300O656610132150	Weldon Creek O-65	222.8	1252.1				1310.6	1320.7		2214.4
300D086620133300	Sainville River D-08	203.0	1702.3				1730.7	1735.2		2651.8
300H346630132000	Arctic Circle Ontaratue H-34	141.7	890.0				971.7	983.6		4075.2
300G556650133000	Arctic Red West G-55	44.6	1103.4					1162.8		3322.3
300O276650132450	Arctic Red River O-27	136.6	1005.8			1034.8	1061.6	1072.6		2154.0
300L506650133150	Martin House L-50	88.0	1303.4					1362.0		2407.9
300M056720134000	Nevejo M-05	74.4	1663.5					1696.8		2378.7
300B256720135301	McPherson B-25	492.3	2914.8					2933.1		4136.1
300I506730135150	Stony I-50	321.9	2115.3					2181.5		3343.0

Unique Well Identifier (UWI)	Short Well Name	KB/RT	Canol	Ramparts	Kee Scarp	Hare Indian	Bluefish Member	Hume	Bear Rock	Total Depth
300A056740134000	Pt. Separation no. 1 (A-05)	18.9	1554.5					1583.7		2445.4
300C786740134000	Ft. McPherson C-78	19.8	1919.6					1941.9		3068.1
300G066740135150	Stony G-06	56.7	1548.4					1599.6		2529.8
300F576710132150	Tree River F-57	93.0	703.8				767.2	783.3		1979.2
300H576710132150	Tree River East H-57	108.2	719.9				794.0	804.7		1981.2
300F796710133000	Clare F-79	108.7	1112.9				1179.6	1197.6		2525.6
300K286710133300	Swan Lake K-28	89.6	1350.3					1423.7		1838.2
300H386720132150	Tree River H-38	79.6	731.5					777.2		1279.2
300D076710130150	Moose Lake D-07	54.0				5.0	172.5	193.0		900.0
300A476710130450	Grandview Hills no. 1 (A-47)	369.5	233.5	267.6		286.5	472.4	479.8		1998.0
300D396710131301	Ontaratue River D-39	244.5	544.0					649.0		1250.0
300B106720131451	Tree River B-10	188.1	518.0					577.0	1042.0	1294.0
300C366720131451	Tree River C-36	135.0	739.5			776.5	832.0	840.5		1878.0
300A426550133001	Cranswick Y.T. A-42	620.1	2108.0					2159.8		4267.2
300K156600133000	Taylor Lake Y.T. K-15	468.8	1303.0				1352.7	1357.6		2378.7
300M696610133450	Peel River Y.T. M-69	291.7	2270.8				2286.0	2300.0		3272.6
300I216620134150	Peel R Y.T. I-21	381.2	1407.6				1446.3	1451.5		2072.6
300H716630134300	Peel Y.T. H-71	513.0	1807.5				1877.6	1886.4		3419.6
300H376640134450	Trail River Y.T. H-37	393.2	2699.3					2704.8		3721.6
300C606650133450	Arctic Red Y.T. C-60	92.0	1633.7					1672.1		2599.9
300G726700134000	Satah River Y.T. G-72	89.6	1811.4					1874.8		2286.0
300F376700134450	Peel Y.T. F-37	54.6	2254.9				2286.0	2288.1		3368.0

Table 3. *Formation tops (in metres) of wells that penetrate the Horn River Group in Peel area. NWT tops after Hogue and Gal (2008) and Yukon tops after Fraser and Hogue (2007). KB = Kelly bushing; RT = rotary table.*

PREVIOUS WORK

Arnica to Hume Formations Succession

Arnica and Landry formations were originally identified in the Camsell Bend and Root River map areas (NTS 95 J and K; Douglas and Norris, 1961). Tassonyi (1969) applied the name Gossage Formation to the carbonate sequence between Ronning Group and Hume Formation which lacked evaporites, in order to differentiate these rocks from evaporitic rocks of Bear Rock Formation defined by Hume and Link (1945) and Bassett (1961). Gossage Formation included the present Arnica and Landry formations (Dolomite and Pellet limestone members), and part or all of Delorme Group (Lower limestone member of Gossage Formation of Tassonyi, 1969). The term Gossage Formation is obsolete (Pugh, 1983; Morrow, 1999).

Arnica and Landry formations were mapped northward into Peel area (Upper Ramparts River, 106 G and Sans Sault Rapids, 106 H map areas) by Aitken et al. (1982) and into Snake River map area (106 F) by Norris (1982a). Norris (1968) used the term Cranswick Formation for a unit of Devonian limestone and shale that lies between an unnamed carbonate and “Road River Formation” or Mount Baird Formation. Morrow (1999) deferred using the term Cranswick for this unit restricted to the basinward edge of Mackenzie-Peel Shelf, and considered it equivalent to Arnica and Landry formations.

Bear Rock Formation was originally defined by Hume and Link (1945) and the name was extended to the subsurface by Tassonyi (1969) to include the lateral facies equivalents of surface

Bear Rock Formation breccias (evaporite and dolostone). Meijer Drees (1993) proposed the name Fort Norman Formation to include subsurface units that are equivalent to Bear Rock, Arnica, and Landry formations. Morrow (1991) included a Landry Member in Bear Rock Formation to account for Landry-like beds within Bear Rock Formation that are not mappable at 1:250,000 scale. Bear Rock Formation is extensive across the northern Mackenzie Mountains (Aitken et al., 1982), although in this present study we redesignate this formation as Bear Rock breccia, a diagenetic facies within the Arnica and Fort Norman formations.

Hume Formation was named by Bassett (1961). Tassonyi (1969) proposed three internal subdivisions in the subsurface. Subsurface descriptions were provided by Meijer Drees (1980) and Pugh (1983). Hume Formation was mapped in Peel area (106 G, 106 H) by Aitken et al. (1982) and in Snake River map area (106 F) by Norris (1982a).

Morrow (1999) measured and described sections of the Arnica to Hume formations succession in the northern Mackenzie Mountains to refine the surface to subsurface stratigraphic framework.

Horn River Group

Tassonyi (1969) reviewed of the usage of the names Hare Indian, Bluefish, Ramparts, and Canol and recommended using the term Horn River Group where Hare Indian and Canol formations could not be differentiated, such as where the intervening Ramparts Formation was missing. Pugh (1983) further clarified relationships between Hare Indian, Ramparts, and Canol formations and grouped them together as Horn River Group to resolve a long-standing nomenclatural problem for the term "Horn River" (Williams, 1983). Bluefish Member was defined by Pugh (1983), formerly the "spore-bearing member" of Tassonyi (1969), and was further described by Al-Aasm et al. (1996). In a surface-subsurface studies across the front of the Mackenzie Mountains, Muir and Dixon (1984; 1985) described facies associations and sea level changes during Hare Indian to Ramparts (Kee Scarp) Formation deposition. Yose et al. (2001) described a sequence stratigraphic framework for the Middle to Upper Devonian succession in Norman Wells area.

Horn River Group was used in surface mapping as far north as 64° (Dahadinni map area, 95 N; Douglas and Norris, 1963). Aitken et al. (1982) mapped undifferentiated Hare Indian–Canol formations, and Hare Indian, Ramparts, and Canol formations in the Upper Ramparts River and Sans Sault map areas (106 G, H). Undifferentiated Hare Indian and Canol formations (with Imperial Formation) were mapped in Snake River map area (106 F) by Norris (1982a). Canol Formation was mapped as a separate formation in Trail River (106 L) and Wind River map areas by Norris (1981a, 1982b).

ARNICA FORMATION AND BEAR ROCK BRECCIA

Arnica Formation (Douglas and Norris, 1961) is a succession of dolostone, distinctly banded in many outcrops, that overlies Delorme Group and underlies Landry Formation. Arnica Formation is bounded by facies changes to the west and southeast in Peel area. West of the western edge of Peel area, Delorme Group and Arnica and Landry formations shale out into Road River Group. In southeastern Peel area (along the Mackenzie Mountains front) Arnica Formation is represented by Bear Rock breccias. The breccias are a surface and shallow subsurface expression, caused by preferential dissolution of evaporites, of the eastward facies change from Arnica dolostone to Fort Norman Formation anhydrite. Western exposures near the shelf edge are dominantly limestone with biohermal to biostromal organic buildups, referred to as Cranswick Formation by Norris (1968). In the present study, Cranswick Formation is not used. Arnica Formation is recognized as lying above Delorme Group and below Landry Formation through much of Peel area.

Bear Rock Formation (Hume and Link, 1945) is a unit of non-bedded, gypsiferous carbonates, carbonate breccia, and gypsum at and near surface. The type section near Tulita is 154 m thick (Morrow and Meijer Drees, 1981). Morrow (1991) referred to the Arnica-Bear Rock Assemblage as an informal grouping to describe the Bear Rock, Arnica, Landry, and Sombre formations across Mackenzie Shelf, where it lies between Delorme Group and Hume Formation. Bear Rock breccias are restricted to the surface and near surface strata, and are herein designated as a facies rather than a formation (see discussion below).

Type and Reference Sections, Origin of Names

The type section of Arnica Formation (503 m thick) is in on the south side of the First Canyon of the South Nahanni River (61°17'N, 124°14'W), Virginia Falls map-area (95 F; Douglas and Norris, 1977a). The formation was named after the Arnica Range in that map area by Douglas and Norris (1961).

The type section of Bear Rock Formation is at the junction of the Great Bear and Mackenzie rivers at Tulita (formerly Fort Norman), Northwest Territories (ca. 64°56'N, 125°45'W). The formation was named by Hume and Link (1945) after Bear Rock, which lies at the junction of these rivers.

In this present study we designate a reference section (LG-B; Figure 5) for Arnica Formation because of the lithological variation in the northern Mackenzie Mountains compared with the type locality. The formation consists of limestone, dolostone, limy dolostone, and breccia. A common lithofacies is heavily burrowed dolostone and limestone. Crinoid and brachiopod limestone is common in thin beds. Brecciated zones have angular clasts and are heavily fractured. Lime mudstone increases upsection and biohermal packstone with abundant corals, stromatoporoids, and crinoids occurs near the top of the section.

Abandonment of Bear Rock Formation and Definition of Bear Rock Breccia

Bear Rock, as a formation, has been applied inconsistently since its definition by Hume and Link (1945). Its definition as a surface unit evolved as mapping progressed through the Interior Plains and Mackenzie and Franklin mountains (reviewed by Meijer Drees, 1993). The discrepancy between surface and subsurface nomenclature for Bear Rock Formation prompted Meijer Drees (1993) to propose Fort Norman Formation for the interbedded succession of anhydritic and dolomitic rocks that underlie and are equivalent to Arnica Formation, while retaining Bear Rock to describe carbonate breccia exposures (and those in the shallow subsurface).

Figure 5. *View of the reference section of Arnica Formation (Section LG-B) looking northwest.*

Bear Rock breccias are more appropriately considered a diagenetic facies primarily of Fort Norman Formation, but also interleaved or intertonguing with Arnica Formation regionally in a narrow zone (figure 10 in Morrow, 1991). Status of the Bear Rock as a formation should be abandoned due to its lack of use in the subsurface, and some ambiguity of its contacts as a mappable surface unit. Bear Rock has been described as containing tongues of Arnica Formation (Williams, 1975; Meijer Drees, 1980; Morrow, 1991) but as a weathering product, Bear Rock is better viewed as zones of brecciation within Arnica Formation (as described in the present study in southeastern Peel area).

Morrow (1991) described and illustrated the types of breccias in Bear Rock (packbreccia and floatbreccia, after Morrow, 1982) and their origin from solution collapse of Fort Norman evaporites and dolostone. In this present study we term this breccia facies as Bear Rock breccia. Textures of these rocks are discussed further under the reservoir rock attributes of the Arnica Formation (Arnica-Landry play section).

Lithology

Lithologies within Arnica Formation change though Peel area and reflect facies changes from dolostone to dominantly anhydrite (Fort Norman Formation) in the east/southeast, to biohermal limestone in the west near the shelf edge. Lithologies are described below from east to west, based on sections along the Mackenzie Mountain front at the margin of Peel area.

Southeast of Peel Area (Powell Creek, Mountain River)

Arnica Formation just southeast of Peel area is mainly represented by Bear Rock breccia and should be referred to as Fort Norman Formation. These are dolomitic and limestone breccias that generally appear massive, weather yellowish-orange to light grey, and form distinctive “hoodoo”-like weathering patterns. Bedding is often partly discernible within the breccia units.

At Powell Creek (Section LP-03; Figure 3), the lower portion of Arnica Formation (Bear Rock facies) is bedded dolostone, with fine, algal lamination. Laminations are disrupted upsection toward the breccia units. The lower dolostone unit is thick- to medium-bedded, finely crystalline, with fenestral vugs filled with gypsum and calcite. There are minor thin, dolomitic wackestone beds. Breccias occur within discrete beds (5 cm to 10 cm thick), or as bedding-parallel lenses, that grade upward in thickness and abundance to massive, chaotic breccias. Clasts are mainly dolostone, subrounded to angular, and chaotic to partly coherent (Figure 6). Clasts, and vugs where clasts are interpreted to have dissolved or weathered away, range up to several metres across. Breccias are generally clast-supported and very poorly sorted. The matrix is limestone or dolostone, with some coarse calcite. Calcite vug and fracture fills are common. Near Powell Creek area, the entire Arnica-equivalent interval is a massive to crudely bedded breccia. These are dominantly particulate rubble and mosaic packbreccias, with some floatbreccias (classification of Morrow, 1982).

Further southeast at Section LP-21 (Figure 3), thin interbeds of both laminated limy dolostone and grey, silty lime mudstone and laminated limestone are preserved within a yellow-grey dolostone breccia.

East of Hume River

In Hume River area, Arnica Formation is dominantly medium grey to grey brown, finely crystalline, medium-bedded, finely laminated to mottled dolostone. Some interbedded, light grey-weathering dolostone and limy dolostone characterizes exposures further west. Breccia intervals are thin- to medium-interbedded, and are more common in the upper of lower parts of the formation. At sections LG-H and LG-22 (Figure 3), breccias dominate the thin Arnica-equivalent interval (mapped as Bear Rock by Aitken et al., 1982). Breccias are generally brown grey, with angular to rounded clasts of dolostone (laminated or massive and often lighter grey-weathering) in a dolomitic to limy matrix (Figure 7). Patches of coarse calcite are common, occurring as cement. Clasts are poorly sorted, mm- to dm-scale, and may exhibit a crude normal size grading. Gypsum in the breccia matrix was rarely noted. Dolostone and breccia are vuggy, with some calcite-filled vugs and fractures.

A thinning-upward cycle occurs at section LP-22 within the breccias. Oolitic textures occur at section LP-22, and amphiporids (replaced by calcite) occur at section LG-H.

West of Arctic Red River

Between Arctic Red River and Cranswick River (Sections LP-05, LG-02, LP-13), Arnica Formation appears fairly uniform with a consistent stripy-weathered appearance (particularly at the base and top of the formation) on successive ridges at the Mackenzie Mountain front. Generally it is grey-brown, blocky to platy-weathering, finely to medium crystalline, medium- to thick-bedded with lesser thin bedding, finely laminated to mottled dolostone with some coarse mottles.

Figure 6. *Solution breccia of Bear Rock facies, Powell Creek (Section LP-03); hammer is 38 cm long for scale.*

Figure 7. *Dolostone breccia in Arnica-equivalent interval, containing polymictic clasts, some with rounded corners that suggest dissolution during solution collapse, Section LP-22.*

Dolostone may be limy, and dolomitic limestone interbeds occur, commonly in cycles (Figure 8). Generally, cycles at the base of the formation feature brown-weathering, mottled dolostone (Figure 9) and/or brown laminated dolostone, capped by light grey-weathering, finely laminated dolostone or limestone. The basal beds may be vuggy and/or feature abundant amphiporids. Mottling is common as lime mudstone mottles in dolomitic matrix, or the reverse. Laminations in the lower beds of the cycle (if present) may be coarse; the tops of the cycles are mainly finely laminated. Cycles are usually about 2 m to 6 m thick (Figure 10).

Figure 8. *Alternating white laminated (background) and medium grey and brown weathering vuggy dolostone (foreground) of Arnica Formation (Section LP-13; hammer for scale).*

Figure 9. *Burrow mottled facies in medium beds of Arnica Formation (hammer for scale).*

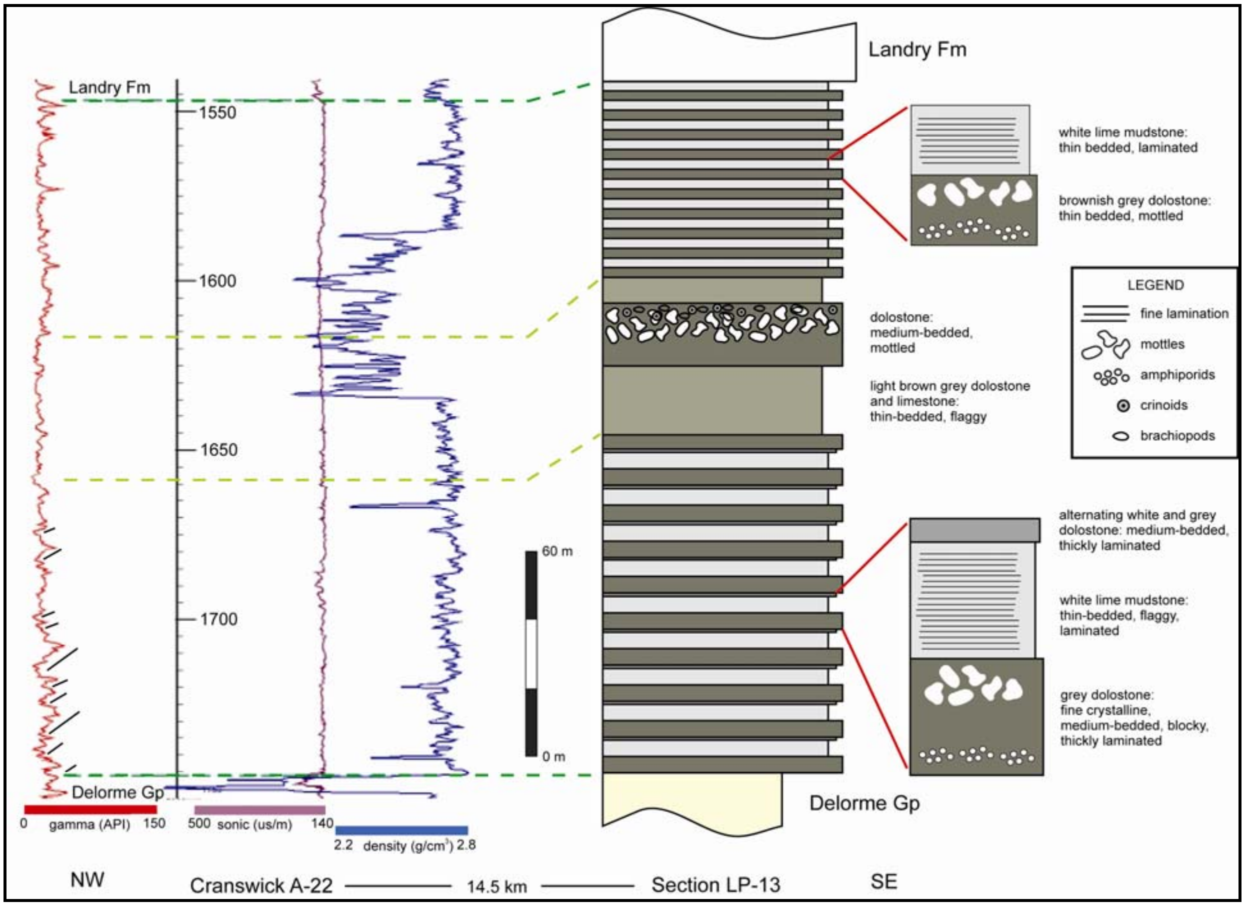

Figure 10. *Scales of cyclicity within Arnica Formation.*

Breccias are present but restricted to rare dm-scale beds. Some interbeds are argillaceous. Thin beds of dolomitic grainstone are rare. Fossils include crinoids, brachiopods, and amphiporids; with rare stromatoporoids and trilobites. Oncolites and peloidal textures are rare. Calcite is common as fracture and vug fill. Pyrite is rare.

Beds, or sets of beds, commonly contain medium crystalline, sucrosic, slightly vuggy dolostone with intercrystalline porosity. These beds are up to 1.5 m thick and occur over width of 40 m to 50 m. They are generally at, but not restricted to, the base of the formation.

West of Cranswick River

Between Cranswick River and Snake River (Sections LG-A4, LG-B2, LG-C) increasing amounts of limestone occur in Arnica Formation mapped in Snake River map area (Norris, 1982a). Dolostone is brown-grey, thin- to medium-bedded, finely crystalline, finely laminated or coarsely mottled. Lime mudstone to packstone is thin- to thick-bedded. Both thinning and thickening-upward cycles occur on a scale of 1 m to 5 m.

The striped weathering pattern persists, typically at the top of the formation. Overall the weathering pattern is more flaggy and platy. Argillaceous interbeds, or wispy argillaceous laminations occur. Limestone and dolomite are closely and cyclically interbedded.

The main difference westward is the presence of resistant beds to massive lenses (biostromes or bioherms) of fossil-rich limestone or dolostone (Figure 11). Biostromal limestone is typically thin- and nodular-bedded. Fossils include tabulate corals, stromatoporoids, and crinoids. At section LG-C (Figure 3), a sucrosic, dolomitized breccia with rounded clasts contains remnant crinoid wackestone beds, that may represent a rubble deposit on the flanks of a bioherm. This breccia is texturally distinct from the Bear Rock breccias further east. Amphiporid beds, and thin crinoid, brachiopod, and coral packstone beds are common outside of the biostromal beds.

Sucrosic dolostone beds (up to 2.5 m thick) with intercrystalline porosity and zones with intercrystalline vugs occur. Chert nodules are sparse. Calcite is common as fracture fills.

Snake River Area

Immediately east and west of Snake River area (Section LG-D2, LG-F1), limestone is dominant. Lime mudstone is medium- to thick-bedded, or massive at the base with laminated tops. Wackestones to packstones are generally-thin bedded. Some limestones are mottled and nodular-bedded. Thinning-upward cycles occur. Dolostones are thin- to medium-bedded and laminated to mottled, and commonly contain amphiporids (Figure 12).

Wackestones to packstones contain crinoids, amphiporids, thamnoporids, and brachiopods. These fossils also occur in the massive biohermal to biostromal units with corals, stromatoporoids, gastropods, bryozoans, and cephalopods. Oolitic grainstone beds occur below the biostromes at section LG-D2. Calcite-filled fractures are common in these beds.

Figure 11. *Outcrop view of massive to crudely bedded biostrome in Arnica Formation, Section LG-B (person for scale).*

Figure 12. *Amphiporid packstone, Arnica Formation, Section LG-D2 (hammer head is 3 cm wide).*

Contacts and Log Response

The lower contact of Arnica Formation with Tatsieta Formation or undifferentiated Delorme Group is sharp and conformable (Figure 13). The lower contact with Mount Kindle Formation is sharp where Arnica Formation equivalent (Fort Norman Formation) is represented by Bear Rock breccia, such as at Powell Creek (Figure 14).

Figure 13. *Tatsieta/Arnica contact (at base of hammer), Section LP-13.*

Figure 14. *Mount Kindle-Bear Rock contact, west side of Powell Creek (Section LP-03).*

The upper contact with Landry Formation is generally sharp and conformable, but in places appears gradational, as thin beds of light-weathering limestone increase in Arnica Formation near the upper contact (Figure 15). In these cases the upper contact is placed at the base of the lowest light-grey weathering lime mudstone bed. Where Landry Formation is absent in eastern sections, the upper contact with Hume Formation is not as well defined such as at Powell Creek (Section LP-03), likely because of some fracturing and brecciation through collapse in overlying Hume Formation. At Mountain River (Section LP-21), however, the upper Bear Rock-Hume contact is sharp.

Tongues of Arnica Formation occur below Road River Formation at westernmost sections such as LG-E, and above Fort Norman Formation at easternmost sections such as LG-Z2. Bed contacts here are sharp but these relationships represent a regional, gradational interfingering of units at facies changes.

In well logs, the basal contact of Arnica Formation with the underlying Delorme Group is generally marked by a gamma anomaly, and the underlying Delorme beds display slightly higher and much more variable gamma ray log values. In some wells the difference is subtle, or sometimes absent. Generally Arnica Formation features a finely ragged gamma signature, often with increased gamma toward the base of the formation, and somewhat blocky sonic log with irregular excursions (Figure 16). The contact with overlying Landry Formation, although in many cases marked by a gamma deflection, is often more readily seen in the density logs, with the change from limestone dominant to dolostone dominant lithologies. The lithological change can be confirmed by examining well sample logs. The lower contact with the cleaner gamma, and blocky sonic log of underlying Mount Kindle Formation, is usually apparent.

Figure 15. *Conformable contact of lime mudstone of Landry Formation with dolostone and lime mudstone of upper Arnica Formation (Section LP-13, view north). Hammer (circled) for scale.*

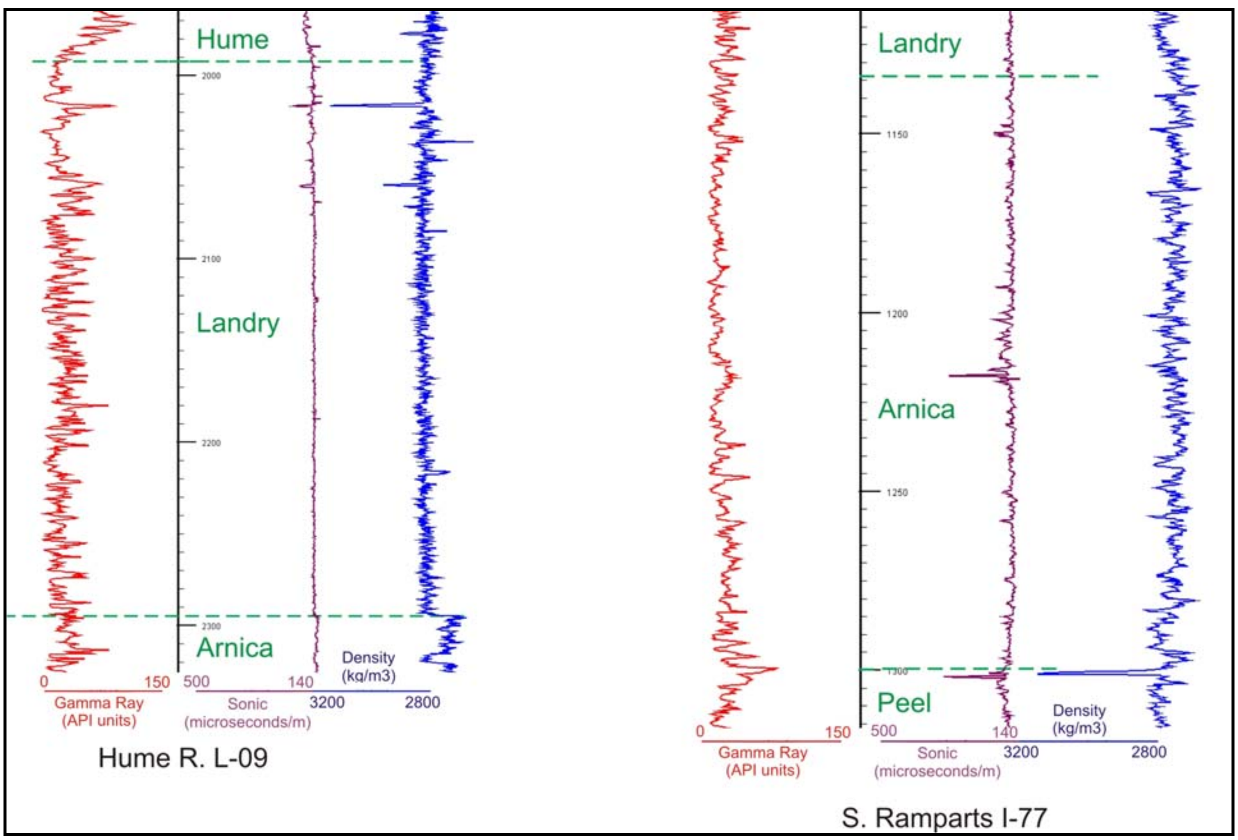

Figure 16. *Log responses of Arnica and Landry formations. Well depths in m; gamma (red), sonic interval transit time (purple) and density (blue) logs at base of figure.*

Distribution and Thickness

Arnica Formation is widely distributed throughout Peel area, although the thickness of the formation is difficult to constrain due to lateral facies changes. Where Arnica Formation overlies Tatsieta Formation, it ranges from 24.1 m thick (Sainville River D-08 well) to 404 m thick (McPherson B-25 well; Table 2). In outcrop, Arnica equivalent Bear Rock breccia ranges from 61 m thick (Section LG-01) to 299.5 m thick (Section LP-21; Figure 17); Arnica Formation ranges from 92 m (Section LG-H) to 364.5 m thick (Section LG-A4; Table 1). A combined Arnica-Landry westward increase in thickness (Figure 18) in contrast to Arnica isopachs which decrease westward (Figure 17), suggest westward facies increase in Landry Formation at the expense of underyling Arnica Formation (see figure 12 in Morrow, 1991).

Local shallow regions on Mackenzie-Peel Shelf during Arnica deposition produced evaporitic conditions. Some cores of Arnica Formation in north central Peel area have anhydritic dolostone (Clare F-79, Martin House L-50, Tree River East H-57) which is not considered Fort Norman Formation, but rather of local origin in shallow marine settings. These shallow regions coincide with a thin Arnica (plus Landry) interpreted to have been deposited on an emergent arch (Figure 18). The interpreted arch trends northeast from the Sainville River wells though the Tree River wells and under the Grandview Hills. Further evidence includes abundant fossils (stromatoporoids, bivalves, and colonial coral) in Arnica Formation between 1263 m and 1289 m in the Tree River East H-57 well cores (Gus Van Husden, pers. comm., 2008), which suggest a potential patch reef development on a shallow high, with some restricted lagoons. Kodiak Energy Inc. shows a feature in their seismic interpretation (flank of a Proterozoic high) in the Little Chicago–Grandview Hills area (Kodiak Energy Inc., 2008), where Arnica level strata also arches or possibly drapes over a high.

A structure contour map of the top Arnica Formation illustrates a general southwestward and westward sedimentary and tectonic dip of the basin (Figure 19). Perturbations of the regional pattern are the result of Arnica Formation being involved in folds and thrusts at the front of the Mackenzie Mountains, and the northwest end of the Franklin Mountains.

LANDRY FORMATION

Landry Formation (Douglas and Norris, 1961) is a unit of shallow water, peloidal lime mudstone, dolostone, and minor shale with rare fossils that underlies Hume Formation and overlies Arnica Formation or equivalent. Aitken et al. (1982) extended Landry Formation from its type area in Root River map area (95 K; Douglas and Norris, 1977b) north to the Upper Ramparts River and Sans Sault Rapids map areas (106 G and H) of Peel area. In the subsurface, Landry Formation is equivalent to the Pellet limestone member of Gossage Formation of Tassonyi (1969). Pugh (1983) proposed that Landry Formation was at least partly time equivalent to Arnica Formation in the subsurface of Peel area. In the present study, Landry Formation is the relatively unfossiliferous lime mudstone lying above Arnica Formation and below Hume Formation. It is recognized as equivalent to the Dsh unit as mapped in Snake River map area (Norris, 1982a) and Mount Baird Formation (Morrow, 1991). These units are considered progressively shalier facies of Landry Formation as it shales into basinal Road River Group within Richardson Trough. Western exposures were also referred to as Cranswick Formation (Norris, 1968; 1985).

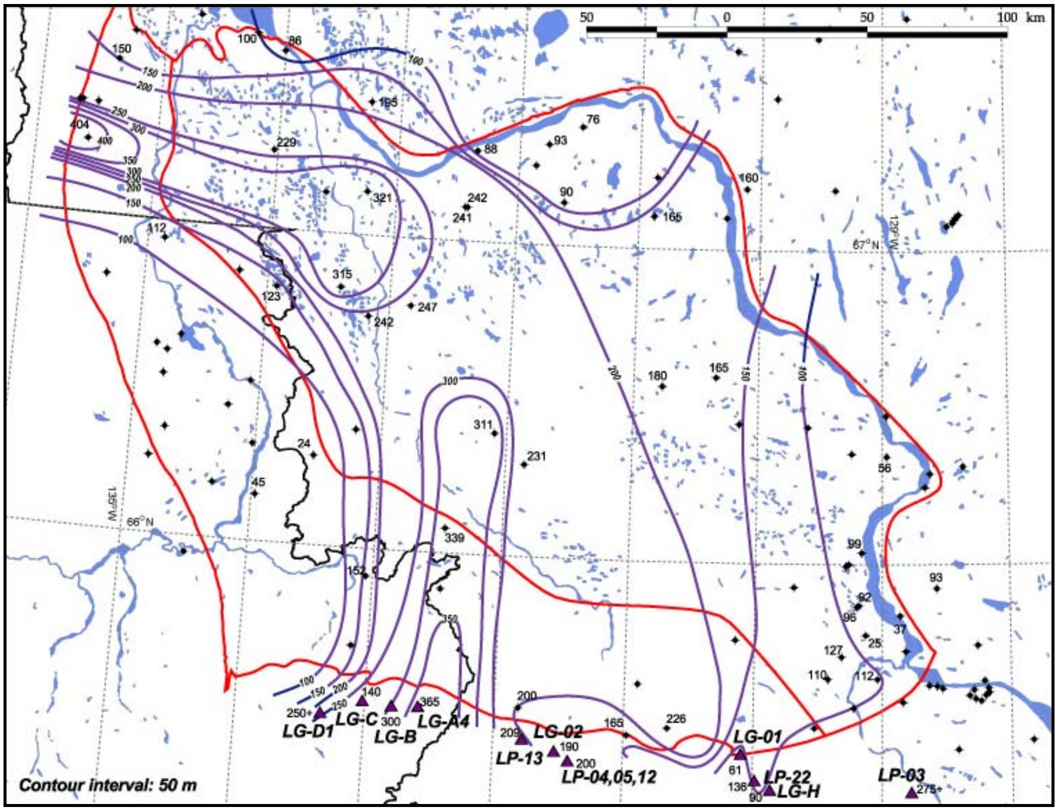

Figure 17. *Isopach map of Arnica Formation in Peel area.*

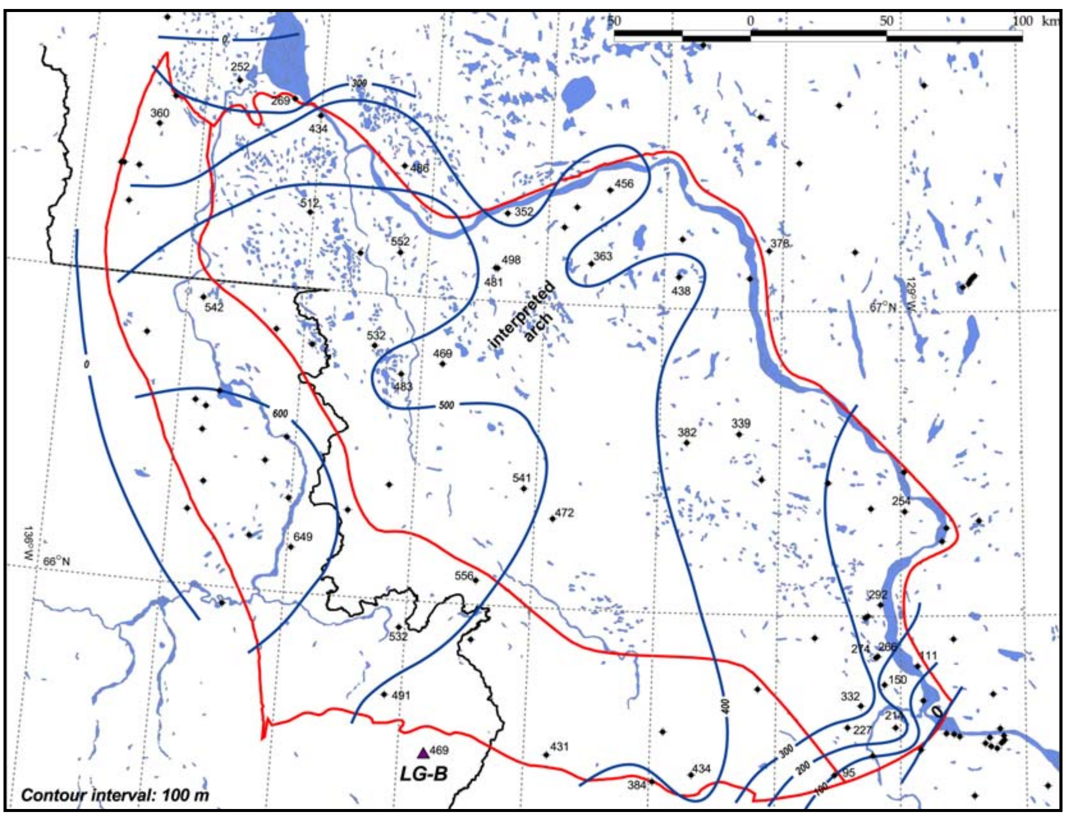

Figure 18. *Isopach map of Arnica plus Landry Formation in Peel area.*

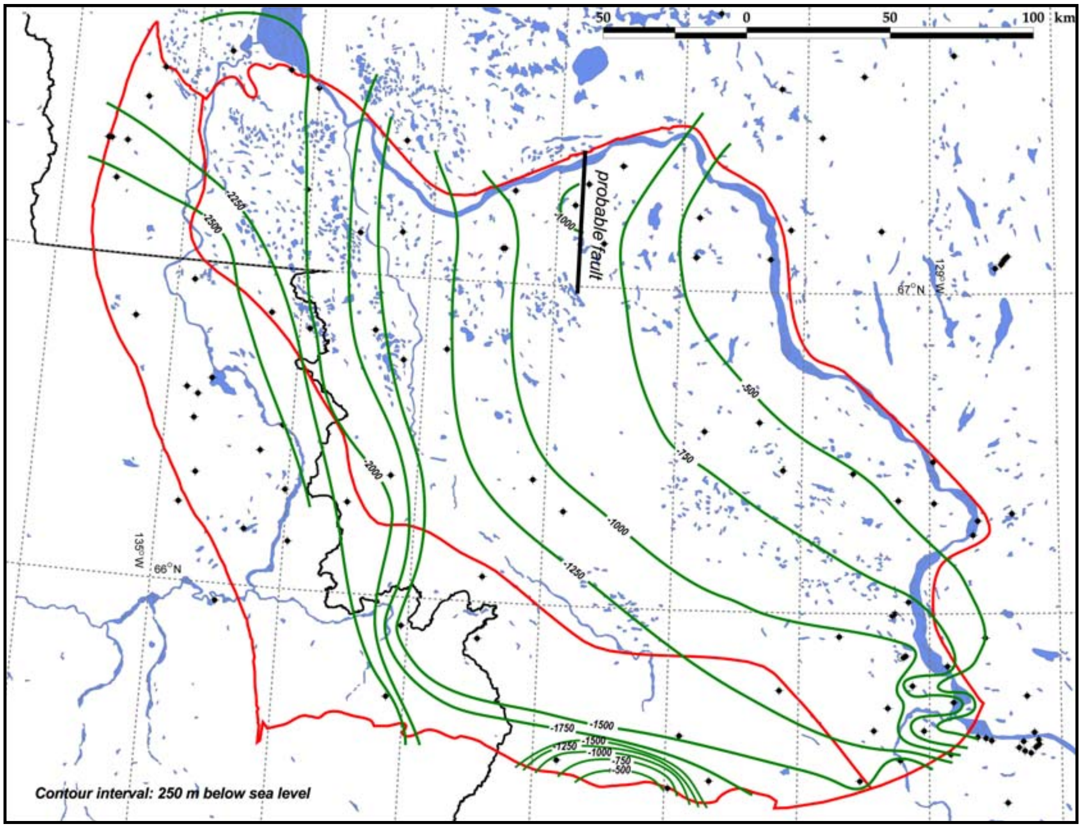

Figure 19. *Structure map of Arnica Formation.*

Type Section and Origin of Name

No type section of Landry Formation was designated by Douglas and Norris (1961) in Root River map area (95 K), who named the formation after Landry Creek in that map area.

In this present study, no complete, well exposed sections of Landry Formation were measured because the formation typically outcrops as talus-covered dip slopes at the toes of ridges forming the front of the Mackenzie Mountains.

Lithology

Landry Formation is generally light grey to dark grey-brown lime mudstone that weathers light grey (Figure 20). It is thin- to thick-bedded, finely laminated, with thin interbeds of argillaceous limestone or calcareous shale. The lower Landry Formation is more resistant than underlying Arnica Formation (Figure 15). The light weathering colour, blocky weathering, medium- and thick-bedded, generally unfossiliferous, dark brown lime mudstone, is characteristic of the formation in Peel area.

Pellets are the most common allochem. Thin, laminated or mottled dolostone interbeds are present locally. Fossiliferous (crinoids, gastropods, and colonial corals) packstone and breccia beds are rare. Erosional and/or scoured bedding contacts are common and a hardground surface occurs at Section LP-14 (measured section in Pierce and Jones, 2009). Some siliceous beds occur. Calcite fracture fills are common.

Locally, cycles are apparent with flaggy, thin beds capped by resistant, medium beds. Alternating limestone and thin dolostone cycles, on a 2 m to 3 m scale, occur at section LG-B (measured section in Pierce and Jones, 2009).

Figure 20. *View southwest to folded Landry Formation in the footwall of Deadend Fault, east of Arctic Red River. Dark weathering rock uphill on the ridge is Arnica Formation in the hanging wall of an unnamed normal fault (see Lemieux et al., 2007). Geologist for scale.*

Dsh unit

At section LG-C, and possibly section LG-D, Landry Formation equivalent is darker grey-weathering and more recessive. Norris (1982a) mapped these rocks (unit Dsh) as being dominantly shale and correlative with Landry Formation. Section LG-C contains mainly thin- to medium-bedded, grey to brown, grey and platy weathering, slightly to moderately argillaceous mudstone, wackestone, and rare packstone with crinoids and rare brachiopods. The unit occurs between Arnica and Hume formations.

Contacts and Log Response

The lower contact with Arnica Formation is conformable, and in most cases is gradational where upper Arnica Formation generally includes increasingly numerous and thicker interbeds of light grey-weathering lime mudstone with dolostone (Figure 15). The base of Landry Formation is taken at the base of the lowest substantial (> 1 m thick) lime mudstone bed, above which dolostones are rare. From a distance (e.g., air photos), the contact appears sharp as darker weathering Arnica Formation underlie lighter, more resistant Landry Formation. Morrow (1991) described a gradational contact with Arnica Formation in his study in the northern Mackenzie Mountains.

The upper contact with Hume Formation is rarely exposed in Peel area. At the Hume River type section (LP-02), it is abrupt, marked by a thin black shale bed (Figures 21, 22). It was described as possibly disconformable with Hume Formation by Bassett (1961), and as diachronous (older in the west and younger in the east) by Norris (1985).

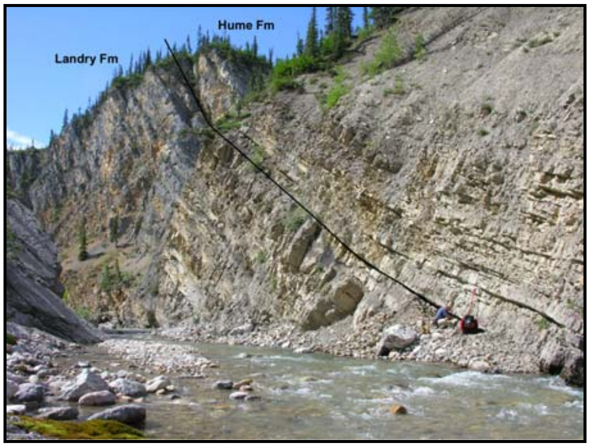

Figure 21. *Landry-Hume Formation contact, view southwest, Section LP-02 (geologist for scale).*

Figure 22. *Lower black shale at hammer head is base of Hume Formation.*

On well logs, the lower contact with Arnica Formation is not usually easily picked. A density log is often useful, as discussed above. The upper contact with Hume Formation is easily delineated by sonic and gamma logs, where the lower argillaceous Hume Formation (gamma high, slow sonic) is abruptly underlain by a clean (low gamma), fast (sonic travel time) limestone (Figure 16). However, west of Snake River, where Hume Formation limestone overlies argillaceous Mount Baird Formation, the opposite log responses might be expected.

Laterally, Landry Formation changes facies with Arnica Formation eastward to Bear Rock breccias and Fort Norman Formation. To the west, Landry Formation shales out to the Dsh unit (= Devonian shale, which is actually argillaceous limestone) in Snake River map area (106 F; Norris, 1982a). Further west within Snake River map area, Landry Formation continues to shale out and is here referred to as Mount Baird Formation (Norris, 1985; see below). Toward Richardson Trough, the formation eventually has basinal equivalents in the Devonian part of the upper Road River Group, but this area was not studied in the current project.

Distribution and Thickness

Landry Formation (and/or equivalent Dsh unit and Mount Baird Formation), occurs throughout Peel area. In the southeast, Landry Formation is less than 20 m thick as it undergoes a facies change to anhydritic rocks of Fort Norman Formation. Landry Formation may not extend as far east as Arnica Formation; at Powell Creek (Section LP-03) and Imperial anticline (Station LP-19c). For instance, there is recognizable Arnica Formation associated with Bear Rock breccia, but not Landry Formation. Landry Formation is 28.7 m thick in Ramparts No. 1 (I-55). To the west and southwest, Landry Formation thickens (Figure 23). Through much of central Peel area, it is 200 m to 250 m thick. The thickness increases to the southwest to more than 600 m (Peel River YT M-69 well, Trail River YT H-37, Peel YT H-71 wells). In the northwest, the formation thins again toward an erosional edge near the Campbell Uplift (Pugh, 1983). The formation does not appear to thin toward the western shelf edge (as Arnica Formation does), but Mount Baird Formation (see below) is included with Landry Formation in well picks, and it essentially represents the shaling out of Landry Formation.

An isopach map for the Arnica plus Landry Formation (Figure 18) for Peel area shows thinning in the extreme southeast (< 100 m) toward a zero edge and thickening to over 600 m just west of the Yukon border. Thinning in the northwest (< 300 m) is also apparent, either toward the northeast deflected platform margin and the erosional edge on flank of Campbell Uplift (Pugh, 1983). The interpreted arch discussed above is apparent in the combined Arnica and Landry isopach in the Arctic Red West G-55, Arctic Red River O-27, and Ontaratue River D-39 wells.

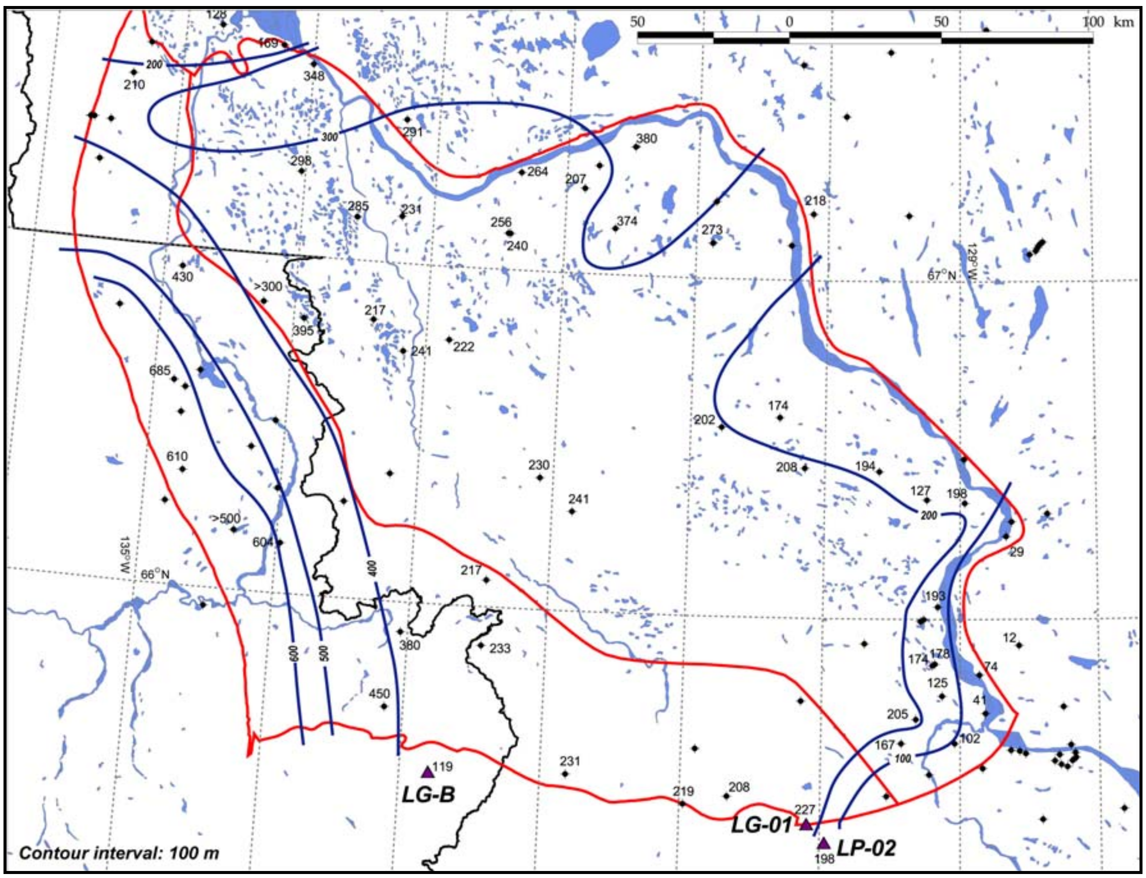

Figure 23. *Isopach map of Landry Formation in Peel area.*

MOUNT BAIRD FORMATION

Mount Baird Formation (Norris, 1985) is a unit of brown to buff-weathering calcareous shale and argillaceous limestone that lies between Arnica Formation or Road River Group and Hume Formation in southwest Peel area. Morrow (1999) grouped the Dsh unit (Norris, 1982a) with Mount Baird Formation. In the present study, Mount Baird Formation is considered the equivalent of Landry Formation (and unit Dsh). It is a unit that becomes increasingly argillaceous as it shales out into the basinal Road River Group at the western margin of Mackenzie-Peel Shelf.

Type Section and Origin of Name

The type section of Mount Baird Formation is section 6 of Norris (1968), just west of Snake River (65° 27-27.5'N and 133° 34-35'W), and a small mesa 3.8 km to the north. Norris (1968) measured 595 m of strata at the type section but may have included overlying Hume Formation, because at the same locality Morrow (1999; his section 32), assigned only 326 m of strata to Mount Baird Formation. The formation was named by Norris (1985) after Mount Baird which is a short distance south of the type section, west of Snake River.

Lithology

Mount Baird Formation was examined (and partially measured) at section LG-E, which is the type locality (Figure 24). The base of the formation is marked by a unit of resistant grey-brown lime mudstone to crinoid-brachiopod wackestone with interbeds of thin- to thick- and wavy- to nodular-bedded, mottled, argillaceous limestone and black shale seams. This basal limestone is overlain by recessive, thin-bedded, grey, argillaceous limestone and limy shale that weathers yellowish grey to brown and platy, with a few resistant thin beds of lime mudstone. Some thickening-up cycles occur. Cross bedding was observed by Morrow (1999).

The yellowish weathering colour and platy to fissile and recessive nature of the outcrop at section LG-E (Figure 25) differentiates it from the grey-weathering, platy and less argillaceous limestone of unit Dsh at LG-C, and light-weathering, resistant, blocky lime mudstones of typical Landry Formation further east in Peel area. The units taken together indicate a progressive shaling of the Landry platform carbonate.

Figure 24. *View southward of Section LG-E, base of section in stream bed near top of photograph.*

Figure 25. *Argillaceous limestone and calcareous shale, Section LG-E, Mount Baird Formation (hammer for scale).*

Contacts and Log Response

At section LG-E, the lower contact with Road River Group and upper contact with Hume Formation were sharp. Norris (1996) reported a disconformable contact with overlying Canol Formation in Snake River map area but Hume Formation was likely included with Mount Baird Formation here.

The formation has not been identified on well logs, as it is grouped with the Landry Formation or equivalents.

Distribution and Thickness

Mount Baird Formation occurs through a relatively small area within Snake River map sheet (106 F; Morrow, 1999), as far east as the headwaters of the Cranswick River (Norris, 1996). Morrow (1999) reported a thickness variation from a feather edge where Landry Formation is mapped furthest west (centre of map sheet 106 F, where it is mapped as unit Dsh), to over 500 m at the west edge of that map area.

FORT NORMAN FORMATION

Fort Norman Formation (Meijer Drees, 1993), south of Peel area, is a unit of anhydrite and dolostone that underlies and is laterally equivalent to Arnica Formation and overlies Tsetso Formation or equivalent (Figure 1). Pugh (1983) recognized the unit in Peel area. In the present study, Fort Norman Formation is considered the evaporite-dominated (interbedded anhydrite, anhydritic dolostone, and dolostone) facies equivalent of Arnica and Landry formations. This facies change occurs over a wide, poorly defined belt. Surface and near surface exposures of thinly interbedded anhydrite and dolostone along the facies change trend have undergone preferential dissolution to create the carbonate collapse breccias mapped as Bear Rock Formation (Morrow, 1999).

Type Section and Origin of Name

The type section of Fort Norman Formation is in the Willow Lake L-59 well, southeast of Peel area. Fort Norman Formation was named by Meijer Drees (1993) after Fort Norman, the previous name for the village of Tulita at the confluence of the Great Bear and Mackenzie rivers. No reference section is proposed in Peel area because the formation is not widely distributed here.

Lithology

The defining feature of Fort Norman Formation is anhydrite (or gypsum in surface exposures). At Section LG-Z1, on the north limb of the Imperial anticline near Stratigrapher Cliffs (Figure 26), a unit of light brown and light grey, thin-bedded, laminated dolostone, thin- to medium-bedded anhydritic dolostone, and thick-bedded laminated gypsum (after anhydrite; Figure 27) is assigned to Fort Norman Formation (mapped as Bear Rock Formation, Aitken et al., 1982).

Contacts and Log Response

The upper contact with Arnica Formation at Section LG-Z1 is sharp and conformable, with recessive anhydritic dolostone of Fort Norman Formation overlain by medium- to thick-bedded Arnica Formation dolostone (Figure 26). This contact is interpreted to represent an interfingering facies change. The lower contact was not observed in outcrop. In the subsurface, Fort Norman Formation unconformably overlies Mount Kindle Formation or sharply overlies Tatsieta Formation/Delorme Group (e.g., Mountain River O-18; Table 2). Density logs should clearly differentiate the evaporite-dominated Fort Norman Formation from carbonate rocks in subsurface sections.

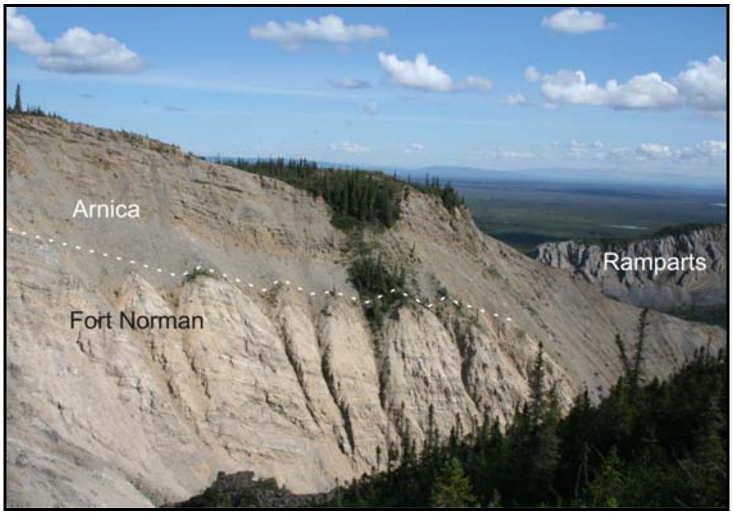

Figure 26. *View northeast to Section LG-Z1 showing light grey weathering Fort Norman Formation (69 m incomplete thickness).*

Figure 27. *Laminated gypsum (after anhydrite) bed above thin-bedded, oil-stained dolostone and anhydritic dolostone, Fort Norman Formation, Section LG-Z1 (lens cap has 8 cm diameter).*

Distribution and Thickness

Fort Norman Formation is restricted to southeastern corner of Peel area. It has been penetrated by only seven wells (Table 2). To the west, the formation gradually changes to Arnica and/or Landry formations. This facies change is expressed in surface exposures as Bear Rock breccia, which occurs in beds in Arnica Formation as far west as Section LG-01, and Manitou Lake L-61 in eastern Peel area.

The thickness of the formation is not well constrained. Small scale, rootless folds in laminated gypsum at Section LG-Z1 indicates that structural thickening and thinning is likely, although these could be sedimentary features (enterolithic-type folding). In the subsurface, the formation ranges from 31.4 m (Hume R. A-53 well) to 122 m thick (Mountain River O-18 well).

Some cores of Arnica Formation in north central Peel area contain anhydritric dolostone (Martin House L-50, Clare F-79, Tree River East H-57). These anhydritic rocks are not assigned to Fort Norman Formation, but maintained within Arnica Formation, perhaps representing localized evaporitic conditions on Mackenzie-Peel Shelf. These interpreted shallow areas coincide with a zone of thinned Arnica Formation deposited on an emergent arch (Figures 17, 18). Cores from Whirlpool No.1 (H-73) do contain anhydrite, interpreted as Arnica/Fort Norman facies transition.

HUME FORMATION

Hume Formation (Bassett, 1961) is a unit of fossiliferous and argillaceous limestone and calcareous shale that lies above Landry or Arnica formations or equivalent (including Bear Rock breccia or Fort Norman Formation in the southeast, and Mount Baird Formation in the southwest). Hume Formation is overlain by Bluefish Member of Hare Indian Formation, or where these are undifferentiated or unrecognized as in western Peel area, by Canol Formation. Hume Formation is the youngest unit of the carbonate succession of Mackenzie-Peel Shelf.

Type and Reference Sections, Origin of Name

The type section of Hume Formation lies in Peel area, on a tributary of Hume River at the Mackenzie Mountains front (65° 20.5’N, 129° 58'W) and was examined during the present study (Section LP-02; Figures 28, 29). Hume Formation was named by Bassett (1961) for Hume River which flows northward, then eastward to Mackenzie River, in southeastern Peel area. Tassonyi (1969) selected Loon Creek No. 1 (H-79) well as a subsurface reference section.

Figure 28. *View north from top of Landry Formation to lower recessive part of the type section of Hume Formation (Section LP-02).*

Figure 29. *Upper resistant part of Hume type section (geologist for scale on bedding plane).*

Lithology

Bassett (1961) recognized five subdivisions at the type section. Tassonyi (1969) favoured a three-fold subdivision due to wide thickness variation of individual units. Pugh (1983) suggested sub-units in the formation are localized and will vary regionally due to abrupt facies and thickness changes.

A more reliable division in the subsurface and in surface exposures is a lower recessive limestone and calcareous shale and an upper resistant limestone. The lower unit is called “Headless Formation” in some industry reports, and is correlative with Headless Member (Meijer Drees, 1993, modified by Pugh, 1993) of Hume Formation in southern Mackenzie Mountains.

At the type section, the lower 72 m of Hume Formation comprises grey, thin- to medium-bedded black to grey shale and laminated lime mudstone to wackestone and packstone interbeds that weather light grey and rubbly. Bedding is irregular, wavy and rhythmic to nodular (Figure 30). Shale is common in the lower part but decreases upward; grainstone beds are common upsection. Two shallowing upward cycles make up the upper part of this unit. The upper 60 m is mainly grey, thin- to thick-bedded lime mudstone to very fossiliferous packstone, with some shale upsection. Bedding contacts are commonly scoured. The topmost bed of Hume Formation is a brachiopod packstone, dominated by *Leiorhynchus* (Lenz and Pedder, 1972).

In general, most sections examined have a lower part that is more thin-bedded, with lime mudstone to wackestone alternating with argillaceous or shaly beds. Bedding is typically nodular, irregular, or scoured. The tops of lime mudstone beds may be planar while the bases are undulose and scoured into underlying recessive argillaceous beds. Iron-stained hardground surfaces are present in the lower unit. Fossil fragments, especially colonial coral heads, are commonly concentrated at the bases of wackestone and packstone beds, and are overturned, which is evidence of transport. Less commonly (e.g., Section LP-14), coral heads and other fossils are undisturbed in life position. Many beds are discontinuous laterally at outcrop-scale.

The upper part of the formation is generally more resistant and contains wackestone, lime mudstone, and packstone, as well as overturned coral heads (Figure 31). Thin shale interbeds and partings between limestone beds are typical. Argillaceous brachiopod packstone beds are typically less resistant than adjacent wackestone beds.

Fossils include colonial corals, brachiopods, solitary corals, crinoids, bryozoans, and cephalopods. Thamnoporids and tabular stromatoporoids occur at Section LG-Z2 (measured section in Pierce and Jones, 2009).

Rare features include breccia beds, dolomitization, siliceous bioclasts, and pyrite replacing fossils. Calcite is common as a fracture filling.

Cyclicity on the scale of 2 m to 10 m is common. These are thickening-up and/or “cleaning-up” (less argillaceous) cycles of a lower, recessive, thin-bedded, nodular and argillaceous limestone that grades upward into more resistant, blocky, medium limestone beds with thin argillaceous seams.

Contacts and Log Response

The lower contact of Hume Formation is sharp and likely conformable, generally marked by black shale beds (Figures 21, 22). Where Hume Formation overlies Bear Rock breccia, the contact is sharp to somewhat gradational, and the lowest Hume beds may be brecciated. In this case, the gradational contact is not depositional.

The upper contact was described as conformable by Bassett (1961) and Tassonyi (1969). Pugh (1983) also favoured an uneroded Hume Formation based on the constant thickness of the formation regionally. Tassonyi (1969), however, suggested erosional surfaces may have been developed locally at the top of coralline-stromatoporoidal accumulations.

From the present study, the contact is an unconformity at all sections in which the base of the lowest bed of overlying Bluefish Member is an erosional scour that downcuts into the upper Hume bed of brachiopod-rich, argillaceous limestone (Figure 32). At outcrop scale, the contact is planar, abrupt, and sharp (Figure 33). This relationship extends from Sections LP-21 westward to LP-14 (Figure 3) and although the erosion is noted on the brachiopod mounds, it is likely more extensive than localized.

Figure 30. *Rubbly weathering, wavy bedded, lenticular lime mudstone with shale interbeds, lower Hume Formation (Section LP-02), hammer for scale.*

Figure 31. *Overturned coral head at arrow, about 25 cm wide, upper Hume Formation limestone and shale interbeds, Station LP-16b.*

Figure 32. *Erosional contact (at hammer head) of Bluefish Member limestone with Hume Formation brachiopod packstone, Station LP-18a.*

Figure 33. *View north to a cliff of upper Hume Formation abruptly overlain by Hare Indian Formation (geologist circled for scale).*

The lower contact is well defined on gamma and sonic logs, as mentioned above. The upper contact in well logs is easily seen in the gamma log (and sonic log) contrast between the highly radioactive Bluefish Member and underlying limestone (Figure 34). Where Canol Formation overlies Hume Formation, the contact is similarly easily resolved by logs.

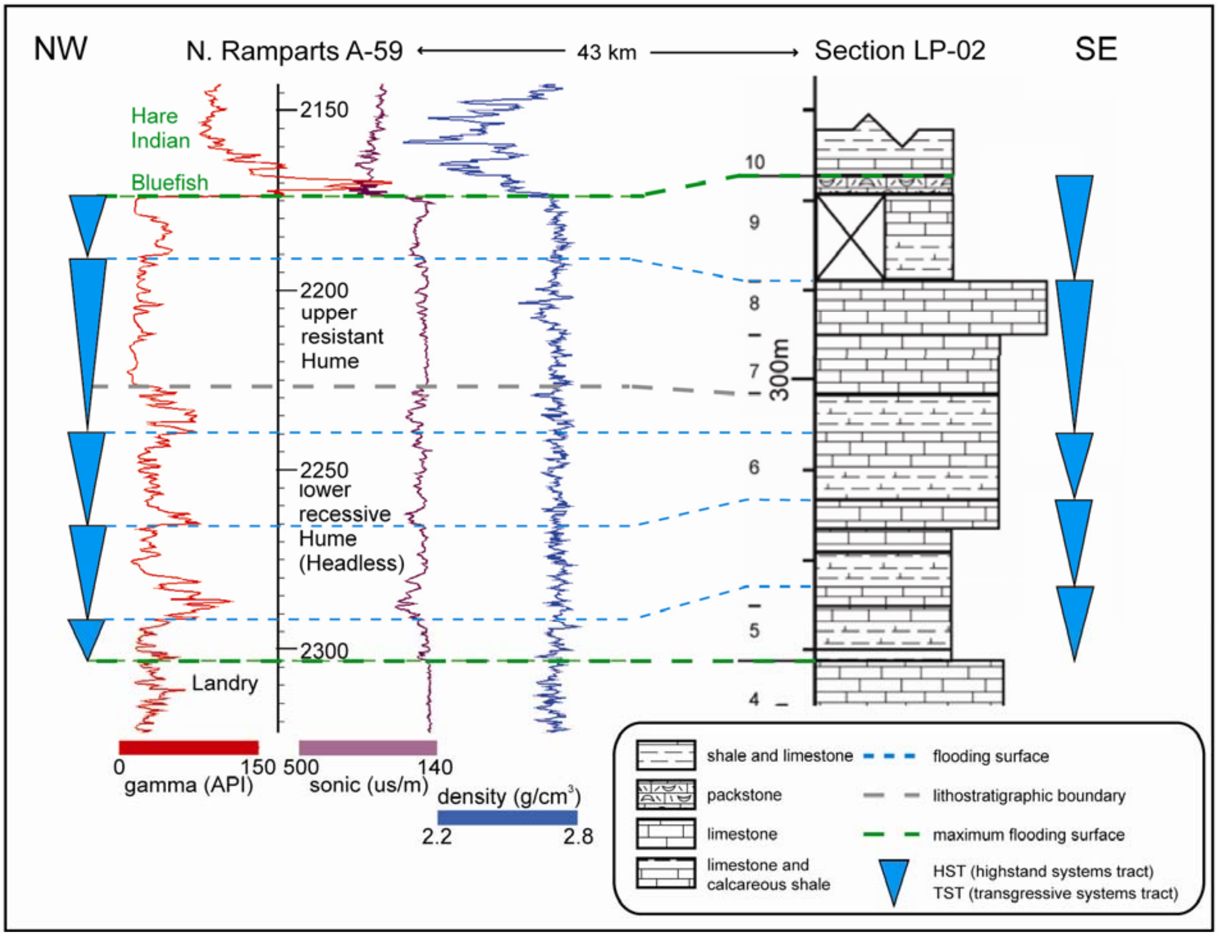

Figure 34. *Log response of Hume Formation and correlation of internal cycles (discussed below).*

Distribution and Thickness

Hume Formation is extensive throughout Peel area. An erosional edge occurs in the northeast corner (Pugh, 1983). In the west, Hume Formation maintains lithological continuity beyond the facies changes in underlying Landry Formation (to Dsh unit or Mount Baird Formation). Thus, the Hume carbonate platform is interpreted to extend further basinward than that of the Landry Formation, before it too "shales out" into Road River Group (Morrow, 1999).

The thickness of the formation is quite uniform through much of Peel area based on measured sections that range from 129 m (Section LP-14) to 146 m thick (Section LP-21). We measured 132 m at the type section (122 m was measured by Bassett, 1961). In the subsurface, the formation thickens to the south and west, from 83 m to 92 m in the Grandview Hills area, to 148 m in Sainville River D-08, 142 m in South Peel D-64, and 166 m in Taylor Lake YT K-15 (Figure 35). A structure contour map of the top Hume Formation shows a southwestward sedimentary and tectonic dip of the basin, with elevation structurally on thrusts in the subsurface of southern Peel Plateau (Figure 36).

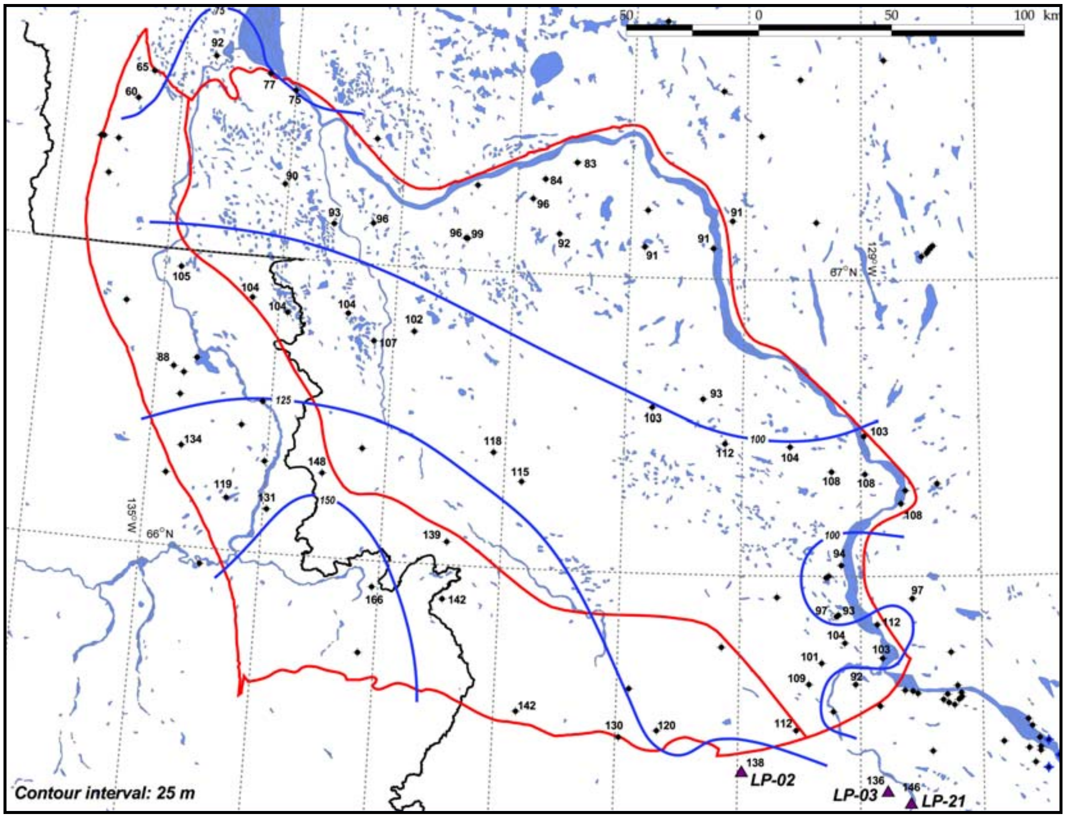

Figure 35. *Isopach map of Hume Formation in Peel area.*

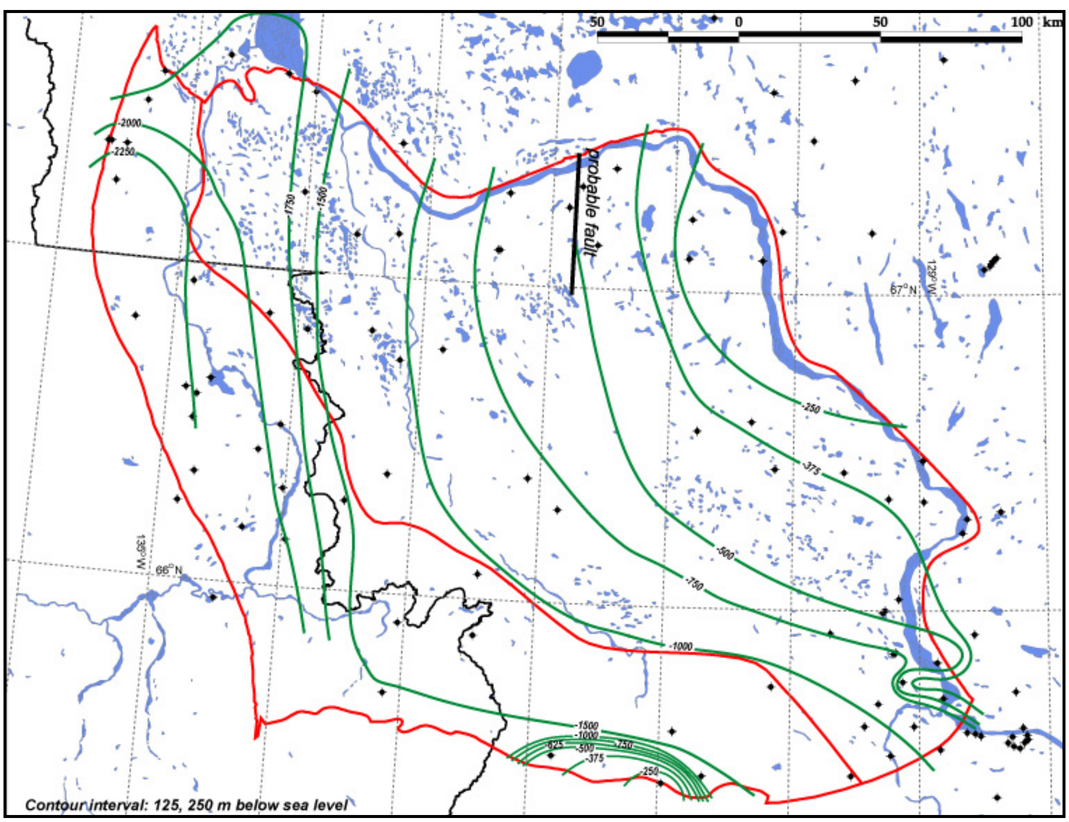

Figure 36. *Structure map of Hume Formation in Peel area.*

HARE INDIAN FORMATION

Kindle and Bosworth (1921) described “Hare Indian shales”, which were later defined as a formation by Bassett (1961). The unit consists of grey or greenish grey, calcareous shale and interbedded limestone that overlies Hume Formation and underlies Ramparts Formation. The basal Bluefish member, proposed by Bassett (1961), is a black to brownish bituminous shale also referred to as the “spore-bearing member” by Tassonyi (1969). Pugh (1983) formalized the Bluefish Member and proposed an informal “Grey shale member” for the upper part of the formation. This nomenclature is adopted in Peel area where Hare Indian Formation consists of a lower Bluefish Member of dark bituminous shale and an upper Grey shale member of green-grey calcareous shale. Hare Indian Formation, together with Ramparts and Canol formations, is part of Horn River Group (Pugh, 1983).

Type and Reference Sections, Origin of Name

The type locality of Hare Indian Formation is in the Ramparts Gorge on Mackenzie River, upstream from Fort Good Hope (Kindle and Bosworth, 1921); however, only the upper 30 m of the formation is exposed (Pugh, 1983). The Bluefish Member type locality is a poor exposure at the confluence of Bluefish Creek and Hare Indian River. Pugh (1983) proposed Powell Creek (65º 10.5’N, 128º 46.5’W) as a type locality due to better exposure. A subsurface reference section was selected by Pugh (1983) at Shoals C-31, where Hare Indian Formation is 29 m thick (Bluefish Member is 13 m thick).

We propose a revised Hare Indian Formation type section at section LP-21 (65º 14.4’N, 128º 35.5’W) on a tributary of Mountain River (Figure 37) where Bluefish Member has better exposure compared with that at Powell Creek. Bluefish Member (25.5 m thick) is exposed in erosional contact with underlying Hume Formation (Figure 38). The upper Grey shale member (28.0 m thick), though not completely exposed, lies beneath Carcajou member of Ramparts Formation and Canol Formation. Bluefish Member consists of thin- to medium-bedded, medium crystalline packstone beds with abundant tentaculitids (Figure 39) and common shale laminae in the basal 6 m. The member contains black, bituminous, fissile shale, some of which is gypsiferous. The upper Grey shale member consists of calcareous shale and lime mudstone that weathers light and dark grey. Thin to medium beds of lime mudstone increase upsection. Medium beds contain brown shale interbeds that are rich in fish scales.

Hare Indian Formation is named for the Hare Indian River, which enters the Mackenzie River north of Fort Good Hope. Bluefish Member refers to Bluefish Creek, a tributary of the Hare Indian River, where Bluefish Member was first recognized (although the exposure here is poor; Tassonyi, 1969).

Lithology

Bluefish Member

Bluefish Member is a black to dark grey, black to grey-weathering shale with thin interbeds of light brown grey to dark and blue grey limestone that weather grey to brown or yellow grey (Figure 40). Wackestone to packstone and rare grainstone interbeds are more common in the lower half of the member, and thicker beds contain shale laminae. The very basal bed is commonly a limestone a few cm thick, or up to 24 cm such as at Gayna River (Station LP-18a; Figure 34). Limestones contain brachiopods, tentaculinids, and fish scales and erosionally overlie upper beds of Hume Formation (Sections LP-02, LP-03, LP-14, LP-21, Station LP-07, Station LP-16b, Station LP-17b, Station LP-18a, and Station LP-21). Thin fibrous calcite beds occur at some locations (Mackenzie, 1972).

Figure 37. *View east of a revised type section (Section LP-21) of the Hare Indian Formation, exposed along a tributary of Mountain River.*

Figure 38. *Sharp, erosional contact (at hammer head) of the basal limestone bed of Bluefish Member and shale of Hume Formation (hammer is 38 cm long).*

Figure 39. *Tentaculitids are common in basal Bluefish Member.*

The black shale is fissile (Figure 41), fetid and petroliferous, slightly or non-calcareous, with some limestone concretions. Tentaculinids and fish scales are common. The shale is commonly gypsiferous, with small radiating gypsum needles on parting surfaces.

Figure 40. *Bluefish-Hume contact at Shortcut Creek (Station LP-18b).*

Figure 41. *Sharp erosional contact (above lens cap) of Bluefish Member black shale over fossiliferous limestone of Hume Formation, Station LP-18b.*

Grey shale member

The Grey shale member was not measured in detail as it is typically recessive, poorly exposed, or covered. It was accessible and well exposed at Section LP-21 (new proposed type section of Hare Indian Formation) where it consists of light grey and yellowish grey, thin- to medium-bedded, calcareous shale and lime mudstone. Westward (Stations LP-07, LP-17a, LP-18a, LP-19c) it consists of micromicaceous, greenish-grey to yellowish-grey weathering, calcareous, finely laminated siltstone, shale, and argillaceous limestone. At Station LP-07, some oil staining was observed in this unit. At Stations LP-18b and LP-19c, the uppermost beds consist of resistant weathering, medium-bedded, burrow mottled limestone interbedded with greenish-grey, calcareous siltstone (Figures 42, 43). There are typically few fossils; brachiopods occurred in the upper part at Station LP-20.

Contacts and Log Response

The lower contact with Hume Formation is everywhere sharp and erosional. The upper contact with Ramparts Formation is gradational, which is especially apparent where Carcajou (shale ramp) member or platform facies of Ramparts Formation is present. The contact between members was not well exposed, but Pugh (1983) describes the transition in the subsurface as a gradual colour change.

The log response of Bluefish Member is distinct, marked by a high gamma spike. There is good contrast on gamma and sonic logs between the radioactive shale and the comparatively clean, blocky limestone of upper Hume Formation (Figure 44). The upper contact of Hare Indian Formation with overlying units is variable, but generally more subtle. In central Peel where Hare Indian Formation underlies Canol Formation, the contact is picked at the base of the higher ragged gamma signature of Canol Formation. Locally there may only be a thin zone of relatively low gamma between the highs of Canol Formation and Bluefish Member. In western Peel area, a

Hare Indian signature cannot generally be resolved. In eastern Peel area, Hare Indian underlies Ramparts Formation. In contrast to limestone dominated Ramparts Formation, the Hare Indian generally has higher and more uniform gamma signature and sonic response typical of shaly beds (Figure 44). Where the Kee Scarp member is developed in Ramparts, it commonly has very high ragged gamma spikes near its base (Carcajou member, etc.). Here the Hare Indian Formation is often thick, with a moderate and even gamma response and sonic response indicative of shale.

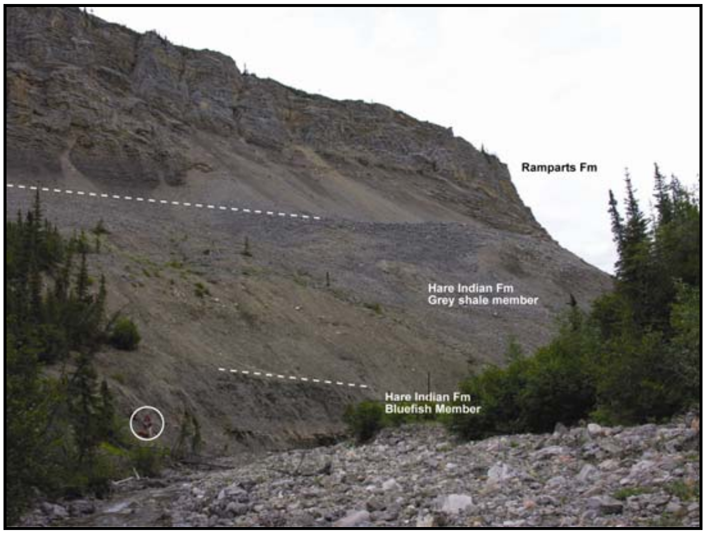

Figure 42. *View northwest to scree-covered Hare Indian Formation (two members) and overlying cliff-forming Ramparts Formation, Station LP-17a, Bell Creek east arm (geologist circled for scale).*

Figure 43. *Limestone and dark grey, calcareous shale of the grey shale member, Station LP-19c (hammer is 38 cm long).*

Distribution and Thickness

In Peel area, Hare Indian Formation extends westward from its type area to Cranswick River area (Figure 45). Black shales of Bluefish Member and Canol Formation form a continuous shale succession up to 200 m thick from Arctic Red River to the Cranswick River area. At the base of this succession, the recessive Bluefish Member is identified by the presence of abundant tentaculitids and Canol Formation by rusty and yellow-weathering, resistant, cliff-forming black shale. The Grey shale member is not present past about 132°W. This westward stratigraphic transition supports the suggestion by Pugh (1983) that the western limit is a depositional edge. Where Hare Indian and Canol formations were undifferentiated in Snake River map area (106 F), Norris (1982a) mapped them as DHCI (with Imperial Formation).

Hare Indian Formation is 165.8 m thick at Powell Creek (Section LP-03, based on Uyeno, 1979) and greater than 195.0 m thick at Gayna Gorge. In the subsurface, complete thicknesses range from 24 m in S. Ramparts I-77 well and 38 m in Arctic Red River O-27 well, to 245 m at Hume River L-09 well in southeast Peel area. Bluefish Member is thickest in eastern and southeastern Peel area (Figure 46), and is on average 12 m thick in outcrop (Muir and Dixon, 1984) and averages 8.4 m in the subsurface (Table 3). A structure contour map of the top Hare Indian Formation shows a southwestward and westward sedimentary and tectonic dip of the basin, and southwestward structural elevation on frontal thrusts in southern Peel Plateau (Figure 47).

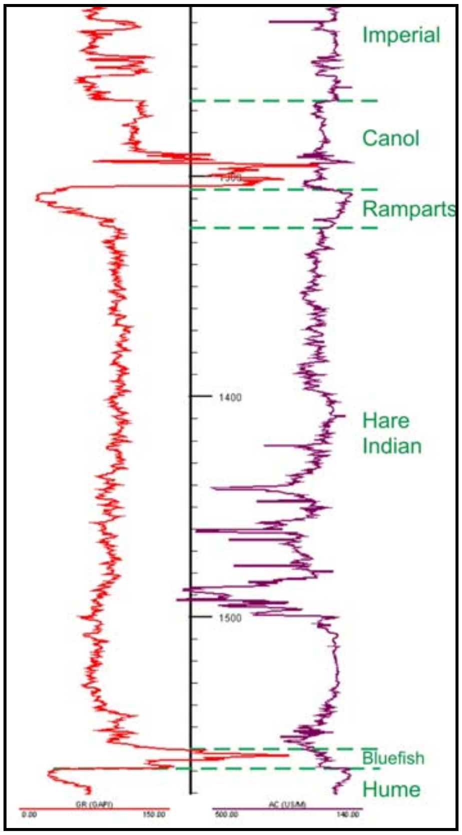

Figure 44. *Log response of formations of Horn River Group, Hume River L-09 well; well depth in m, gamma (red), and sonic interval transit time (purple).*

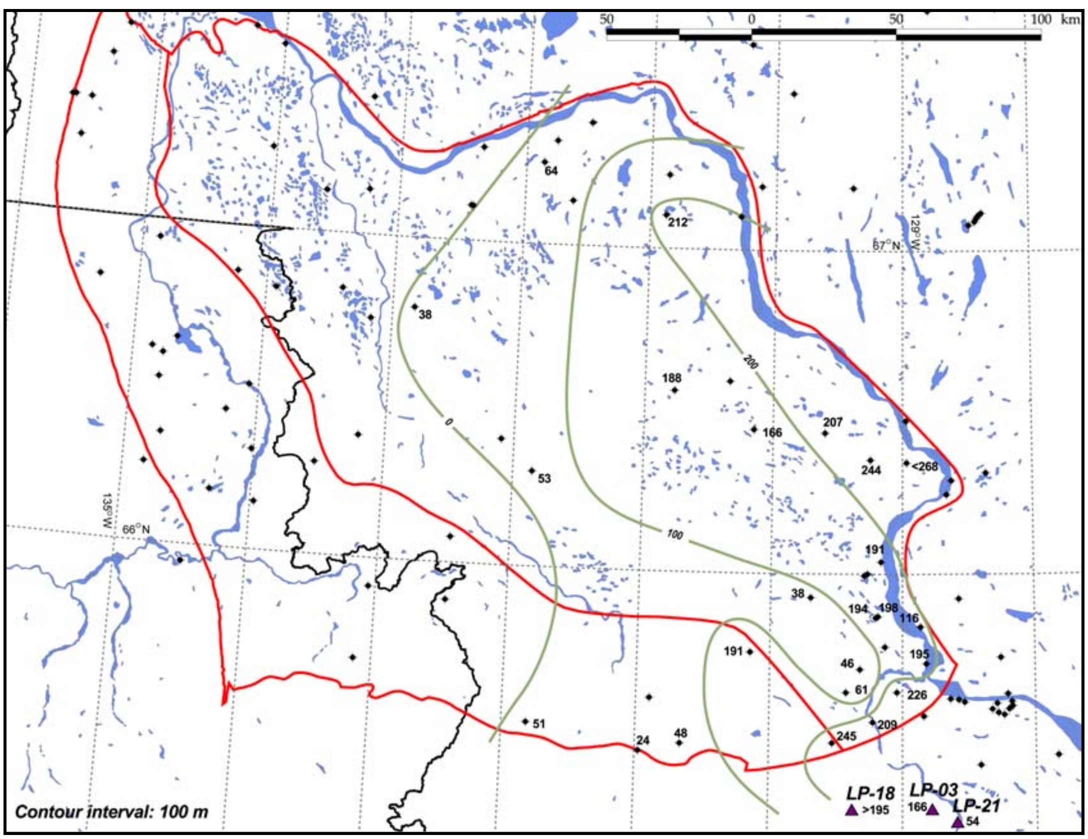

Figure 45. *Isopach map of Hare Indian Formation in Peel area.*

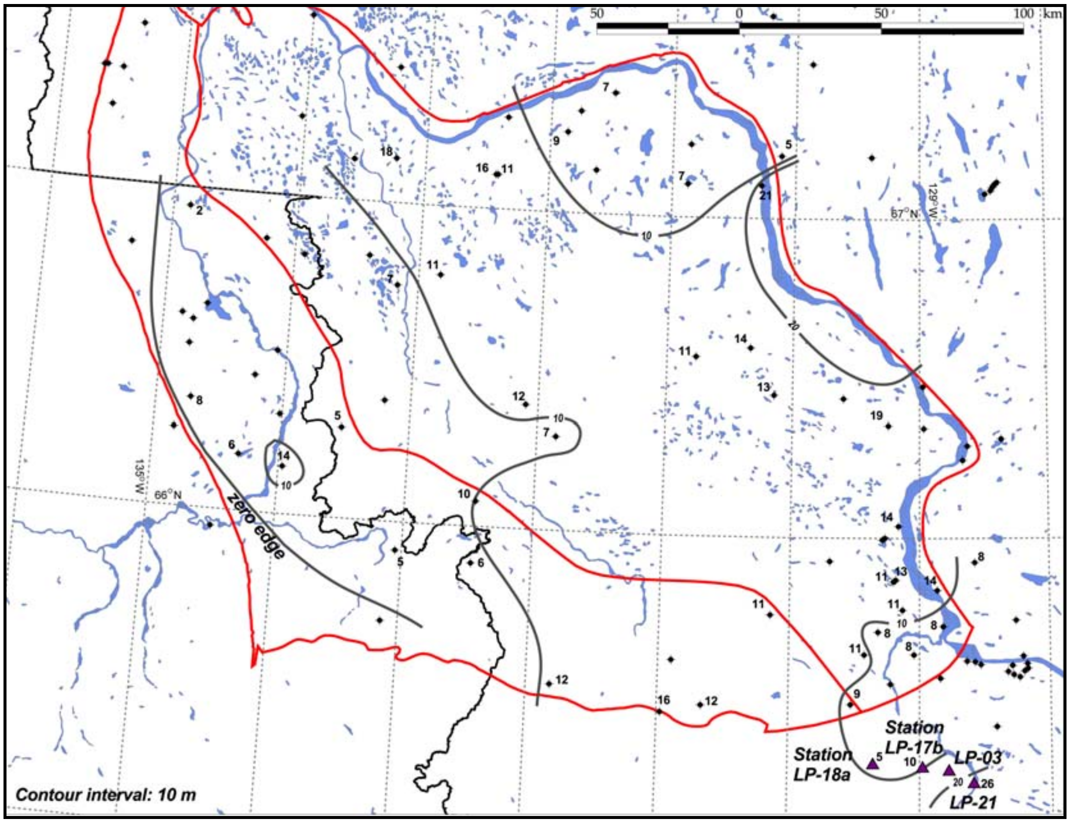

***Figure 46.** Isopach map of Bluefish Member in Peel area.*

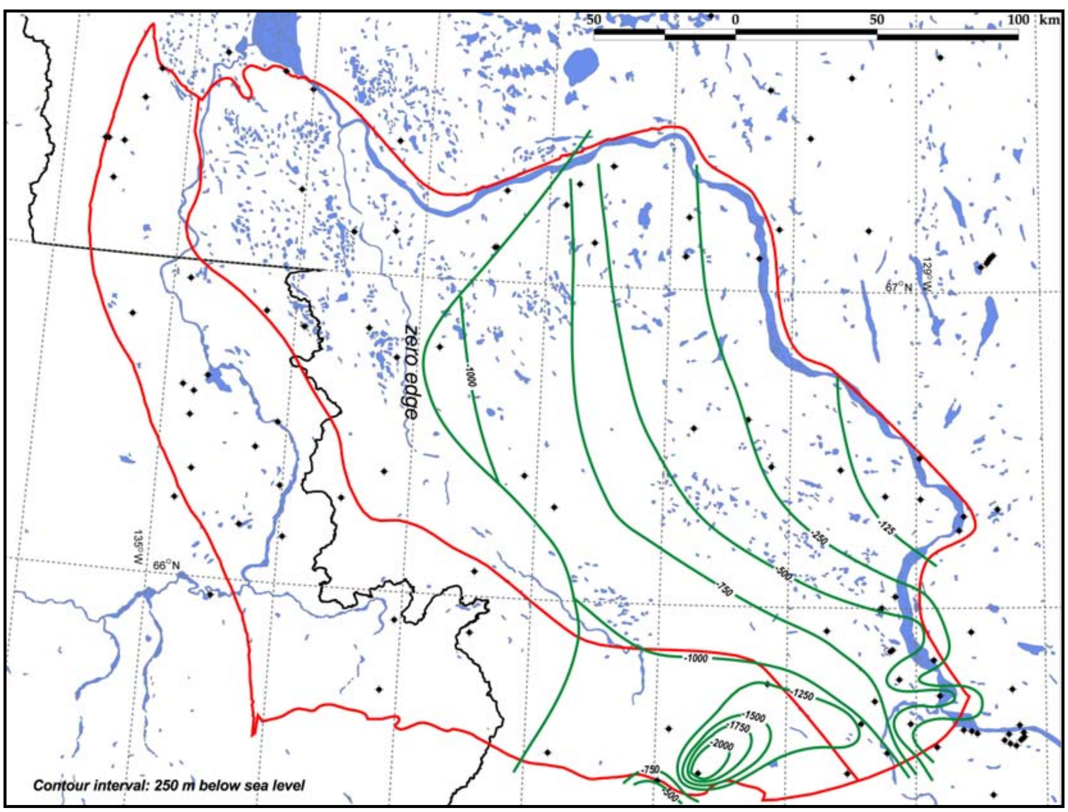

***Figure 47.** Structure map for Hare Indian Formation in Peel area.*

DEFINITION OF RAMPARTS FORMATION

Ramparts Formation (Kindle and Bosworth, 1921) was also called Kee Scarp Formation (Bassett, 1961). Pugh (1983) defined four informal sub-units of the Ramparts Formations: 1) siltstone lentil as a discontinuous calcareous siltstone unit deposited at the periphery of carbonate build-ups and which grades or passes laterally into the platform member; 2) platform member that contains a range of argillaceous to bioclastic limestones, separated from the overlying reef member by the "Carcajou marker" (Tassonyi, 1969; Pugh, 1983); 3) reef member that includes all reef and their interfingering facies; and 4) sandy member that consists of detrital quartz siltstone, very fine-grained sandstone, silty shale, siltstone, and discontinuous beds of silty bioclastic limestone (Mackenzie et al., 1975). Current nomenclature (Jones and Gal, 2007) favours calling the reef member the Kee Scarp member.

The sandy member was mapped as "D4" by Cook and Aitken (1975) and has also been referred to as "Charrue sandstone" by Williams (1986a). The Carcajou marker was described by Al-Aasm et al. (1996) as up to 7.6 m thick of dark grey, pyritiferous, calcareous mudstone, coral floatstone, and carbonate-concretion bearing mudstone and wackestone, lying at the top of the ramp (platform) facies. The term "allochthonous beds" refers to "unnamed beds" (Braun, 1966), allochthonous reef debris, and limestone turbidites (Mackenzie, 1970, 1973), "allochthonous limestone unit" (Pugh, 1983) or "reef debris" (Morrow and Geldsetzer, 1988). The unit was deemed unmappable by Aitken et al. (1982) but represents a transitional unit of reef debris deposited along the Ramparts Formation reef flanks, and is well exposed at Powell Creek (Section LP-03).

Muir and Dixon (1984) and Muir (1988) divided the Ramparts Formation into a lower ramp member (basal shale-ramp facies overlain by platform margin facies), and an upper platform-reef member containing rimmed carbonate platform facies (including Carcajou member) overlain by two reef cycles.

Type Section and Origin of Name

The type section of Ramparts Formation is at the "Ramparts" of the Mackenzie River which is a prominent cliff face 1 km to 2 km southwest of Fort Good Hope (66.198ºN, 129.0ºW; Figure 48). Kee Scarp member is named after the ridge called Kee Scarp in the Norman Range, 9.3 km east-northeast of Norman Wells (65.28 ºN, 126.72ºW; Figure 49).

Lithology

In Peel area, Ramparts Formation was examined at Sections LP-03, LP-21 (Carcajou marker), LG-Y2, and LG-Z3 and at seven stations (Table 1).

At Powell Creek (LP-03), the basal part of Ramparts Formation contains rhythmically interbedded dark grey shale and limestone which are part of the ramp facies (Figure 50). The upper part contains more limestone beds as well as thick-bedded, erosionally-based, sediment gravity flows carbonate debris flows ("allocthonous beds"; Figure 51), black shale laminae and lenses at the base of allochthonous beds, and some bituminous, nodular limestone interbeds. Ramp facies were also examined in the basal Ramparts Formation at Bell Creek (east arm, Station LP-17a; Figures 52, 53) and Gayna River (Station LP-18a) where black, calcareous shale is interbedded with medium-bedded, brown-weathering lime mudstone. At the west arm of Bell Creek (Station LP-17b), similar ramp facies occur and contain limestone slump debris, nodular bedded limestone, and calcareous shale and siltstone.

Figure 48. *"The Ramparts", type locality for Ramparts Formation, view northwest from Mackenzie River.*

Figure 49. *Kee Scarp, the type locality for Kee Scarp member, view south.*

Figure 50. *Geologist at the base of the allochthonous beds, Ramparts Formation, Powell Creek.*

Figure 51. *Stromatoporoid and coral debris in talus of allochthonous beds, Ramparts Formation, Powell Creek (hammer is 38 cm long for scale).*

Figure 52. *Transition from shaly ramp to cliff-forming platform facies in lower Ramparts Formation, Bell Creek, Station LP-17a.*

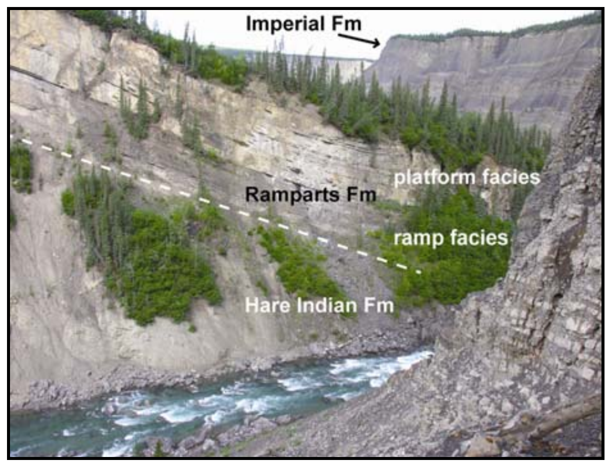

Figure 53. *Ramp and platform facies of Ramparts Formation at Gayna River (Station LP-18a). Canol Formation is only a few metres thick and tree-covered.*

Platform facies are resistant and cliff-forming limestones that were not examined in detail except in talus blocks (Figure 54) and as exposed along Mackenzie River at Carcajou Rock (Station LP-19a; Figure 55). Muir (1988) divided this unit into 12 main subfacies and described the faunas of each. At Section LP-21 (Figure 37), the Carcajou marker, which is part of the upper platform-reef member, consists of dark grey and black shale with interbeds of thin-bedded lime mudstone that weather brownish-grey.

Contacts and Log Response

The lower contact of Ramparts Formation with Hare Indian Formation was described as conformable and gradational by Pugh (1983). The upper contact of Ramparts Formation may be the sub-Cretaceous unconformity or the ultimate drowning of the reef complex by Canol or

Imperial formations (Aitken et al., 1982). Lower transitional shale-ramp facies of Ramparts Formation are gradational with basin margin facies of Hare Indian Formation and these are also in part time-equivalent (Muir and Dixon, 1985).

Figure 54. *Thamnoporid and stromatoporoid rudstone, platform-reef member, Ramparts Formation, Station 17b (hammer is 38 cm long for scale).*

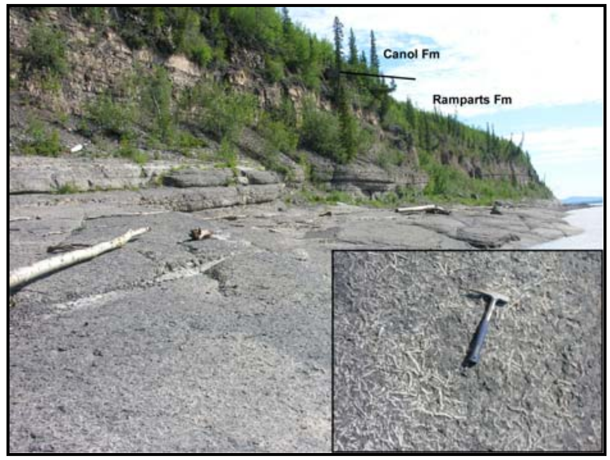

Figure 55. *View southeast along east bank of Mackenzie River toward "Carcajou Rock", a cliff of Ramparts Formation. Inset of bedding plane in foreground which contains thamnoporid rudstone of the platform-reef facies.*

In Peel area, the gradational lower contact was covered where Hare Indian Formation is overlain by the platform member of Ramparts Formation (e.g., Station LP-17a, Figure 42; Powell Creek, Figure 50); however, this lower contact is more abrupt where platform facies are absent and black shale of the Carcajou marker overlies silty limestone in upper Hare Indian Formation (Figure 37). In this study, the upper contact with Canol Formation is sharp at Sections LP-03, LP- 21 and Stations LP-19b and LP-20, but gradational over a few metres at Powell Creek.

Log responses of the lower contact of Ramparts Formation with underlying Hare Indian Formation were discussed above. The upper contact with Canol Formation is very distinct on gamma and sonic logs. A high, spiky gamma of basal Canol shales abruptly gives way to Ramparts limestone which has a rather blocky sonic log signature in the upper part of the formation (Figure 44).

Distribution and Thickness

Ramparts Formation outcrops in Peel area from east and west of the Mackenzie River (Stations LP-19a, 19b), to the western part of San Sault Rapids map area (just west of Gayna River, Station 18b). The formation is only 8-12 m thick where exposed at the nose of Imperial anticline (Greenwood, 1969). The western edge is a depositional zero edge (Pugh, 1983), and measured thicknesses up to 157 m, between Bell and Powell Creek have been reported (Greenwood, 1969; Figure 56).

In Peel area, Ramparts Formation occurs in 22 wells. Hogue and Gal (2008) differentiated Kee Scarp member only in Mountain River O-18 (Table 3), but it is more widespread. The thickness in the subsurface varies from 5.4 m in S. Ramparts I-77 well to 232 m in Mountain River A-23 (Figure 56). A structure contour map for the formation shows a southwestward sedimentary and tectonic dip in Peel area (Figure 57).

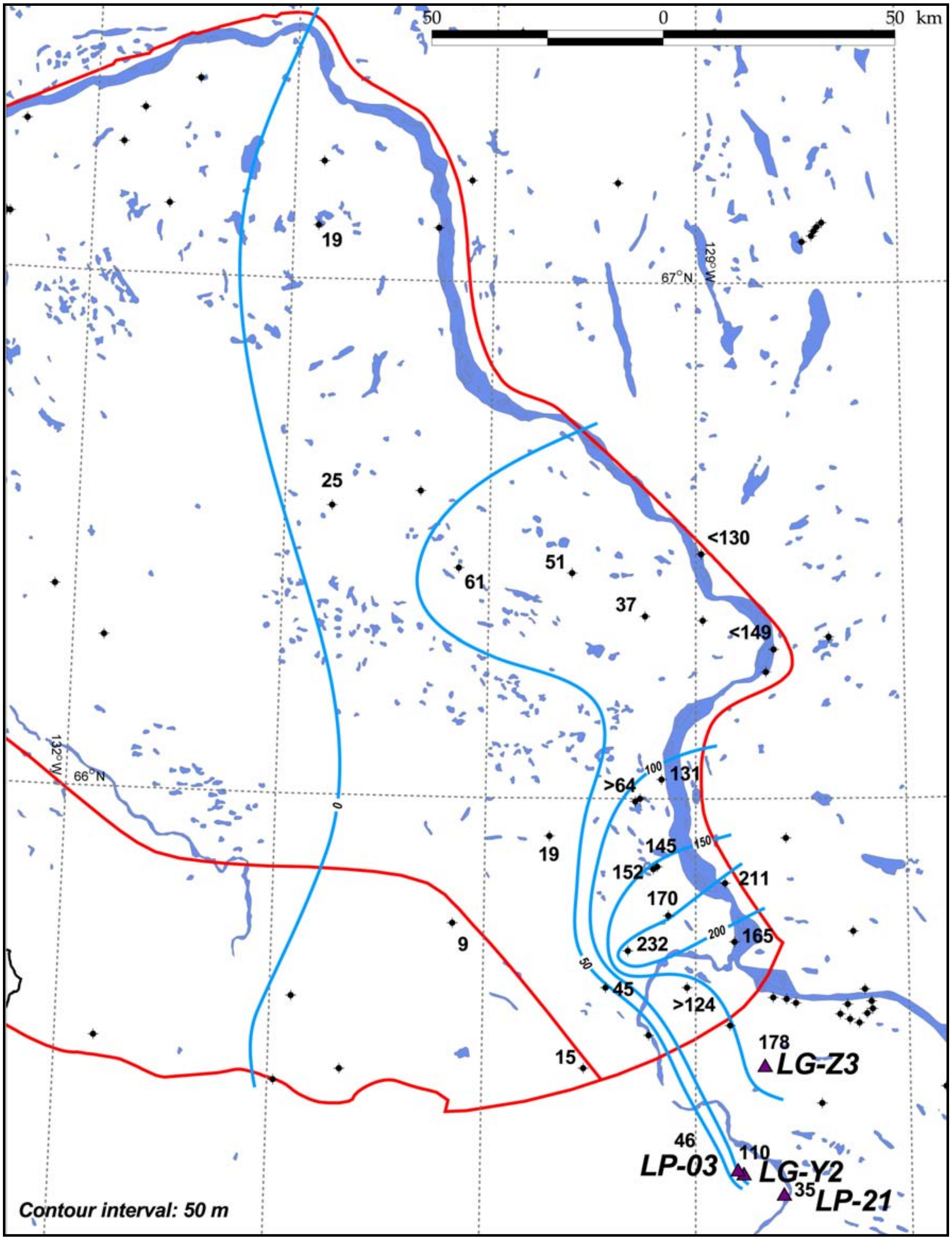

Figure 56. *Isopach map of Ramparts Formation in Peel area.*

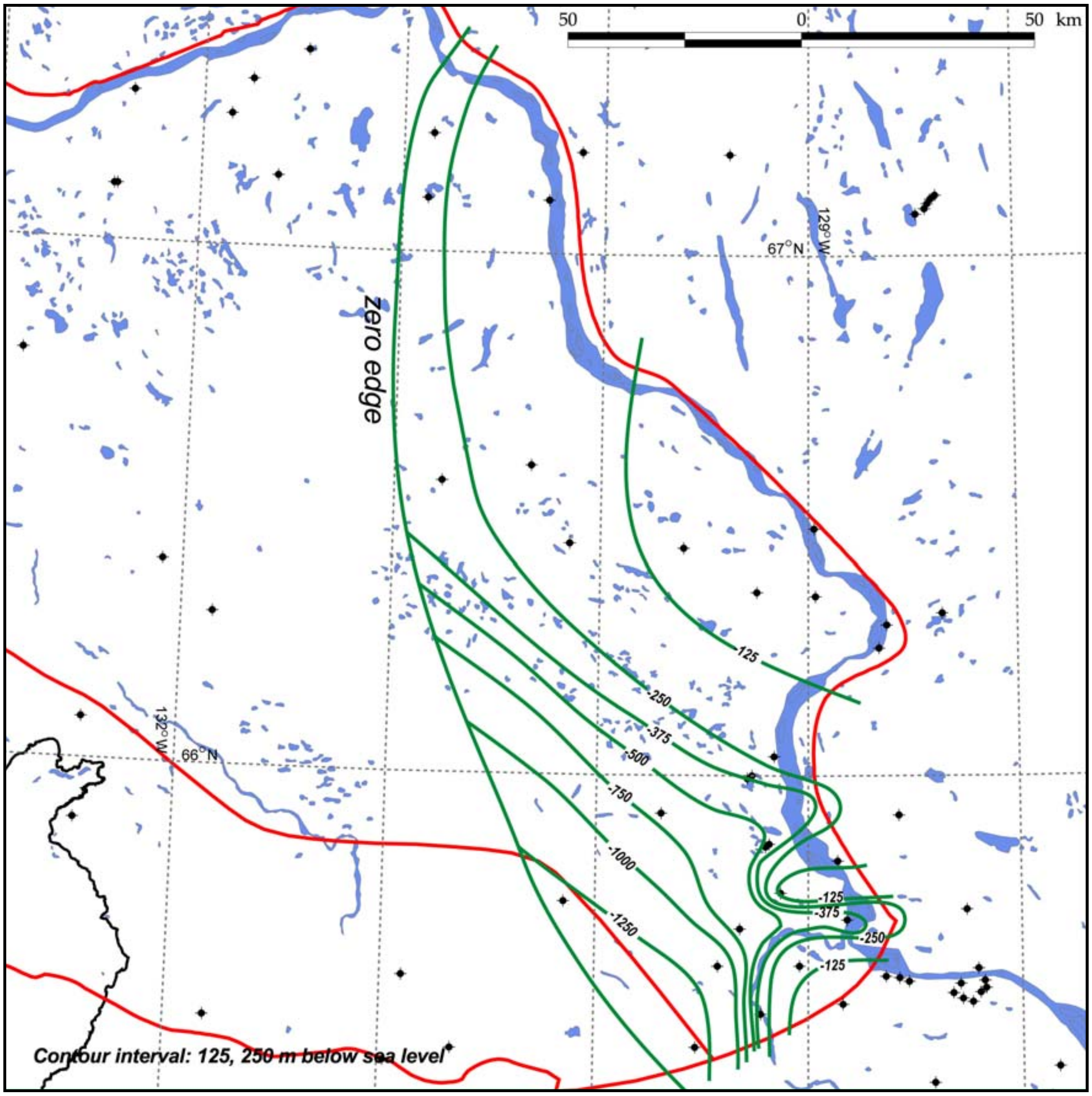

Figure 57. *Structure map of the Ramparts Formation in Peel area.*

CANOL FORMATION

Canol Formation is defined as the black shale unit that overlies either Ramparts Formation, or where this is absent, Hare Indian Formation (Bassett, 1961). In western Peel area, where Hare Indian and Canol formations were mapped previously as an undifferentiated shale succession, Canol Formation is distinguished from the tentaculitid-bearing Bluefish Member of Hare Indian Formation. Canol Formation is overlain by Imperial Formation or is truncated by the sub-Cretaceous unconformity. Tassonyi (1969) defined informal lower, middle and upper members.

Type Section and Origin of Name

The type section of Canol Formation is along the northwest side of Powell Creek (65.28 ºN, 128.77ºW; Figure 58) as defined by Bassett (1961). The formation was named after camp Canol on the Mackenzie River across from Norman Wells.

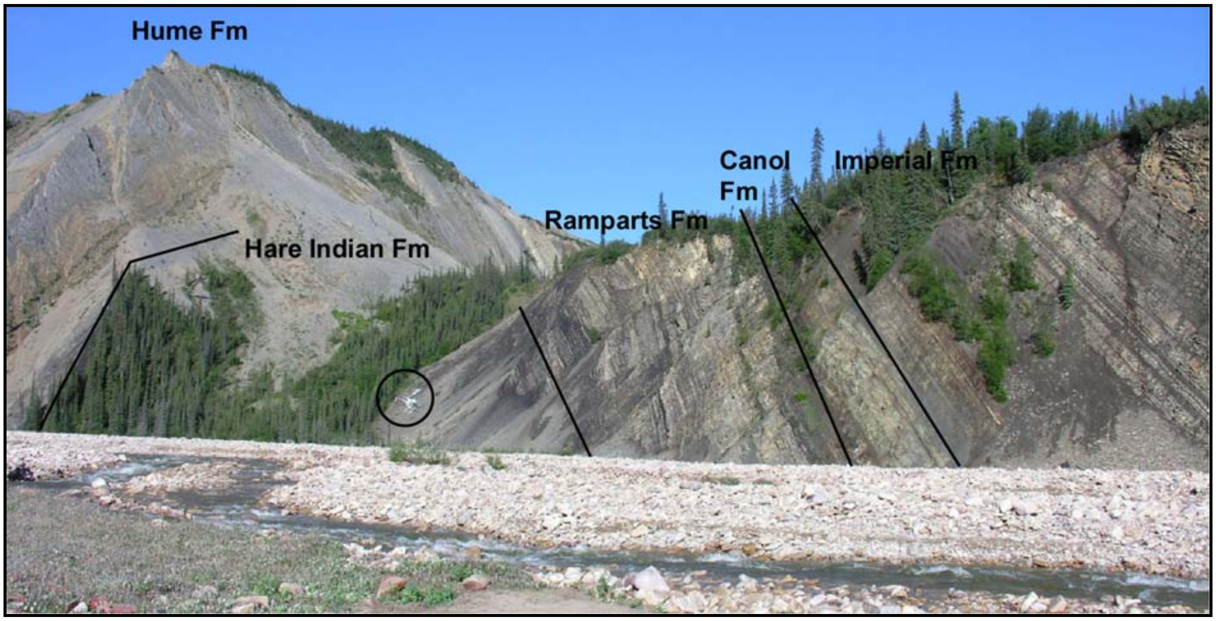

Figure 58. *Type section of Canol Formation, northwest side of Powell Creek (Section LP-03); helicopter circled for scale).*

Lithology

Organic-rich, black, siliceous shale of Canol Formation is more resistant than shale of underlying Hare Indian Formation and also contains chert, mudstone with carbonate concretions, calcisiltite, and graded crinoidal grainstone (Muir and Dixon, 1984). At the type section in Peel area, Canol Formation consists of dark grey to black shale that weathers sulphur-yellow due to jarosite (Aitken et al., 1982) and thin-bedded siltstone with common calcareous concretions (Figure 59). At Section LP-21 (Figure 37), the formation consists of light brown and black shale, rare interbeds of medium grey, finely laminated, lime mudstone and fetid, silty lime mudstone.

Canol Formation strata crop out along the western and eastern flanks of the Richardson Mountains as mapped by Norris (1981a, b) on Trail River (106 L) and Eagle River (116 I) map sheets. In the present study, Canol Formation strata were measured on Tetlit Creek, a tributary of the Road River and Trail River, and examined on Road River (measured sections in Pierce and Jones, 2009). Canol Formation at these exposures forms meandering canyons of cliff-forming black, organic-rich siliceous shale interbedded with black chert. Shale and chert are coated with a distinctive apple-green to yellow patina. Chert beds, up to 20 cm thick, are separated by thinly to thickly laminated shale that ranges from sooty to well indurated (Figure 60; Allen and Fraser, 2008). Mineralization (pyrite?) is common as both thin laminae and nodules up to 25 cm across, creating a rust weathering colour. Barite nodules occur at Trail River (Morrow, 1999).

Contacts and Log Response

The nature of the lower contact of Canol Formation is a contentious issue (Pugh, 1983). Muir and Dixon (1984, 1985) suggested Canol Formation to be both time-equivalent and younger than Ramparts Formation. Alternatively, Norris (1996) maintained that the base does not interfinger with underlying Ramparts Formation but variably overlies the Hume Formation, Hare Indian

Formation, Ramparts Formation or allochthonous beds, Mount Baird Formation, or Road River Group in Richardson Trough. Norris (1996) and Pugh (1983, 1993) suggested the upper contact with Imperial Formation is sharp but conformable. Alternatively, Yose et al. (2001) illustrated basin-equivalent shales of Canol Formation as time-equivalent in part with Imperial Formation. Morrow (1999) suggested Canol Formation of Richardson Trough represents a condensed section and that no unconformity at the base of Canol Formation was apparent (Figure 61).

Figure 59. *Canol Formation shale weathers black and yellow and contains large concretions (at arrows), Powell Creek.*

Figure 60. *Close up of Canol Formation on Trail River showing the nature of the chert and shale interbeds. Hammer for scale is 30 cm long.*

Figure 61. *Sharp and conformable contact of Canol Formation with underlying Road River Group (informal Vittrekwa formation of Cecile et al., 1982), Trail River map area (106 L).*

Canol Formation is generally readily distinguishable from overlying siliciclastic units (Imperial Formation or Cretaceous units) in gamma logs by its high, ragged response (Figure 44). In outcrop from Peel area, high gamma black shales of Canol Formation are overlain by an approximately 20 m thick shale interval of Imperial Formation characterized by relatively low gamma, brown, and recessive weathering (Figure 62). Overall the formation has a high gamma response throughout, but in subsurface logs in western Peel area, there are often discrete gamma highs at the top and the base of the formation. In this case, the lower gamma spike probably corresponds to Bluefish Member as observed in outcrop.

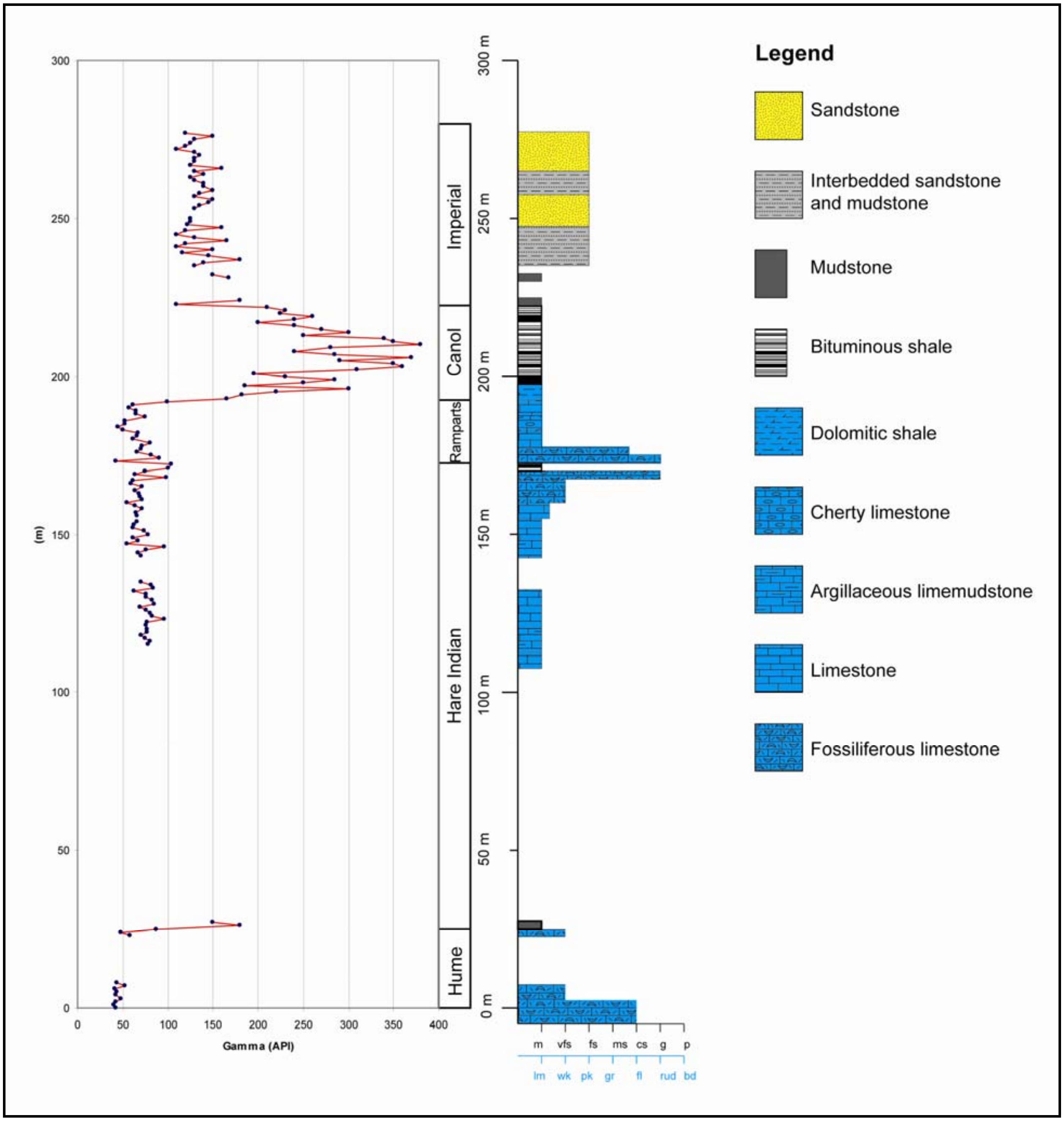

__Figure 62.__ Section 07-TH-31, top of Hume Formation to lower Imperial Formation. Hand-held scintillometer was used for gamma ray profile, measurements were taken at 1 m intervals.

Distribution and Thickness

Canol Formation crops out along the front of the Mackenzie Mountains to Snake River area and along the east and west flanks of the Richardson Mountains. It is 16.2 m thick at its type section (Uyeno, 1979) and 93.3 m thick at Section LP-21. Canol Formation is penetrated by 50 wells in Peel area (Table 3) and ranges in thickness from 5 m (Hume River D-53 well, where it is probably eroded somewhat on sub-Cretaceous unconformity) to more than 100 m (Ontaratue River D-39). It thickens in central Peel area and also westward in Richardson Trough (Figure 63), where on Trail River (east flank of the Richardson Mountains), the formation is 220 m thick. A structure contour map for the formation shows a southwestward and westward sedimentary and tectonic dip in Peel area, and structural elevation in southern Peel Plateau (Figure 64).

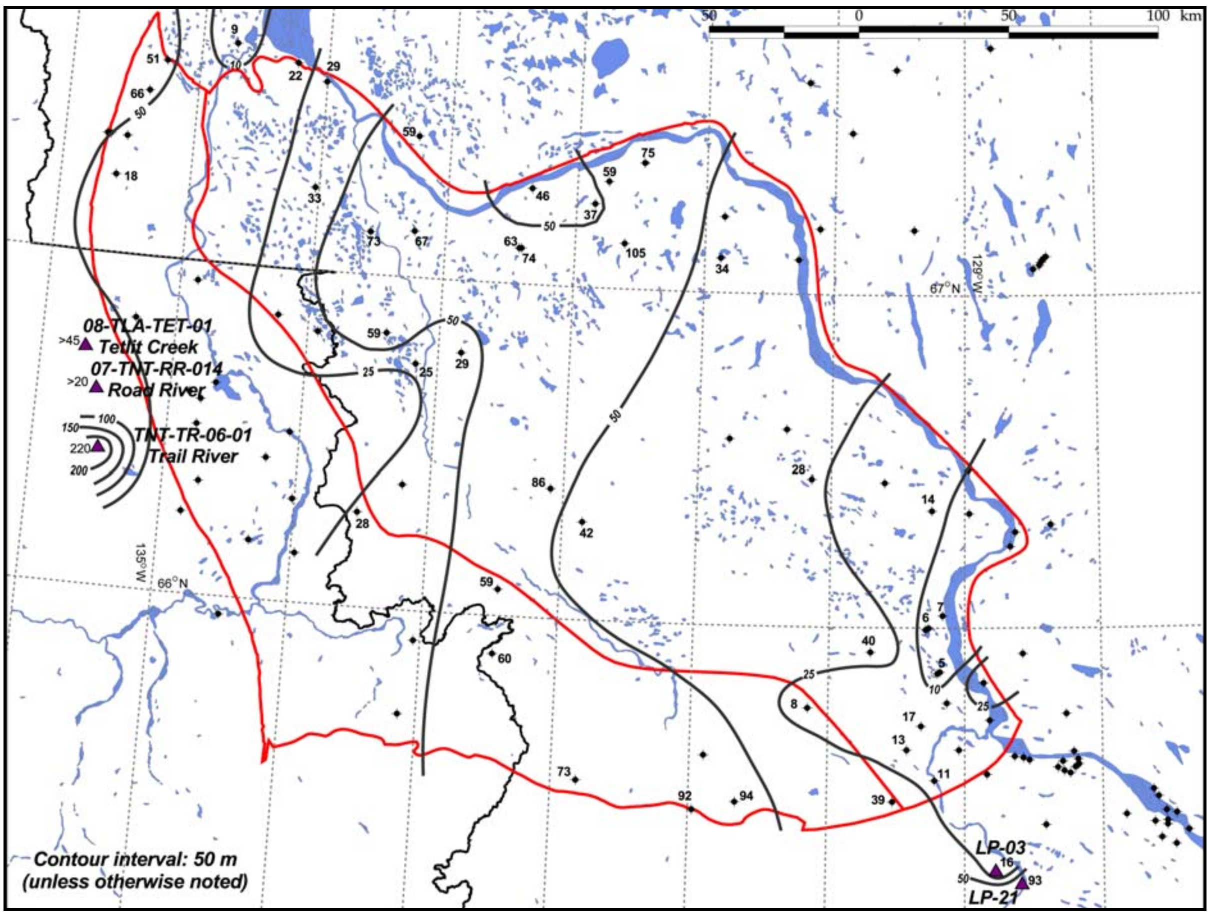

Figure 63. *Isopach map of Canol Formation in Peel area.*

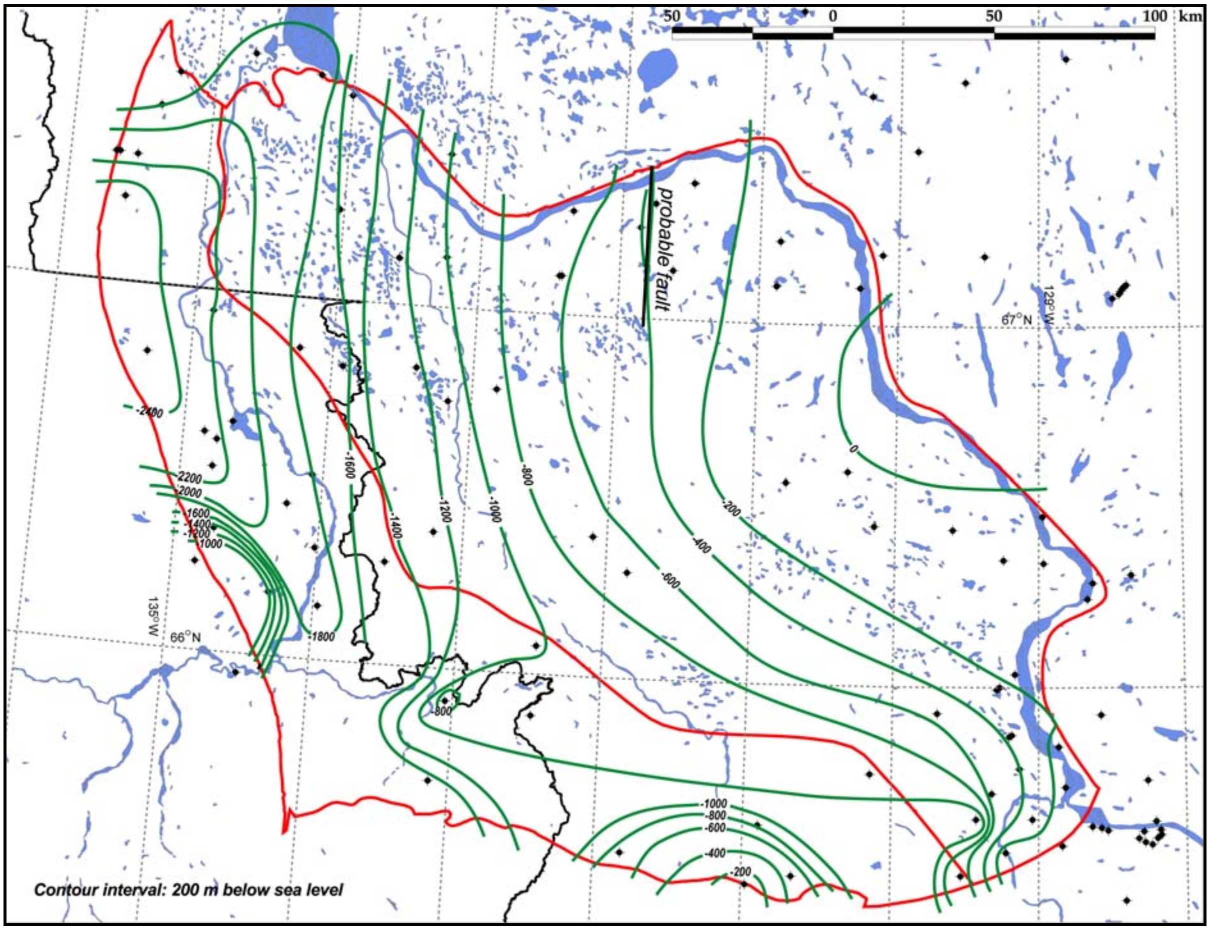

Figure 64. *Structure map of Canol Formation in Peel area.*

PALEONTOLOGY AND AGE

Arnica to Hume Formations Succession

Arnica and Landry formations are more fossiliferous toward the shelf edge, where biohermal limestone, crinoids, and brachiopods occur in Arnica Formation and corals occur in Landry Formation (Section LG-B). Conodonts from three sections of Arnica Formation (LG-A2, LG-A4, LG-B) suggest ages ranging from Early Devonian (Late Emsian) to early Middle Devonian (early Eifelian) and possibly to latest Middle Devonian (Figure 1, Table 4). This is similar to the age of Arnica Formation in southern Mackenzie Mountains, (late Emsian to early Eifelian; Chatterton, 1979). Fossils are rare in Bear Rock breccia. Northeast of Peel area, an ostracod reported from Colville Hills by Cook and Aitken (1971) suggested a Middle Devonian (Eifelian) age. South of Peel area, an early Eifelian age for the upper part of Bear Rock breccia was determined from conodonts by Chatterton (1979). The age of the Fort Norman Formation is not known.

The age of Landry Formation is late Early to early Middle Devonian (late Emsian to early Eifelian; *serotinus* to *costatus* conodont zones; Table 4). This is consistent with a late Emsian to early Couvinian age reported in the northern Mackenzie Mountains by Morrow (1991) and with those reported by Chatterton (1979) in the southern Mackenzie Mountains.

Conodonts collected from Mount Baird Formation (Section LG-E) suggest an Early Devonian (Emsian) to possibly Late Devonian age (Table 4). Morrow (1999) suggested the formation was Eifelian or younger which is consistent with findings from the present study.

Conodonts from the base of Hume Formation (Section LG-D) are early Middle Devonian (early Eifelian) in age. A spot sample from Flyaway Creek (fault repeat of Hume Formation, above measured section LP-14), returned a late Early to early Middle Devonian age (latest Emsian to early Eifelian; *patulus* to *costatus* zones). Samples from near the top (Section LP-21) yielded an age range of Middle to early Late Devonian (mid-Eifelian to early Frasnian; *costatus* to lower *asymmetricus* zones) and from Station LP-07, a late Middle Devonian age is suggested (early to mid-Givetian; *ensensis* to middle *varcus* zones; Table 4). These ranges are similar to those given by Uyeno (1991) at Powell Creek (our section LP-03), and from the southern Mackenzie Shelf (lower Eifelian to possibly Givetian; Chatterton, 1979).

Diverse fossils of the Hume Formation were described in a number of studies (e.g., Bassett, 1961; Warren and Stelck, 1962; McLaren, 1962; Pedder, 1964, 1975, 1982; Norris, 1968; and Chatterton, 1979).

Sample	GSC location #	Section/ Station	Formation	Metreage	easting	northing	Age or Zone	CAI
06LP-07-06	C-473010	Station LP-07	Canol	base	131d18.463m	65d24.509m	probably early Late Devonian (Frasnian; Zone 1), or late Givetian to Zone 4 (disparilis to lower asymmetricus zones)	--
06LP-21-09	C-473032	LP-21	Canol	28.3	128d35.536m	65d14.438m	early Late Devonian (early Frasnian; punctata to hassi zones, Zones 5-10)	--
06LP-19-06	C-473027	Station LP-19A	Ramparts	ca. 30 m	128d25.406m	65d36.793m	late Middle Devonian (mid-Givetian; lower hermanni Zone) to early Late Devonian (early Frasnian; Zones 1 to 4)	--
06LP-07-03	C-473008	Station LP-07	Hare Indian	base	131d18.548m	65d24.465m	late Middle Devonian (mid-Givetian; middle varcus Zone)	--
LP-05-R10 & 10A	C-455052, C-455053	East Hume R.	Hume	top	129d57.588m	65d20.361m	Early to Middle Devonian (Emsian-Eifelian; patulus to costatus zones)	2
07LG-7-H	C-477014	LG-D	Hume	base	133d19.731m	65d29.763m	early Middle Devonian (early (Eifelian)	2
06LP-07-04	C-473009	Station LP-07	Hume	top	131d18.548m	65d24.459m	late Middle Devonian (early to mid-Givetian; ensensis to middle varcus zones)	--
06LP-21-05	C-473031	LP-21	Hume	ca. 145 m	128d35.677m	65d14.381m	early Middle to early Late Devonian (mid-Eifelian to early Frasnian; costatus to lower asymmetricus zones)	--
LP-05-S4	C-455033	Flyaway Creek	Hume	top	132d02.053m	65d26.710m	late Early to early Middle Devonian (latest Emsian to early Eifelian; patulus to costatus zones)	5
07LG-8-A	C-477015	LG-E	Road River Gp	1.5	133d34.817m	65d27.241m	early Middle to latest Middle Devonian	2
07LG-8-D	C-477016	LG-E	Road River Gp	55.5	133d34.846m	65d27.302m	Devonian	2

Sample	GSC location #	Section/ Station	Formation	Metreage	easting	northing	Age or Zone	CAI
07LG-8-F	C-477017	LG-E	Mount Baird	3	133d35.058m	65d27.401m	Early to Late Devonian	4
07LG-8-I	C-477018	LG-E	Mount Baird	middle	133d35.250m	65d27.584m	Early Devonian (Emsian)	4
LP-05-R8	C-455050	Rumbly Creek	Landry	middle	131d24.937m	65d22.917m	late Early to early Middle Devonian (late Emsian to early Eifelian; serotinus to costatus zones)	2
07LG-10-H	C-477023	LG-A4	Landry	base	132d35.340m	65d30.530m	early Middle Devonian (early (Eifelian)	2
07LG-10-I	C-477024	LG-A4	Arnica	198.5	132d35.289m	65d30.437m	early Middle Devonian (early (Eifelian)	2
07LG-4-E	C-477004	LG-A2	Arnica	214	132d30.809m	65d30.736m	Early Devonian (Late Emsian) to latest Middle Devonian	2
07LG-6-J	C-477009	LG-B	Arnica	241.7	132d47.408m	65d30.591m	Early Devonian (Late Emsian) to latest Middle Devonian	2

Table 4. *Ages or zones based on conodont samples, and conodont colour alteration indices (CAI) for select samples (from McCracken, pers. comm. and 2008, Uyeno, 2008).*

Horn River Group

Conodonts from the base of Bluefish Member at Station LP-07 yielded a late Middle Devonian age (mid-Givetian; middle *varcus* Zone; Figure 1, Table 4). Conodonts from the upper Hare Indian Formation suggested a range from lower *varcus* Zone to *hermanni* Zone (Uyeno in Muir, 1988). Macrofossils from Hare Indian Formation are Givetian in age (Tassonyi, 1969; Lenz, 1972).

One conodont sample from Ramparts Formation at Carcajou Ridge (Station LP-19a) suggested an age range of late Middle Devonian (mid-Givetian; lower *hermanni* Zone) to early Late Devonian (early Frasnian; Zones 1 to 4; Table 4). Samples through Ramparts Formation in the northern Mackenzie Mountains indicated an age range from lower *varcus* to lowermost *asymmetricus* zones (Givetian to early Frasnian; Uyeno in Muir, 1988).

Conodonts from Canol Formation at Station LP-07 yielded an age suggesting early Late Devonian (Frasnian; Zone 1), or late Givetian to Zone 4 (*disparilis* to lower *asymmetricus* zones), and those from 28 m above the base of Canol Formation at Mountain River (Section LP-21) yielded an early Late Devonian age (early Frasnian; *punctata* to *hassi* zones, Zones 5-10; Figure 1, Table 4). Conodonts from the lower part of Canol Formation at Powell Creek and Hume River also indicated a Frasnian age (Lenz and Pedder, 1972; Braun et al., 1989).

FACIES DISTRIBUTIONS AND STRATIGRAPHIC CORRELATION

Arnica to Hume Formations Succession

Arnica and Landry formations form an extensive package of carbonate rocks across Peel area, and undergo a facies change westward and southward to shale-dominated equivalents in Richardson Trough and Selwyn Basin (Mount Baird Formation and Road River Group). These formations shallow in northcentral Peel area in a region where there may have been an emergent arch in the Devonian (Figure 65). The formations also shallow and thin to the southeast; this is marked by the occurrence of Bear Rock breccia and Fort Norman Formation. In general, Arnica and Landry formations thicken westward and southwestward (Figures 17, 18, 23); the region of thickest Arnica Formation in central Peel area lies further east than the thickest Landry Formation, which may thicken westward at the expense of Arnica Formation as part of a facies transition.

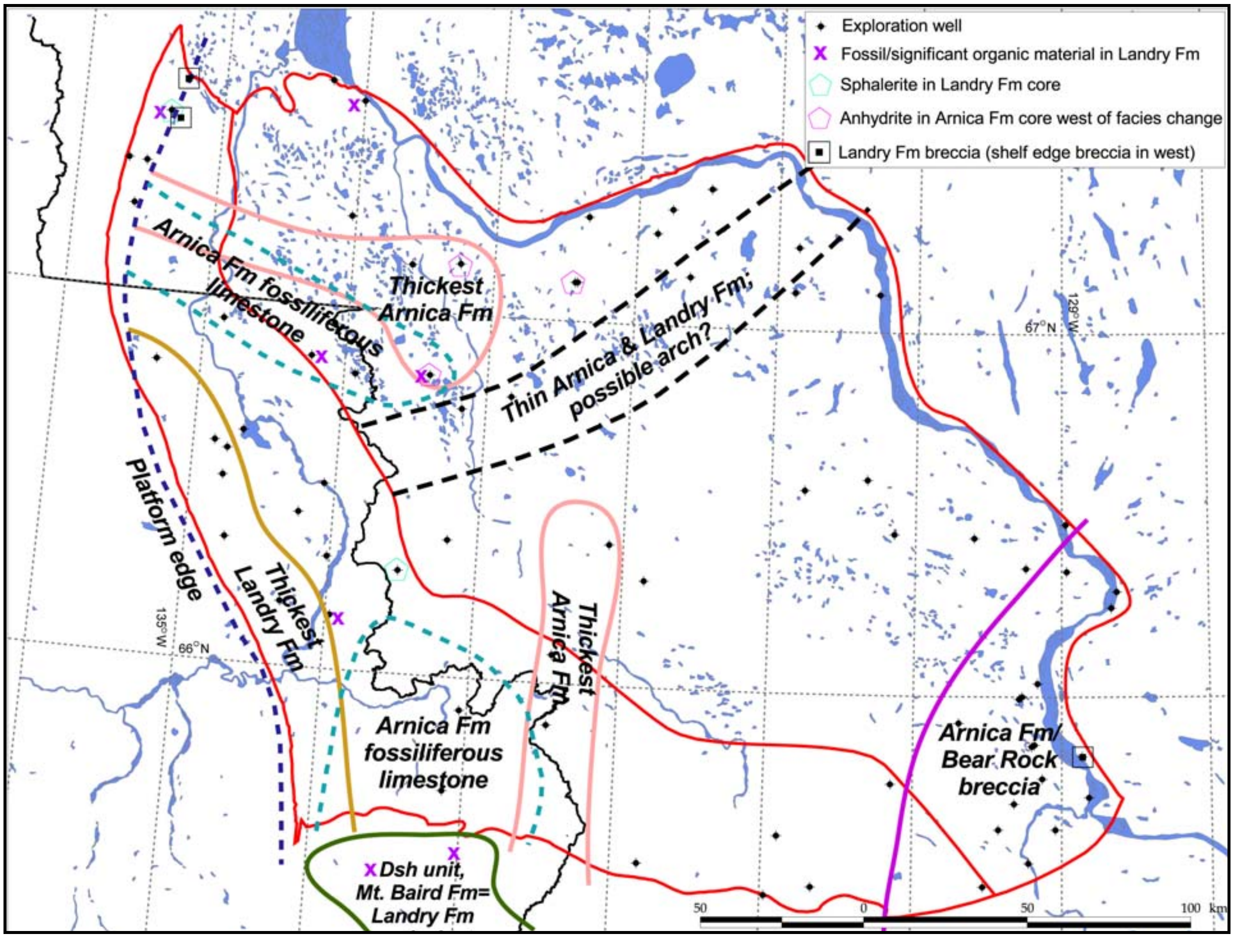

***Figure 65.** Facies map of Arnica and Landry formations in Peel area.*

An east to west cross-section across the northern Mackenzie Mountains from new measured sections illustrates facies changes within Arnica Formation from Bear Rock breccia at Powell Creek (Section LP-03), to dolostone dominated, cyclical subtidal/intertidal facies (See Figure 10 for detail), to biohermal limestone in western sections (Sections LG-B2, LG-D2; Figure 66). Internal correlation of Arnica Formation is difficult due to these facies changes, but the depositional setting generally changes from restricted marine in the east to open marine in the west. Arnica Formation sits on a transgressive surface, marking relative sea level rise from peritidal conditions of underlying Delorme Group. The basal part of Arnica Formation may be interpreted as a transgressive systems tract, with a flooding surface and early highstand deposits represented by an increase in open marine faunas and bioherm development in the western sections. Intertidal and subtidal-dominated facies pass upward to lime mudstone of Landry Formation which likely represents restricted marine conditions.

Hume Formation is also extensive across Peel area and maintains a fairly constant thickness (Figure 35). From eastern sections (LP-21, LP-03) to Section LP-14, there are two general divisions in the Hume Formation: a lower shaly part and upper thick bedded limestone part (Figure 67). The upper part of Hume Formation becomes recessive and shaly in western sections (LG-E, LG-D2, LG-C; sections in Pierce and Jones, 2009) and westward of Peel area, the upper part of the Hume is poorly developed and thins over Mount Baird Formation to merge with Road River shales (Morrow, 1999). Brachiopod-rich mud banks developed locally at the top of the Hume Formation (Sections LP-21, LP-03, LP-02; Figure 67). The sharp but conformable contact with the Landry Formation is interpreted as a transgressive surface. The lower, argillaceous limestones rich in fossils are interpreted as a transgressive systems tract, and the upper beds represent highstand deposits. The erosional upper contact with the Bluefish Formation is a regional erosional surface, possibly a transgressive surface of erosion merged with a flooding surface.

Horn River Group

Hare Indian and Ramparts formations are restricted to eastern Peel Plain area, and Canol Formation is fairly continuous across Peel area (Figures 45, 46, 56, 63). Bluefish Member is a useful marker, representing a flooding surface and onset of basinal deposition (Figure 68). Hare Indian Formation in the subsurface thickens east toward Mackenzie River and thins westward to a zero edge west of Arctic Red River. In outcrop, the Grey shale member thickens where ramp facies of Ramparts Formation are present (Muir, 1988), such as up to >150 m at Bell Creek and >180 m at Gayna River. Two distinct lobes of thick Grey shale member are discernible from the isopach map: a southwest trending one in the Mountain River area, and a north-northeast trending one along the Mackenzie River (Figure 45). Williams (1985) indicated this trend and isopach maps of Pugh (1983) illustrate the north-northeastern lobe. These lobes may represent prograding banks from a single divergent, or two distinct siliciclastic point sources. This member also becomes siltier westward, but has some darker shale in the east such as at Powell Creek and Mountain River.

Lower transitional shale-ramp facies of Ramparts Formation are gradational with basin margin facies of Hare Indian Formation and these are also in part time-equivalent (Muir, 1988). Dark shale dominated facies of this shale ramp occur in the Bell Creek and Powell Creek sections (Figures 52, 53), and in Mountain River O-18 well (Figure 68). The Carcajou marker (Tassonyi, 1969) is a particularly recessive interval that Muir and Dixon (1984) placed at the top of their shale ramp and below the platform member and is also picked in the O-18 well (Figure 68). In Peel area, the Kee Scarp reef facies present at Norman Wells do not occur in outcrop (but are picked in O-18 well, Figure 68); however, there are reef facies (Williams, 1985) at Bell Creek, Powell Creek west, and Carcajou Ridge (Stations 17a, b; LG-Y2, and LP-19a) that abruptly thin westward (Figure 69). Allochthonous facies are limited to Powell Creek area, and the Charrue sandstone is limited to northeastern Peel area (Figure 69).

Canol Formation is fairly continuous across Peel area, with an average thickness of 45.0 m, but generally thickens westward (Figures 68, 70). Its facies variations were not studied in detail. At sections where the Ramparts platform facies was thick, the overlying Canol Formation was only a few metres thick (e.g., Gayna River and Bell Creek).

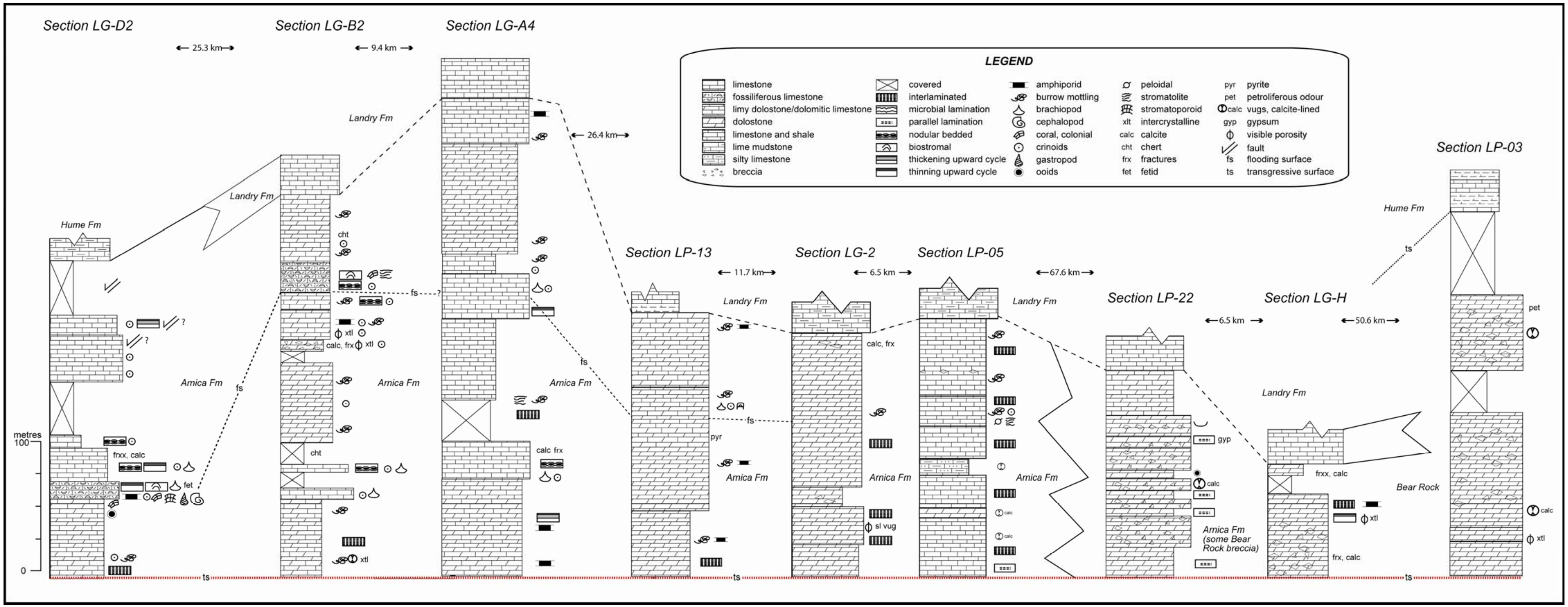

Figure 66. An east to west stratigraphic cross-section of Arnica Formation (and Bear Rock facies) across the northern Mackenzie Mountains (see Figure 3 for section locations).

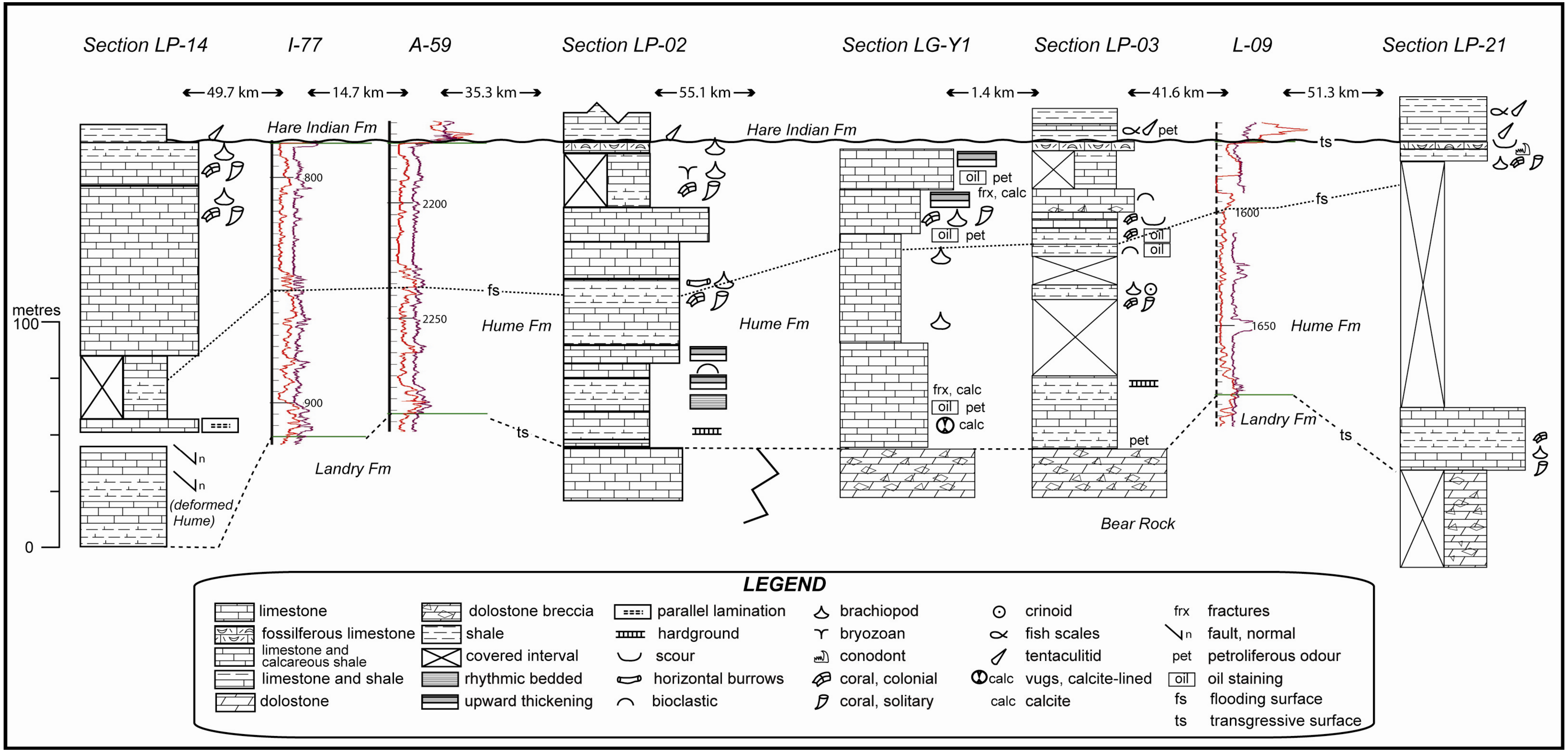

Figure 67. *An east to west stratigraphic cross-section of Hume Formation across the northern Mackenzie Mountains (see Figure 3 for section locations; log responses for select wells include gamma in red and sonic in purple).*

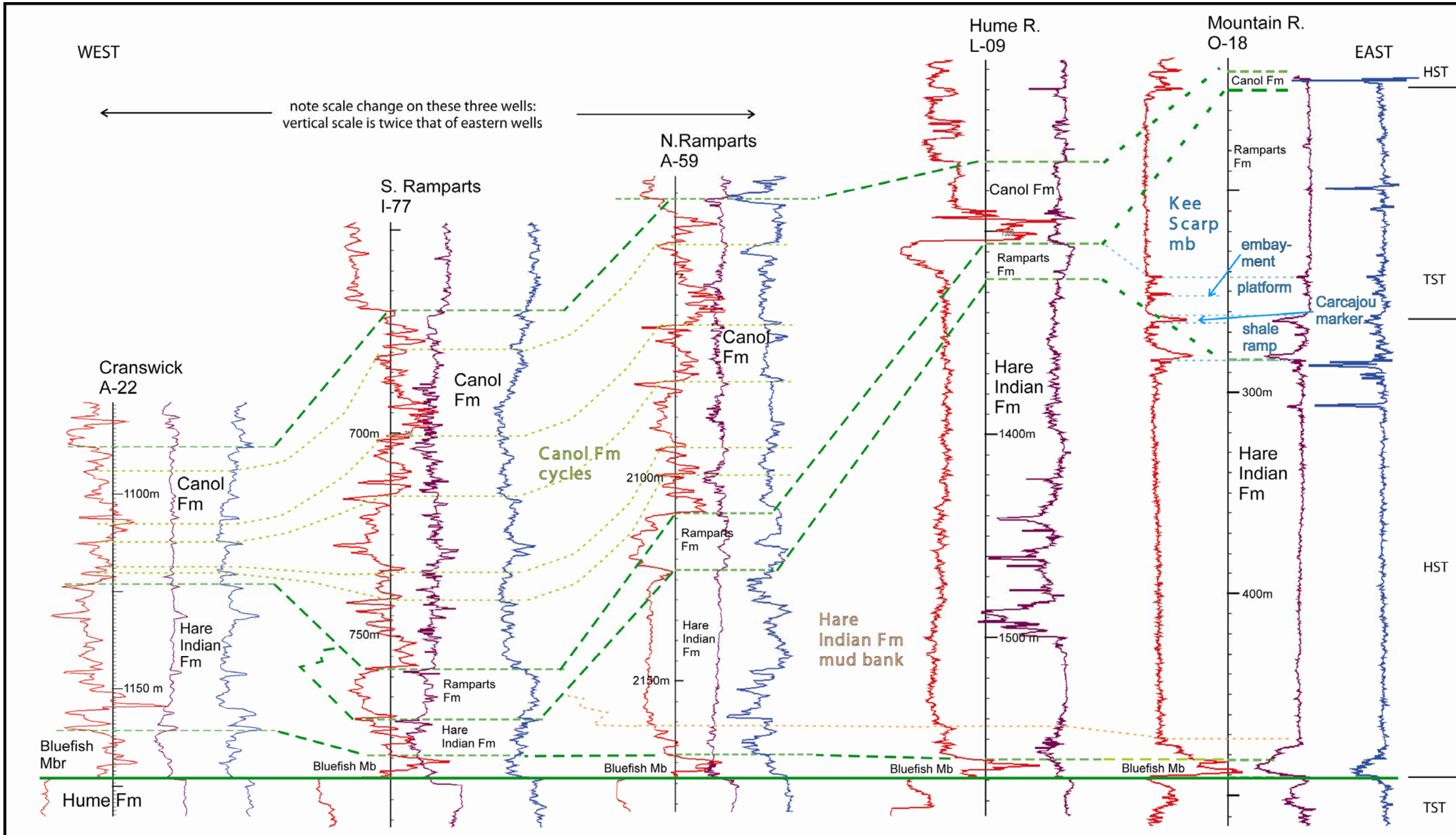

Figure 68. *Subsurface correlation from Mountain River O-18 to Cranswick A-22, showing the log responses (gamma in red, sonic in purple, density in blue) of formations within the Horn River Group (TST = transgressive systems tract; HST = highstand systems tract).*

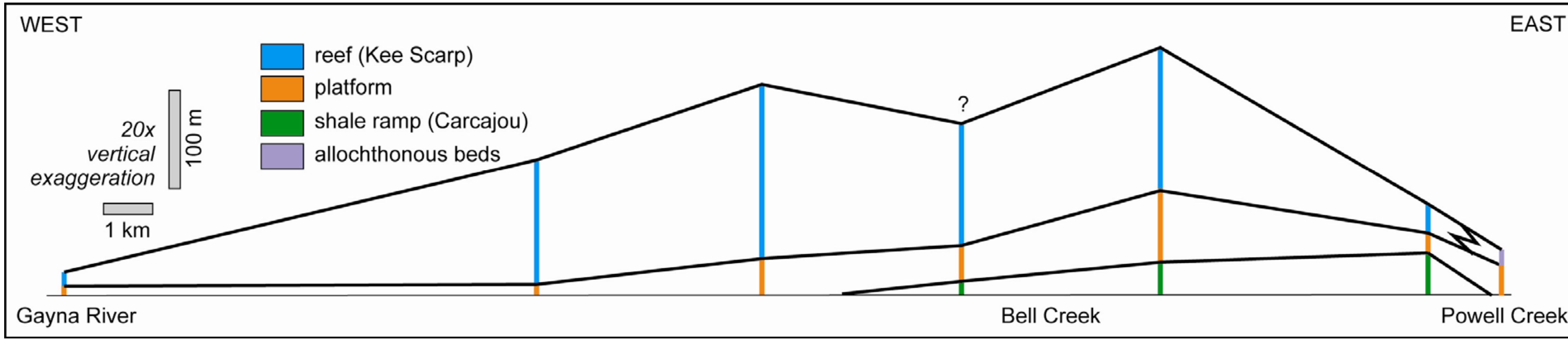

Figure 69. *Westward thinning of Ramparts Formation facies between Powell Creek and Gayna River (Section LP-03 and Station LP-18a, Figure 4).*

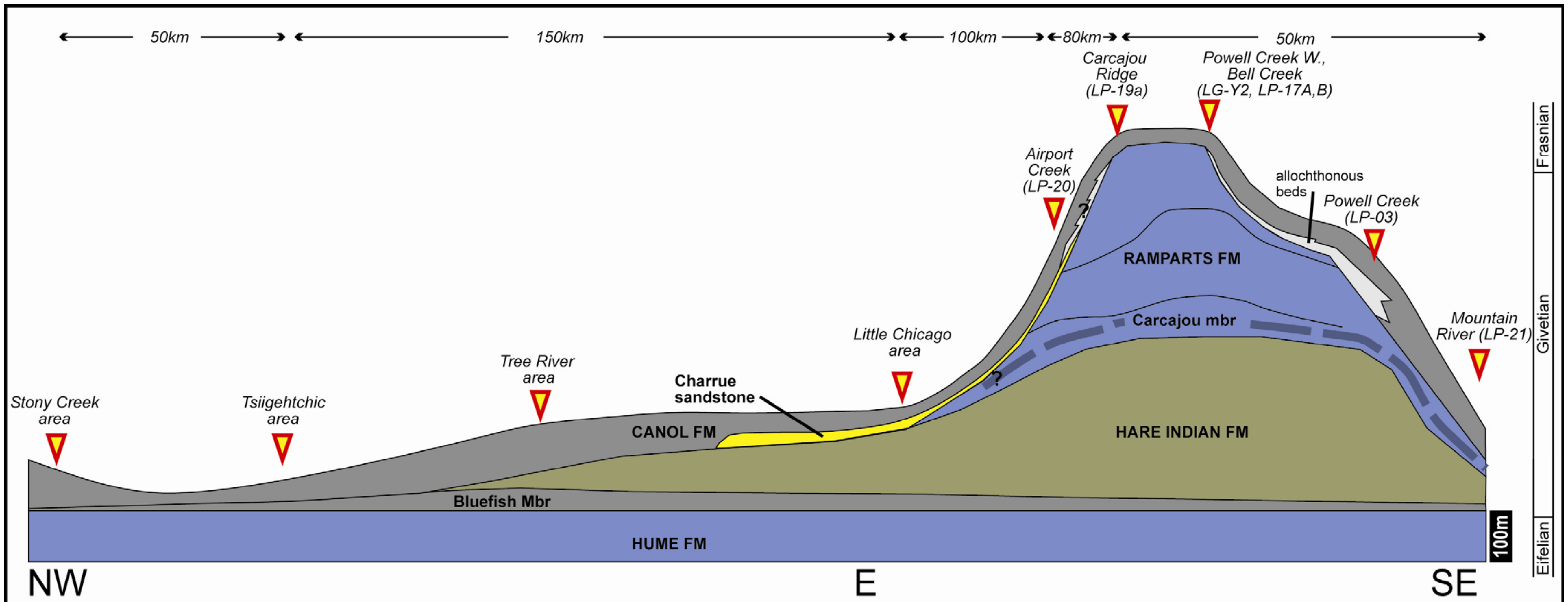

Figure 70. *Schematic distribution of Horn River Group facies in Peel area, from southeast to east to northwest showing westward thinning of the Hare Indian Formation, eastward isolation of the Ramparts Formation and its reef facies, and continuity of Canol Formation.*

Correlation of Horn River Group based on sequence stratigraphy follows the two large-scale, second-order sequences interpreted by Yose et al. (2001) in the Norman Wells area in which the upper Hume is part of a transgressive systems tract (TST); Bluefish Member lies on a major flooding surface and together with the Grey shale member represents a highstand systems tract (HST). Carbonates of Ramparts Formation are interpreted as an early transgressive phase (low relief ramp) and late transgressive phase of bank and reef development. Following drowning of the reef, Canol Formation represents deposits of a highstand systems tract (Figure 68).

DISCUSSION AND DEPOSITIONAL HISTORY

Arnica to Hume Formations Succession

In Peel area, the transition from silty, shallow water carbonates of Delorme Group to cleaner carbonates of Arnica and Landry formations suggest continued transgression of the Kaskaskia Sequence across Mackenzie-Peel Shelf. Arnica Formation contains open marine fossils in westernmost sections, including corals, brachiopods, conodonts, abundant large burrows, and biohermal buildups near the shelf edge. The formation is characterized by repetitive, colour-banded weathering patterns in which brown weathering, thickly laminated and burrow mottled dolostone alternates with white to light grey weathering, laminated, thin-bedded lime mudstone. Morrow (1991) suggested the dark beds represent subtidal conditions while the lighter coloured beds represent intertidal deposits that have undergone exposure and bleaching. Landry Formation is predominantly lime mudstone with sparse fossils. Morrow (1999) suggested that elevated salinities may account for the sparse fauna.

During the Early Devonian, the eastern part of Peel area was a shallow, restricted marine peritidal to evaporitic environment (Fort Norman Formation and Bear Rock breccia). The facies change from open marine settings of Arnica-Landry deposition to restricted settings of Fort Norman Formation occurs over a wide belt, suggesting a very low gradient. There may have been a separate restricted sub-basin during deposition of Arnica Formation in the Tree River/Martin House area around an interpreted arch (Figure 65).

Morrow (1999) interpreted a phase of post-Landry and pre-Hume regression during which basinal shale and limestone of Mount Baird Formation were deposited as a lowstand wedge west of the Arnica shelf-edge. At Sections LG-E and LG-F, however, Arnica Formation limestone is still present suggesting that Mount Baird Formation extends east of the Arnica shelf-edge and that Arnica carbonates prograded further basinward than those of Landry Formation.

A renewed phase of relative sea level rise in the Eifelian established widespread, open marine conditions of Hume Formation, indicated by its abundant fauna containing cephalopods and in place corals (e.g., Flyaway Creek, Section LP-14). Hume Formation shallows upward in eastern sections and is shalier overall west of Peel area.

Horn River Group

The sharp transition from Hume platform to basinal facies of Hare Indian Formation in the early Givetian represents a rapid transgression and drowning of the platform by anoxic waters. Hare Indian Formation (Bluefish Member) was interpreted by Muir and Dixon (1984) as a basin facies based on bituminous, pyritiferous, laminated shale and laminated calcisiltite. Depositional conditions involved low sedimentation rates, little or no wave mixing, and anoxic conditions (Al-Aasm et al., 1996). Gradational interbedding of Bluefish Member with the Grey shale member represents a decreasing rise in sea level and shift from anoxic conditions to a basin margin setting (Muir and Dixon, 1984). Muir and Dixon (1984) interpreted the Grey shale member calcisiltites as turbidites based on their lateral extent, load casts, and common normal grading and the increased carbonate with corals and quartzose tempestites in the upper 20 m as shallower shelf deposits (above storm wave base). These turbidites and shale interpreted as background hemipelagic sedimentation represent progradation of a Hare Indian clastic wedge, and continued basin fill by ramp facies of the lower Ramparts Formation (Muir, 1988). Ramparts isopachs have a north-south trend that approximates the Ramparts shelf margin (Figure 56). Williams (1985) represented the Grey shale member as a clinoform facies, prograding (northward and westward) into the basin.

Muir and Dixon (1984) interpreted lower Ramparts Formation as a continued buildup on the existing Hare Indian mud bank, with carbonate platform buildup in areas of less clastic input. There was a drowning event again at or near the top of the carbonate platform (Carcajou marker). The Kee Scarp reefal member grew in cycles as a “keep-up”/“catch-up” reefal phase, with developed reef margins, interior lagoons, and reef foreslopes. Finally, the continued transgression drowned the reef. The drowning occurred later in Mountain River area than at the reef in Norman Wells (Muir and Dixon, 1984). Some reef debris was shed off the flanks in chaotic breccias, and as graded carbonate turbidites (Mackenzie, 1972). In core of the Ramparts Formation (Hume River A-53, core data in Pierce and Jones, 2009) there are cavities that are geopetally filled with debris and later calcite infill. This may suggest exposure of the reef. An anoxic basinal setting with low sediment input was extensive across Peel area during deposition of Canol Formation.

The sequence stratigraphic framework of Yose et al. (2001) that is extended west to Peel area (Figure 68), also included three third-order cycles to document the cyclicity within the Kee Scarp reef. Muir (1988) similarly described cycles of aggradation and shoaling from bank inception to terminal drowning. The organic-rich, shaly Carcajou subfacies that separate the lower ramp facies (which would form part of the late HST with the Hare Indian Formation) from the platform facies are also likely a third-order cycle of deepening to carbonate platform inception. The allochthonous beds exposed at Powell Creek contain evidence of mass flow deposition and may represent highstand shedding.

Two main lithofacies of Canol Formation, black laminated shales and crinoidal grainstone-peloidal calcisiltite, represent deeper marine, anoxic to dysoxic environments (Al-Aasm et al., 1996). The Canol-Ramparts contact may be locally disconformable Muir and Dixon (1984). Canol Formation is relatively thin over the top Ramparts Formation, and thins to only a few metres in the Gayna River area; westward it represents a condensed basinal sequence together with Hare Indian Formation in Snake River area, although it thickens to over 200 m in Richardson Trough.

In summary, the Arnica to Canol succession represents part of the Kaskaskia Sequence, correlative to other Devonian sequences through the western Canadian Devonian seaway. The Arnica-Landry-Bear Rock-Fort Norman and Mount Baird formations correlate to the Bear Rock-Stone assemblage, the Hume and Hare Indian formations correlate to the Hume-Dunedin

Assemblage, and the Ramparts and Canol formations correlate to the Fairholme Assemblage (of Morrow and Geldsetzer, 1988).

Two phases of fine siliciclastic input (Bluefish Member and Canol Formation) mark basin deepening and a shift in tectonic regime from a passive continental margin to a foreland setting by the Late Devonian to Carboniferous (Yukon and Ellesmerian foldbelts, Richards et al., 1996; Lane, 2007). This transition is broadly coeval with a shift to younger crustal sediment sources indicated by Nd isotopes throughout the Canadian Cordillera (Garzionne et al., 1997) and the Canadian Arctic Islands (Patchett et al., 1999). Recent studies have shown that Yukon Tanana Terrane originated as an arc built upon North American continental crust in the Early Devonian (e.g., Nelson and Gehrels, 2007). Arc construction on the western Laurentian margin in the Devonian could therefore reconcile the westward deepening basin observed in Peel area and previously published Nd isotope data of Garzionne et al. (1997), which included samples of both Canol and Imperial formations from the Richardson Mountains.

PETROLEUM PROSPECTIVITY – LOWER TO UPPER DEVONIAN STRATA

Arnica-Landry Platform Play

This play includes all pools and prospects hosted in vuggy, porous, and fractured carbonate and carbonate breccias of Arnica and Landry formations. Hume Formation, though not considered a reservoir (Williams, 1986b), also has some shows. The play is conceptual within Peel area and through much of the Interior Platform of the Northwest Territories (Hannigan et al., 2006), as no discoveries have been made. Gas and oil shows have been found in drill stem tests in Landry and Arnica formations in Peel area.

A fairly recent discovery of gas and light oil/condensate in Mackenzie Plain in the Summit Creek B-44 well, which is considered to be only the second commercial discovery in that region since Norman Wells in 1920, has elevated this play in the Mackenzie Plain to established status (Figure 71). The Summit Creek B-44 discovery is in a thrust-faulted anticlinal trap near the Mackenzie Mountains front. Production tests yielded flows of about 6 000 000 m^3/day (20 MM cf/day) gas and 1002 m^3/day (6300 bbl/day) hydrocarbon liquids (Husky Energy, 2005).

Arnica and Landry formations are widespread in the subsurface of Peel area, and as such the play can be considered to extend virtually throughout the area, limited by areas of shallow subcrop and outcrop (Figure 10.5.13 in Chapter 10, this volume). The western limit of the play area coincides with the western shelf edge of Mackenzie-Peel shelf, which is close to the western boundary of Peel area.

Few quantitative estimates of the Arnica-Landry Platform play endowment in the Northwest Territories and Yukon have been published. In an unpublished report, Drummond (2008) made a quantitative assessment of the Arnica-Landry Platform play in the Sahtu and Gwich'in Settlement Areas of the NWT, which includes Peel area. Osadetz et al. (2005) made quantitative estimates for a number of plays in the Yukon portion of Peel area, which included parts of Arnica-Landry platform play (Table 5).

Play Name (Osadetz et al., 2005)	Play Area	Mean Play Potential, expected Number of Pools
Paleozoic Carbonate Platform Play	Yukon portion of Peel Plain	$272 \times 10^6 m^3$, 1 pool
Paleozoic Carbonate Margin Play	Yukon portion of Peel Plateau	$4460 \times 10^6 m^3$, 7 pools

***Table 5.** Quantitative estimate of mean play potential for Paleozoic Platform and Margin plays in the Yukon portion of Peel Plateau and Plain, from Osadetz et al. (2005).*

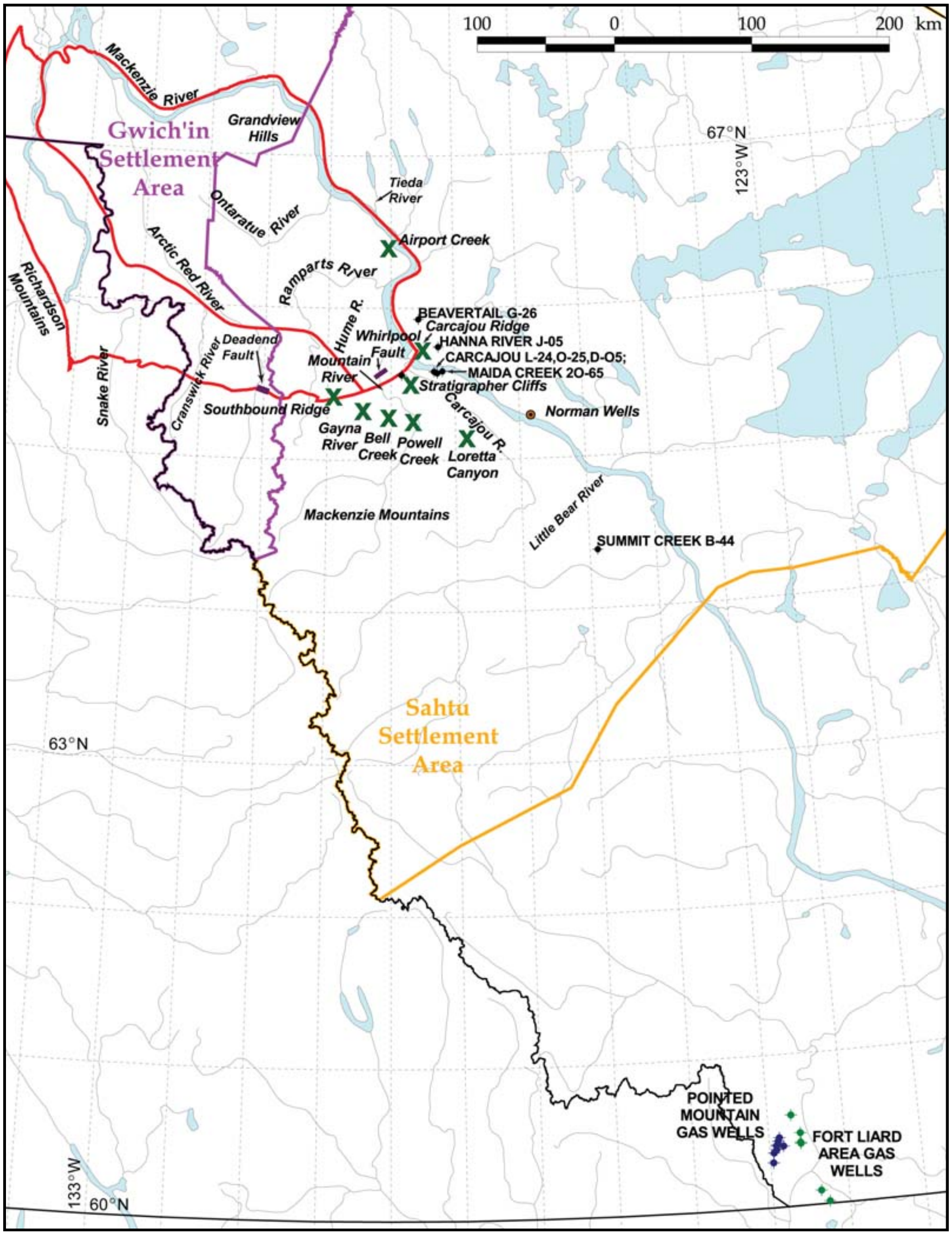

***Figure 71.** Regional index map for locations discussed in the text.*

National Energy Board (2000) evaluated a Paleozoic Carbonate play in Yukon, with reservoirs in Hume, Landry, and Arnica formations. They estimated a mean value of 24.7 x 10^9 m^3 (878 Bcf) of natural gas in this play. Additionally, the Devonian isolated reefs play (in Yukon) Arnica, Landry, Hume platforms was estimated to contain a mean 10.56 x 10^9 m^3 (375 Bcf) of natural gas, and 2.72 x 10^6 m^3 (17.13 MMbbl) in this play. Yukon assessments (National Energy Board, 2000) also included a Fractured Arnica Dolomite play in the Yukon (mean 1.2 x 10^9 m^3, 42.46 Bcf) of natural gas, and 0.26 x 10^6 m^3 (1.65 MMbbl) in this play. Osadetz et al. (2005) discounted this play because of its requirement for diagenetic dolomitization of the reservoir, similar to the Manetoe or Presqu'ile dolomite of southern NWT. Widespread dolomitization of this type is not known in Arnica Formation within Peel area. The present study shows, however, that hydrothermal dolomite in Arnica Formation is likely associated with major faults.

There have been several indications of hydrocarbons in the Arnica and Landry formations, as well as a few shows in Hume Formation, particularly in eastern Peel area. In the Mountain River H-47 well, gas was estimated to flow at 2, 493 m^3/d (88 Mcf/day) from Landry Formation limestone (Holmes and Koller, 1972). Also in the Landry Formation, a small amount of oil (39.2° API) was recovered on drill stem test (DST) in Shoals C-31 (Evans, 1966). A DST over a 3 m interval of Hume Formation in Ramparts I-55 was estimated to flow at 7, 108 m^3/d (251 Mcf/day; Soul, 1960a).

Slightly gassy water and slightly gassy mud were recovered on DST from near the top of the Arnica Formation (1351-1359 m) in Ontaratue H-34. Gas cut water was obtained on a DST from the Arnica Formation at Hume River D-53 at 1113-1146 m, and gas cut water was reported to flow from the Loon River No.1 (H-79) well from near the top of the Landry Formation (288 m). Gas cut mud was found on DST at 770-780 m in the Landry Formation in Grandview Hills No. 1 (A-47) well. Oil flecked water was obtained on a DST from Bear Rock breccias (Arnica equivalent) just east of Peel area at Hanna River J-05 (at 591-650 m), and oil stained mud was observed on a DST from 326-350 m (Landry and Arnica formations) at Beavertail G-26. Gas cut mud flowed from a well kick in the Hume Formation at 1637 m in Hume River L-09.

Oil staining has been observed in many well cuttings samples in eastern Peel area, and gas anomalies noted during drilling of more recent wells (e.g., Mountain River O-18, Sperry Creek N-58) in southeast Peel area. In the current study, oil stained Arnica Formation rocks (and equivalents) have been observed at Powell Creek, Statigrapher Cliffs area, and Loretta Canyon southeast of Peel area (Figure 71).

Reservoir Rocks

Arnica Formation and equivalents have potential as reservoirs (Tassonyi, 1969; Pugh, 1983) with significant sections of sucrosic dolomite, vuggy dolomite, porous bioclastic and biostromal limestone in the west, and carbonate breccia in the east. Landry Formation in outcrop is mainly tight lime mudstone, although it is associated with a number of shows. It is speculated that fracture porosity and porous breccias near the eastern facies limit are the main reasons for Landry shows (in particular Shoals C-31).

Arnica Formation

Arnica Formation dolostones have favourable reservoir qualities over appreciable thicknesses throughout the Interior Platform of NWT (e.g., National Energy Board, 1996). Vuggy, pinpoint, intercrystalline, and fracture porosity (porosity terminology after Lucia, 1995, Choquette and Pray, 1970) have been inferred from drill cuttings and streaks of porosity to 6% to 20% estimated (e.g., Canadian Stratigraphic Services (2000) Ltd. [1974] log of Hume River D-53 well estimates of 4% to 6% porosity with streaks up to 20% through the interval 1136 m to 1159 m). Langton (1989) described Arnica Formation carbonates in southeastern Peel area as having intercrystalline, vuggy, and fracture porosity, ranging from 6% to 12%. Gal (2005) reported an apparent 46 m thick porous zone (4% to 10%) in Arnica Formation based on neutron logs in Mountain River A-23; however, the upper part of this interval recovered water on DST. Several cores cut in Arnica Formation have been analysed for porosity and permeability in well history reports (Table 6).

In the present study, porous Arnica Formation rocks were found in a number of facies and lithologies, discussed and illustrated below.

Sucrosic Dolostone with Intercrystalline Porosity

Significant thicknesses of porous sucrosic dolostone (Figures 72, 73, 74, 75; crystal texture terminology after Sibley and Gregg, 1987) occur within Arnica Formation at several sections between Southbound Ridge and Cranswick River and beyond, at the Mackenzie Mountains front along south central Peel area. Similar textures were seen in drill cores and inferred in well cuttings. In outcrop locations, the sucrosic dolostone occurs as dm to m scale beds over gross intervals of tens of metres.

Well Name	Interval (m)	Porosity (%)	Permeability (mD)	Comments
Arctic Red River O-27	1583.2-1590.4	11.1	14.28	--
Tree River F-57	1164.6-1169.2	10.8	0.8-1000+	Open fractures give highly variable but high permeability (and porosity).
Hume River D-53	1144.0-1151.6 1152.7-1155.4	4.6 7.2	4.29 23.29	--
Grandview Hills No.1 (A-47)	957.5-980.8	3.8	Mostly <0.1	Little permeability.
Mountain River O-18	789.0-797.8	3.7	49.44	Up to 13% porosity, and 819 mD permeability in fractured sample.
Tree River H-57	1198.8-1206.3	3.4	1.82	--
Mountain River H-47	753.0-757.6	2.8	1.56	--

Table 6. *Measured porosity from well cores from samples of Arnica Formation in Peel area.*

Figure 72. *Outcrop of Arnica Formation sucrosic dolostone with intercrystalline porosity.*

Figure 73. *Arnica dolostone from Arctic Red River O-27 well. Intercrystalline and small vug porosity (Table 6). Footage indicated, arrow points up hole.*

Figure 74. *Well cuttings sample from Ontaratue K-04 well, 984.8m (3230 ft) in Arnica Formation. Sucrosic dolostone with good intercrystalline porosity. White scale bar is 1 mm.*

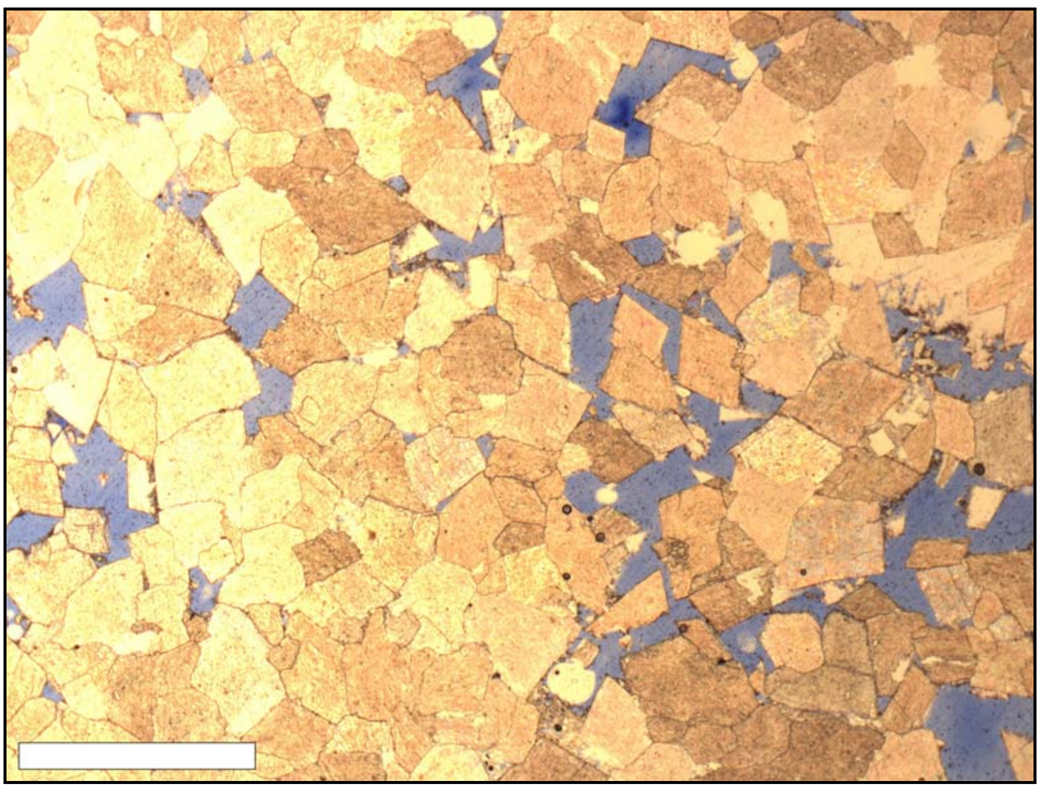

Figure 75. *Sample 2006LG-10-A, Arnica Formation sucrosic dolostone with intercrystalline porosity. Plane polarized light. White scale bar is 1 mm.*

Biostomal/Biohermal Limestone with Inter-organic Porosity

In western exposures of Arnica Formation near the plaftform edge, richly fossiliferous limestone beds are common. These may have biostromal or biohermal forms, and are mainly made up of wackestones and packstones (Figure 76). Typically the matrix material is lime mud, but there is often some inter-organic (and locally intra-organic) porosity. In outcrop samples, however, this porosity is likely enhanced by surface leaching.

Figure 76. *Arnica Formation crinoid packstone, Section LG-B.*

Carbonate breccia with Inter- and Intra-clast Porosity

In southeastern Peel area where Arnica Formation undergoes gradual facies change to evaporite-dominated Fort Norman Formation, thin breccia beds are interbedded with Arnica dolostones. Individual breccia beds are decimetre-scale and fairly rare on Southbound Ridge, but these become progressively more abundant toward the east where by Powell Creek, the entire Arnica interval is a massive to crudely bedded breccia (Figure 77). Interbedded breccias in westernmost exposures are most commonly cemented or particulate crackle- to mosaic packbreccias (classification of Morrow, 1982). Thicker and more massive breccias in the east were mapped by most workers as Bear Rock Formation. These again are dominantly particulate rubble and mosaic packbreccias, with some floatbreccias. Coarse calcite cementation is common. Clasts are dolostone and/or limestone, and matrix particulate usually limestone. Anhydrite is rare. Coarse calcite cement is common as patches and irregular fracture fills. These breccias have intra- and interclast porosity at a variety of scales (Figure 78, 79). Large vugs are common, generally caused by dissolution of clasts.

The genesis, distribution, and age of the breccias have been a matter of some debate (Morrow, 1991). Breccias were most likely formed by selective dissolution of anhydrite in an interbedded dolstone/anhydrite sequence that is transitional Arnica/Fort Norman Formation. Stephanian (1999) presented evidence for subaerial exposure in eastern Peel area near this facies change, and multiple phases of dissolution and precipitation affecting porosity. In addition, the breccias are believed to be a surface and near sub-surface feature, and their formation may have been associated with pre-Cretaceous exposure, Laramide uplift and deformation, or even more recent. If they are recently formed, then Bear Rock breccias are possibly of limited value as reservoirs. However, they are oil stained at Powell Creek, Imperial anticline, Loretta Canyon, and areas further to the southeast in Mackenzie Plain (i.e., Little Bear River; Figure 71).

Figure 77. *Bear Rock particulate rubble packbreccia at Powell Creek with interclast vugs.*

Figure 78. *Bear Rock particulate and cemented rubble packbreccia in Mountain River H-47. Intra- and interclast porosity is apparent. Note white calcite cement in matrix. Footage indicated, arrow points up-hole, white scale bar is 5 cm.*

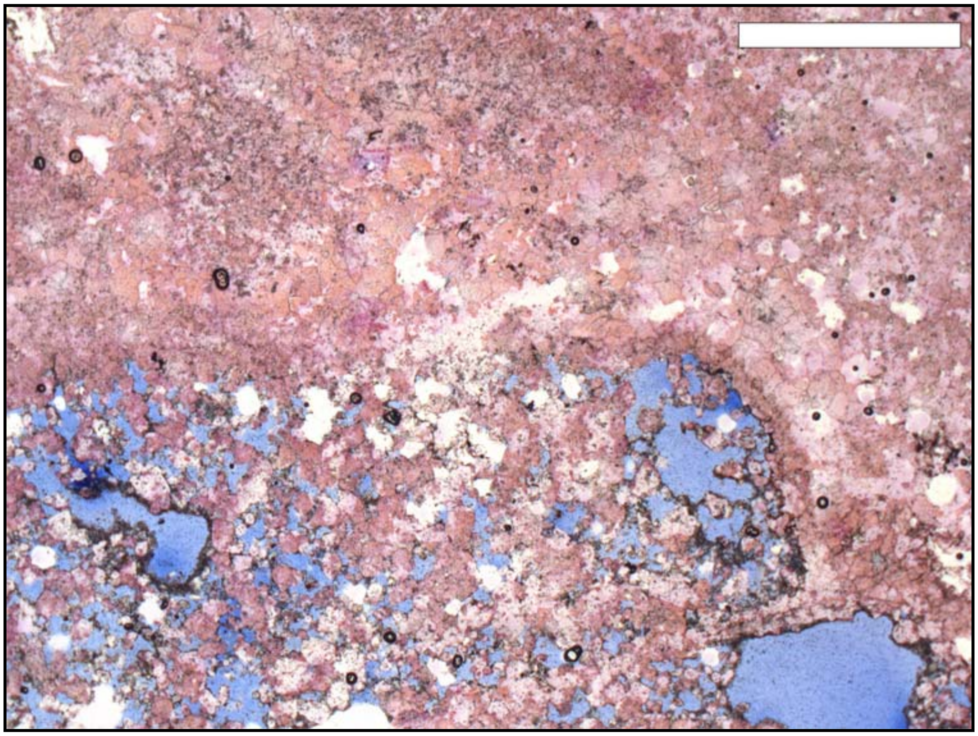

Figure 79. *Sample 07LG-15-a1, Bear Rock breccia. Individual clasts show high porosity. Plane polarized light. White scale bar is 1 mm.*

In summary, there is a wide range of porosity types in Arnica Formation. Table 7 summarizes standard core analyses of Arnica Formation outcrop samples. Diagenetic coarse hydrothermal "Manetoe" dolomitization that makes Arnica Formation an attractive reservoir south of Peel area (e.g., Pointed Mountain and Fort Liard fields) area does not extend north of 63°30' latitude (Morrow et al., 1990). No evidence of widespread, regional, and strong diagenetic dolomitization of this interval was seen in Peel area with the exception of local dolomitization associated with a fault (discussed below).

Overall, the formation can be expected to contain intervals tens of metres thick with 3% to 10% porosity and probably permeabilities around 1 mD to 2 mD. As with Landry Formation, fracturing can increase permeability.

Sample	Porosity (%)	Permeability (mD)	Comments
07LG-15-A	7.0	0.01	Bear Rock limestone breccia, Arnica equivalent.
07LG-6-K	6.5	22.7	Lime packstone from bioherm.
06LP-22-09	6.1	1.99	Dolostone Bear Rock breccia.
06LP 10-02	6	1.94	Sucrosic dolostone.
06LP 13-10	4.2	0.06	Slight vuggy amphiporid dolostone.
06LP 10-04	2.5	0.11	Fine to medium-crystalline dolostone.
06LG 08-04	1.7	0.14	Sucrosic dolostone.

Table 7. *Measured porosity from cores cut from outcrop samples of Arnica Formation.*

Hydrothermal Dolomite associated with Fault Zones

In one location, diagenetic and possibly hydrothermal dolomite was observed in Arnica Formation associated with a fault zone. At the mapped location of the Deadend Fault just east of Arctic Red River (Aitken et al., 1982), an approximately 3 m thick tabular zone of light tan-grey coloured, recrystallized, medium to coarse crystalline and slightly vuggy dolomite was found in Arnica Formation, close to or in the immediate footwall of the Deadend Fault (Lemieux et al., 2007; Figure 80). Rock fabric was destroyed due to recrystallization, and small saddle dolomite crystals lined vugs (Figure 81). The tabular zone appeared to be concordant with bedding which dipped shallowly south. This location was exposed in a small stream cut, and could not be followed very far because of talus cover. However, it does suggest that major fault zones, such as Deadend Fault, which are associated with Laramide deformation, may have focused heated fluids and caused alteration of surrounding carbonates. It is likely that there are blind structures of a similar nature along the front, and outboard of the Mackenzie Mountains.

Traces of sphalerite (ZnS) with pyrite observed in two cores of the Landry Formation (Stony I-50 and Sainville River D-08), and one in Arnica Formation (Tree River F-57, Figures 65, 82, 83) in Peel area may be further indications of hot hydrothermal fluids, which may also be have been associated with hydrothermal dolomitization and creation (or destruction) of porosity. It is notable that these three wells are outboard from the mountain front, and hence may be associated with reactivated basement faults. The Tree River F-57 well is along a fault mapped by Pugh (1983) in strata as young as Delorme Group (and likely younger; Figure 19). Figure 83 shows other occurrences of sphalerite, galena, barite, and other minerals in the study area.

Figure 80. *View southeast across approximate trace of Deadend Fault (dashed black line) east of Arctic Red River. The fault places Franklin Mountain Formation over Arnica Formation. The approximate extent of a massive, medium to coarse crystalline, whitish vuggy dolomite, believed to be associated with the fault, is indicated by white dashed lines. Backpack for scale (circled).*

Figure 81. *View west toward possible hydrothermal dolomite associated with Deadend Fault. The upper contact of the massive dolomite is shown (dashed white line). Note massive nature of outcrop. Hammer for scale (circled). Inset is close-up of the dolomite. Note the fabric and crystal-lined vugs. Scale card divisions in cm and mm.*

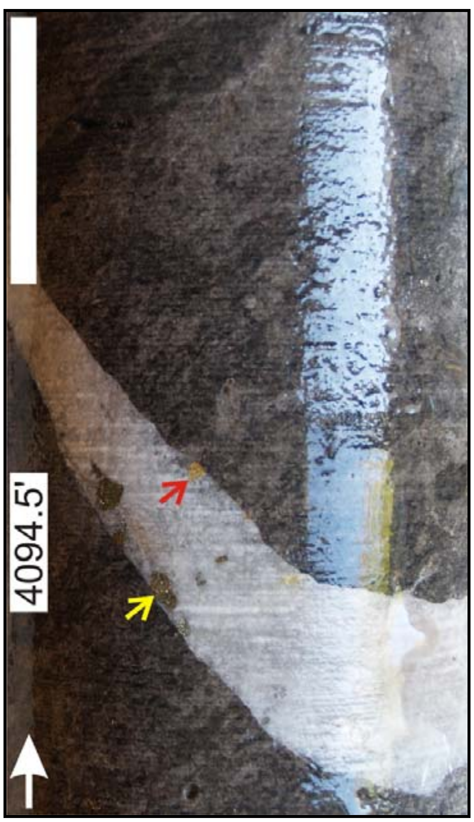

Figure 82. *Arnica Formation core from Tree River F-57 well at 1248.3 m (4094.5 ft). Note specks of pyrite (yellow arrow) and sphalerite (red arrow) in crosscutting calcite-filled fracture. White scale bar on core is 5 cm long, arrow indicates top direction.*

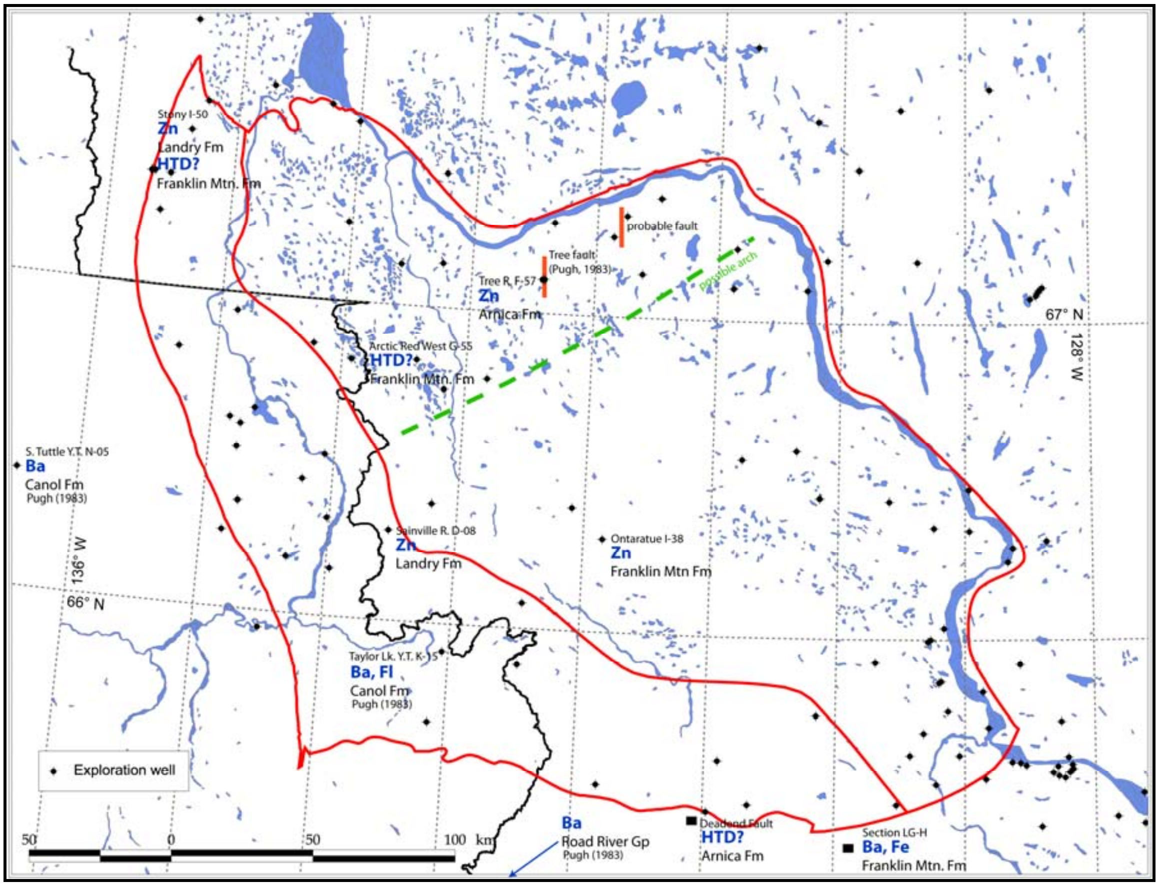

Figure 83. *Map of mineral occurrences and tectonic features in Peel area from outcrop, drill core, well cuttings and mapping. Ba=barite, Zn=sphalerite, Fl=fluorite, Fe=pyrite, iron oxides; HTD=possible hydrothermal dolomite which might indicate fault zones; orange lines indicate faults inferred from structure contours; green dashed line indicates possible regional arch in Lower Devonian rocks inferred from isopach maps.*

Landry Formation

Landry Formation has often been cited along with Arnica Formation as a potential reservoir in the Lower Devonian interval. From examination of several stratigraphic sections during this study, Landry Formation appears to have poor reservoir potential compared to Arnica Formation. The lithology is almost invariably a tight lime mudstone, in places argillaceous. There have been a number of oil and gas shows obtained during DSTs from the formation (see above), however, which suggests that these may be due to fracture porosity and permeability, and/or brecciation of the unit at its facies change to Fort Norman Formation (i.e., Bear Rock breccia). For example, a lost circulation zone in Mountain River A-23, at 1087 m may indicate possible cavernous porosity or permeable fracture zones. High water flow on DST in Landry Formation in Loon River H-79, with no porosity noted in core or well cuttings, may also indicate a fractured zone (Soul, 1960b). Pelletoidal facies of Landry Formation limestone locally shows evidence of leaching that increases porosity (Tassonyi, 1969).

Porosity in Landry Formation has been described as intra-oolitic and intra-pelletoidal, earthy, pinpoint, vuggy, intercrystalline, and/or sucrosic (in dolomitized sections), and fractured in selected Canstrat logs. The best porous intervals described from samples were: 1) Grandview Hills No. 1 (A-47) with about 4% in basal 30 m of Landry Formation, and streaks of intercrystalline and vuggy porosity to 12%; 2) traces of inter-pelletoidal porosity in Tree River F-57 and Hume River D-53 wells; and 3) vuggy and fracture porosity in Grandview L-26 well. Porosity in wells in the Grandview Hills has been noted by Gus van Heusden, (pers. comm., 2008). Thin intervals of cored Landry Formation do have high porosity: Tree River H-38 well included values of 4.8% porosity over 82 cm and 4.2% over 70 cm (in the interval from 875 – 877 m), and Grandview Hills No.1 (A-47) well averaged 7.1% porosity over 66 cm at 774.65 m depth (Hu, in press a). Porous intervals in Landry Formation were rarely inferred from selected well logs within Peel area. No outcrop samples were collected from Landry Formation for core analysis during the course of this study.

In some cores of Landry Formation from western Peel area, organic packstone and wackestones occur. This suggests that biohermal or biostromal buildups, analogous to those in Arnica Formation, may occur at the western margin of Landry Formation carbonate platform. Primary inter- or intra-organic porosity, or secondary porosity through dissolution, associated with fossiliferous Landry facies is possible.

In summary, porosity in Landry Formation may be found in pelletoidal facies, in fractured and/or brecciated rocks, and in dolomitized intervals. The latter are perhaps more common in north and northeast Peel area, and in particular around Grandview Hills. Porosities up to 4% to 6% over mainly metre-scale intervals might reasonably be expected.

Hume Formation

A brief discussion of Hume Formation is warranted, as it is commonly included in conceptual hydrocarbon plays in the region. Tassonyi (1969) and Gilbert (1973) mention reservoir potential in Hume Formation reefal banks or buildups are apparent. Meding (1998) mentioned possible stromatoporoid buildups at the western platform edge of Hume Formation; however, this western edge is at or beyond the western margin of Peel area. Williams (1986b) concluded that Hume Formation has poor prospects as a reservoir which is supported by the current study. Osadetz et al. (2005) examined a conceptual play based on reefal buildups from the Hume platform in Peel Plateau and Plain of Yukon, and noted the possibility of this play in NWT. Gal (2005) presented some seismic evidence of a possible buildup on the Hume carbonate platform in northeastern Peel area. Small organic buildups on Hume Formation are known on the Carnwath platform east of Peel area (Gilbert, 1973).

Hume Formation is widespread throughout Peel area. Generally it is a fossiliferous and argillaceous wackestone and lime mudstone without porosity. Outcrops and cores examined in the current study were non-porous. Few instances of intraorganic porosity were seen, but these were ineffective. Fracturing is expected to be the only viable method to create reservoir characteristics.

A carbonate buildup on the regional Hume platform in Peel area was penetrated in the Manitou Lake L-61 well (Williams, 1986b; Morrell, 1995). An alternative interpretation is that the buildup is Ramparts Formation lying directly on Hume Formation, without an intervening Hare Indian Formation mud bank, or that Hare Indian Formation here is dominantly carbonate. Well history reports identify fine crystalline to fragmental and pelletoidal limestone in the upper part (operator's Ramparts Formation) and very fine crystalline limestone in the lower part (operator's Hare Indian equivalent) of the carbonate buildup above the regional Hume Formation platform. The only fossils mentioned are *Amphipora*. From the lithological description is does not appear to be a true reefal buildup.

Source Rocks

Few suitable source rocks occur in carbonates of Arnica to Hume formations succession. Shale interbeds within Landry Formation were postulated as source beds by Langton (1989) in southeastern Peel area, but no substantial organic shale interbeds occur in Landry Formation. A few thin black shales lie near the contact with overlying Hume Formation at Section LP-02 (Figure 67).

At the western margin of Peel area, Devonian formations gradually transition into basinal equivalent black shales and limestones of Road River Group. These were likely rich source rocks (Chapter 4, this volume). Landry Formation appears to "shale out" further east than Arnica Formation. Units mapped as D_{sh} (Norris, 1982a) and Mount Baird Formation (Norris, 1985) are equivalents to Landry Formation exposed at the Mackenzie Mountains front in the Snake River area. The D_{sh} unit, as mapped at Section LG-C, is actually argillaceous limestone. Mount Baird Formation samples (examined at section LG-E) do not have high TOC (0.07%, 0.20%, and 1.1%).

A systematic study of several wells in Peel area by (Geochem Laboratories and AGAT Consultants, 1977) yielded average total organic carbon (TOC) values for Landry Formation (0.31%, n=92), and Arnica Formation (0.33%, n=86). A total of nine TOC values above 1% were obtained and six of these were from the Grandview Hills No.1 (A-47) well.

Samples analyzed by Snowdon (1990) from Cranswick A-22 well had overall higher TOC values, with averages of 0.98% TOC (n=25) in Landry Formation and 1.19% TOC (n=22) in Arnica Formation. Some systematic contamination is suspected here, based on comparison to other well data in the same study and examination of lithologies in a nearby outcrop section. For example, average TOC for these formations in Stony I-50 are all less than 0.22% TOC (Snowdon, 1990). Samples collected and analysed by Feinstein et al. (1988) from these formations in the Ontaratue H-34, Ontaratue K-04, Stony I-50, and Arctic Red Y.T. C-60 wells ranged from 0.04% to 0.57% TOC, with one anomalous exception in Landry Formation in the latter well which yielded 3.22% TOC.

Few samples were collected from outcrop during the present study. These included: 0.13% TOC from Landry Formation, and three samples of Mount Baird Formation yielding 0.07%, 0.20%, and 1.1% TOC.

In summary, total organic carbon values for these formations are low and their potential can be rated as poor. Geochem Laboratories and AGAT Consultants (1977) interpreted the Lower Devonian to have poor source rock potential.

There is not sufficient data to confidently assess the type of kerogens present in these rocks based on pseudo-van Krevelen type crossplots of hydrogen and oxygen indices (HI vs OI). Geochem

Laboratories and AGAT Consultants (1977) state that these strata contain predominantly herbaceous organic matter in poor to fair amounts, and secondary coaly kerogen in western Peel area.

These formations are generally mature to overmature in Peel area. A limited number of vitrinite reflectance equivalent determinations from Landry Formation range from 0.46%Ro in Grandview Hills No.1 (A-47) to 1.19%Ro in Ontaratue H-34 (Geochem Laboratories and AGAT Consultants, 1977; Stasiuk and Fowler, 2002). Reflectance values in Arnica Formation range from 0.9%Ro in Ontaratue K-04 to 3.3%Ro in Cranswick A-22. Thus Arnica and Landry formations are overmature through western and south-central Peel area. There are no published determinations from Delorme Group strata, but these can be expected to be overmature, except perhaps in the northeast Peel area.

Rock-Eval data (T_{max}) generally agree with the vitrinite reflectance equivalent data for Landry Formation in the Ontaratue K-04 and H-34 wells (Feinstein et al., 1988). In the Cranswick A-22 well, T_{max} values from Arnica Formation (Snowdon, 1990) are mainly unreliable, with other values indicating maturities just above to just within the oil window.

Oil-stained samples of Fort Norman and Arnica formations collected during the current study at Imperial anticline, just southeast of Peel area, were sub-mature to just mature. Meaningful T_{max} values were not obtained from Mount Baird Formation samples collected in western Peel area, and these are assumed to be overmature.

Landry and Arnica formations are at maturity in eastern and northeastern Peel area; however, there are very little effective source rocks within this section. Elsewhere, these strata are overmature.

It is assumed that the oil (and possibly gas) shows associated with Arnica and Landry formations (from DST data) are "out-of-place"; that is, sourced from overlying Hare Indian and Canol formations. It is possible that bitumen in vugs and fractures, seen in some cores, may be from older sources such as Road River Group. The basal Bluefish Member of Hare Indian Formation and Canol Formation are rich source rocks that are mature throughout a large part of eastern Peel area (see Chapter 10, this volume). These are likely to be effective source rocks for Arnica or Landry formation reservoirs where the two could be structurally juxtaposed.

Seal and Overburden Rocks

The top of Landry Formation lies at depths of 250 m to 350 m below surface in northeast and eastern Peel area; this increases to over 2,000 m in the west and southwest (Figure 23). The formation rises at the Mackenzie Mountain front, and where it is involved in folds and faults of the Franklin Mountains. The thickness of Landry plus Arnica formations is about 400 m through much of Peel area, and over 400 m in the west (Figure 18).

Hume Formation, mainly tight and argillaceous limestone, could be a top seal for Landry Formation. Fort Norman anhydrite and anhydritic dolostone could form both top and lateral seals for Arnica and Landry formations at their eastern facies changes. 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. The tight carbonate facies in Landry Formation could be a good seal for the better Arnica reservoir rocks (e.g., Tassonyi, 1969), although it is probably prone to fracturing. At the western extent of Arnica Formation, a facies change to Road River Group shale might provide a sealing rock, although the general geometry of the basinward slope will preclude an effective updip seal without some structuring. At Section LG-E, a tongue of Road River Group shale and tight limestone is seen to extend eastward over top Arnica Formation limestone.

There are sufficient overburden rocks above Landry and Arnica formations through much of Peel area, although their effectiveness as seals is not known. The overlying rocks at the eastern and western facies changes, from platform carbonate rocks to anhydrite and shale, respectively, probably provide good seals.

Traps

A variety of stratigraphic and structural traps in Landry and Arnica formations (and possibly Delorme Group) can be envisioned. Dixon et al. (2007) listed five classes of plays in Paleozoic platform carbonates in their summary of hydrocarbon potential of the northern Interior Platform, four of which are applicable here: 1) up-dip pinch outs of porous intervals, as sub-plays of which can be distinguished a) porous dolostone pinch-out at eastern facies change to anhydrite (Aitken et al., 1982), b) porous breccia zones (Bear Rock breccia) in shallow subsurface near the eastern facies change, c) porous sucrosic dolostone pinching out along regional dip within tight dolostone; 2) fault traps, with possibly associated enhanced porosity and permeability due to fracturing and/or dolomitization; 3) traps associated with the carbonate to shale transition and possible development of shelf-edge reefs or biostromes, particularly in Arnica Formation, and a related possible trap due to pinch out of porous carbonate tongue into surrounding basinal shale, although in the latter case the regional western dip makes for problematic up dip seals; 4) dolomitization of platform carbonates, which although not regionally recognized in Peel area, may instead be associated with faults as noted above.

In addition to these trap styles, we add: 5) patch reefs in Arnica Formation at eastern facies change, sealed by Fort Norman Formation anhydrite (Langton, 1989), 6) porosity traps related to subaerial exposure and karsting in the eastern extent of Arnica-Landry exposures (e.g., Stephanian, 1999); 7) porosity related to the unconformity at top Delorme Group (although no evidence was seen in field exposures for increased porosity at this contact), and probably most importantly, 8) structural traps (simple to complex or faulted anticlinal folds and domes) at the margins of the Mackenzie and Franklin mountains. Some smaller outboard of the mountain fronts are known.

Regarding the latter trap type, Lemieux et al. (2008) analyzed structural closures at the Arnica-Landry level from publicly available seismic maps from Peel area. From the limited data, structures commonly 10 km to 20 km long and a third to one half as wide were indicated just outboard of the Mackenzie Mountains front, at the north end of Snake River map sheet (106 F). Much smaller closures (mainly 1 km to 2.5 km by 2 km to 4 km) were indicated further north, along Peel River south of Fort McPherson.

Timing of Generation, Migration, and Accumulation

Shale of Road River Group may have reached maturity in Carboniferous time (Link and Bustin, 1989). Migration up the regional dip into moderately structured Arnica biostromes, or zones of sucrosic dolomite porosity, is possible. Initially oil was probably formed in Road River source rocks, and later gas may have flushed out the earlier oil. Laramide structures would have formed too late to trap any migrated Road River hydrocarbons, although there may have been some remigration.

Lower Devonian rocks, although not good source material, probably reached at least early maturity though most of Peel area in the late Paleozoic (i.e., under burial by Tuttle and Imperial formations).

Middle Devonian source rocks are mature in eastern Peel area and overmature in the southwest. It is probable that these units reached maturity in Late Cretaceous and perhaps as late as Eocene (see Chapter 10). Thus, maturity in these source rocks may have been prior to or coeval with Laramide structures. In either case, the Middle Devonian source rocks may have had a better chance to fill structural traps in Arnica-Landry reservoirs, where there was a juxtaposition of the two. Otherwise tight Middle Devonian Hume Formation may have blocked the migration of Canol/Bluefish sourced hydrocarbons.

If Bear Rock breccias are considered a potential reservoir rock, they are restricted to outcrop and shallow subcrop, and are thus subject to breaching and degradation. Development of these breccias may be fairly recent if they are derived from dissolution and collapse due to meteoric waters. If brecciation occured pre-Cretaceous, there may be traps beneath Cretaceous cover. In Shoals C-31 well, there is evidence in core for distinct episodes of brecciation. Bear Rock breccias are oil-stained at Powell Creek, Imperial anticline, and other locales (which might indicate modern migration from shallow sources).

Qualitative Evaluation, Risks, Best Parts of Play (Fairways)

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 Peel Plain of Yukon, west part of current Peel 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. Additional risks for this play include isolation from effective source rocks. Reservoir quality is a lesser risk, but the lack of Manetoe-type regional hydrothermal dolomitization is a major negative factor (Osadetz et al., 2005).

If Middle/Upper Devonian source rocks are assumed to be the most viable source rocks for this play, there must be structural juxtaposition with reservoir rocks. This type of situation, inferred from seismic evidence, was tested by Mountain River O-18 well (Chevron Canada Resources, 1990a), although Arnica Formation was not evaluated by DST.

The preferred scenario of a structural association of Arnica (and/or Landry) reservoirs and younger source rocks would suggest a play fairway in southeastern Peel area, proximal to the Mackenzie and Franklin mountain fronts, possibly near the facies change from Arnica to Fort

Norman Formation, and within Canol–Bluefish zone of maturity. This “fairway” is much reduced from the overall conceptual play area.

Overall, the play is here considered to have moderate potential in Peel area.

Kee Scarp Play

This play includes all pools and prospects hosted in the stromatoporoid-coral “reefs” or banks of Kee Scarp member of Ramparts Formations. This includes back-reef or lagoonal facies, and higher energy fore-reef facies of Kee Scarp member. Other members of Ramparts Formation, most particularly the “Charrue” sandstone, and non-reefal (platformal) Ramparts Formation are possible reservoirs. The play is conceptual within Peel area, as no economic discoveries have been made, although many shows have been found. Reservoirs within underlying Hare Indian Formation are also included here. Furthermore, the potential source rocks of Bluefish Member and Canol Formation, especially the latter unit, may be considered unconventional reservoirs.

The Kee Scarp play is established in Mackenzie Plain, southeast of Peel area, based on the Norman Wells discovery. Gal (2005) delineated a fairway that represented the established play, which extended from the Norman Wells area to just southeast of Peel area.

The Norman Wells field lies in the Kee Scarp reef, an atoll-like bank which is up to 130 m thick (Yose et al., 2001). The Norman Wells field was discovered by Imperial Oil in 1920, although large-scale production was not attained until 1985. The field had about 108 million m^3 (680 million barrels) of original oil in place (38.5° API; Yose et al., 2001). As of June 2008, the field had produced a cumulative 37.45 million m^3 (236 million barrels, National Energy Board data). Monthly production through the first part of 2008 averaged about 74 000 m^3. Solution gas is also produced; until recently, some was reserved for local use in the community, but currently it is re-injected into the reservoir. Monthly natural gas production through the first part of 2008 averaged 83.5 x 10^3 m^3 (National Energy Board data). Canadian Gas Potential Committee (2006) estimated 623.2 x 10^6 m^3 (220 Bcf) gas in place in the field.

Ramparts Formation occurs in subsurface and outcrop in eastern Peel area. The western limit of the play is at about 131° longitude, at the depositional limit of the formation. The eastern and southern margins of Peel area are near the play area limit, due to outcrop, or shallow subcrop beneath Late Devonian or Cretaceous siliciclastics (Figure 10.5.12, Chapter 10, this volume). Williams (1985) mapped the Kee Scarp reefal member as being limited to southeastern Peel area, with the Charrue sandstone member subcropping in the Ontaratue River and Grandview Hills area. Hare Indian Formation occurs throughout eastern Peel area between 132° and 133°W.

No published quantitative estimates of Kee Scarp play endowment in Peel area (or elsewhere in NWT) have been made. In an unpublished report, Drummond (2008) made a quantitative assessment of the Kee Scarp play in the Sahtu and Gwich’in Settlement Areas of the NWT, which includes Peel area. Any quantitative estimate for the region would be heavily influenced by the in-place resource of the discovered Norman Wells field.

Nearby and within Peel area, there have been several indications of hydrocarbons in the Ramparts, and some within Hare Indian and Canol formations. Ramparts Formation shows have largely been in southeast Peel area, and just southeast of the study area in the lower Carcajou River area. Oil staining has been observed in many well cutting samples, cores, and outcrops of Ramparts Formation. The most important Ramparts Formation hydrocarbon show is the Carcajou D-05 well, just southeast of Peel area, 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.

Source rocks may also form potential reservoirs. In Tree River H-38 well, a gas flow of 17,700 m^3/d (0.5 Mmcf/day) was estimated from Canol Formation at 721 m depth when the well kicked during drilling (Morrell, 1995). Hare Indian Formation has siltstone in its upper part which may have porosity (Tassonyi, 1969). Devlan Exploration Ltd. (2003) reported a gas anomaly in Hare Indian Formation siltstone in Tree River C-36 well; however, this may have been from the Imperial Formation. Table 8 lists hydrocarbon shows, including those in the Carcajou wells just southeast of Peel area.

Well Name	Depth (m)	Hydrocarbons
Carcajou D-05	566.5-568.5	Perforated interval; gas on flow test #3 estimated at 33,980 m^3/d (1.2 Mmcf/d).
Hume River O-62	497-520	Gas flow on DST #1, estimated at 425 m^3/d (15,000 Mcf/d). Gas to surface in 11 minutes.
Carcajou O-25	599-619	Gas flow on DST #1, too small to measure. Gas to surface in 10 minutes.
Carcajou L-24	1160-1189	Gas flow on DST #1, too small to measure. Gas to surface in 31 minutes.
Maida Creek 2O-65	549-573	Gas on DST #1, too small to measure. Gas cut mud and gas cut water.
Hume River D-53	490-535	Gas cut, slightly oil cut mud on DST #1.

Table 8. *Hydrocarbon shows in Ramparts Formation from wells within and near Peel area.*

Ramparts Formation in outcrop is often oil stained and has a petroliferous odour. Typically, thamnoporid/stromatoporoid floatstones and packstones have brown coloured, oil saturated matrix material while the fossil fragments are unstained. Such oil stains occur at least from Bell Creek to Powell Creek, and along the Imperial anticline between Mountain River and section LG-Z3, at a minimum (Figure 71). Bitumen is also found locally in some outcrops, including oil stained rocks. Oil staining in the core examined was ubiquitous (Figure 84).

Figure 84. *Core of Ramparts Formation Hume River D-53, about 507 m depth. Note oil stained matrix in floatstone packstone. Top of core is to left, scale card divisions in cm.*

Reservoir Rocks

Ramparts Formation

At Norman Wells, the Kee Scarp reefal member, and in particular the reef margin, foreslope, and high energy shoal facies exhibit the highest porosity and best reservoir potential (Al-Aasm and Azmy, 1996; Yose et al., 2001). Reefal facies occur in eastern Peel area (Figure 85). Based on Middle Devonian paleolatitudes, inferred trade winds, currents, and nutrient supply, reef growth was favoured on what became the steeper, northwest facing margin of the Kee Scarp bank or reef (Habicht, 1979; Fischbuch, 1984; Kaldi, 1989, Al-Aasm and Azmy, 1996; Yose et al., 2001). The same paleoenvironment for southeastern Peel area is inferred.

Porosity at Norman Wells is mainly “chalky porosity” formed by diagenesis and recrystallization to microcrystalline limestone (Kaldi, 1989, Al-Aasm and Azmy, 1996), with tiny pores generally less than 10 microns in size (Al-Aasm and Azmy, 1996). Matrix permeabilities are low (2 mD to 4 mD) and natural fracture systems have enhanced the reservoir qualities (Yose et al., 2001). Oil staining was prevalent in several core samples (Figures 86, 87).

In Peel area, lithologies are similar to Kee Scarp reef at Norman Wells. It is not known if the same diagenetic history has affected Ramparts Formation in Peel area, although some dolomitization, and common calcite-filled fractures, were observed. At Norman Wells, dolomitization occurred late in the paragenetic sequence (Al-Aasm and Azmy, 1996).

Figure 85. *Contact (at hammer head) between lower, bedded platformal facies and overlying massive reefal facies (Kee Scarp member) of Ramparts Formation, Carcajou Ridge.*

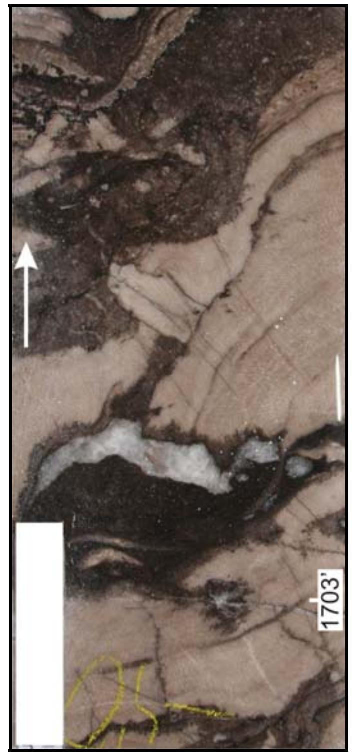

Figure 86. *Core of Ramparts Formation Hume River O-62, about 519 m depth. Note that oil staining of stromatoporoid, along fracture, pre-dates deposition of the calcite fracture fill (circle). Top of core indicated by arrow, white scale bar is 5 cm long, footage indicated.*

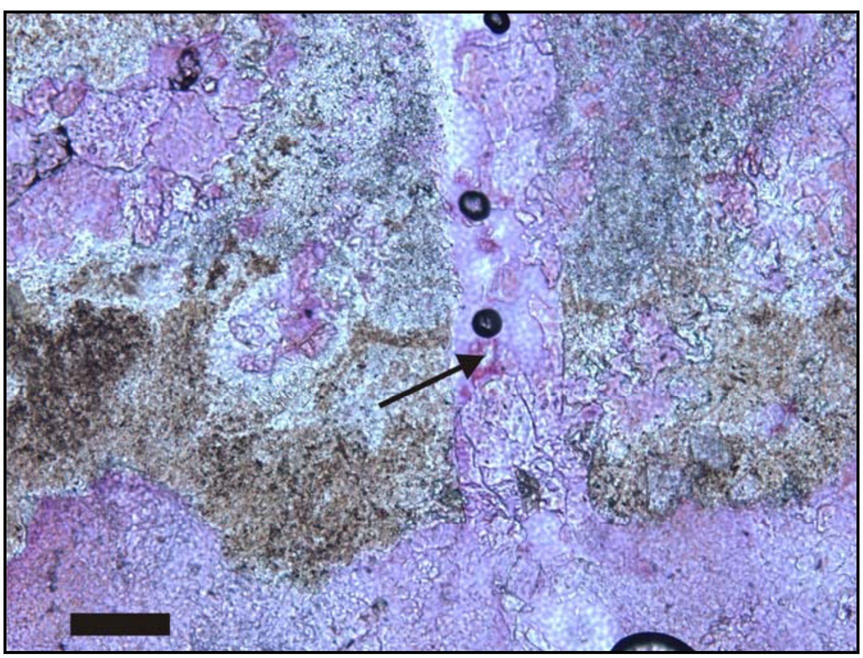

Figure 87. *Sample 07LG-12-C Ramparts Formation. Oil stained rock (brown) is cross-cut by calcite filled fracture (black arrow). Note fragment of oil stained wall-rock (white arrow) entrained in fracture filling, indicating calcite fracture filling was a late stage event. Plane polarized light, black scale bar is approximately 0.1 mm.*

A number of core porosity and permeability measurements have been carried out on Ramparts samples and compiled by Hu (in press a). Those from within an adjacent Peel area are tabulated below (Table 9).

Well Name	Interval (m)	Porosity (%)	Permeability (mD)	Comments
Grandview Hills no.1 (A-47)	275.8-278.3	14.9	0.11	Over 2.6m, Charrue sandstone.
Hume River A-53	252.9-257.5	9.56	6.96	11.6% maximum porosity, 92.1 mD maximum permeability.
Hume River O-62	504.0-520.4	1.87	0.06 hz	7.3% maximum porosity, 0.58 mD maximum permeability. 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	1.2	1.66	1.8% maximum porosity, 55.8 mD maximum permeability (high in fractured interval).
Airport Creek No.1 (D-72)	112.8-121.9	7.32	8.9	9.3% maximum porosity, 29 mD maximum permeability. Only 1.28 m of interval analyzed. High permeability in fractured interval.
South Maida Creek G-56	526.2-565.5	3.83	0.1	9.8% maximum porosity, 0.73 mD maximum permeability. 97% of interval analyzed.
Carcajou D-05	546.0-563.7	1.4	2.27 hz	2.9% maximum porosity, 17.4 mD maximum permeability. Gas on flow test #3 (566.5-568.5 m) estimated at 33 980 m^3/d (1.2 Mmcf/d).
Maida Creek F-57	464.3-480.8	6.37	0.36	8.8% maximum porosity, 1.4 mD maximum permeability. Only 3.33 m of interval analyzed.

Table 9. *Weighted average porosity and permeability of Ramparts Formation from core measurements from wells within and near Peel area. Information compiled from Gal (2005) and Hu (in press a).*

Hu (in press b) made a petrophysical study of well logs to estimate Ramparts Formation porosities in a number of wells in Peel area (Table 10).

Well Name	Interval (m)	Porosity (%)	Permeability (mD)	Comments
Hume River A-53	238.35-241.1 251.61-262.89 267.9-271.27 272.64-281.03 336.04-342.29	7.2 9.5 8.7 6.6 9.3	0.56 4.56 2.44 0.50 21.20	--
Mountain River O-18	149.6-263.4 264.6-266	2.2 6.7	7.59 3441.66	Average permeability highly skewed by some multi-darcy streaks, generally values are <0.1 mD.
Mountain River H-47	188.98-193.85 347.47-350.52	6.7 5.4	134.63 11.66	Average permeability does not include 3 extremely high outliers, varies from <3 to over 800 mD.

Table 10. *Average porosity and permeability of Ramparts Formation from petrophysical log calculations from wells within Peel area. Compiled from Hu (in press b).*

In the current study, only two outcrop samples were analyzed for porosity and permeability (Table 11). Many outcrops appeared tight, without visible inter-organic or chalky porosity, hence these were not sampled.

Sample	Porosity (%)	Permeability (mD)	Comments
06LP-20-04	10.6	0.87	Fossiliferous beds (corals / stromatoporoids / amphiporids / ?bryozoans) – reefal or fore-reef?, Airport Creek.
06LP-19-01	0.5	0.05	Massive reefoid facies, Carcajou Ridge.

Table 11. *Porosity and permeability of outcrop samples of Ramparts Formation within and adjacent to Peel area.*

In summary, carbonate members of Ramparts Formation can be expected to contain intervals 10 m to 20 m or more thick with 6% to 10% porosity and permeabilities in the millidarcy range, with some high streaks. It is beyond the scope of this regional study to relate porosity and reef facies, but using Norman Wells as an analog, one might expect the north and western edges of the reefal Kee Scarp member to host facies with higher porosities.

Charrue Sandstone

This unit was not seen in outcrop or logged in cores in the current study, although it is cored in the Grandview Hills No.1 (A-47) well where it yielded 14.9% porosity (Table 9). The unit is a marine quartz siltstone to very fine-grained, well sorted quartz arenite, with subangular and subrounded grains, a few accessory minerals, and quartz overgrowths (Mackenzie et al., 1975; Williams, 1985). The Charrue sandstone is up to 21 m thick in subsurface and 18 m in outcrop, and is distributed west and north of the carbonate members of Ramparts Formation in northeast Peel area (Figure 70).

Source Rocks

Middle and Upper Devonian shale of Hare Indian, Ramparts, and Canol formations are the main source rocks in Peel area based on literature review, field examination, and analyses of outcrop samples.

Hare Indian Formation

The basal Bluefish Member of Hare Indian Formation is a lithologically distinct black to brownish-black shale, lying abruptly over Hume Formation limestone (Figure 88). It is almost 20 m thick and widely distributed through Peel area. Geochem Laboratories and AGAT Consultants (1977) systematically sampled several wells in Peel area for total organic carbon (TOC), resulting in a range from 1.7% to 6.4% TOC over five samples. National Energy Board (2000) gave an average of 2.90% TOC for the Hare Indian Formation, with a range of 0.43% to 6.40%, in Peel Plateau and Plain. Al-Aasm et al. (1996) reported values of 0.35% to 10.34% TOC (5.83% average) from the Bluefish Member. A range of 0.28% to 2.99% TOC from the upper member of Hare Indian Formation was reported by Al Aasm et al. (1996). Samples analysed by the Geological Survey of Canada were compiled by Pyle et al. (2006a), where well samples range from 2.6% to 6.27% TOC. Several samples were collected from outcrop during the present study (average TOC = 6.68%; Table 12).

Figure 88. *Bluefish Member of Hare Indian Formation, lying above Hume Formation at section LP-02. Sharp contact lies above the hammer. In the background, dark Canol Formation is seen overlying light-coloured upper member Hare Indian Formation.*

Sample	TOC (%)	T_{max} (°C)	S_1, S_2	Comments
C-455006	2.58	--	0.00, 0.06	Reported in Pyle et al., 2006b
C-455014	11.92	446	0.02, 29.55	Reported in Pyle et al., 2006b
06LP-07-01	6.84	596	0.02, 0.44	Reported in Gal et al., 2007
06LP-14-04	0.48	606	0.01, 0.04	Reported in Gal et al., 2007
06LP-16-05	0.74	607	0.01, 0.05	Reported in Gal et al., 2007
06LP-17-03	7.86	454	1.05, 14.26	Reported in Gal et al., 2007
06LP-17-06	7.08	452	1.34, 12.66	Reported in Gal et al., 2007
06LP-17-09	9.56	448	0.71, 15.55	Reported in Gal et al., 2007
06LP-18-01	10.10	470	1.64, 8.02	Reported in Gal et al., 2007
06LP-18-03	5.68	468	1.09, 4.43	Reported in Gal et al., 2007
06LP-19-13	7.15	450	0.97, 13.28	Reported in Gal et al., 2007
06LP-21-06	7.82	445	0.93, 15.55	Reported in Gal et al., 2007
06LP-21-12	7.92	449	0.95, 10.37	Reported in Gal et al., 2007
06-TH-02-E	8.90	448	0.68, 13.01	Reported in Gal et al., 2007
06-TH-16-D	5.82	607	0.19, 0.10	Reported in Gal et al., 2007
07LG-16-C	6.38	446	0.67, 10.59	--

Table 12. *Rock-Eval and TOC results from outcrop samples of Bluefish Member.* S_1 *and* S_2 *are Rock-Eval parameters expressed as mg hydrocarbon/mg rock.*

In summary, total organic carbon values for Bluefish Member are high and the potential as a source rock is excellent. Based on pseudo-van Krevelen type crossplots (HI vs OI), type I (or possibly type II) kerogen is indicated (Gal et al., 2007), thus the unit is oil prone.

Bluefish Member ranges from just mature to overmature in Peel area. A sample of upper Hare Indian Formation shale from Airport Creek was immature, thus the lower boundary of the oil window is bracketed as a roughly northwest-trending line running about through the "Ramparts" on Mackenzie River (Figure 71). Feinstein et al. (1988) reported vitrinite reflectance (%Ro) for Bluefish Member from two Peel area wells. In Shoals C-31 well at 701 m, 0.72%Ro was determined. In North Ramparts A-59 well, Bluefish Member at 2173 m had a reflectance of 2%Ro. Rock-Eval data (Pyle et al., 2006b; Gal et al., 2007; data in Pierce and Jones, 2009) further indicate the range of maturities throughout Peel area.

Ramparts Formation

The platform member of Ramparts Formation in places comprises thin- to medium-interbedded limestone and black shale (Figure 89). The underlying shale ramp facies, and the Carcajou marker (Tassonyi, 1969) which lies between the shale ramp and platform, also have considerable black organic shale interbeds (Muir and Dixon, 1984). The Carcajou marker is apparent in many subsurface logs as a strong gamma kick, lying below the massive-looking reefal Kee Scarp member. The dark shale beds of Ramparts Formation are apparent in outcrop from Bell Creek to Powell Creek and the LP-21 section on Mountain River (Figure 71).

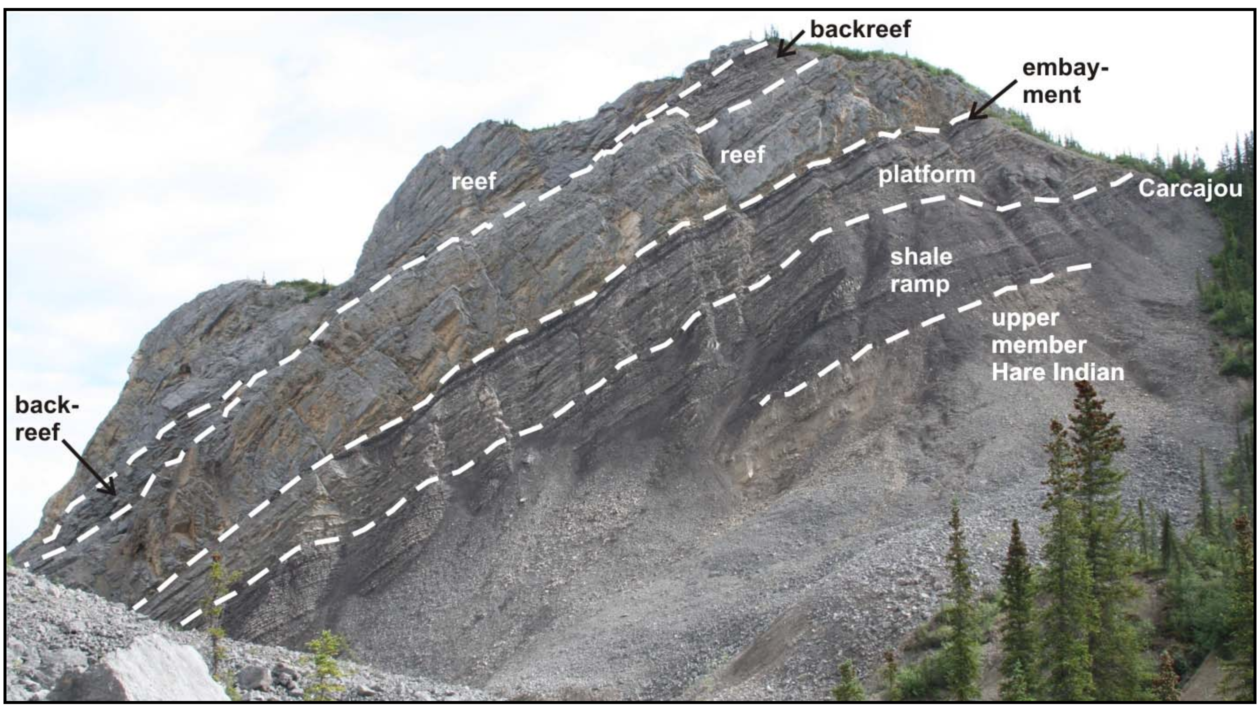

Figure 89. *View northeast to bluff of Ramparts Formation, east branch of Bell Creek. Shale ramp (Carcajou) facies contain organic-rich black shales. A few black shale interbeds occur at the top of the platform facies (embayment facies recognized locally by Muir and Dixon, 1984).*

There are few reported analyses of TOC from these shaly Ramparts Formation beds. Pyle et al. (2006a) compiled maximum TOC values from well samples reported in the literature, which ranged from 0.47% to 0.76% TOC from samples from the top Ramparts Formation in Hume River L-09, Sans Sault No.1 (H-24), and Ontaratue K-04 wells to 3.32% TOC from Grandview Hills No.1 (A-47) well. The latter sample is likely from a shaly bed within the Charrue sandstone. Samples from S. Ramparts I-77 well, reported as 2.03% TOC by Pyle et al. (2006a), are likely from Hare Indian Formation rather than Ramparts, according to formation tops picks of Hogue and Gal (2008). Several samples were collected from outcrop during the present study (average TOC = 5.07%; Table 13).

Sample	TOC (%)	T_{max} (°C)	S_1, S_2	Comments
06LP-17-04	6.45	451	0.22, 14.53	Reported in Gal et al., 2007
06LP-17-05	1.92	455	0.06, 2.05	Reported in Gal et al., 2007
06LP-17-08	2.43	459	0.85, 4.39	Reported in Gal et al., 2007
06LP-18-05	4.81	456	0.88, 6.07	Reported in Gal et al., 2007
06LP-19-14	9.43	453	0.80, 24.06	Reported in Gal et al., 2007
06LP-19-15	12.43	449	0.14, 34.48	Reported in Gal et al., 2007
07LG-16-D	6.17	451	0.53, 17.6	--
07LG-15-C	3.58	446	0.25, 8.13	--
07LG-15-D	7.80	446	1.66, 19.40	--
07LG-15-E	0.58	447	0.13, 1.23	--
H731645	0.15	436	0.04, 0.17	Whirlpool No.1 (H-73) well, 1645 ft depth, well cuttings

Table 13. *Rock-Eval and TOC results from outcrop samples and one well of Ramparts Formation. S_1 and S_2 are Rock-Eval parameters expressed as mg hydrocarbon/mg rock.*

In summary, total organic carbon values for Ramparts Formation are high and the potential as a source rock is excellent. Based on pseudo-van Krevelen type crossplots (HI vs OI), type I kerogen is indicated (Gal et al., 2007), thus the unit is oil prone.

Ramparts Formation ranges from mature to overmature in Peel area, mainly on the basis of Rock-Eval data (Table 13) from the current study. New Rock-Eval analyses from well cuttings of the Whirlpool No.1 (H-73) well indicate a T_{max} of 436°C, and Feinstein et al. (1988) reported vitrinite reflectance of 0.68 %Ro from about the middle of Hare Indian Formation from Ontaratue K-04 well, which somewhat constrains Ramparts maturity. Mature Ramparts Formation lies in roughly the same area as mature Bluefish Member, in southeast to central Peel area (Chapter 10, this volume). Thickness of the shale ramp/Carcajou marker is not well constrained in Peel area, but ranges from several metres to a few tens of metres in gross thickness, lying under the presumed best reservoir facies of Kee Scarp member.

Canol Formation

Canol Formation is an organic-rich shale (Figure 90), characteristically siliceous, that is well known as an excellent potential source rock as proven at Norman Wells (Snowdon et al., 1987). It is widely distributed throughout Peel area where it overlies Ramparts Formation in southeast Peel area, Hare Indian Formation further west, and Hume Formation in western Peel area where Hare Indian Formation is absent or cannot be differentiated.

Figure 90. *Exposure of Canol Formation, Rumbly Creek, showing typical weathering pattern and colours. Dall sheep (circled) for scale.*

Geochem Laboratories and AGAT Consultants (1977) systematically sampled several wells in Peel area for total organic carbon (TOC), resulting in a range from 0.63% to 5.47% and an average of 2.59% TOC over 21 samples. Link et al. (1989) reported TOC values of 1.5% to 8.6% TOC from Peel Plateau and Richardson Mountains. National Energy Board (2000) reported an average of 3.73% TOC (range 0.76% to 6.95%) for Canol Formation in Peel Plateau and Plain. Al-Aasm et al. (1996) reported values from Canol Formation from 1.37% to 6.68% TOC (5.16% average). Samples collected by the GSC compiled by Pyle et al. (2006a) indicate maximum values of well samples ranging from 2.18% to 7.47% TOC. Several samples were collected from outcrop during the present study (average TOC = 4.85%; Table 14).

Sample	TOC (%)	T_{max} (°C)	S_1, S_2	Comments
C-455004	4.60	--	0.00, 0.05	Reported in Pyle et al., 2006b
C-455007	8.51	497	0.17, 2.51	Reported in Pyle et al., 2006b
06LP-07-05	6.80	596	0.02, 0.60	Reported in Gal et al., 2007
06LP-14-06	3.10	603	0.03, 0.18	Reported in Gal et al., 2007
06LP-14-07	7.54	602	0.01, 0.45	Reported in Gal et al., 2007
06LP-17-12	5.04	446	1.66, 12.85	Reported in Gal et al., 2007
06LP-17-13	3.12	446	0.46, 4.89	Reported in Gal et al., 2007
06LP-18-11	8.29	456	1.81, 9.83	Reported in Gal et al., 2007
06LP-19-03	5.61	442	1.45, 21.08	Reported in Gal et al., 2007
06LP-19-05	6.75	440	1.47, 21.77	Reported in Gal et al., 2007

Sample	TOC (%)	T_{max} (°C)	S_1, S_2	Comments
06LP-19-16	5.90	448	1.19, 14.63	Reported in Gal et al., 2007
06LP-20-02	4.89	424	0.14, 6.96	Reported in Gal et al., 2007
06LP-20-03	2.92	487	0.02, 0.32	Reported in Gal et al., 2007
06-TH-06-E	6.13	594	0.02, 0.50	Reported in Gal et al., 2007
WGZ-012-06	7.30	467	0.49, 4.12	Reported in Gal et al., 2007
WGZ-013-06	3.52	459	0.15, 1.36	Reported in Gal et al., 2007
WGZ-014-06	2.89	465	1.29, 2.02	Reported in Gal et al., 2007
06TNT-TR-001A	5.33	610	0.02, 0.04	Reported in Gal et al., 2007
06TNT-TR-002	4.06	609	0.01, 0.06	Reported in Gal et al., 2007
06TNT-TR-003	3.75	424	0.02, 0.02	Reported in Gal et al., 2007
06TNT-TR-004	4.39	488	0.01, 0.06	Reported in Gal et al., 2007
06TNT-TR-024B	3.70	610	0.01, 0.05	Reported in Gal et al., 2007
06TNT-TR-024C	5.05	610	0.02, 0.08	Reported in Gal et al., 2007
06TNT-TR-024E	5.63	609	0.01, 0.12	Reported in Gal et al., 2007
06TNT-TR-024G	3.34	609	0.01, 0.03	Reported in Gal et al., 2007
06TNT-TR-024I	6.19	609	0.01, 0.16	Reported in Gal et al., 2007
06TNT-TR-024K	6.25	610	0.03, 0.10	Reported in Gal et al., 2007
07LG-11-A	0.68	605	0.00, 0.03	--
08LG-3-A	9.49	439	4.17, 41.44	--
07TNT-RR-14A	0.20	422	0.01, 0.03	Reported in Allen and Fraser, 2008
07TNT-RR-14B	2.41	607	0.02, 0.06	Reported in Allen and Fraser, 2008
07TNT-SR-40A	4.94	608	0.01, 0.06	Reported in Allen and Fraser, 2008
07TNT-SR-40B	6.92	607	0.02, 0.09	Reported in Allen and Fraser, 2008
07TNT-SR-41A	3.08	607	0.02, 0.05	Reported in Allen and Fraser, 2008
07TNT-SR-41B	3.16	607	0.01, 0.03	Reported in Allen and Fraser, 2008
07TNT-SR-41C	3.18	607	0.02, 0.05	Reported in Allen and Fraser, 2008

Table 14. *Rock-Eval and TOC results from outcrop samples of Bluefish Member. S_1 and S_2 are Rock-Eval parameters expressed as mg hydrocarbon/mg rock.*

Canol Formation outcrop samples from the present study in Peel area confirm the excellent source rock potential. Based on pseudo-van Krevelen type crossplots (HI vs. OI), type I (or possibly type II) kerogen is indicated (Gal et al., 2007), thus the unit is oil prone.

Canol Formation ranges from immature to post-mature in Peel area, based on Rock-Eval data from the current study. Vitrinite reflectance measurements from well samples, compiled for Peel area by Pyle et al. (2006b) and for Canol-aged rocks throughout the Western Canada Sedimentary Basin compiled by Stasiuk and Fowler (2002) provide further information. Data indicate immature Canol Formation along the northeast edge of Peel area, and increasing maturities to the southwest, forming a northwest-trending swath of Canol Formation within the oil window (see Chapter 10, this volume). Maturity levels quickly increase toward the fronts of the Mackenzie and Richardson mountains, presumably due to increased burial, and some complications in the trends are evident, probably due to structuring along the mountain fronts. Thicknesses of Canol Formation, where it lies in the oil window range, from 5 m to over 70 m in northern Peel area.

Unconventional Reservoirs

Although an evaluation of unconventional hydrocarbon potential and play types is largely beyond the scope of this report, it should be noted that these Middle to Upper Devonian rocks have potential to be unconventional "tight" reservoirs. Canol Formation, because of its greater extent and thickness generally in Peel area, may be investigated in the future. Since Canol Formation is at outcrop or shallow subcrop along Mackenzie River in northeast Peel area, and is mature just below or just into the oil window here, it may have potential as an oil shale. Furthermore, because Canol Formation is generally quite cherty or siliceous, and generally highly fractured in outcrop (Figure 91), it may be amenable to stimulation in subsurface as a shale gas reservoir, or natural fracture systems may be sufficient to provide required permeability.

Figure 91. *Exposure of Canol Formation, Powell Creek. Concretion in the middle ground is about 1 m long. Note the abundance of fractures at a high angle to bedding.*

The gas show in Tree River H-38 well [an uncontrolled flow of sweet gas estimated at 17.7 x 10^6 m^3/day (500 mcf/day; Imperial Oil Enterprises, Ltd., 1967) may be indicative of the potential of fractured Canol Formation as a reservoir.

Seal and Overburden Rocks

Ramparts Formation outcrops in northeastern Peel area, from the "Ramparts" of Mackenzie River upstream of Fort Good Hope, downstream along the river valley. The Charrue sandstone, or sandy thin Ramparts Formation, outcrops along Mackenzie River valley northwest of the Tieda River area (Figure 71). In addition, Ramparts Formation outcrops in folded and faulted structures of the Franklin Mountains, such as East Mountain and Imperial anticline, and along the Mackenzie Mountain front as far west as Gayna River. However, the formation dips south and west in Peel area, to as deep as 1208 m in Hume River L-09 (Figure 3). The probable edge of Kee Scarp member in southeast Peel area (Williams, 1985) lies at depths of 125 m below sea level northwest of the "Ramparts" on Mackenzie River, to over ten times that depth in the upper Hume River area (Figure 57).

Canol and Imperial formations shale and siltstone overlie Ramparts Formation. These are proven (though leaky) seals at Norman Wells, where the depth to reservoir is only 350–650 m (Yose et al., 2001). Canol Formation seems prone to fracturing, and it is likely Imperial Formation that performs as the seal (e.g., Yose et al., 2001). Where Canol and Imperial formations are removed by pre-Cretaceous erosion, at the southeastern edge of Peel area between the Manitou L-61 and Shoals C-31 wells, basal Cretaceous siliciclastics form a poor seal (e.g., Williams, 1985).

Traps

Traps in the Ramparts Formation can be considered primarily stratigraphic traps, associated with particular facies of the Kee Scarp member reefal facies. By analogy with the Norman Wells oil field, it may be that the northern and western edges of the reef member were conducive to well-developed reef margins and foreslopes, and high-energy shoals that are the best facies for reservoir properties (Al-Aasm and Azmy, 1996; Yose et al., 2001). Muir and Dixon (1985) indicated reef margins and foreslopes developed on both the west and east sides of the Kee Scarp member outcrop exposed between Gayna River and Powell Creek. Muir and Dixon (1984) indicated a shoal facies at the very top of the westward facing Kee Scarp member outcrop about 8 km west of Bell Creek.

Kee Scarp member has been studied, explored, and outlined fairly well by seismic surveys (Williams, 1985). Several exploration wells have been drilled, without real success (e.g., Carcajou D-05, Hume River O-62); many seemingly focused on structural highs on the Kee Scarp member or at the reef margin (Gal, 2005). In some instances, it seems that potentially better parts of the formation were not tested during DSTs (Figure 92).

The important diagenetic and possibly structural controls on Ramparts Formation traps are not as well understood in Peel area. In addition to diagenetic microporosity traps (Kaldi, 1989; Al-Aasm and Azmy, 1996), stratigraphic traps may be found in 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). The Charrue sandstone member may be involved in stratigraphic pinchout traps or intra-formational porosity traps, or even fault traps in the Grandview Hills area. Structural or structural-stratigraphic hybrid traps may be important, in the area at the front of the Mackenzie Mountains and at the Franklin/Mackenzie mountains transition area (Lemieux et al., 2007).

Potential unconventional reservoirs in Canol Formation and Bluefish member, mentioned briefly above, of course do not require the same sort of trapping geometries typically associated with reefal rocks.

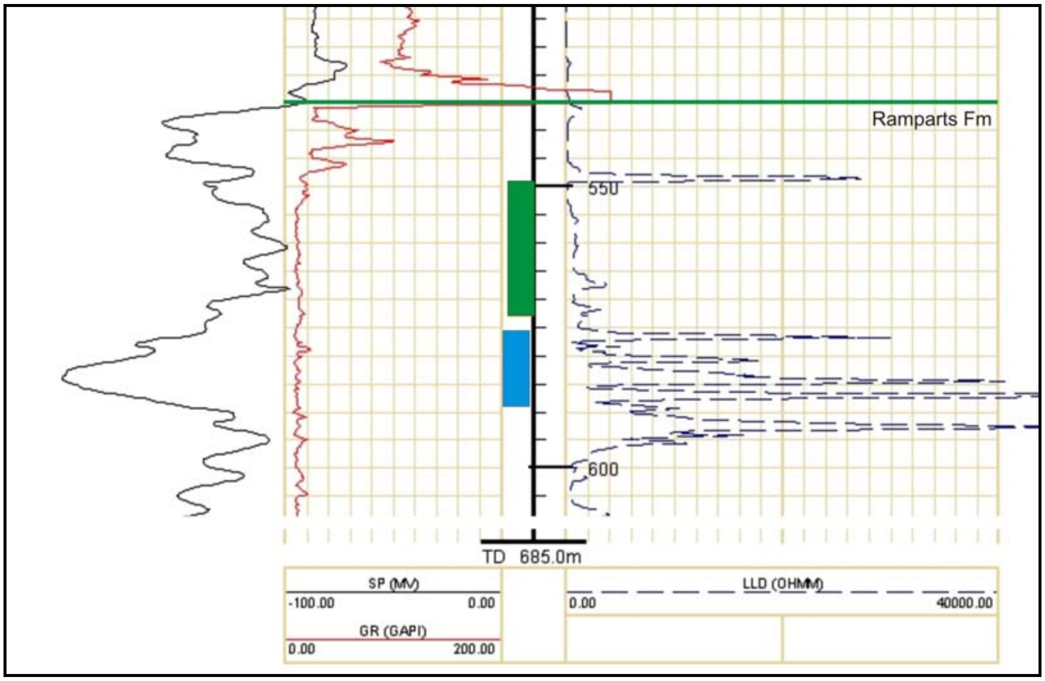

Figure 92. *Gamma (red), self potential (SP; black solid), and deep resistivity (black dashed) logs from Maida Creek O-65 well. Top Ramparts Formation indicated by green line. The green bar from about 550 m indicates the interval tested by DST #1, which recovered 48 m gas-cut mud, 189 m slightly gas-cut mud, and 93 m muddy water. The SP deflections and resistivity kicks further downhole (blue bar, 550 m to 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 (after Gal, 2005).*

Lemieux et al. (2008) compiled areas of closure from publically available seismic time-structure maps of Ramparts Formation in the Mackenzie valley region. A number of such closures were identified in the extreme southeast corner of Peel area and adjacent Carcajou River area. Larger, probably structural closures, up to 4 km by 12 km, were indicated, possibly related to the Whirlpool Fault and the Franklin/Mackenzie mountains transition (Lemieux et al., 2007). A number of these were apparently tested, for example, in Hume River L-09 and Mountain River O-18 wells. Further to the northwest, scattered small domal closures, generally 1 km to 2 km across, were identified in the lower Hume and Ramparts rivers area.

Timing of Generation, Migration, and Accumulation

Bluefish Member, shaly beds of Ramparts Formation, and Canol Formation likely reached maturity through burial under Cretaceous (Albian and younger) siliciclastics though much of Peel area, according to simple 1-D burial history models (Chapter 10, this volume). Expulsion and migration may have occurred in the latest Cretaceous up into the Eocene. This is favourable timing for Ramparts Formation reservoirs, and also for structural traps that may have formed in response to Laramide orogeny.

In areas along the Mackenzie Mountain front, and into the Yukon sections of Peel Plateau, Canol is overmature to post-mature. In western Peel area Canol Formation might have passed into the oil window as early as late Paleozoic time, through burial under Imperial and Tuttle Formation and equivalents (e.g., Link and Bustin, 1989). A large part of Canol Formation subcrop in central and southeastern Peel area is in the oil window presently. Outcrops of Ramparts Formation, in breached structures such as Imperial anticline, and homoclinal panels as at Powell Creek, are oil stained, so it is clear that oil was present in these rocks. Cored intervals examined are also commonly oil-stained.

Much of this oil was probably sourced from more mature Bluefish and Canol formations situated down dip in the basin. Some may have been generated in situ from shale ramp and Carcajou marker beds in Ramparts. At Powell Creek, however, at least some of the oil in Ramparts Formation is from an older oil source, probably Cambro-Ordovician in age (K.G. Osadetz, personal communication, 2008; see Chapter 10, this volume). In addition, at Powell Creek and Imperial anticline, there is bitumen, locally in fractures, indicating more biodegraded, and possibly older oil, in samples that are oil saturated and petroliferous. Further, there is evidence that calcite-filled fractures, presumably associated with Laramide stresses and orogeny, post-date oil stained rocks (Figure 93). Therefore multiple generations of hydrocarbon formation, expulsion, migration, and accumulation are possible, as is a continuum of structural trap formation, all of which serve to complicate questions of timing.

Figure 93. *Float sample of Ramparts Formation, Powell Creek. The rock is oil stained, the surface shown here is bitumen coated, and calcite-filled fractures cut the rock.*

Qualitative Evaluation, Risks, Best Parts of Play (Fairways)

The Canol/Bluefish-Ramparts petroleum system is one of the lowest risked in Peel area as far as mature and voluminous source rocks are concerned, but it still has significant exploration risks illustrated by the poor discovery record in the Ramparts Formation in Mountain River/Carcajou River area adjacent southeast Peel area. Some of the major risks include: reservoir quality (in particular the diagenetic aspect of microporosity); trap formation (many of the large structures are breached or near surface and prone to leakage), hydrocarbon degradation (shallow reservoirs, proximity to outcrop), and lack of viable seal (especially where Ramparts Formation is at shallow depths, overlain by subcropping Canol or Cretaceous rocks).

In Peel area, the probable best part of the Kee Scarp play is restricted to the distribution of known and probable Kee Scarp (reefal) member (Williams, 1985), and reduced in areas where Ramparts Formation outcrops, is at near surface, or where Cretaceous rocks overlie Ramparts Formation. These factors result in a narrow, curving, wedge-shaped area roughly between Airport Creek No.1 (D-72) in the north, Hume River I-66 in the west, Hume River L-09 in the southwest, Sans Sault No.1 (H-24) in the southeast, and the Mackenzie River in the east (Chapter 10, this volume).

Gal (2005) ranked the potential of this play as high within the southeastern part of the present study's Peel area, as well as in the lower Mountain River/Carcajou River area. In the current study we propose a more moderate ranking, because of the restricted favourable reefal area, and trapping and reservoir risks.

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Chapter 7 – Upper Devonian to Carboniferous Strata I – Imperial Formation Play

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This chapter consists of three sections. The first section (7.1) is an examination of Imperial Formation sedimentology and stratigraphy; for the most part, this section is taken from Hadlari et al. (in press). The second section (7.2), Tylosky et al.'s examination of the ichnology of Imperial Formation, is based on the senior author's B.Sc. thesis research. Sections 7.1 and 7.2 are based predominantly on examination of Imperial Formation in the Northwest Territories. References cited in these first two sections are combined. It should be noted that Imperial Formation extends westward into Yukon's Richardson Mountains and Eagle Plain, where there are variations in lithology and ichnology from what is presented in sections 7.1 and 7.2. Chapter 8 (this volume) addresses several aspects of Imperial Formation, including its relationship to Tuttle Formation and other Upper Paleozoic strata, at the far western extent of the study area in Yukon. The third section (7.3) reviews aspects of petroleum geology of Imperial Formation in light of new data collections. The authors of each individual section are indicated. Some repetition of material in the introductory parts of each section is to be expected.

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7.1 SLOPE AND SUBMARINE FAN DEPOSITIONAL SYSTEM OF IMPERIAL FORMATION

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Abstract

In Peel Plateau and Plain regions, at the front of the Mackenzie Mountains, the Upper Devonian Imperial Formation was deposited by a fan-slope complex that prograded southwest from an eastern basin margin. At the base of Imperial Formation, laterally extensive submarine fan deposits are composed of intercalated sandstone lobe and lobe fringe deposits. Sandstone lobes are composed of thick-bedded turbidites reflecting high sediment fallout rates. Lobe fringe deposits are thin-bedded turbidites deposited under upper flow regime conditions. Overlying submarine fan deposits, slope facies are shale-dominant, but include turbidites deposited by both fine-grained dilute flows and thin-bedded facies deposited under upper flow regime conditions but low sediment fallout rates.

At the eastern edge of the study area, at the formation's type section on Imperial River, shallow marine deposits are preserved above and below slope deposits, with no submarine fan deposits at the base of the section. The succession at Imperial River is interpreted to record early shelf construction near the basin margin followed by transgression and establishment of a deep water, although still continental, basin. Near the western edge of the study area, at Flyaway Creek, Imperial Formation is composed entirely of shale, marking the western extent of well developed base-of-slope submarine fan deposits.

7.1.1 Introduction

Imperial Formation is widely distributed throughout northern Northwest Territories (NWT) and Yukon (Figure 7.1.1; Martin, 1959; Gordey et al., 1992). It records Late Devonian marine siliciclastic deposition coeval with uplift of a clastic source to the north during the Ellesmerian Orogeny (Martin, 1959; Lane, 2007). Near the northern edge of the Mackenzie Mountains, Imperial Formation has been interpreted as shelf sandstones and basinal turbidites that are speculated to be derived from the north and east (e.g., Braman, 1981; Braman and Hills, 1992).

Most of the published work on Imperial Formation was based on regional mapping projects conducted in the 1940s and 1960s (e.g., Laudon, 1950; Bassett, 1961; Norris, 1968, 1985; Norris, 1982; Aitken et al., 1982). One of the objectives of the Peel Project is to refine the sedimentology and stratigraphy of Imperial Formation. In this report we present sedimentology based on outcrop studies and integrate historical seismic and well log data into a depositional model. A version of this report is submitted for publication in an external journal (Hadlari et al., in press).

Regional Geology and Previous Work

From Cambrian to Early Devonian time in the vicinity of Mackenzie Mountains, the Interior Platform of North America was characterized by carbonate deposition on the passive western margin of Laurentia (e.g., Pugh, 1983; Fritz et al., 1991; Cecile et al., 1997). Black shales of Hare Indian and Canol formations overlie the carbonate platform, marking the onset of siliciclastic deposition. Sandstone, siltstone, and shale of Upper Devonian Imperial Formation record sediment influx due to uplift of a clastic source (e.g., Gordey et al., 1992; Lane, 2007). To the north and west of the study area, including the Richardson Mountains, the clastic sediments have been interpreted as derived from the north and west (Pugh, 1983; Norris, 1985; Braman and Hills, 1992), but in the vicinity of Norman Wells the clastic source was speculated to have been from the east (Figure 7.1.2; Chi and Hills, 1976; Braman and Hills, 1992). Embry and Klovan (1976) suggested that Imperial Formation in the NWT was sourced from the northeast, ultimately from the Ellesmerian Orogen of the northern Canadian Arctic Islands.

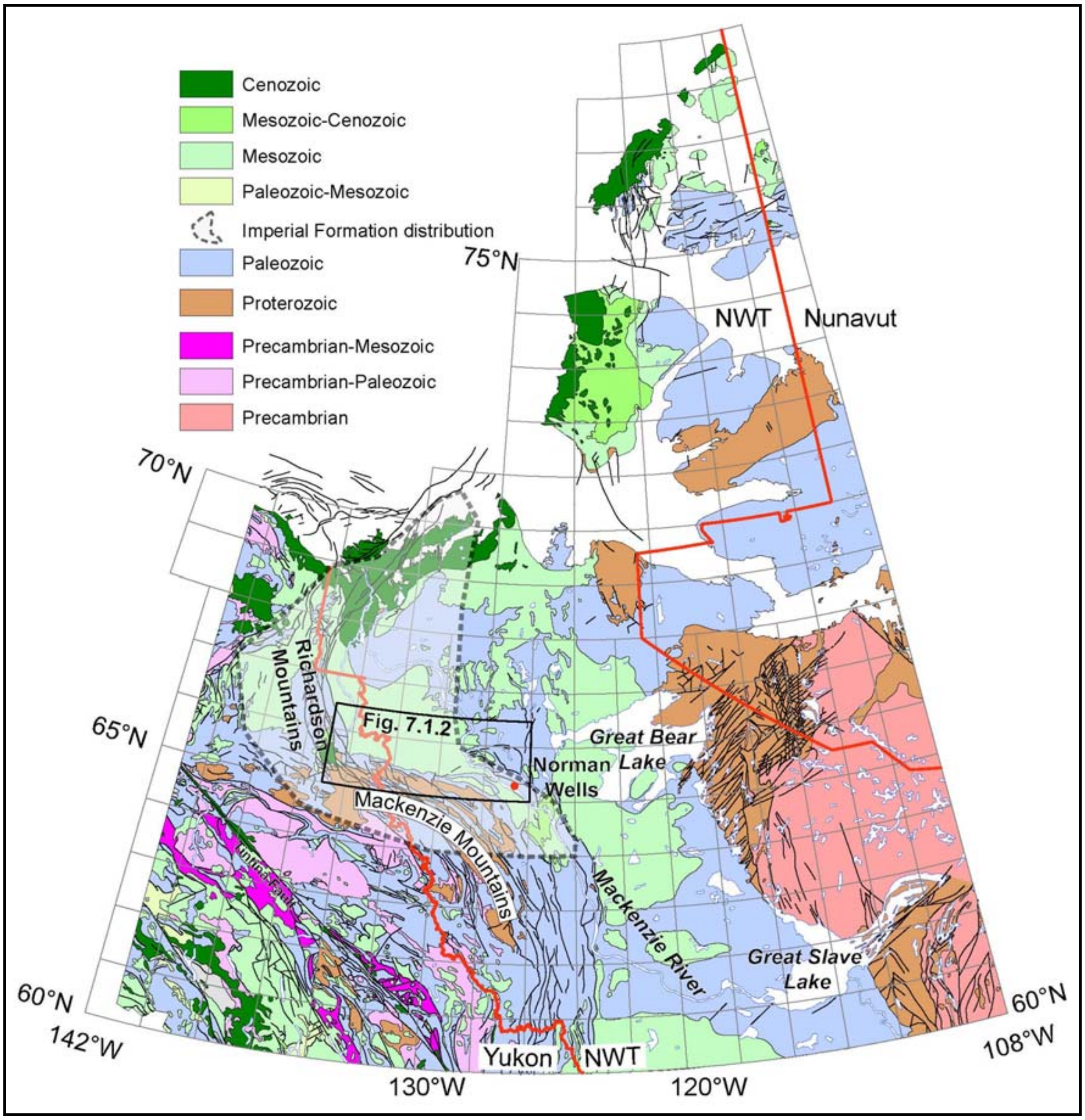

Figure 7.1.1. *Geology map of Yukon, Northwest Territories, and Nunavut showing location of study area. Geology after Wheeler et al. (1997). Shaded area indicates surface and subsurface distribution of Imperial Formation after Norris (1985), Coflin et al. (1990), and Gordey et al. (1992).*

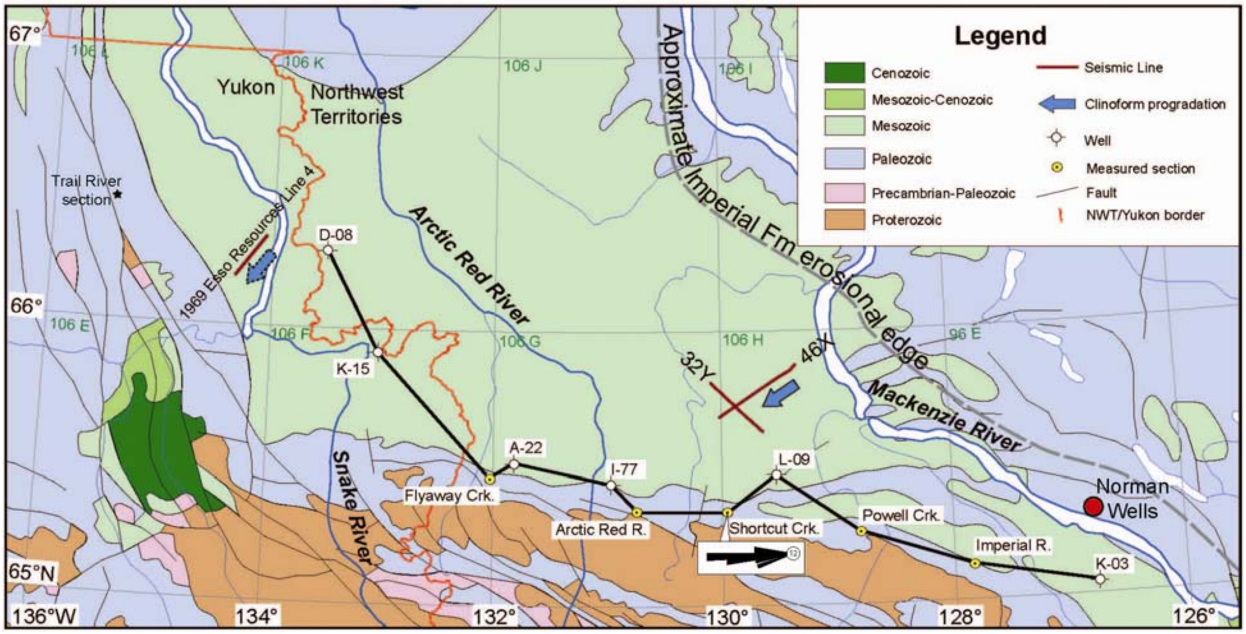

Figure 7.1.2. *Map of study area showing location of measured sections, wells, and seismic lines. The clinoform dip direction from 1969 Esso Resources Line 4 is approximate because it is based on a single line (figure 12 of Osadetz et al., 2005). Paleocurrent data from Shortcut Creek were derived from ripple crests, primary current lineation, and flute marks. The eastern erosional edge of Imperial Formation is indicated by a dashed line.*

The modern definition of Imperial Formation was introduced by Bassett (1961), comprising sandstone, siltstone, and shale that conformably overlie Canol Formation black shale (Figure 7.1.3). Based on a conodont association of the lower *Mesotaxis asymmetrica* Zone, Canol Formation is Frasnian in age (Uyeno, 1979). Palynomorphs indicate that the age of Imperial Formation in Peel area is Frasnian-Famennian (Braman, 1981; Braman and Hills, 1992).

To the south, for example in the Nahanni area (NTS 105 I), Imperial Formation is generally correlated with Earn Group (Gordey and Anderson, 1993). Within Earn Group, cherty shales of Portrait Lake Formation are considered to be correlative with Canol Formation (Cecile, 2000) and latest Devonian to earliest Mississippian siliciclastic turbidites of Provost Formation are correlative with Imperial Formation (Gordey and Anderson, 1993).

In the eastern portion of the study area Imperial Formation is unconformably overlain by Cretaceous rocks (Aitken et al., 1982). West of Arctic Red River, Imperial Formation is conformably overlain by a succession of sandstone, conglomerate, and shale. Pugh (1983) proposed that this succession composes Tuttle Formation, for which the lower contact is the lowest medium- to coarse-grained sandstone and/or conglomeratic sandstone within the overall conformable succession. The contact between Imperial and Tuttle formations is essentially a grain size based facies boundary and therefore diachronous (Pugh, 1983). Within the study area Pugh (1983) designated intervals containing medium- and coarse-grained sandstone that overlie Imperial Formation as Tuttle Formation (Sainville River D-08, Taylor Lake YT K-15, and A-1 Cranswick A-22 wells). An equivalent interval on the Snake River map sheet (NTS 106 F; Norris, 1982) is designated “Mo” and correlates with Tuttle Formation in the subsurface (Pugh, 1983; Allen and Fraser, 2008; Chapter 8, this volume). For simplicity we retain the Imperial

Formation - Tuttle Formation terminology. Based on palynology Tuttle Formation is mainly Famennian in age, but uppermost Tuttle Formation at Trail River (NTS 106 L; Figure 7.1.2) has yielded Tournaisian (Early Carboniferous) palynomorphs (Braman, 1981; Braman and Hills, 1992). See Chapter 8 (this volume) for further discussion of Tuttle Formation.

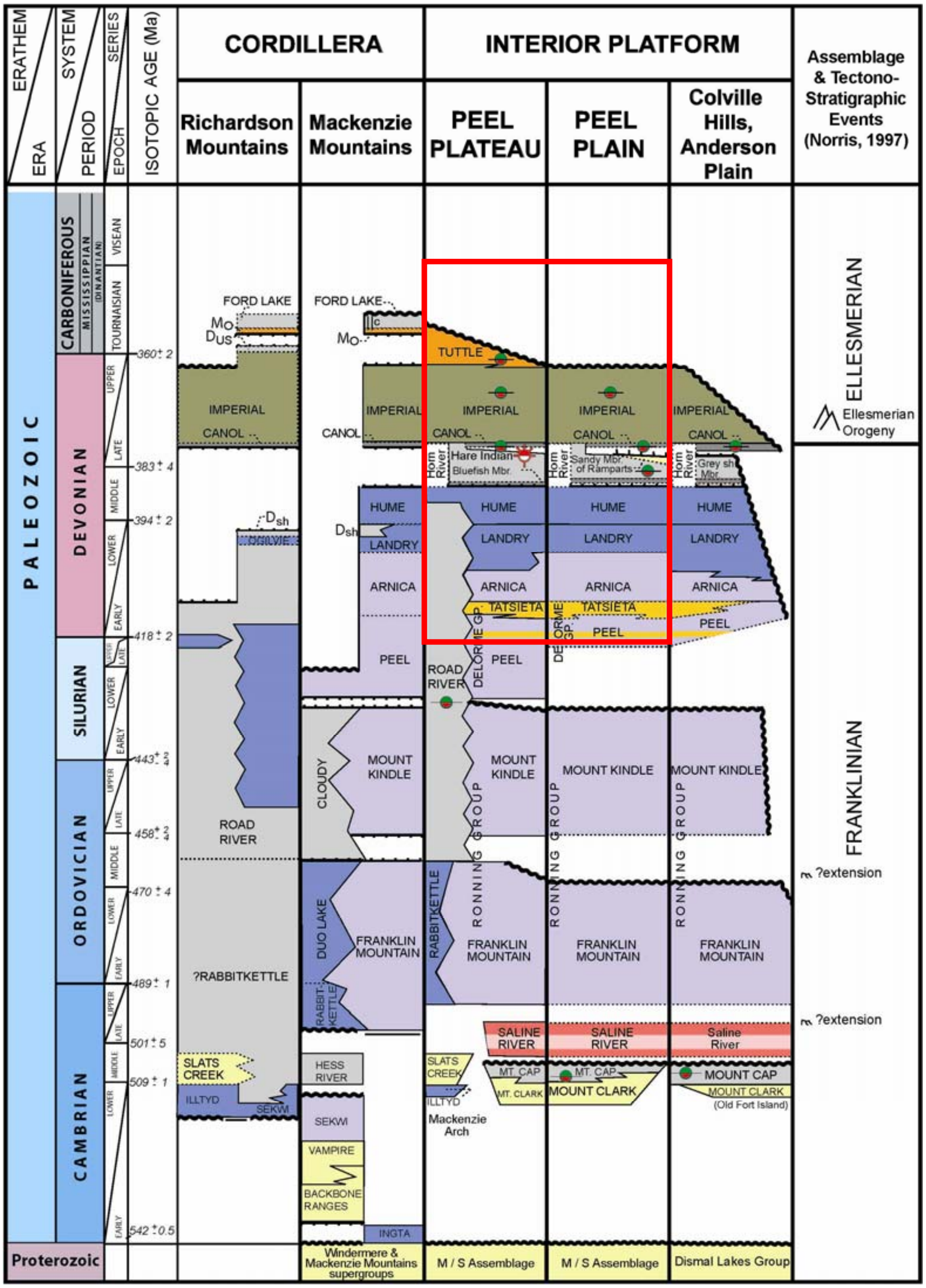

Figure 7.1.3. Stratigraphic chart of Peel Plateau, Peel Plain, and surrounding exploration areas (reproduced from Chapter 1, this volume; modified after Morrow et al., 2006) with Devonian and Carboniferous formations of Peel area in red box. Geology is summarized by Pyle et al. (2006); time scale ages after Gradstein et al. (2004); see Figure 2 in Chapter 1 (this volume) for legend.

Of the five measured stratigraphic sections in the study area (Figure 7.1.4), reports on three have been previously published. The Imperial River section was described by Laudon (1950) and proposed as the type section for Imperial Formation by Basset (1961). Chi and Hills (1976) provided introductory palynology followed by more detailed palynology by Braman and Hills (1992), which included additional sections from Arctic Red River and Powell Creek. Sedimentary interpretations were of sublittoral sheet sandstones and deep marine shales at Imperial River with sandstone turbidites at Arctic Red River (Braman and Hills, 1992). The section at Arctic Red River was first described by Norris (1968; 1985).

7.1.2 Seismic Data

Seismic lines 46X and 32Y are oriented approximately perpendicular to each other (Figure 7.1.2). Imperial Formation in 46X shows clinoforms that dip to the southwest (Figure 7.1.5). Clinoforms extend from the top of Imperial Formation to the base over a distance of approximately 10 km to 15 km, which indicates that within Imperial Formation individual lithologies are not laterally continuous. Imperial Formation reflectors in line 32Y are parallel to bounding surfaces (Figure 7.1.6). This relationship suggests that the dip direction of Imperial Formation clinoforms is approximately southwest, consistent with limited paleocurrent data that are west-directed (Figure 7.1.2). West of well D-08, a previously published 2-D seismic line (Figure 12 of Osadetz et al., 2005; 1969 Esso Resources Line 4) exhibits approximately southwest-dipping clinoforms within Tuttle Formation.

Clinoforms spanning the full thickness of Imperial Formation indicate that the succession was formed by a prograding system that would have resulted in basin floor deposits overlain by slope deposits. In the study area, slope progradation during deposition of Imperial and Tuttle formations was from northeast to southwest (seismic lines) and east to west (paleocurrents) with an inferred northeastern and eastern sediment source region.

7.1.3 Sedimentology

Unless otherwise noted, Imperial Formation sandstones within the study area display a narrow grain size range of very fine- to fine-grained sand. Bedforms were, therefore, generally limited to plane beds and ripples. Facies description (Figure 7.1.7) will primarily utilize the turbidite subdivisions of Bouma (1962): T_a, massive or graded sandstone; T_b, plane parallel laminae; T_c, ripples, wavy or convolute laminae; T_d, upper parallel laminae; and T_e, interturbidite mudstone. The turbidite subdivision of Lowe (1982) for high-density sandy turbidites will also be used: S_1 shows bedload structures such as plane lamination and cross-stratification; S_2 contains inverse grading and basal shear laminations; and S_3 is structureless or normally graded, deposited by suspension, and equivalent to T_a of Bouma (1962). Description of fine-grained deposits employs the T_0-T_8 divisions of Stow and Shanmugam (1980) that subdivide the Bouma T_c-T_d-T_e interval.

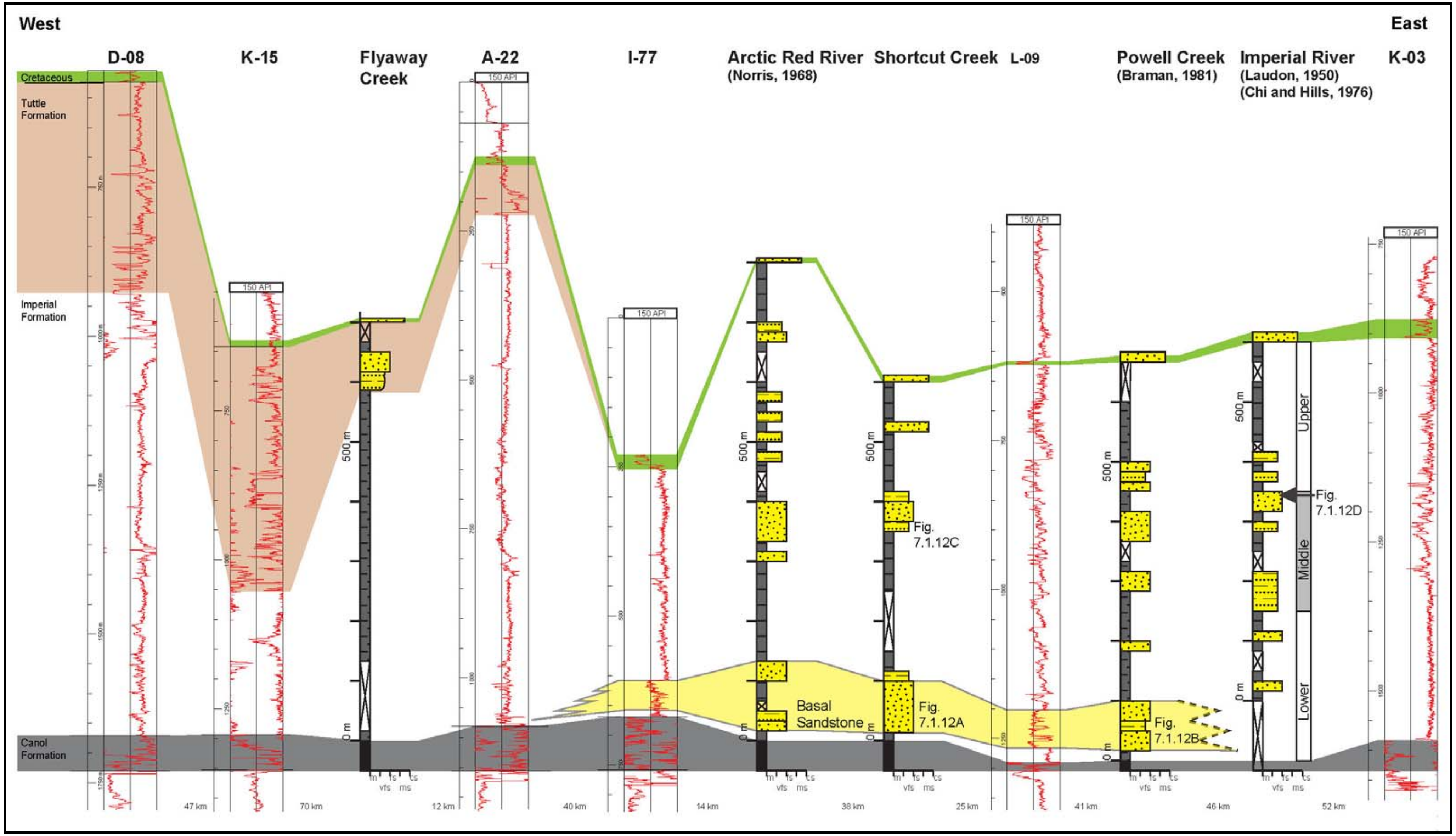

***Figure 7.1.4.** West-east stratigraphic cross-section of Imperial Formation based on measured sections and gamma ray well logs. Datum is the base of Canol Formation. Grain size: m = mudstone; vfs = very fine sand; fs = fine sand; ms = medium sand; and cs = coarse sand.*

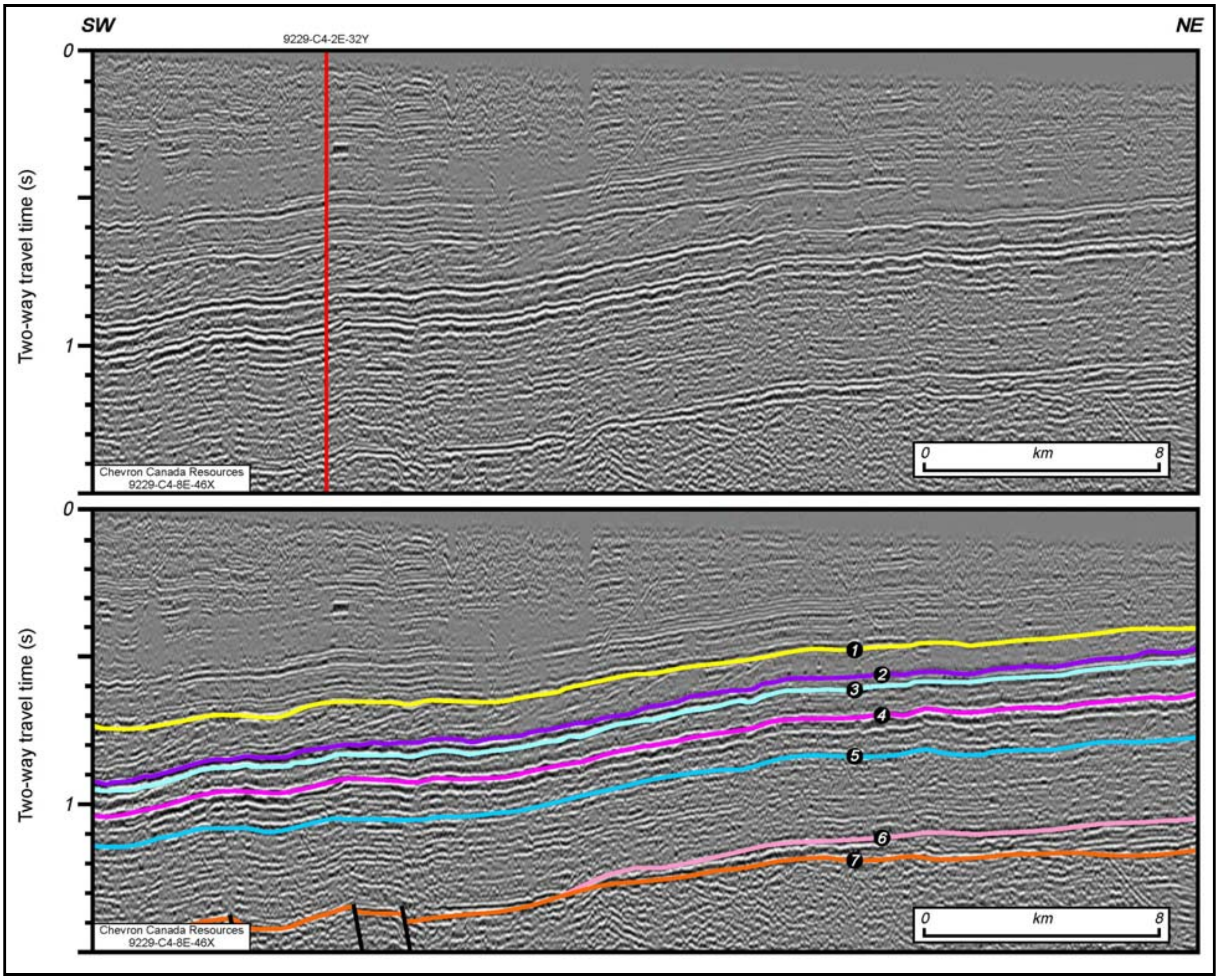

Figure 7.1.5. *Uninterpreted and interpreted versions of 1989 Chevron Canada Resources Limited Line 9229-C4-8E-46X. Note southwest-directed clinoforms within Imperial and Hare Indian formations. See Figure 7.1.2 for location of line. Intersection with seismic line 32Y (Figure 7.1.6) is indicated. Interpretation of reflectors: 1, top of Imperial Formation (base of Cretaceous succession); 2, top of Canol Formation; 3, top of Hare Indian Formation; 4, top of Hume Formation; 5, top of Mt. Kindle Formation; 6, top of Saline River Formation; 7, base of Phanerozoic. Modified after interpretation by B.C. MacLean, Geological Survey of Canada - Calgary.*

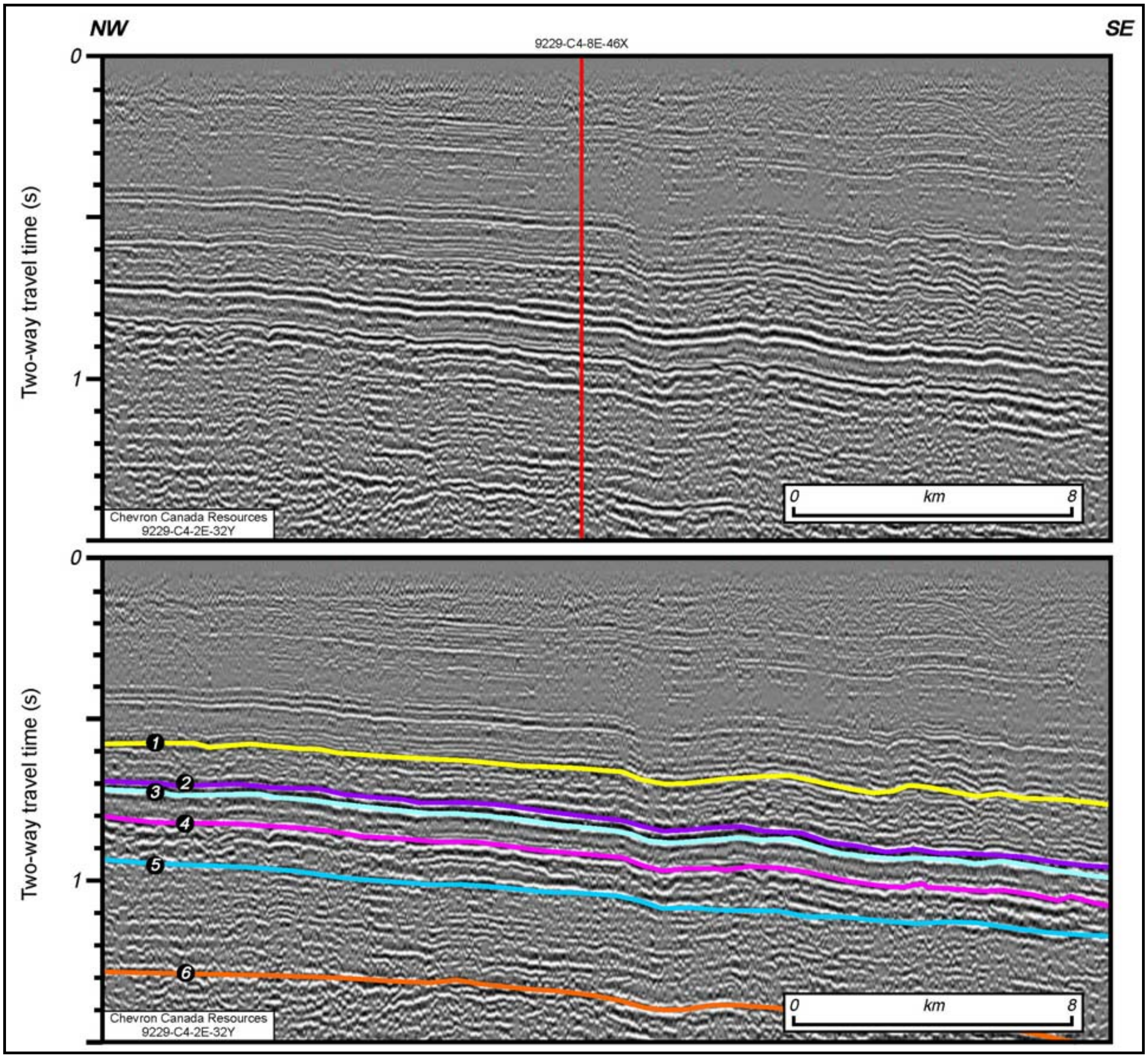

Figure 7.1.6. *Uninterpreted and interpreted versions of 1988 Chevron Canada Resources Limited Line 9229-C4-2E-32Y. Note the relatively flat reflectors within the Imperial Formation. See Figure 7.1.2 for location of line. Intersection with seismic line 46X (Figure 7.1.5) is indicated. Interpretation of reflectors: 1, top of Imperial Formation (base of Cretaceous succession); 2, top of Canol Formation; 3, top of Hare Indian Formation; 4, top of Hume Formation; 5, base of Devonian succession; 6, base of Phanerozoic. Modified after interpretation by B.C. MacLean, Geological Survey of Canada, Calgary.*

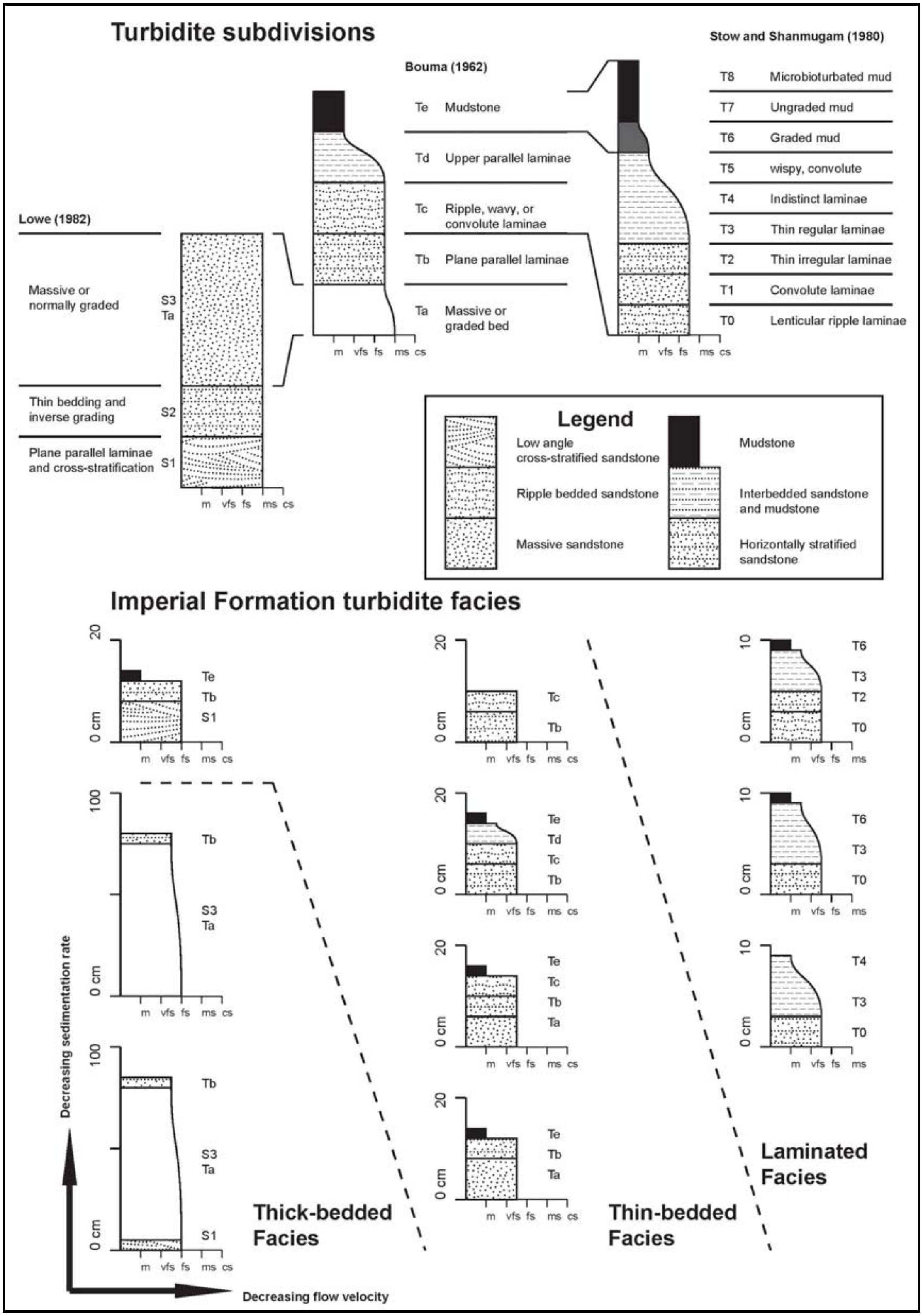

__Figure 7.1.7.__ Turbidite facies of Bouma (1962), Stow and Shanmugam (1980), and Lowe (1982). Imperial Formation turbidites are sub-divided into thick-bedded, thin-bedded, and laminated lithofacies.

Lithofacies

Thin-bedded Facies

Thin-bedded facies comprise 10 cm to 30 cm thick beds of sandstone interbedded with mudstone laminae (A and B in Figure 7.1.8). Sedimentary structures include massive beds, low-angle cross-stratified beds, plane parallel-lamination and associated primary current lineation, ripple cross-lamination, and climbing ripples. The most common depositional units comprise massive to parallel-laminated (T_a-T_b) and parallel-laminated to cross-laminated sandstone overlain by silty mudstone (T_b-T_c-T_e). Less common (but more complete) are Bouma sequences of massive to parallel-laminated sandstone overlain by mudstone (T_a-T_b-T_d-T_e). A rare sedimentary structure is low-angle cross-stratification of thin beds of sandstone.

Most occurrences of thin-bedded facies are heterolithic, however, a minor sandstone-only subfacies is described here as *thin-bedded sandstone*. It consists of horizontal-tabular parallel-laminated sandstone and ripple cross-laminated sandstone (T_b-T_c; C in Figure 7.1.8). Primary current lineation on bedding planes is a ubiquitous association with the parallel-lamination (D in Figure 7.1.8).

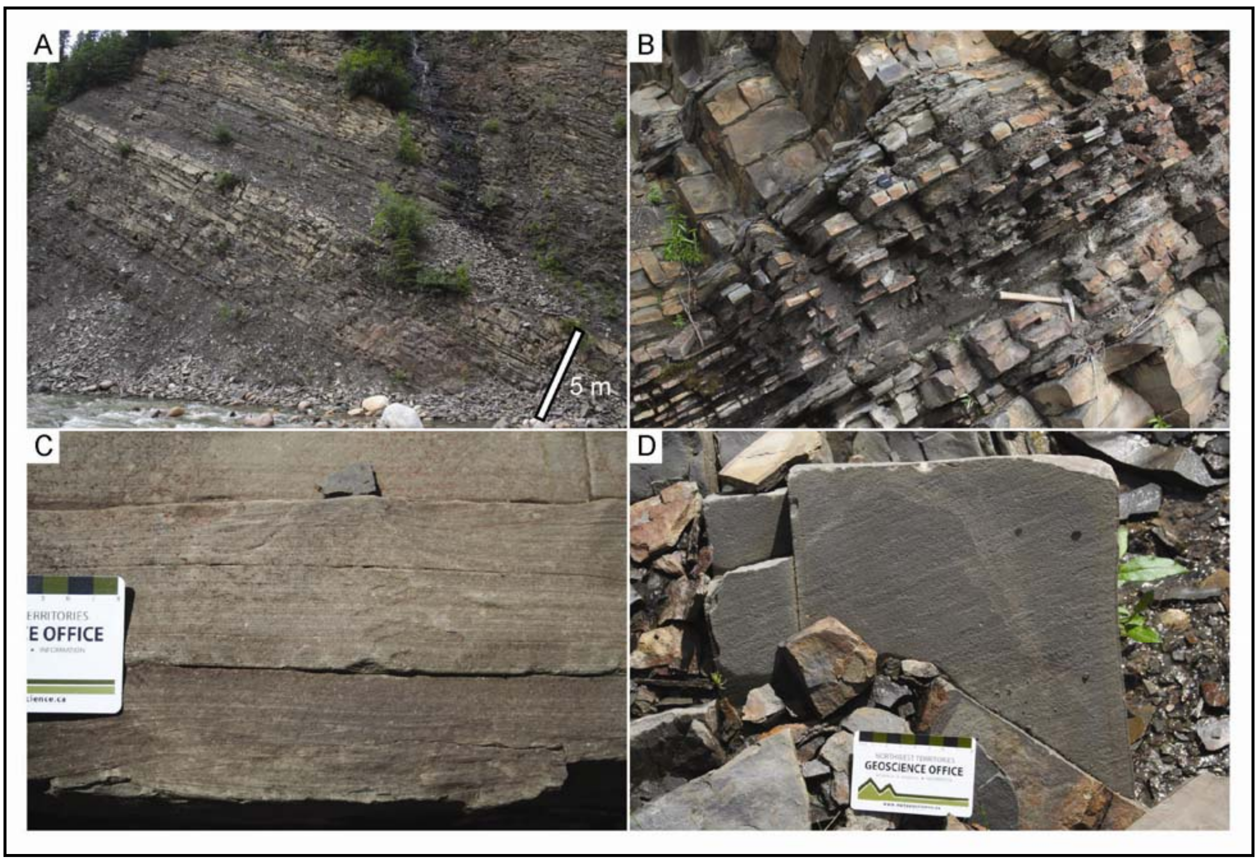

Figure 7.1.8. *Thin-bedded facies outcrop photographs: (A) alternating thin- and thick-bedded facies, note 5 m thick amalgamated thick-bedded sandstone overlying and overlain by thin-bedded facies; (B) thin-bedded facies above 25 cm long hammer; (C) Bouma T_b-T_c couplets of the thin-bedded sandstone subfacies; and (D) plan view of primary current lineation associated with parallel laminae (T_b).*

Thin-bedded facies represent typical low-density sediment gravity flow deposits with the Bouma (1962) sequence of structures that develop in fine-grained sand. A complete succession of structures is: massive bed, plane parallel lamination, ripple cross-stratification and/or climbing ripples, laminated sandstone, overlain by mudstone. These were formed under decelerating flow conditions as the sediment gravity flow deposited part of its sediment load. The absence of obvious graded beds is attributed to the limited grain size of sand available to the sediment gravity flow.

Low-angle cross-stratified sandstone with foresets that dip opposite to inferred paleoflow direction indicate upflow bedform migration and are therefore interpreted to represent stratification formed by upper-flow regime antidunes (Alexander et al., 2001).

The thin-bedded sandstone subfacies is interpreted to represent passage of sediment gravity flows under conditions of minimal deposition. Without rapid sediment fallout rates to inhibit development of bedforms, thin parallel-laminated sandstone records upper flow regime plane beds that formed during passage of the flow; ripple cross-lamination records flow deceleration experienced at the tail of the flow.

Thick-bedded Facies

Thick-bedded facies is typified by 70 cm to 100 cm thick beds of sandstone (A in Figure 7.1.8; A in Figure 7.1.9). These beds are massive T_a units that commonly exhibit diffuse horizontal lamination which is difficult to observe and only visible on fresh faces (B in Figure 7.1.9). The grain size is fairly uniform but some beds grade from fine sandstone at the base to very fine sandstone at the top. Mudstone clasts are rare and oriented parallel to lamination. The geometry is generally horizontal-tabular, but rare beds have a scoured base overlain by a thin bed of low-angle cross-stratified sandstone (C in Figure 7.1.9). Upper portions of thick T_a beds are commonly succeeded by 10 cm thick intervals of horizontal-parallel laminated sandstone (B in Figure 7.1.9).

Thick-bedded turbidite facies compose 10 m to 15 m thick amalgamated sandstone bodies. T_a-T_b units are successively stacked with tabular geometry but these beds have been observed to be discontinuous. Amalgamated sandstone intervals rarely have erosive bases that cut into thin-bedded facies below (A in Figure 7.1.8). Tops of amalgamated sandstone bodies are sharp.

Bouma T_a-T_b packages are interpreted to represent rapid deposition from a waning sediment gravity flow. In rare instances, the parallel-laminated or low-angle cross-stratified base of T_a beds is considered to be the S_1 subdivision of Lowe (1982), recording initial bedload deposition, subsequently overwhelmed by rapid sediment fallout and thus overlain by suspension deposits of S_3/T_a massive sandstone. Turbulence is indicated by the erosive base of some beds, and the bedload process of S_1 is considered to be scour and migration of antidunes (cf. Alexander et al., 2001). As the sediment gravity flow passed, lower sediment fallout rates allowed bedforms to develop again producing the upper T_b division of plane parallel laminae (Lowe, 1982).

The erosive base of rare amalgamated sandstone intervals, and rare lateral discontinuity of beds within, might suggest that amalgamated thick-bedded sandstones were deposited in channels;

however, the vast predominance of tabular geometries (e.g., A in Figure 7.1.8; A in Figure 7.1.9) could be indicative of a more lobe-like setting (e.g., Mattern, 2002).

Figure 7.1.9. *Thick-bedded facies outcrop photographs (lens cap is 4.5 cm): (A) horizontal-tabular, thick-bedded sandstone, note 1.5 m bar for scale; (B) massive to parallel-laminated T_a-T_b intervals; and (C) scoured and low-angle cross-stratified base (S_1) of a thick massive sandstone bed (S_3).*

Shale Facies

Fine-grained facies of Imperial Formation are generally laminated with a shale texture. Lithologies include brown and grey mudstone, silty or sandy mudstone, siltstone, and rare thin sandstone beds. This facies weathers recessively reaching thicknesses up to hundreds of metres.

The shale facies records suspension-dominated deposition. Large thicknesses of uninterrupted shale indicate that large volumes of mud were supplied to the system with minimal to no intervening bedload deposition.

Laminated Facies

Laminated facies comprise inter-laminated sandstone and mudstone that are distinct from the thin-bedded facies. This facies weathers recessively, but in rare outcrops sedimentary structures observed include sandstone to siltstone graded laminae and thin beds (A in Figure 7.1.10), parallel-laminated beds that grade from sandstone to siltstone (B in Figure 7.1.10), and starved ripples (C in Figure 7.1.10). Depositional packages fall within the fine-grained turbidite subdivisions of Stow and Shanmugam (1980): (1) ripple cross-laminated sandstone (T_0), often starved, overlain by upward-fining inter-laminated sandstone, siltstone (T_1-T_3), and mudstone (T_6); (2) laminated sandstone (T_0) overlain by laminated sandstone and siltstone (T_3), capped by mudstone (T_6); and (3) sharp based sandstone with indistinct lamination (T_0) overlain by laminated upward-fining sandstone and siltstone (T_3-T_4).

Laminated, graded sandstone beds were deposited from fine-grained, low-density sediment gravity flows. The succession of ripple cross-laminated sandstone to laminated sandstone indicates that the majority of deposition occurred under lower flow regime conditions. Deposition was largely from suspension, except for the development of ripple bedforms (Stow and Shanmugam, 1980).

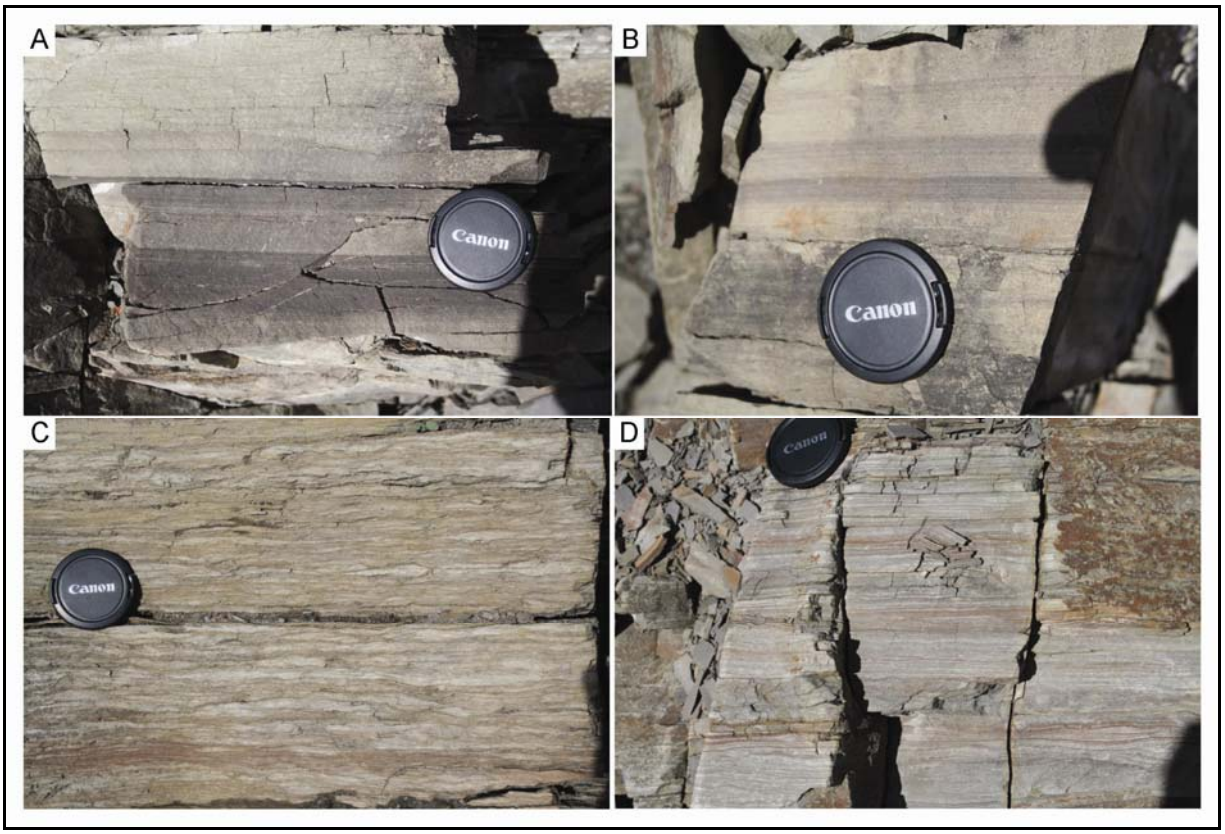

Figure 7.1.10. *Laminated facies outcrop photographs (lens cap is 4.5 cm): (A) graded beds with diffuse lamination from fine sandstone to siltstone and mudstone, overlain by thin graded laminae; (B) multiple upward-fining beds of graded sandstone and siltstone laminae; (C) starved ripples interlaminated with siltstone and mudstone; and (D) upward-fining beds of graded sandstone, undulatory parallel lamination, and graded sandstone and siltstone.*

Cross-stratified Sandstone Facies

The distinctive feature of cross-stratified sandstone facies is hummocky cross-stratification (A in Figure 7.1.11). Common sedimentary structures are parallel lamination and ripple cross-stratification; less common are low-angle cross-stratification and hummocky cross-stratification.

Some beds have irregular scoured bases. B in Figure 7.1.11 shows two depositional units: (1) small-scale hummocky cross-stratification overlain by ripple cross-lamination, and (2) parallel-lamination overlain by ripple cross-lamination. This facies forms amalgamated sandstone units approximately 5 m thick. Cross-stratified facies contain both horizontal and vertical burrows.

Hummocky cross-stratification records deposition above storm wave base. Single depositional units record waning currents from storm events. Trace fossils record bioturbation between storm events. Intervals of cross-stratified sandstone facies without mudstone interbeds are interpreted to record a shoreface depositional setting, which is very different from the preceding lithofacies. Cross-stratified sandstone facies was only observed at Imperial River.

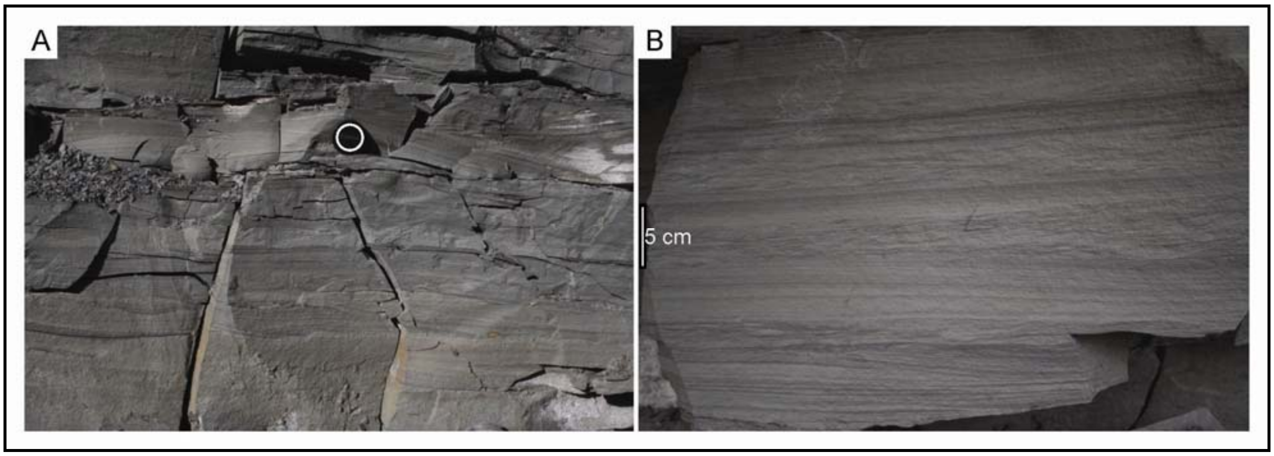

Figure 7.1.11. *Cross-stratified facies outcrop photographs: (A) approximately 10 cm thick bed behind 4.5 cm lens cap (under white circle) displays hummocky cross-stratification; and (B) parallel- to cross-laminated intervals interpreted as storm deposits, note small-scale hummocky cross-stratification in lowermost bed.*

Facies Successions

Basal Sandstone Unit

The lowest sandstone interval, approximately 100 m thick, of Imperial Formation is very similar at Powell Creek, Shortcut Creek, and Arctic Red River sections. The interval is composed of an alternation of thin- and thick-bedded facies (A and B in Figure 7.1.12). Approximately 10 m thick intervals of thin-bedded facies have upward-thickening sandstone beds, upward-decreasing mudstone proportion, and therefore an overall upward-coarsening trend. Approximately 10 m thick intervals of amalgamated thick-bedded facies, that overlie thin-bedded facies, have sharp bases and sharp tops. Thick-bedded facies indicate deposition under predominantly upper flow regime conditions during very rapid sediment fallout rates. Stacking of upward-thickening, thin-bedded and amalgamated thick-bedded sandstones form upward-coarsening packages. These upward-coarsening packages are interpreted to represent prograding sandstone lobe fringes and lobes typical of an outer submarine fan depositional setting (e.g., Mutti, 1977; Mattern, 2002). Upward-thickening, thin-bedded turbidites represent prograding lobe fringe areas adjacent to lobes. The sharp bases of the amalgamated thick-bedded facies indicate that lobe activation was an episodic process, such as a lateral migration event at a more proximal fan or slope location.

This is further indicated by sharp tops of amalgamated thick-bedded units that represent lobe abandonment events.

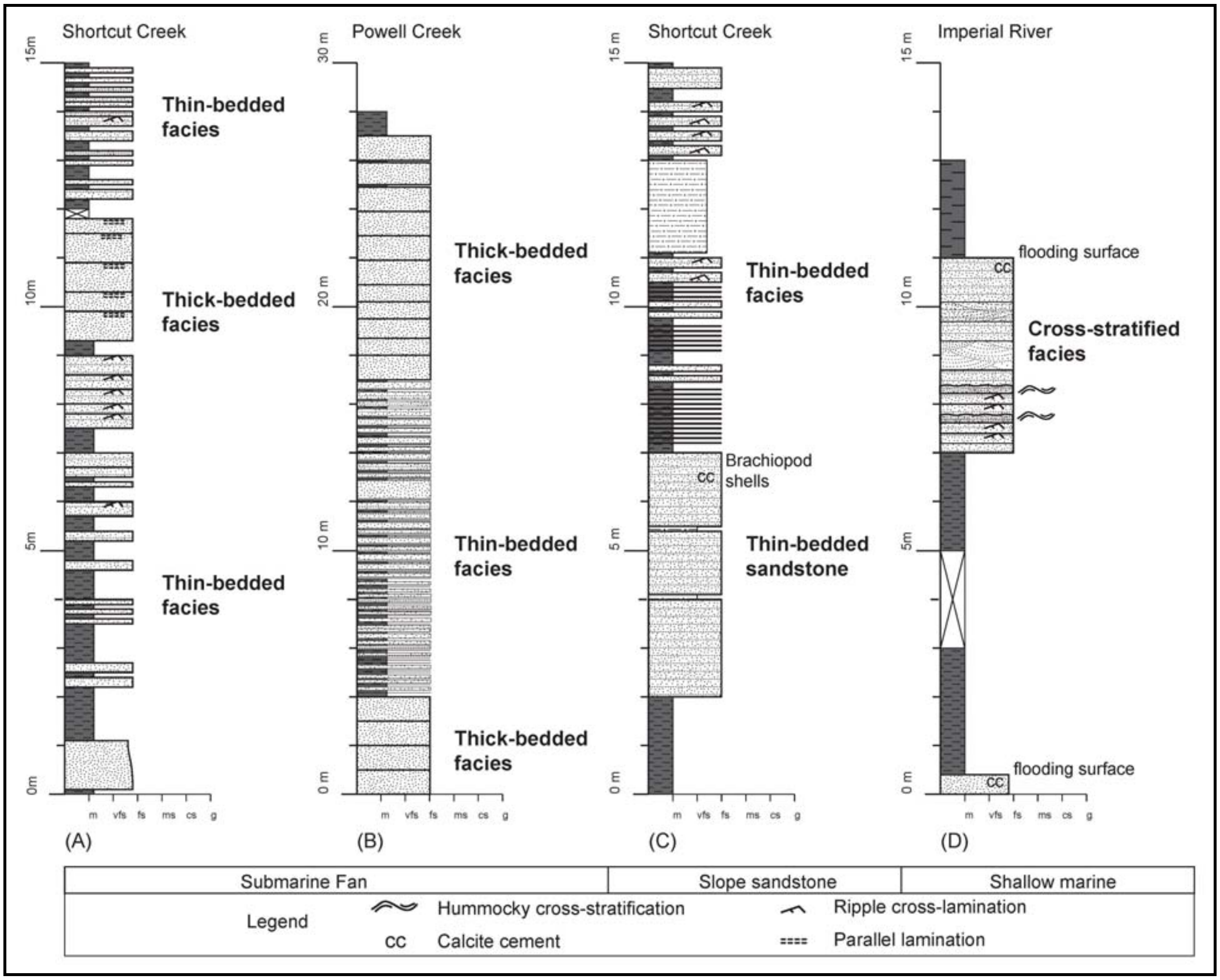

Figure 7.1.12. *Imperial Formation facies successions: (A) upward-thickening sandstone beds of the thin-bedded facies overlain by amalgamated thick-bedded facies from basal sandstone at Shortcut Creek interpreted as submarine fan lobes and lobe fringes; (B) similar upward-coarsening successions at Powell Creek, note the change in scale; (C) thin-bedded slope facies from Shortcut Creek, cc = calcite cement; and (D) mudstone to amalgamated shoreface sandstone intervals bounded by flooding surfaces from Imperial River (Figure7.1.4). Grain size: m = mudstone; vfs = very fine sand; fs = fine sand; ms = medium sand; cs = coarse sand; and g = granule.*

According to facies models for submarine fans (e.g., Mutti, 1977), continued fan progradation should result in deposits with coarser grain size and upward-fining facies successions characteristic of channelized transport across the inner and middle fan. The upper 20 m of the basal sandstone at Shortcut Creek has an upward-fining character; specifically, the proportion of mudstone increases relative to sandstone, however, the grain size of the sand is constant (very fine to fine). At Powell Creek the basal sandstone is overlain by a 10 m thick ripple laminated sandsheet and then by recessive shale facies. The character of the transition between basal sandstone and the overlying shale seems to indicate fan abandonment rather than simply progradation of a fan-slope system. This could be the result of migrating lateral sediment distribution and sediment flux related to changes in relative sea level superimposed on an overall progradational fan-slope system. Alternatively, because the inner fan cannot be identified based on grain size, and limited outcrop extent makes identification of channels difficult, the thin to abrupt upward-fining top of the basal sandstone may represent abandonment of an inner fan distributary channel followed by slope progradation.

Our preferred interpretation for the top of the basal sandstone is that it represents progradation of a particular fan-slope system defined by: fine-grained sediment supply (maximum of fine-grained sand); a mud-dominated lower slope; very limited development of typical inner fan facies; extensive sandy lobes typical of an outer fan environment; and high flow energy lobe fringe areas. Sediment gravity flows reached high flow velocities near the base of the slope. At the base of slope, with a decrease in gradient they rapidly deposited the coarsest load fraction, which was fine sand. Without a coarse sand fraction flows were either weakly channelized or rapidly transformed to unconfined flows. After rapid deposition to form sandy lobes, sand-rich flows traversed lobe fringe areas under upper flow regime conditions and deposited the remaining sediment load. An overall predominance of lobe deposits over channel deposits is similar to observations by Pyles (2008) from a Carboniferous submarine fan in Ireland, where channels were previously well studied but composed less than 7% of the total cross-sectional area of the fan, whereas lobes were the dominant architectural element by area.

Upper Imperial Formation

Above submarine fan deposits of the basal sandstone unit, the rest of Imperial Formation comprises approximately 100 m thick intervals of shale facies variably intercalated with laminated facies, thin-bedded sandstone facies, and lesser thick-bedded facies (e.g., Figure 7.1.4; C in Figure 7.1.12). This was a shale-dominant depositional environment that experienced deposition by suspension (shale facies) and low-density fine-grained sediment gravity flows (laminated facies). Thin-bedded sandstone facies indicate that areas of active sand deposition experienced low sediment fallout rates, consistent with the relatively low overall proportion of thick-bedded facies. It is proposed that these features are indicative of a slope depositional environment. This interpretation is supported by the presence of numerous clinoforms within Imperial Formation imaged by seismic (Figures 7.1.5, 7.1.6).

The predominance of fine-grained facies resulted from bypassing of the main sediment gravity flow body and preferential deposition by the diffuse tail, and/or margins, of bypassing flows. Such a process explains mud deposition on the slope and sand-dominated deposition of the submarine fan. Large scale lateral sediment flux patterns would have controlled deposition of sandstone intervals up to 50 m thick. Brachiopod, coral, and crinoid macrofossils are more common in upper portions of Imperial Formation indicating greater proximity to benthic communities in shallower water.

7.1.4 Stratigraphy and Discussion

Imperial River Section

We divide the Imperial Formation at the type section, Imperial River (Figure 7.1.2), into lower, middle, and upper parts (Figure 7.1.4). The lower interval contains thin-bedded turbidite and shale facies similar to slope deposits elsewhere. A conglomerate containing calcite-cemented lithoclasts and shell debris marks the base of the middle interval. This middle interval comprises upward-coarsening facies successions which culminated in deposition of a shoreface sandstone unit (D in Figure 7.1.12). The shoreface sandstone is considered to be equivalent to the sublittoral sandsheets described previously (Chi and Hills, 1976; Braman and Hills, 1992). Within the middle interval thin beds composed of rugose and tabulate corals occur within sandstone intervals up to 10 m thick. The middle interval is sharply overlain by shale and thin-bedded facies of the upper interval. Facies of the upper interval are part the deep water slope facies succession previously described, for which the lower contact is interpreted to be a significant flooding surface (Chi and Hills, 1976; Braman and Hills, 1992). Traces of the *Nereites* ichnofacies are preserved within shales overlying the flooding surface (section 7.2). Two interpretations are offered for the succession of slope-shoreface-slope deposits. It is speculated that the shallow marine deposits record local shelf development within an overall prograding slope system, which would therefore have a lowstand wedge geometry (A in Figure 7.1.13). Alternatively, the succession could record an early phase of shelf construction near the eastern basin margin which was subsequently submerged and overlain by a larger scale prograding slope system (B in Figure 7.1.13). Palynology indicates that Imperial Formation is younger from Imperial River westward, with no data east of Imperial River, and therefore consistent with both hypotheses (Braman and Hills, 1992).

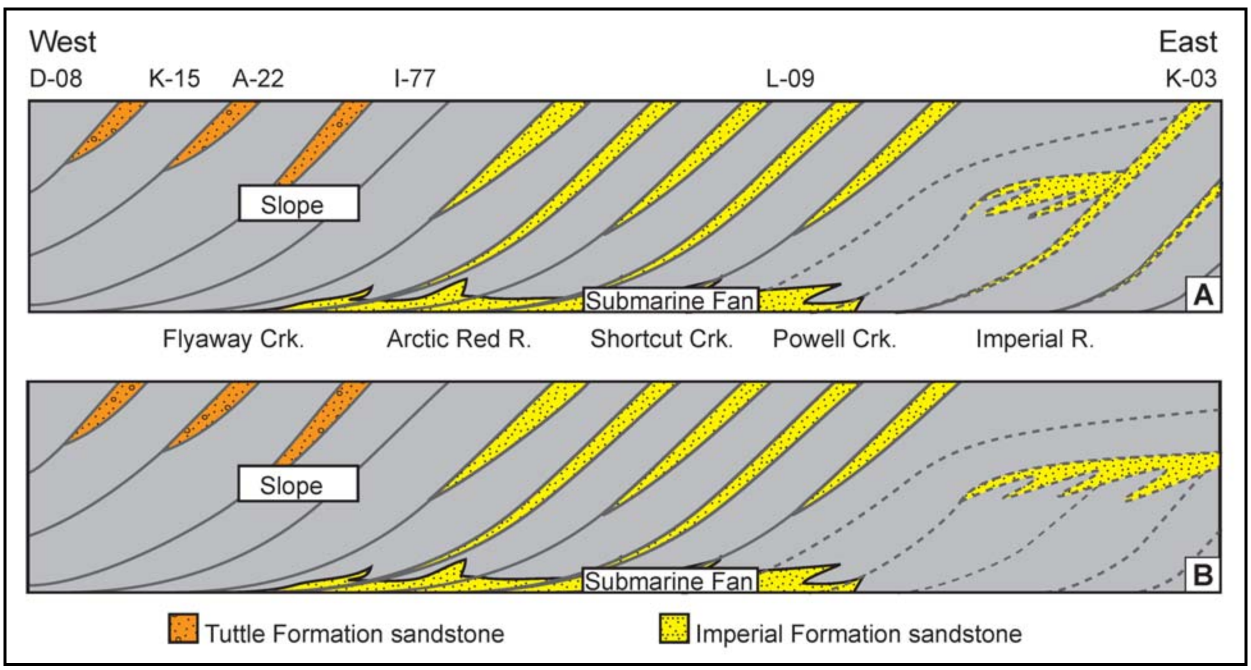

Figure 7.1.13. *Cartoon west-east cross-section of Imperial and Tuttle formations. Fine-grained sandstones of Imperial Formation extend west to Arctic Red River. Submarine fan deposits extend from Powell Creek to Arctic Red River. At Flyaway Creek and further west, Imperial*

Formation is primarily shale; Tuttle Formation is medium-grained sandstone deposited near the top of the preserved slope. Note that each section/well is spaced further apart than the top-to-base clinoform distance (e.g., Figure 7.1.5), not as indicated. Two alternatives are presented for the Imperial River section: (A) lowstand wedge deposited within the slope followed by slope progradation; or (B) initial, relatively small-scale slope and shelf constructed at the eastern margin of the basin, followed by subsidence and progradation of a larger slope system.

The key difference between these two interpretations is the eastern extent of the Upper Devonian basin; because of the location of the erosional edge (Figures 7.1.1, 7.1.2) it is not possible to directly discern whether facies continue to shallow eastward or if deep water deposits lay to the east. Now, considering that the north-south trending reefs of Ramparts Formation represent the shallow water eastern edge of the basin in the Middle Devonian (Pugh, 1983), the simplest explanation is that the shallow water deposits at Imperial River indicate an Upper Devonian continuation of a basin geometry deepening to the west (B in Figure 7.1.13).

Base of Imperial Formation

Below Imperial Formation, black shales of Canol Formation are widely distributed throughout Peel area. Canol Formation is easily identified on well logs by high gamma ray signatures, generally greater than 300 API units (e.g., Figure 7.1.4). In outcrop, Canol Formation shales measured 300-450 API (measured with a hand-held scintillometer). The base of Imperial Formation is a regionally extensive, recessive weathering, 10 m to 15 m thick, brown non-bituminous shale, which has measured 150-180 API in outcrop and is generally less than 150 API in well logs. The contrast in gamma radiation between the Canol and Imperial formations shales makes the base of Imperial Formation readily identified on well logs. This brown shale sharply overlies Canol Formation and is included in the Imperial Formation definition as set out by Bassett (1961).

Submarine Fan

West of Imperial River the brown recessive-weathering shale at the base of Imperial Formation is overlain by a basal sandstone unit that extends from the Powell Creek section approximately 150 km west to the S. Ramparts I-77 well (Figure 7.1.4). It may not be strictly continuous, but along this length it is interpreted as a submarine fan deposited at the base of a slope (Figure 7.1.13). Paleocurrents inferred from flute casts, current ripples, and primary current lineation indicate westward paleoflow.

Our preferred interpretation that the basal sandstone records progradation of a submarine fan with minimal development of inner fan, channelized facies, is consistent with the model presented by Heller and Dickinson (1985) for a delta-fed turbidite system. In that model, sediment is transported to the basin by prograding delta lobes and no individual slope canyon incising the shelf serves as a sediment point source, hence the basinal turbidite succession shows less pronounced differentiation into distinct channels (Heller and Dickinson, 1985). The delta that probably fed the fan-slope system of Imperial Formation has not been preserved, likely having been eroded with the Upper Devonian shelf below the sub-Cretaceous unconformity.

Slope

Above the basal sandstone unit the rest of Imperial Formation is a shale-dominant succession of intercalated shale, thin-bedded sandstone, and minor thick-bedded turbidite facies (Figure 7.1.4). The depositional environment is interpreted as a slope setting, similar to fine-grained, suspension-dominated, upper slope deposits described by Shultz et al. (2005). In seismic sections the dip of clinoforms indicate that the slope prograded west-southwest. In general, the Imperial Formation is therefore an upward-shoaling succession that records submarine fan and slope progradation (Figure 7.1.13). It is inferred that the immediate sediment source was a delta and so the “slope” may be referred to as prodelta system; however, delta and shelf deposits are not preserved in the study area and our terminology thus favours “slope”.

Sandstone bodies that are part of the slope system are interpreted to have been deposited by sediment gravity flows, and so they likely represent channel complexes that dip parallel to slope clinoforms. It is probable that these complexes would have been broader than outcrop exposures within the field area, with outcrops generally less than 100 m in strike length, and so a channel geometry would not be apparent. The measured sections and logs in Figure 7.1.4, which are further apart than the top-to-base clinoform spacing in Figure 7.1.5, means that in a clinoform-parallel relationship, the slope sandstone units are not laterally correlative, temporally or lithologically.

7.1.5 Conclusion

The Upper Devonian Imperial Formation was deposited by a westward prograding submarine fan and slope complex at the Mackenzie Mountain front in the Peel Plateau and Plain regions west of Norman Wells. Delta or shelf deposits were generally not preserved, with the exception of shoreface sandstones that record shelf construction at the type section of Imperial Formation at the eastern edge of the study area.

The slope that prograded southwestward into the basin was dominated by fine-grained sediments. Laminated facies record deposition by dilute, fine-grained sediment gravity flows. Slope sandstone intervals of thin-bedded facies record upper flow regime conditions and relatively low sediment fallout rates. Slope sandstones are postulated to be discontinuous, clinoform-parallel sandbodies.

Very fine- to fine-grained sandstone deposits of the submarine fan at the base of Imperial Formation extend across most of the study area. Prograding lobe fringe areas and lobes typify fan facies successions. Lobe fringe areas, characterized by thin-bedded facies, were traversed by flows under upper flow regime conditions but low sediment fall out rates. Amalgamated sandstone intervals of massive thick-bedded facies indicate that lobes were sites of rapid sediment fallout.

The slope-fan complex prograded to the western edge of the study area; where, at Flyaway Creek, Imperial Formation is a shale succession overlain by Tuttle Formation. Within the study area sandstone and conglomerate of Tuttle Formation were derived from approximately northeast reflecting both rejuvenation and an increase in the grain size of sediment supplied to the southwest prograding system.

Acknowledgements

The authors of this section wish to acknowledge the leaders of the Peel Project, Adrienne Jones and Leanne Pyle. GIS expertise of Kelly Pierce and Doug Irwin, publications efforts of Karen MacFarlane, literary acumen of Erin Palmer, and field assistance by Danielle Thomson were vital. We thank B.C. MacLean who provided the seismic interpretation. Comments by Len Gal, Tiffani Fraser, Tammy Allen, Ashton Embry, and Robert Sharp significantly improved an early version of the manuscript.

7.2 SEDIMENTOLOGY AND ICHNOLOGY OF IMPERIAL FORMATION FROM FLYAWAY CREEK, SHORTCUT CREEK, AND IMPERIAL RIVER

S.A. Tylosky, T. Hadlari, and O. Catuneanu

Abstract

The upper Devonian assemblage (Frasnian to Famennian in age) within the Peel Plateau and Plain consists of a turbidite succession approximately 700 m to 800 m thick. The sediment supply was craton derived as illustrated by paleoflow directions from east to west, and by the northeast-to-southwest progradation of clinoforms that can be observed on seismic lines, which indicates the succession youngs westward.

The easternmost, and therefore oldest, of the three localities studied is the Imperial Formation type section at Imperial River. The type section records a change from slope deposits and distal *Cruziana* ichnofacies at the base to shallow marine and proximal *Cruziana* ichnofacies at the top, indicating the establishment of a siliciclastic shelf. The uppermost deposits of this shelf contain beds of corals and wave-formed structures such as hummocky and swaley cross-stratification. The top of the shelf succession is a carbonate-cemented surface burrowed by *Trypanites* ichnofacies traces and is interpreted as a hardground. Sharply overlying the hardground is black shale succeeded by interlaminated sandstone and shale, which contain traces of the *Nereites* ichnofacies. This succession is interpreted as a major transgression that submerged the siliciclastic shelf.

West of Imperial River, at Shortcut Creek, a basal sandstone interval containing *Cruziana* ichnofacies is interpreted as submarine fan deposits. Overlying the submarine fan deposits is a succession of mudstone and sandstone interpreted as slope deposits. Slope sandstones are interpreted as turbidites containing shell debris and proximal *Cruziana* ichnofacies. Following submergence of the shelf preserved at Imperial River, the section at Shortcut Creek shows that siliciclastic infill of the basin was achieved by a submarine fan and slope complex that migrated southwestward.

Sandstones of the submarine fan had graded to shale by the most westward locality, Shortcut Creek. The lower slope was also characterized by deposition of mudstone. At the top of the preserved Shortcut Creek section sandstones correlated as Tuttle Formation, interpreted as turbidites, and exhibiting a distal *Cruziana* ichnofacies are considered to have been deposited within a slope setting.

7.2.1 Introduction

The study area is located west of Norman Wells within the NWT (Figure 7.1.1). Locations of the detailed stratigraphic sections at the Imperial River type section, Shortcut Creek, and Flyaway Creek are depicted in red on Figure 7.1.2. The purpose of this study is to determine a plausible depositional environment for Imperial Formation and to expand regional geological knowledge through detailed facies analysis of three stratigraphic sections. The sedimentology of these sections will be compared to seismic lines and paleoflow indicators to determine the basin fill geometry. Ichnology samples were collected from outcrop sections to determine the depositional environment of the Imperial Formation. Imperial Formation is Frasnian to Famennian in age

(Late Devonian; Figure 7.1.3). It consists of very fine- to fine-grained sandstone, shale, and siltstone. This formation has been interpreted as a transgressive marine shale (Laudon, 1950) and as an open shelf shallow marine environment (Braman, 1981).

Previous Work

Lithology and Sedimentology

The stratigraphic cross section in Figure 7.2.1 shows the studied Imperial Formation well logs and measured sections. Canol Formation is a black fissile bituminous mudstone that underlies Imperial Formation and is interpreted as a marine shale (Basset, 1961) deposited at the close of the Frasnian (Pyle et al., 2007). Laudon (1950) indicated that the limestone content increases towards the top of Canol Formation (Pugh, 1983).

The conformable contact between Imperial and Canol formations is at the highest occurrence of the black marine bituminous shale (Robbins, 1960). The black shale of Canol Formation is overlain by dark grey shale alternating with fine-grained sandstones that grade into the lowest massive sandstone of Imperial Formation. Sandstones within Imperial Formation are very fine-grained with low porosity and permeability (Zantvoort, 2007). The gamma ray log signatures show the contact between Canol and Imperial formations with a transition from values over 300 API in Canol Formation to low gamma ray values averaging 150 API in Imperial Formation (Pugh, 1983).

Imperial Formation is conformably overlain by Tuttle Formation, where present, or unconformably overlain with a significant unconformity by the Albian age Martin House Formation. Lutchman (1977) conducted a litho-environmental facies analysis of Tuttle Formation from the study of cores, logs and drill cuttings; the findings indicated a fluvio-deltaic origin.

A heavy mineral suite is present within Imperial Formation and is a stable suite common to Late Paleozoic age rocks (Robbins, 1960). The high percentage of mica and chlorite within Imperial Formation sandstones, results in the greenish grey colour of the sandstone (Robbins, 1960). The cement within the sandstones is one of calcite, glauconite, hematite, and siderite. The modal percentage of cement in the sandstones is 5% to 15% (Robbins, 1960).

Biostratigraphy

The fossil spore assemblage of Imperial Formation is biostratigraphically younger than those within Canol Formation (Robbins, 1960), although the biozone extends into Canol Formation, as no lower boundary of the microspore assemblages was found (Braman and Hills, 1992). The megaspore zonations are the *Devonica* zone at the base followed by the *Magnifica* zone from the middle to the top of the Imperial River type section (Chi and Hills, 1974). The *Devonica* zone contains a miospore assemblage *Archaeoperisaccus* indicative of a late Frasnian age (Chi and Hills, 1974). The *Devonica* zone correlates with the macrospore assemblages found by Braman and Hills (1992). The *Magnifica* megaspore zone includes miospore zones of *Hymenozonotriletes denticulatus*, *Lophozonotriletes cristifer kedo*, *Naumova* and *Archaeozonotriletes* sp (Chi and Hills, 1974).

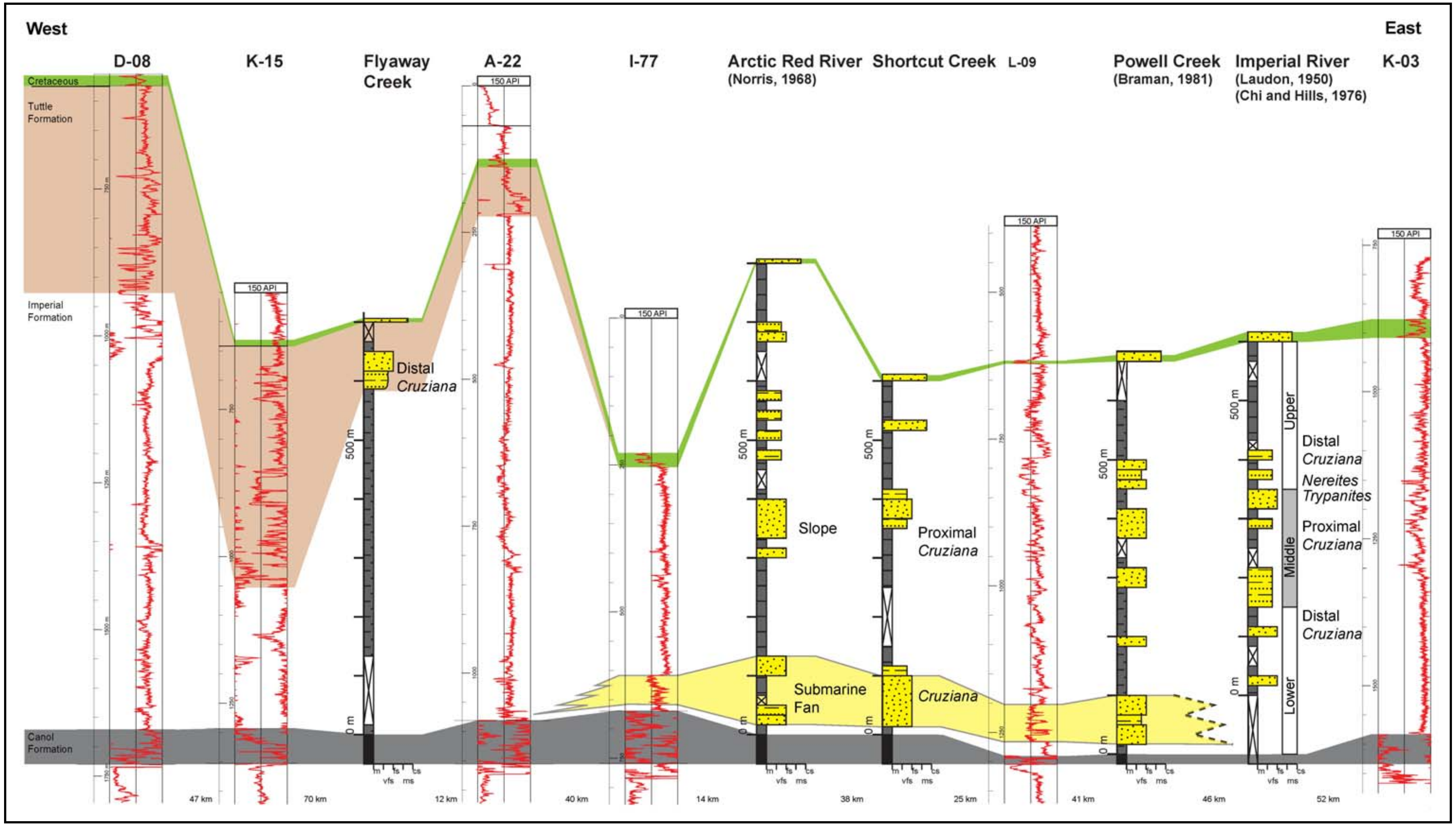

Figure 7.2.1. *Regional cross-section correlating well logs and stratigraphic sections of Imperial and Tuttle formations. The datum is the base of Canol Formation. Note the distribution of ichnofacies.*

These miospore assemblages suggest an early to middle Famennian age (Chi and Hills, 1974). The correlation between the two ages suggest that the division between the Frasnian and Famennian occurs at the middle of the Imperial River type section (Chi and Hills, 1974). This abrupt change in palynomorph assemblages suggests a small hiatus towards the middle of the Imperial Formation here.

Depositional Environment

During Frasnian time, emplacement of granitic intrusions in northern Yukon Territory was coeval with clastic wedge progradation within a starved basin (Pugh, 1983). Towards the end of Frasnian time, the seas briefly regressed resulting in shallow, warm water conditions in an epicontinental sea; this advanced southward across the cratonic platform resulting in siliciclastic deposition of the Upper Devonian Imperial and Tuttle formations. Deposition of Imperial Formation is interpreted as synorogenic with the Ellesmerian Orogeny (Richards et al., 1997).

Braman and Hills (1992) suggest that the sediment source originated from the northeast because the facies observed at the Imperial River type section are similar to sublittoral sheet sandstones described by Goldring and Bridges (1973); whereas in the west, turbidite facies were observed. These different depositional packages suggest that the basin deepens westward towards what is now the Yukon. Goldring and Bridges (1973) describe the shallow marine facies as having sandstone beds with a thickness of 5 cm to 70 cm separated by interbeds of mudstone. Sedimentary structures include low angle parallel lamination less than 5 degrees, marked by lenses of shelly material occurring towards the base of the beds. According to Robbins (1960) Imperial Formation was deposited in a environment similar to the shallow marine environment inferred at the base of the type section. The fossils occurred below wave base, but were from an environment shallow enough for the development of warm water organisms including brachiopods, gastropods, stromatoporoids, crinoids, molluscs, arthropods, algae and megaspores (Robbins, 1960). Towards the middle of the section the environment grades into a higher energy marine environment and finally into an offshore environment at the top of the section (Chi and Hills, 1974).

7.2.2 Sedimentology and Ichnology

Description of Imperial Formation sedimentology and ichnology is divided into three parts based on the depositional system outlined in section 7.1. The first part addresses intervals from Flyaway Creek and Shortcut Creek interpreted to have been deposited in a slope setting. The second section examines submarine fan facies from Shortcut Creek. The third section addresses unique features of the measured section at Imperial River.

Slope Deposits

Shale Facies

The shale facies is found throughout Imperial Formation and contains predominantly silty black shale at Flyaway Creek to brown shale with concretionary layers and cone-in-cone structures at Shortcut Creek. At the Flyaway Creek locality the colour banding alternates between copper-coloured red layers and black layers; both are a few centimetres thick. The colour zonation alternates with the percentage of silt present; the higher silt content is in the copper-coloured sections. Ironstone bands present range in thickness from a few cm to 70 cm. In some locations these bands are horizontally continuous for 10 m to 12 m, with the bands pinching out into copper-coloured black shale. Loosely consolidated ball-shaped nodules found have two distinct mineralogies: siderite and dolomite.

The grain size, silt content, and colour suggest that sediment deposition was by pelagic sedimentation in an offshore environment. The environment must have contained low oxygen levels as the ironstone concretions form in an anoxic environment.

Slope Sandstone: Flyaway Creek

Imperial Formation at Flyaway Creek is represented by a very thick shale succession. Overlying the shale is a sandstone interval approximately 50 m thick (Figure 7.2.1). Comparison with A-1 Cranswick A-22 well, one of the wells initially recognized as containing Tuttle Formation (Pugh, 1983), suggests that this sandstone unit correlates to lowermost Tuttle Formation.

The Tuttle Formation sandstone interval comprises tabular thin-bedded sandstone and mudstone laminae with abundant trace fossils on bedding planes (Figure 7.2.2). The dominant sedimentary structures are plane parallel lamination and ripple cross lamination. Ichnofossils from the sandstone at Flyaway Creek include *Paleophycus*, *Phycosiphon*, *Cruziana*, *Lorenzinia, Helminthopsis*, *Helminthoida*, *Thalassinoides*, and *Planolites* (Figure 7.2.3).

The sedimentary divisions in this facies are interpreted based on the classic turbidite facies model of Bouma (1962). The succession of sedimentary structures from planar beds transitioning into rippled cross laminated sandstones, T_c, and overlain by laminated mudstone, T_e, reflects the succession of bedforms that would be formed by a decrease in flow velocity. This succession represents Bouma subdivision T_b through T_e.

The traces found at the Flyaway Creek locality (Figure 7.2.3) exhibit behaviors present in the distal *Cruziana* ichnofacies, the second deepest ichnofacies group found in these three outcrop studies. The burrows have been passively in filled with very fine grained sandstone in a consolidated silty clay host substrate. The burrows dominantly exhibit resting behaviors and large horizontal dwelling structures that are substrate controlled. These tunnels were likely formed by an arthropod (M. Gingras, pers. comm., 2008).

Slope Sandstone: Shortcut Creek

At Shortcut Creek a detailed section was measured at the base of a thick sandstone interval within the middle portion of Imperial Formation (Figure 7.2.4). Based on the depositional model presented in section 7.1, this stratigraphic position is postulated to have been a slope setting.

The base of the thick sandstone interval in the middle of the section is gradational as indicated by metre-scale sandstone intervals interbedded with shale (Figure 7.2.4). One specific sandstone in this locality displays massively bedded sandstone transitioning into low-angle cross-stratified sandstone (A in Figure 7.2.5), followed by a coquina or shell hash layer (B in Figure 7.2.5) a few centimetres thick with fossilized spiriferid brachiopods, crinoids and molluscs. This interval transitions directly into parallel laminated sandstone, a weakly bioturbated calcareous zone (D in Figure 7.2.5), with a mud couplet at the top (C in Figure 7.2.5). The contact between this sandstone, the overlying shale, and the underlying shale is sharp. The specific ichnogenera include *Rhizocorallium* (B in Figure 7.2.6), *Paleophycus* (C in Figure 7.2.6), *Thalassinoides*, and *Planolites* (D in Figure 7.2.6).

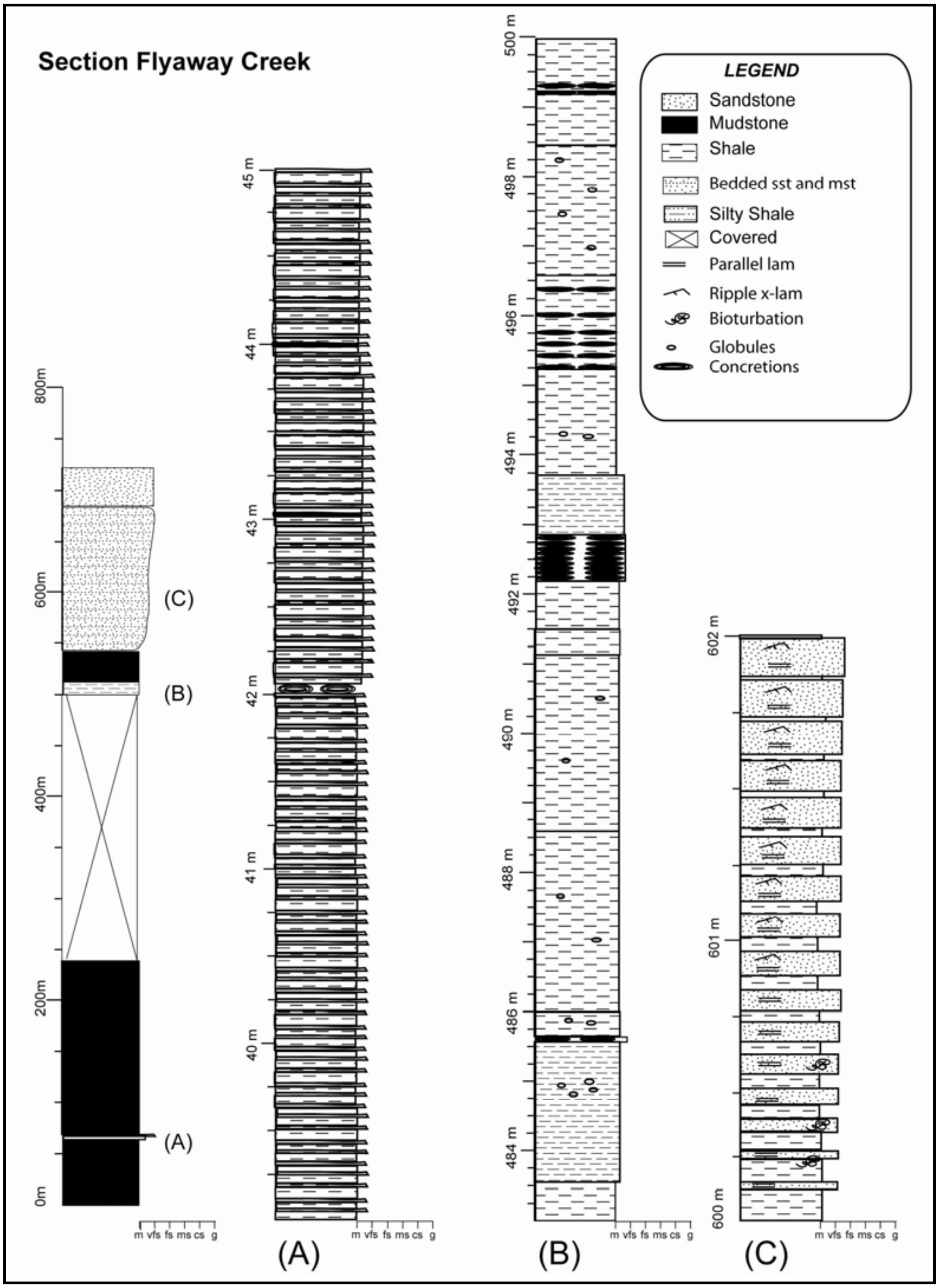

Figure 7.2.2. *Flyaway Creek stratigraphic sections: (A) shows compositional banding of copper-coloured iron stained layers and black shale in the shale facies; (B) shows the shale facies with scattered concretionary layers; and (C) shows thin-bedded sandstone.*

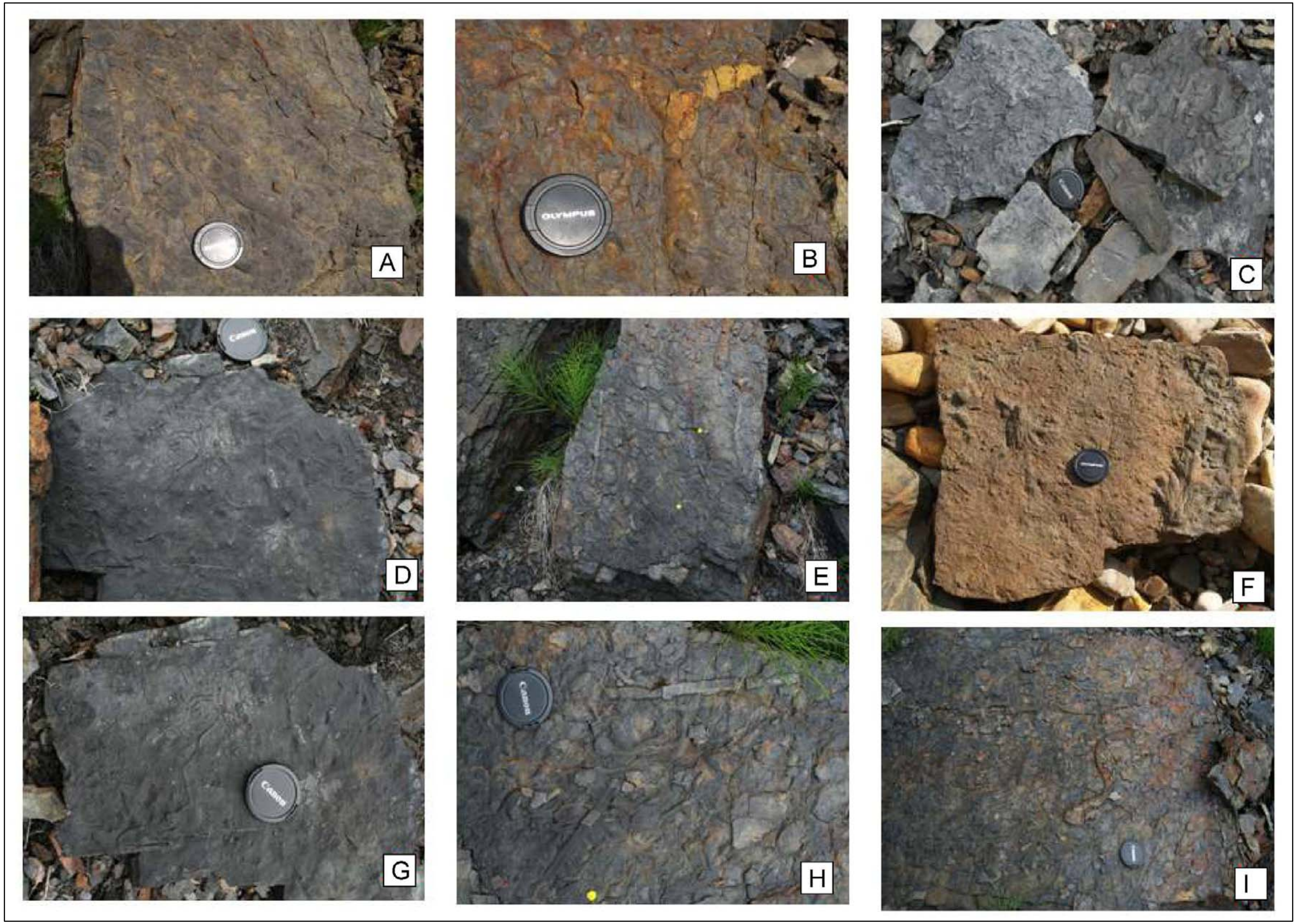

Figure 7.2.3. *Ichnofossils from the Flyaway Creek Section: (A)* Cruziana*; (B) passively in filled horizontal resting trace (unclassified); (C)* Thalassinoides, Paleophycus, *and* Lorenzinia*; (D)* Helminthopsis*; (E)* Planolites *and* Cruziana*; (F) (Unclassified) resting trace; (G)* Helminthoida*; (H)* Planolites, Cruziana, *and* Paleophycus*; and (I) passively in filled (unclassified) grazing trace.*

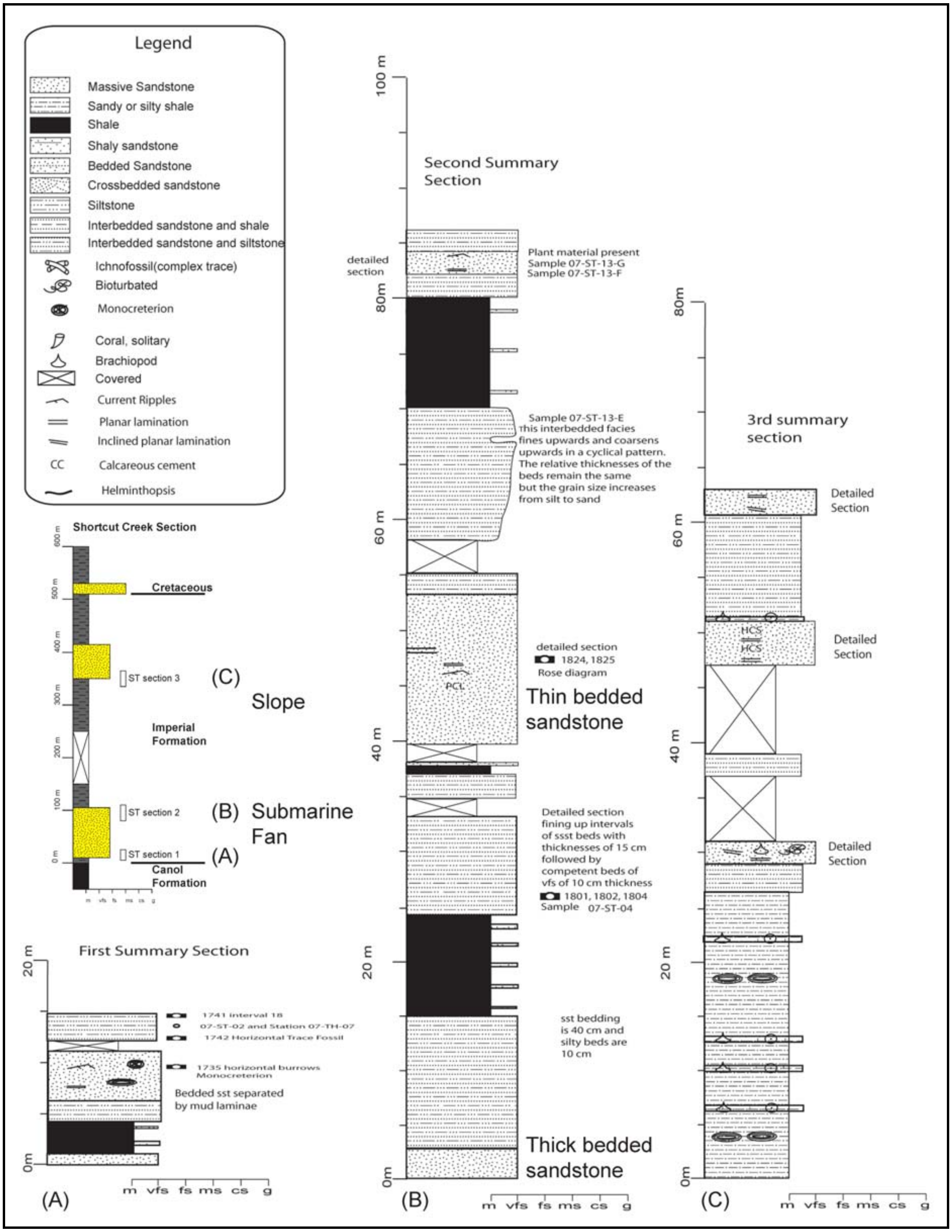

Figure 7.2.4. *Detailed stratigraphic sections at the Shortcut Creek outcrop location: (A) stratigraphic section showing thin bedded and thick bedded facies; (B) section showing paleoflow indicators and thin- and thick-bedded facies; and (C) section showing slope sandstone facies.*

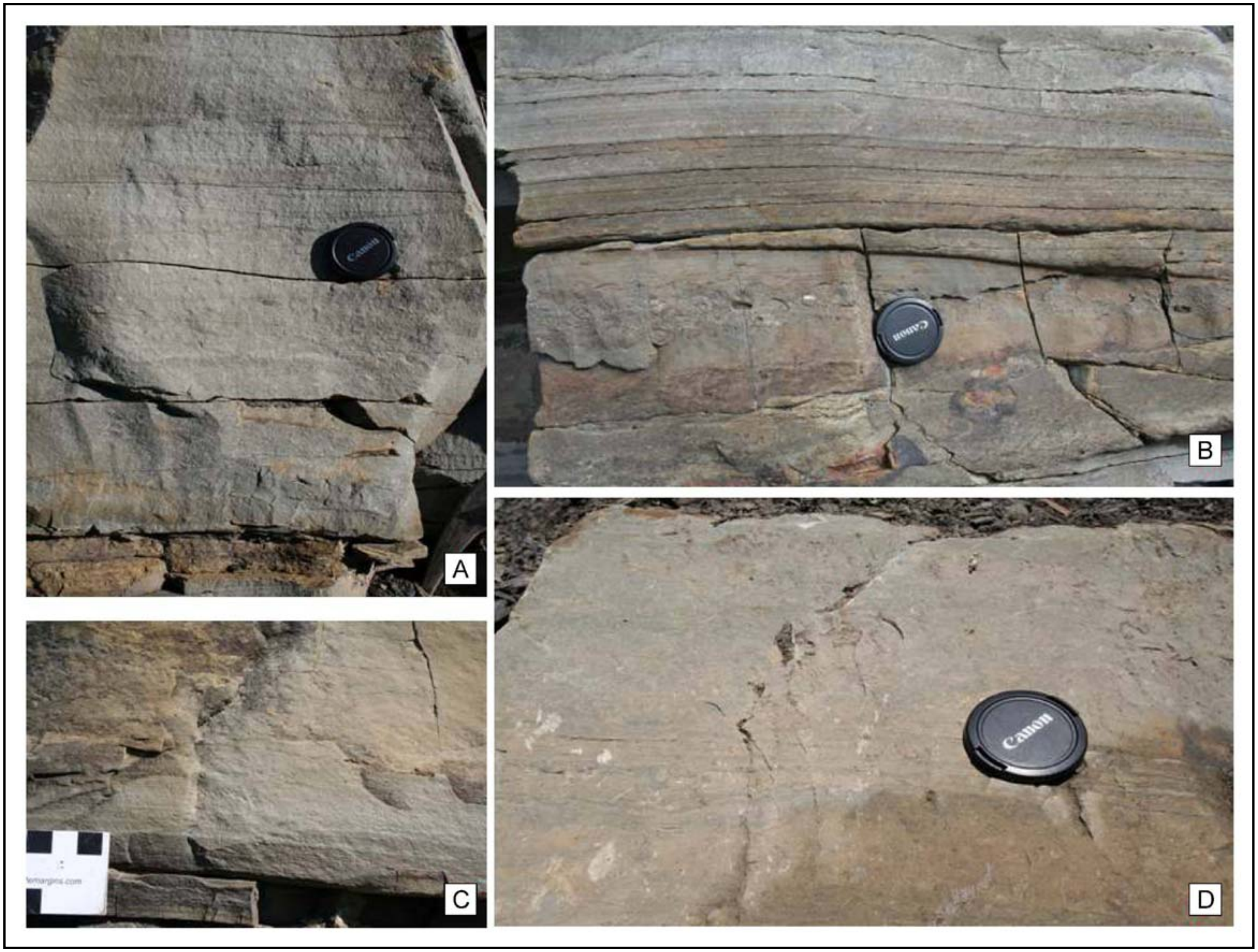

Figure 7.2.5. *Outcrop photos of slope deposits: (A) massive lamination into low angle cross-stratification; (B) coquina shell hash layer containing brachiopods and other molluscs; (C) Calcareous zone; and (D) mud couplets at the very top of the sandstone. Pictures courtesy of L.P. Gal.*

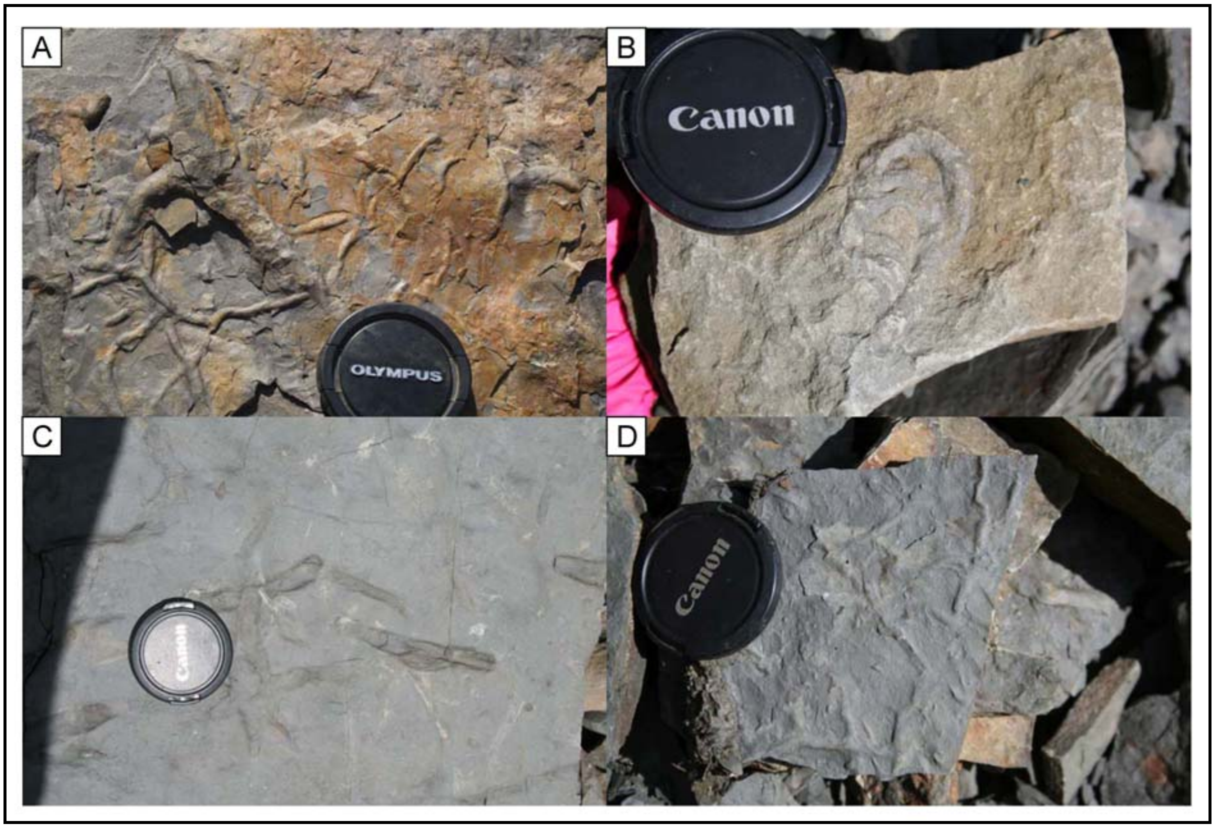

Figure 7.2.6. *Shortcut Creek slope facies trace fossils: (A)* Paleophycus*; (B)* Rhizocorallium*; (C)* Paleophycus*; and (D)* Thalassinoides *and* Planolites*.*

The coquina shell hash layer indicates that sediment was transported from water depths shallow enough for the development of organisms like brachiopods, bivalves, and crinoids. Sedimentary features such as massive beds, parallel lamination, and sandstone laminae that grade to mudstone are interpreted as T_a-T_b-T_d-T_e turbidites (Bouma, 1962).

The presence of the *Rhizocorallium* trace with a high depositional rate suggests this trace is an escape structure. The assemblage of trace fossils is assigned to proximal *Cruziana* ichnofacies.

Submarine Fan Deposits: Shortcut Creek

Thin-Bedded Facies

The thin-bedded facies is dominated by interbedded sandstones and mudstones with a bedding thickness of 1 cm to 30 cm (Figure 7.2.7). The sandstones appear massive on the weathered surface, but show parallel lamination on a fresh surface and at some locations, a transition from massively bedded fine-grained sandstones to parallel laminated to ripple cross-laminated sandstones. The sandstones are coppery red and the mudstones are dark grey to brown. The sandstone beds thicken upwards to a maximum thickness of 20 cm and the silty mudstones thin and grade upwards to a minimum thickness of 1 cm; the reverse of this bedding pattern is also found. The sandstone beds thin and the shale intervals increase in thickness over an interval of 5 m to 10 m (Figure 7.2.4). Some sandstone beds exhibit lateral thickness variations and a scoured surface into the underlying shale can be observed. Paleocurrent indicators are present at the

Shortcut Creek locality and include sole marks, flute marks, primary current lineation, and ripple cross laminations (Figure 7.2.8).

Ichnofossils are rare within the thin bedded submarine fan facies at Shortcut Creek, but include *Lorenzinia*, *Thalassinoides*, and *Chondrites* (Figure 7.2.9).

The transition from massive into planar laminated sandstones is interpreted as a decrease in the rate of deposition. This is followed by planar beds that transition to rippled cross laminated sandstones interpreted as a decrease in flow velocity. This succession represents Bouma subdivision T_a through T_e (Bouma, 1962). With T_a representing the massive deposition and T_e the shale interval. The disarticulated intervals present are T_b, T_d, T_e; T_a, T_b, T_e; T_b, T_c and T_d. The combination varies between beds, but it always indicates a decrease in flow velocity in a thin-bedded package (Mutti, 1977).

The outcrop shows climbing ripples, sole marks, and planar current lineation along the surface and base of the bedding plane. The rose diagram presented on the basemap shows that flow occurred from east to west (Figure 7.1.2). Bioturbation of sediment was minimal and the opportunistic traces are attributed to *Cruziana* ichnofacies.

Thick-bedded Facies

The thick-bedded facies is dominated by interbedded very fine- to fine-grained sandstone with bedding thicknesses of 70 cm to 100 cm. The fine sandstone shows massive bedding as well as parallel lamination and slightly inclined planar laminations on a fresh surface. The geometry of the beds is tabular. There is a distinct change in grain size from fine sand overlain by very fine sand with an undulatory top. Directly above and beneath this interval, slightly inclined planar lamination is present with a shallow slope of five degrees. This is capped with very fine silty sandstone grading into a shale lithology. The contact between beds is sharp and continuous along the bedding plane. Trace fossils are absent from the thick-bedded facies.

The deposition of T_a-T_b-T_c in a thick geometry suggests that deposition was quite rapid, interpreted to be due to a waning sediment gravity flow. The slightly inclined lamination at five degrees suggests a flow regime in the antidune range (Alexander et al., 2001). The rate of deposition coupled with the sedimentary structures suggests that the deposition location could be a highly aggradational and high energy setting. The increased degree of deposition limits the development of trace fossils found within the thick-bedded turbidites, due to lower oxygen levels and decreased food supply induced by constant deposition (Leszczynski and Seilacher, 1991).

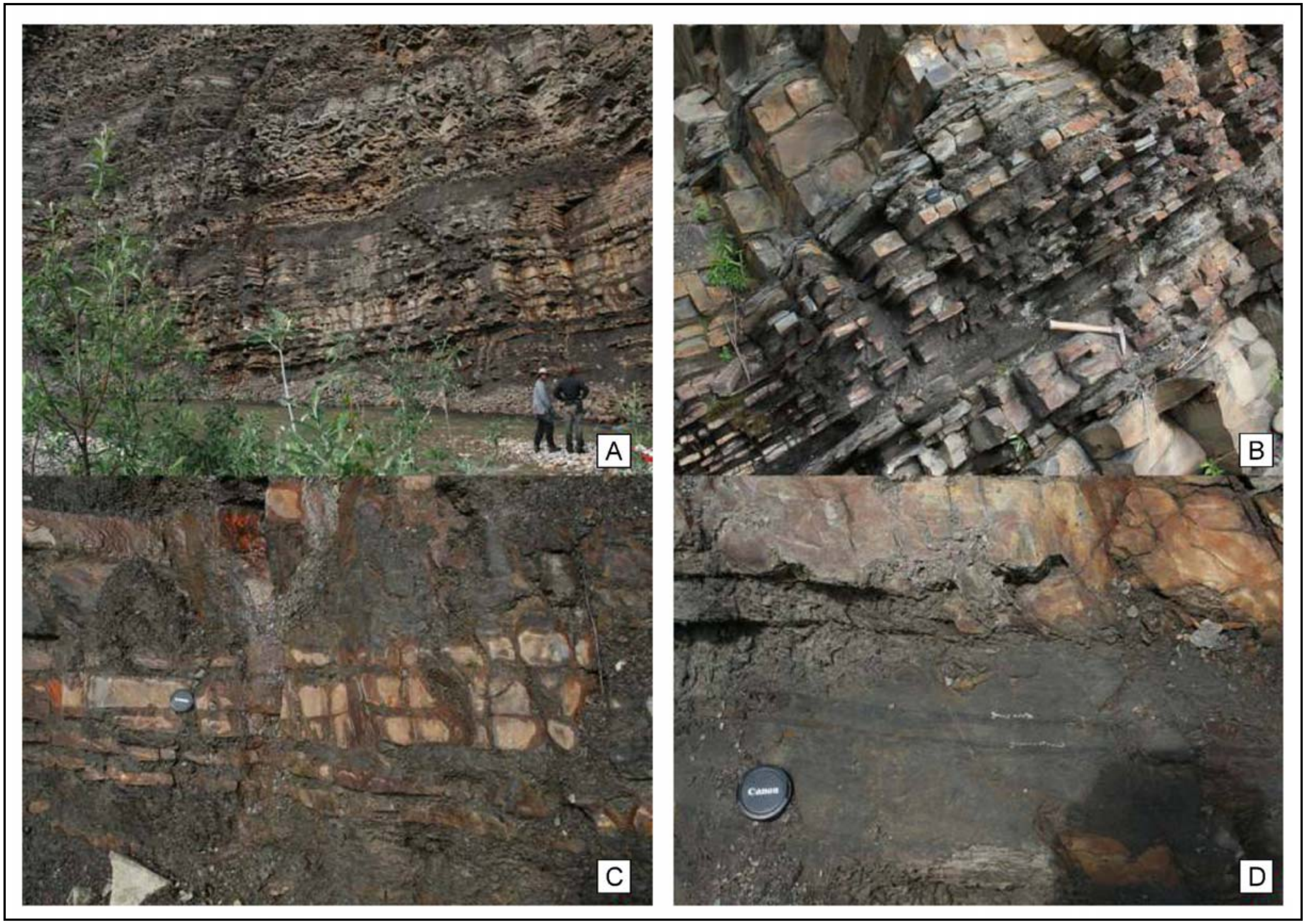

Figure 7.2.7. *Outcrop pictures of the Shortcut Creek locality: (A) shows alternation of thick-bedded facies and thin-bedded facies at stratigraphic section (A in Figure 7.2.8); (B) close juxtaposition of thick- and thin-bedded turbidites; (C) gradational change from shale to sandstone at the base of Imperial Formation; and (D) mud couplet at base of Imperial Formation.*

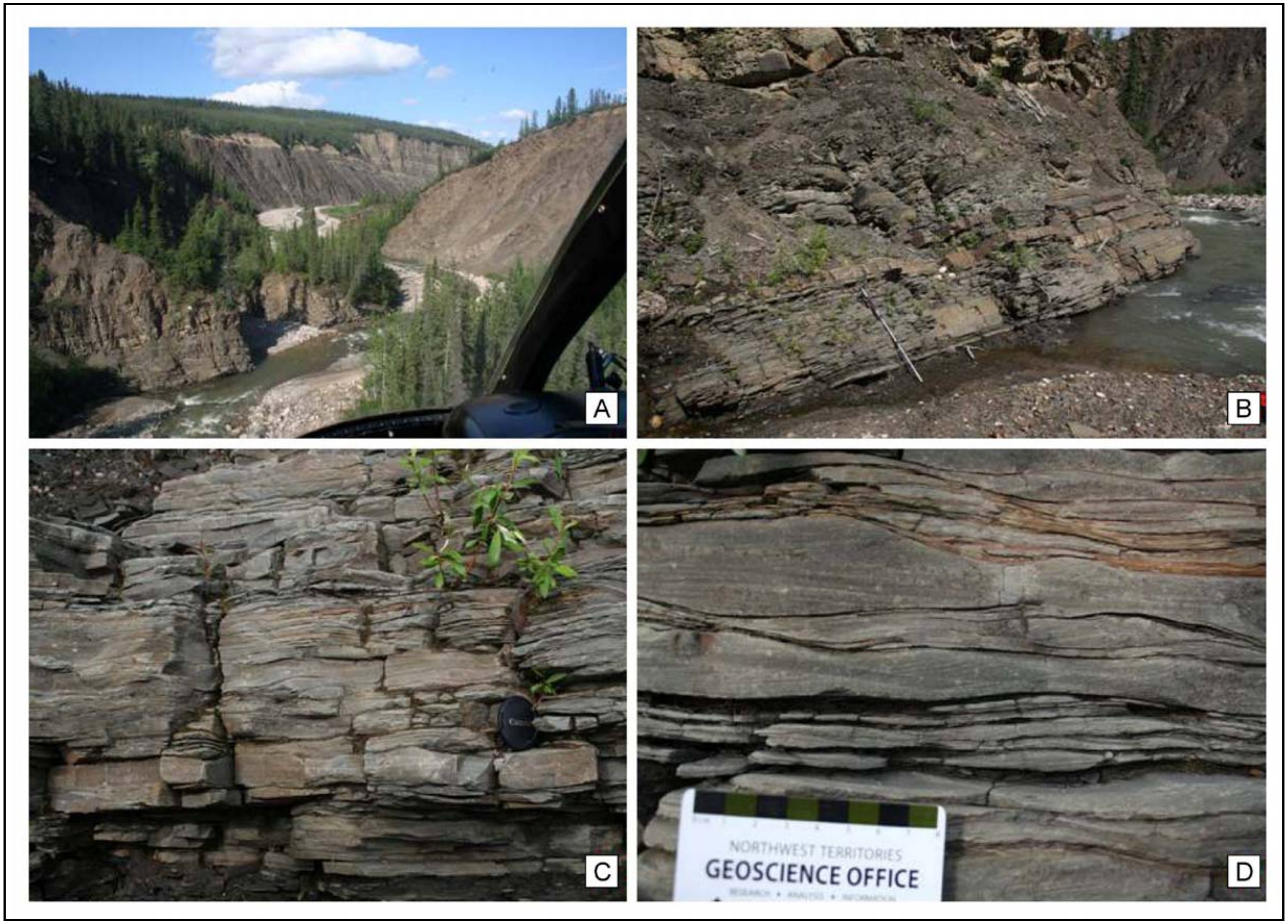

Figure 7.2.8. *Outcrop photos at Shortcut Creek of paleoflow indicators: (A) section photo of Shortcut Creek locality; (B) outcrop of thin-bedded turbidite, pogo is 1.5 m for scale; (C) section showing thinly bedded sandstones and aggrading ripples capped with mud drapes; and (D) ripple cross-lamination.*

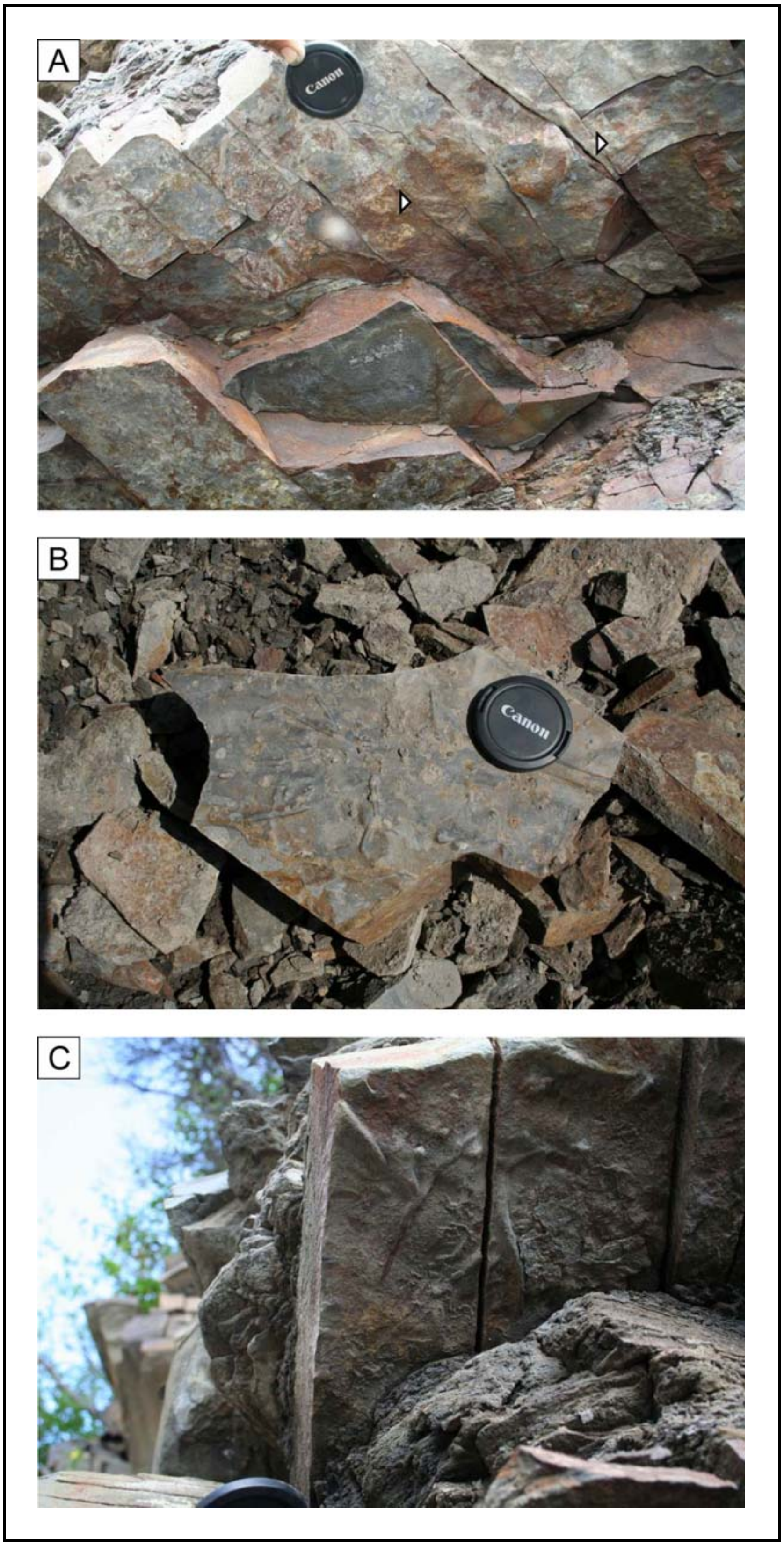

Figure 7.2.9. *Submarine fan ichnology at Shortcut Creek: (A)* Lorenzinia *(?; indicated by small arrows); (B)* Chondrites *and* Lorenzinia*; and (C)* Thalassinoides.

Imperial River Section

The Imperial River section is subdivided into lower, middle, and upper intervals (Figure 7.2.1). The sandstones of the lower interval have similar features to sandstones interpreted as slope deposits in other sections, such as at Shortcut Creek. The base of the middle interval is defined by a lithoclastic conglomerate (Figure 7.2.10). The middle interval comprises a succession of mudstone and sandstone interbedded at approximately 10 m to 20 m scale. The sandstone of the middle interval are subdivided into two facies based on sedimentary structures: lower shoreface and upper shoreface. The base of the upper interval is a black shale overlying a carbonate cemented surface interpreted as a hardground (Figure 7.2.11). There is a distinctive trace fossil suite near the base of upper interval.

Lower Shoreface Facies

The lower shoreface facies is dominated by massive and planar laminated sandstone with rare ripple cross lamination. Fine-grained sandstone has bedding 10 m to 20 m thick. The base of this facies is determined by the presence of a conglomerate layer composed of calcitic lithoclasts. Directly above this sandstone an interval of greenish grey massive sandstones are separated by interbedded mudstones of a similar colour with a bedding thickness of 3 cm to 20 cm. *Hexagonaria* corals are present within a mudstone matrix at the top of these sandstones. The dominant cement is glauconitic, but calcite and siderite cement are also present (Robbins, 1960). Ichnofossils include *Crossopodia, Teichichnus, Thalassinoides, Planolites, Paleophycus, Lorenzinia,* and *Cruziana* (Figure 7.2.12).

The presence of two large sandstone bodies that have a thickness of 10 m to 20 m showing massive and planar laminated sedimentary structures, with a few areas of hummocky cross stratified sandstone, suggests the presence of a lower shoreface sand body. This, coupled with the presence of glauconitic and calcite cement, suggests that the area is a shallow marine environment. The presence of colonial corals also suggests that the facies was in relatively shallow water depth. This is interpreted as the lower shoreface to slope transition with the sandstones representing the shoreface (Walker and Plint, 1992) and the proximal *Cruziana* ichnofacies representing the top of the slope.

Upper Shoreface Facies

Distribution of upper shoreface facies is limited to a single sandstone interval 5 m thick at the top of the middle subdivision of the Imperial River section (Figure 7.2.11). The base of the sandstone beds are scoured and show cross-stratification. The sandstone is greenish grey, grading from medium- to fine-grained sand. The sedimentary structures range from massive to disrupted parallel lamination to ripple cross lamination, low angle planar cross lamination and hummocky and swaley cross-stratification.

The presence of wave formed structures such as hummocky and swaley cross-stratification in this unit indicate that this sandstone was deposited in shallow marine setting, above storm wave base, such as in an upper shoreface environment (Walker and Plint, 1992).

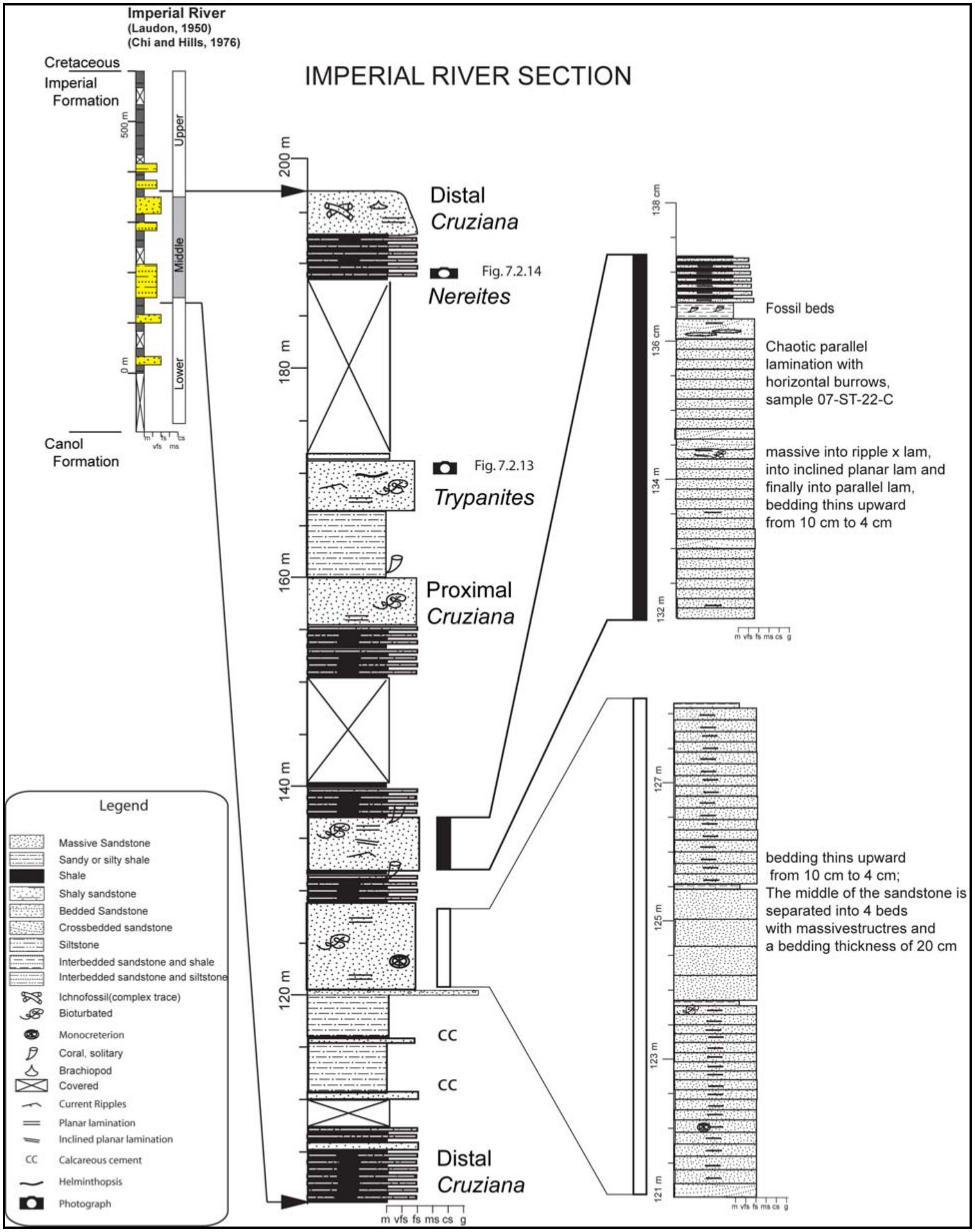

Figure 7.2.10. *Imperial River measured section with detail of the sandstones at the base of the middle interval.*

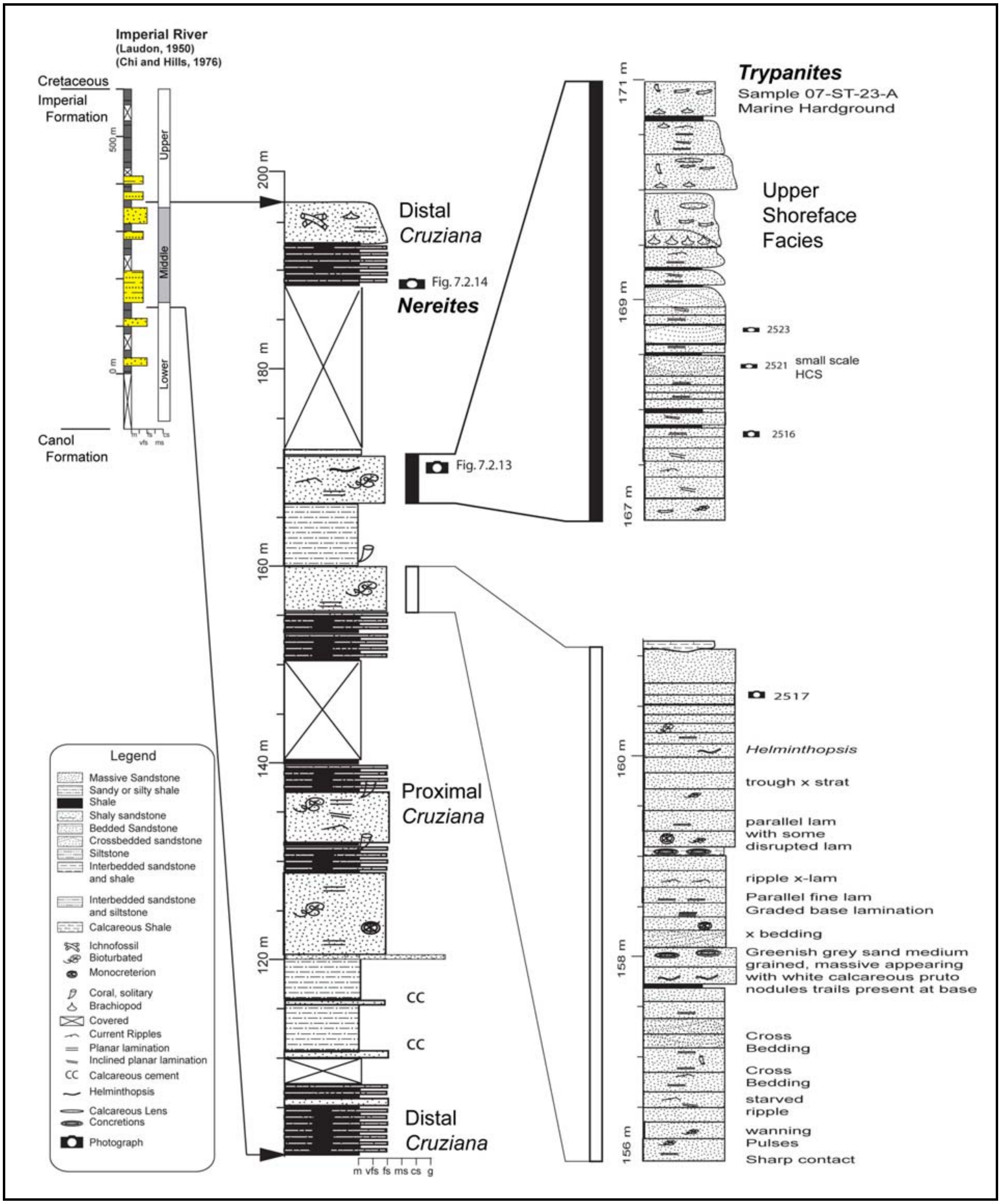

Figure 7.2.11. *Imperial River measured section with detail of the sandstones at the top of the middle interval. Note stratigraphic position of hardground and* Nereites *ichnofacies.*

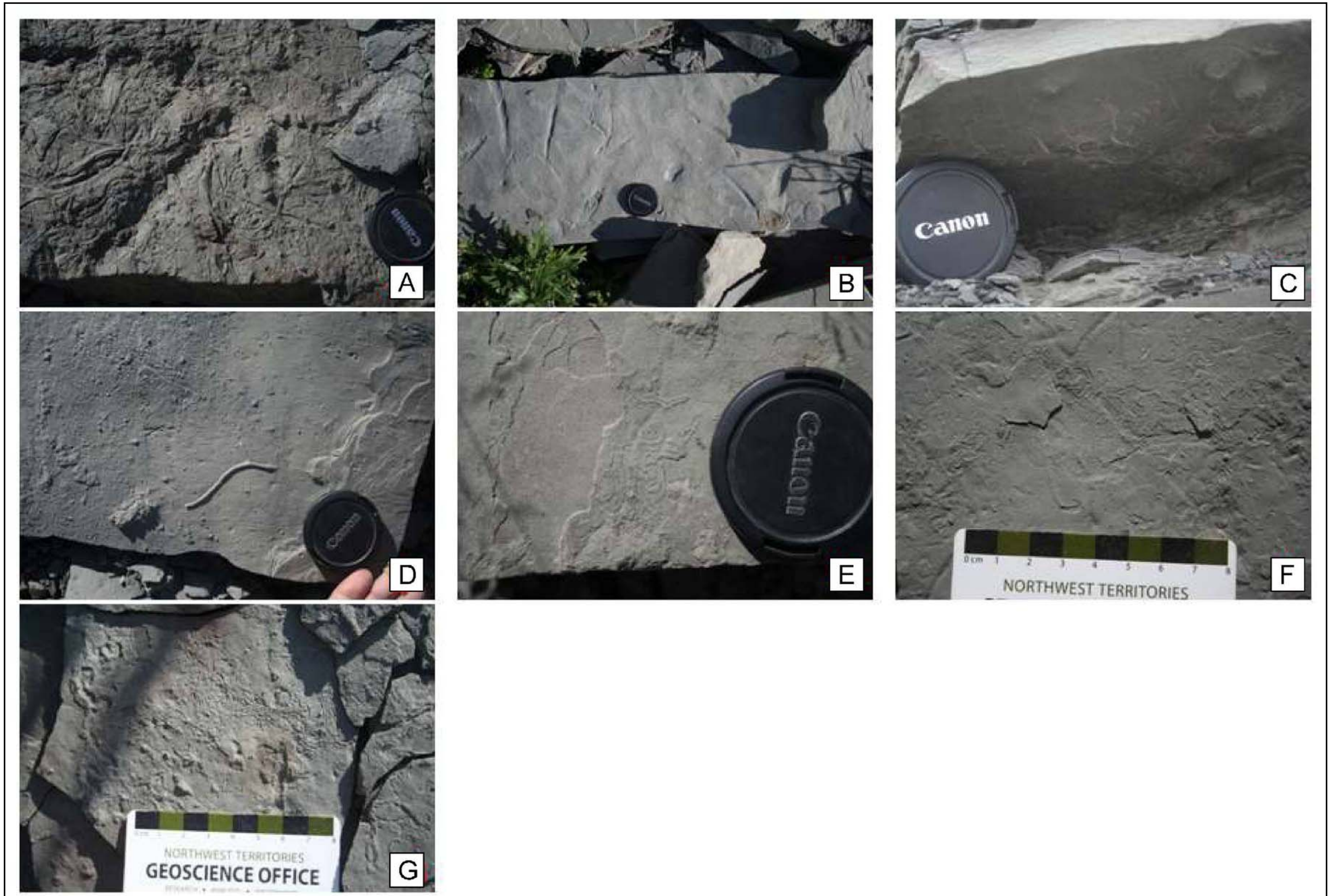

Figure 7.2.12. *Ichnofossils present in the third, fourth and seventh sandstones at the Imperial River type section: (A)* Crossopodia, Teichichnus, *and* Thalssinoides*; (B)* Planolites *and* Paleophycus*; (C)* Lorenzinia*; (D)* Thalassinoides*; (E)* Cruziana*; (F)* Planolites *and unidentified trace; and (G) unidentified trace.*

Marine Hardground

The top of the upper shoreface sandstone is bioturbated (Figure 7.2.13). The top few centimetres are a red calcareous interval that shows horizontal, vertical, and U-shaped burrows (Figure 7.2.13). Vertical and tear-shaped burrows are filled with black shale and iron-stained calcareous sediment with burrow sizes between 2 mm to 1 cm cutting through a calcite dominated host substrate (A in Figure 7.2.13).

The vertical and tear shaped burrows compose *Trypanites* ichnofacies developed within a lithified sandstone. This represents a period of non-deposition. The accommodation space has been filled and the area may have been subaerially exposed.

Figure 7.2.13. *Marine hardground: (A) photomicrograph of a burrow that cuts through sandstone; and (B, C) outcrop photographs of* Trypanites *ichnofacies traces.*

Nereites Ichnofacies

This interval overlies the marine hardground facies (Figure 7.2.11). It includes mudstone and laminated fine-grained sandstone with glauconitic cement and calcite cement. The difference between this facies and both the thin-bedded turbidite facies and the slope sandstone facies is the representative trace fossils present. These include: *Lorenzinia*, *Nereites*, *Planolites*, *Paleodictyon*, *Pro-Paleodictyon*, *Cosmorhaphe*, *Phycosiphon, Palaeophycus, Scolicia, Spirohaphe, Isopodichnus,* and *Helminthoida* (Figure 7.2.14).

The behaviors of the ichnofauna in the top sandstone at Imperial River show feeding, farming and grazing traces, with specific ichnogenera of *Nereites*, *Paleodictyon*, *Pro-Paleodictyon, Isopodichnus, Spirohaphe, Planolites, Helminthoida* and *Scolicia*. These traces belong to the *Nereites* ichnofacies that are found in deep sea abyssal plain environments. This ichnofacies is only found in the upper interval of Imperial Formation at Imperial River (Figure 7.2.11). The presence of this ichnofacies indicates quiet stable conditions before transgression and turbidite deposition. Braman (1992) noted that there was a small hiatus between *C. deliquescens-A. opiparus* and *V. preanthoideus-A. famenensi*s within the same interval.

The sedimentology indicates that this is a similar environment to the thin-bedded deposits, found in the lower and upper subdivisions of the Imperial River section. A possible explanation is that the sandstone containing the *Nereites* ichnofacies was deposited following a major transgression.

7.2.3 Discussion: Depositional Environments

Imperial River

The depositional environments in the east at Imperial River are characterized by a slope, lower shoreface, upper shoreface, and lower slope complex. Divisions are based on a conglomerate at the base of the shallow marine facies and a *Trypanities* ichnofacies at the top of the shallow marine succession. The ichnofossils suggest a distal *Cruziana* ichnofacies below the conglomerate (lower subdivision of Imperial River section), a proximal *Cruziana* ichnofacies above the conglomerate (middle subdivision), a *Trypanities* ichnofacies at the contact with a *Nereites* ichnofacies in the sixth sandstone above the contact (upper subdivision), and a distal *Cruziana* ichnofacies in the seventh sandstone.

The contact between the *Trypanities* ichnofacies and overlying shale represents a major transgression (Fig. 7.2.11). Across this surface Chi and Hills (1974) noted a change in palynomorphs suggesting a hiatus from a Frasnian to Famennian age. Above this surface we note the occurrence of the deep sea *Nereites* ichnofacies, indicative of an abyssal plain, and a distal *Cruziana* ichnofacies within overlying thin-bedded sandstone. The next couple hundred metres of section are recessive shales.

Shortcut Creek

The submarine fan depositional environment at the Shortcut Creek locality is represented by both thin- and thick-bedded turbidite facies. Rare traces from the submarine fan deposits at the base of the section suggest a distal *Cruziana* ichnofacies. The vertical facies transitions from submarine fan to slope deposits. The proximal *Cruziana* ichnofacies associated with slope sandstone units are represented by *Rhizocorallium, Paleophycus, Thalassinoides* and *Planolites*.

Figure 7.2.14. *Ichnofossils present at the Imperial River type section within the seventh sandstone (*Nereites *ichnofacies): (A)* Lorenzinia*; (B)* Nereites*; (C) unidentified trace; (D)* Nereites *and* Planolites*; (E)* Pro-Paleodictyon *and* Paleodictyon*; (F)* Cosmorhaphe *and* Phycosiphon*; (G)* Cosmorhaphe *and* Palaeophycus*; (H)* Pro-Paleodictyon *and* ?Helminthoida*; (I) Planolites and* Cosmorhaphe*; (J) plant debris; (K)* Paleodictyon*; and (L)* Planolites, Cosmorhaphe *and* Palaeophycus.

Flyaway Creek

The Flyaway Creek locality contains a facies dominated by black shale and ironstone concretions. The substrate must be oxygen deprived to allow the development of ironstone concretions and the environment must have had low energy conditions as the ichnofossils are large resting traces that have been passively infilled (Figure 7.2.3). The grain size is predominantly shale to silty shale. The overall stratigraphic section shows a shallowing trend as the facies transition from offshore mudstone into a thick sandstone unit (Tuttle Formation). The association of passively infilled, substrate controlled trace fossils and turbidites are interpreted to record deposition on a slope turbidite complex that has also been subjected to pelagic sedimentation.

7.2.4 Conclusion

Seismic (section 7.1) and paleocurrent data indicate that the sediment source was derived from the craton to the east. A lower to middle shoreface environment initially developed in the east at Imperial River. Following development of a *Trypanites* ichnofacies-bearing hardground and a major transgression, the initial shelf was overlain by deposits containing the abyssal plain *Nereites* ichnofacies. At the Shortcut Creek locality the lower intervals containing sedimentary structures and ichnological structures are indicative of a submarine fan depositional environment, deposited as thick-bedded turbidites; this transitions into a proximal *Cruziana* ichnofacies-bearing upper slope environment towards the top of the section. The Flyaway Creek locality in the west grades from offshore deposits into a thin-bedded turbidite facies containing distal *Cruziana* ichnofacies towards the top of the section, which is part of Tuttle Formation.

Acknowledgements

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7.3 ASPECTS OF IMPERIAL FORMATION PETROLEUM GEOLOGY

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Abstract

Shales within Imperial Formation demonstrate fair potential as source rocks, with total organic carbon (TOC) values of generally 0.5% to 1.5 %. There is a suggestion that TOC values increase systematically from east to west across the study area, probably in response to depositional environments and proximity to Richardson Mountains. The shales are largely gas prone, and vary in maturity from oil zone to dry gas zone across Peel area. Thermal maturity increases to the west and south in proximity to the Richardson and Mackenzie mountains, due to increased burial; but also due to sampling bias in outcrop samples, since older (and more thermally mature) rocks outcrop as one moves toward the core of the Richardson Anticlinorium.

Fine- to very fine-grained sandstones in Imperial Formation are quartzose, generally well-sorted, and contain sub-angular clasts. Clay minerals are a common component. They are tight, with permeabilities mainly less than 1 mD. The highest porosities (over 20%) are found just southeast of Peel area. This is also the area where Imperial Formation sandstones are slightly coarser grained, and were deposited in a lowstand wedge or fan setting, in contrast to the turbiditic sands further west. Detailed sample transects along and across individual sand beds or packages indicate fairly consistent porosities and low permeabilities.

Imperial Formation has been considered as a conceptual play by previous workers; it is recognized that both stratigraphic and structural traps are possible. A few gas shows associated with the formation are known from Peel area. Imperial Formation probably generated gas in latest Paleozoic time in Peel Plateau, but perhaps not until late Cretaceous time in eastern Peel Plain. Play potential is considered moderate, with exploration risks at play and prospect levels, concerning reservoir, seal, stratigraphic trap closure, and shallow depths. Overarching concerns regarding the poorly understood tectonic and diagenetic history, and long periods of preservation required, are play level risks in Peel Plateau. Potential for unconventional tight gas resources have not been explored here, but may warrant future consideration.

Imperial Formation Conceptual Play

Imperial Formation contains the elements of a conceptual hydrocarbon play in Peel area. There is potential for source rock, reservoir rock, and sealing cap rocks within the formation. For the purposes of this discussion, we will consider the Imperial Formation conceptual play (Imperial Play) to include all pools and prospects hosted in porous, very fine-grained quartzose sandstones of Imperial Formation. In addition to source rocks within the formation itself, alternate source rocks may include adjacent Canol or Tuttle formations or Ford Lake Shale, or conceivably Cretaceous shale. Likewise, Imperial Formation could provide a source of hydrocarbons for Tuttle or Cretaceous reservoirs.

Imperial Formation is widespread in the surface and subsurface of Peel area, except in the northeast where it has been removed by pre-Cretaceous erosion. As such the play can be considered to extend through much of the area, limited by areas of shallow subcrop, and outcrop, and missing strata (Gal and Udell, 2005; Lemieux et al., 2008; Figure 7.3.1).

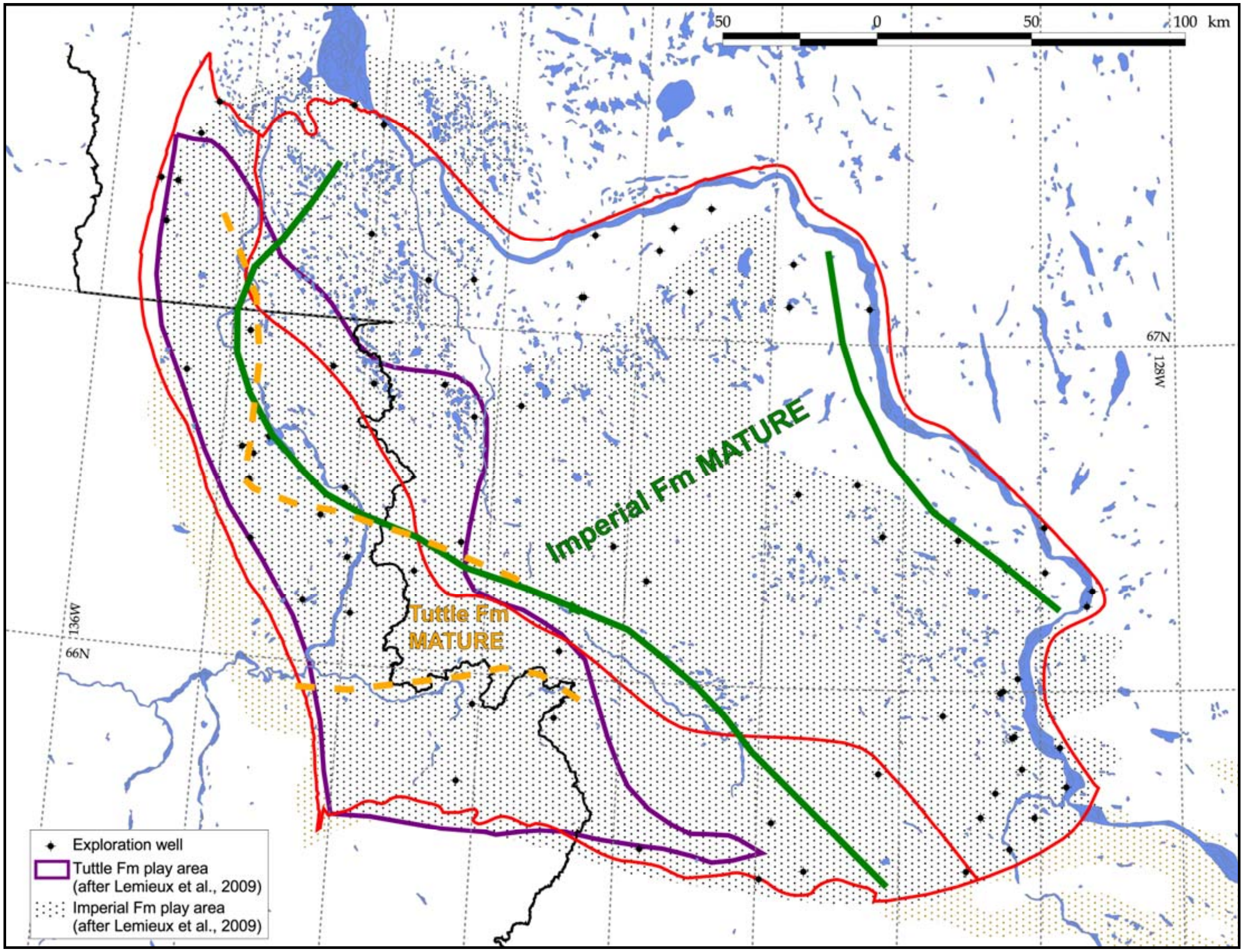

Figure 7.3.1. *Play map for a conceptual Imperial Play. The play area (stippled) is after Lemieux et al. (2008), and is essentially the same as Gal and Udell (2005). Mature Imperial Formation (within the oil window) is indicated by the bounding green lines. Tuttle Formation maturity and play areas are also shown. This figure is discussed further in Chapter 10 (this volume).*

No discoveries have been made within Peel area, although some shows have been indicated by drill stem tests (DST). This play is also conceptual though much of the Interior Platform of the Northwest Territories (NWT; e.g., Canadian Gas Potential Committee, 2005; Gal and Udell, 2005; Hannigan et al., 2006; Pyle et al., 2008). Minor oil production from Imperial Formation was reported at Norman Wells; this oil was probably leaking from the Ramparts Formation reservoir (Pyle et al., 2008) and likely sourced in Canol Formation (Snowdon et al., 1987).

Few quantitative estimates of the Imperial Play endowment in the NWT have been published. In an unpublished report, Drummond (2006) has made a quantitative assessment of the Imperial Play in the Sahtu and Gwich'in Settlement Areas of the NWT, which includes Peel area. Osadetz et al. (2005) made quantitative estimates for a number of plays in the Yukon portion of Peel area, which included correlatives of Imperial Play (Table 7.3.1).

Play Name (from Osadetz et al., 2005)	Play Area	Mean Play Potential, expected Number of Pools
Peel Plain Upper Paleozoic Clastics Play	Yukon portion of Peel Plain	7260 x 10^6 m^3, 9 pools
Peel Plateau Upper Paleozoic Clastics Play	Yukon portion of Peel Plateau	7799 x 10^6 m^3, 2 pools
Peel Plateau Upper Paleozoic Clastics Play- west of Trevor Fault	Yukon portion of Peel Plateau, west of Trevor Fault	105 x 10^6 m^3, 1 pool

Table 7.3.1. *Quantitative estimate of mean play potential for Upper Paleozoic Clastics plays in Yukon portion of Peel Plateau and Plain from Osadetz et al.(2005).*

National Energy Board (2000) evaluated a Paleozoic and Cretaceous Clastic play in the disturbed belt (west of Trevor Fault) in Yukon, which would include a conceptual Imperial Play, although it could be that any contribution from Imperial Formation would be subordinate to Tuttle and Cretaceous formations there. National Energy Board (2000) did not evaluate an Upper Devonian clastic play in the Yukon portion of Peel Plain, although they evaluated plays in both Mississippian and Cretaceous clastics.

There have been some indications of hydrocarbons in Imperial Formation in Peel area; see Table 7.3.2 for significant results.

Well Name	Depth or DST interval (m)	Hydrocarbons noted
Hume R. O-62	496.8-520.3	gas to surface, too small to measure
Ramparts River F-46	971; 1095-1098	gas shows on gas detector
Sperry Creek N-58	870-871.2; 906-907; 1062.4-1064.4	dry gas
Tree River H-38	721.2	sweet gas blowout

Table 7.3.2. *Hydrocarbon shows from Imperial Formation in Peel area wells (after Pyle et al., 2008). Note that Tree River well blowout was likely sourced in Canol Formation.*

Oil stained Imperial Formation has been noted at Thunder River N-73 and Hume River D-53 wells. In the current study, oil stained Imperial Formation was observed at Imperial River section (see sections 7.1 and 7.2) and observed and sampled at Katherine Creek, southeast of Peel area (see Chapter 10, this volume).

An interesting occurrence of massive bitumen is hosted in the Imperial Formation just north of the community of Tsiigehtchic, NWT, near the northern margin of Peel area (Norris and

Cameron, 1986; Pyle et al., 2007; Figure 7.3.2). A (?formerly) flowing lacustrine gas seep, underlain by Imperial Formation, has been mapped in Arctic Red River map area (106 N4/1; Norris, 1968; Pugh, 1983).

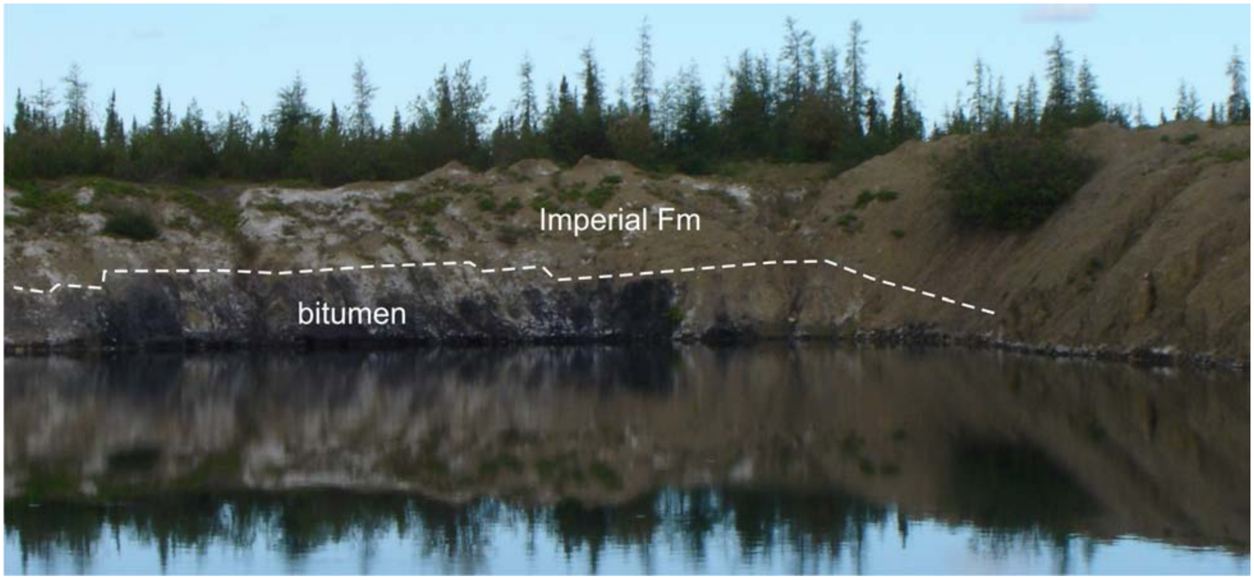

Figure 7.3.2. *Massive bitumen occurs apparently conformable with Imperial Formation (contact indicated by dashed white line)in an abandoned pit just west of the Dempster Highway, and north of Rengleng River. The bitumen mass is at least 2 m thick. Note the whitish efflorescence, associated with pyrite and/or pyrrhotite in the Imperial Formation siltstone, probably occurring as an alteration product associated with the bitumen.*

Reservoir Rocks

The siltstones and very fine-grained sandstones of Imperial Formation are the most prospective reservoirs, and the formation has been described as becoming sandier to the west and north (e.g., Pugh, 1983). One core sample cut from Imperial Formation in a well intersection in Peel area was analysed for porosity and permeability; a 1.88 m section from the East Hume River N-10 well yielded a weighted average of 7.1% porosity and 5.28 mD permeability. Hu (in press) estimated porosity of sections of Imperial Formation, from petrophysical logs, in the Attoe Lake I-06 and Sainville River D-08 wells; some of the better intervals are tabulated in Table 7.3.3. The Arctic Red F-47 well had a 6.1 m interval of fair to good intergranular porosity (Pyle et al., 2008).

Well Name	Interval (m)	Weighted average Porosity (%)	Weighted average Permeability (mD)
Attoe Lake I-06	347.17-352.5	15.15	249
	885.9-887.88	13.6	83
Sainville River D-08	726.95-730.3	15.0	146
	878.43-881.33	18.1	312
	885.44-888.34	10.3	23
	922.93-929.69	13.8	106

Table 7.3.3. *Estimated porosity and permeability from Imperial Formation well logs from Peel area (from Hu, in press).*

In the present study, a number of outcrop locations were sampled, and core plugs cut and analysed by standard methods for porosity and permeability. The lithologies were mainly fine- or very fine-grained sandstones, and a trend was apparent in that locations from around southeast Peel area yielded generally higher porosities than samples from Arctic Red River area (Table 7.3.4) and certainly from Snake River area (07TNT** samples, Table 7.3.5; Allen and Fraser, 2008). Laboratory porosity and permeability results from outcrop samples are in Table 7.3.5.

Region of Peel area	Section or Station	Typical Porosity Range (%)
Southeast of Peel area	Imperial River (Imperial Formation type section)	10-22
Southeastern Peel area	Powell Creek	7-9
South central	Elbow Creek tributary (Shortcut Creek)	4-6.5
South west	West of Arctic Red River	3-10

Table 7.3.4. *General range of porosities from Imperial Formation outcrop samples, illustrating east to west decline in porosities (after Zantvoort, 2007).*

Sample	Porosity (%)	Permeability (mD)	Lithology
WGZ-007-06	0.50	0.005	sandstone
WGZ-009-06	4.7	0.02	sandstone
WGZ-015-06	4.6	0.03	sandstone
WGZ-032-06	14.1	0.02	--
WGZ-033-06	24.7	0.10	--
07WZ-22F	7.2	0.005	Massive sandstone
07WZ-23K	9.4	0.030	Massive sandstone
07WZ-24G	10.4	0.005	Bedded sandstone
07WZ-23D	8.6	0.010	Massive sandstone
07WZ-22A	4.0	0.005	Cross-bedded sandstone
07WZ-23B	7.3	0.010	Massive sandstone
07WZ-24I	13.5	0.030	Massive sandstone
07WZ-9E	6.5	0.050	Massive sandstone
07WZ-14B	5.2	0.040	Massive sandstone
07WZ-24J	15.3	0.080	Massive sandstone
07WZ-24A	11.7	0.020	Carbonate conglomerate
07WZ-16A	9.9	0.010	Bedded sandstone
07WZ-16C	3.8	0.005	Bedded sandstone
07WZ-13A	3.3	0.005	Massive sandstone
07WZ-23G	7.9	0.005	Massive sandstone
07WZ-10A	0.5	0.005	--
07WZ-25C	15.2	0.180	Massive sandstone
07WZ-16B	4.6	0.005	Massive sandstone
07WZ-14A	5.9	0.005	Massive sandstone
07WZ-24C	22.1	0.100	Massive sandstone
07TNTR-33B	1.3	0.01	sandstone
07TNTTR-33 scree	0.5	0.01	sandstone
07TNTSR41-E	0.7	0.02	sandstone

Table 7.3.5. *Measured porosity and permeability from Imperial Formation outcrop samples.*

Zantvoort (2007) considered the best reservoir potential to be in the eastern part of Peel area. Generally, sandstones with the best porosity were found along the Imperial River section, southeast of Peel area. Sandstones from Imperial River section are interpreted as forming in a lowstand wedge, deposited during a drop in base level (section 7.1). These sands are older than the westward-occurring, turbidite-related, clinoformal sandstone bodies that were deposited after base level had increased (section 7.1). Overall, the grain size is generally coarser in eastern Peel area, and cross-laminae up to medium-grained size were observed in one cross-bedded sandstone unit at Imperial River section.

Field observations of measured sections along the southern margin of Peel area, west of Imperial River section, suggest that the fine-grained greenish grey sandstone units in the upper half of Imperial Formation would make better reservoirs than the lower sandstone units (Zantvoort, 2007; Pyle et al., 2008). Imperial Formation sandstones from western Peel area typically are clay rich, which occludes porosity.

In southwestern Peel area, Imperial Formation sandstone in the eastern Richardson Mountains is very fine- to fine-grained, and is characterized by quartz with minor chert. Porosity and permeability were negligible in samples from western Peel Plateau and in the eastern Richardson Mountains outcrop samples (Allen and Fraser, 2008).

The better porosities in the east may also be due to relatively less burial and/or lack of diagenesis. Porosity enhanced by weathering (meteoric waters) at Imperial River section is unlikely because the permeabilities are uniformly low across the sample set, very rarely exceeding 1 mD. Imperial Formation reservoirs can, for the most part, be considered tight sandstones.

In an attempt to assess the lateral variations of the porosity and permeability in individual sandstone bodies, two sand units at Imperial River section, and another at Katherine Creek southeast of Peel area, were sampled on lateral transects. Samples were taken at 5 m intervals as far as was practical, and attempts were made to remain within the same bed. The porosity and permeability of these samples are tabulated below, and represented graphically in figures 7.3.3 to 7.3.5. A permeability versus porosity cross plot for all Imperial Formation samples is shown in Figure 7.3.6.

From these sampled transects, it is apparent that there is a fair uniformity of porosity and permeability within each sand unit. The upper sandstone at Imperial River section (Transect 1) shows an interesting gradual decrease in porosity from southwest to northeast, up the original depositional dip. It is not known, however, if sedimentological, diagenetic, or weathering factors are mainly responsible for this. At Katherine Creek (Transect 3), there is a marked higher porosity zone near the northwestern side of the sample transect. Unlike the Imperial River section transects (1 and 2), Katherine Creek was sampled closer to along strike than along depositional dip. At Katherine Creek, there was a lower laminated and an upper massive sand (Figure 7.3.4). Most samples were taken near the top of the laminated sand, with a few massive samples from the northwestern end of the sample transect. However, these lithological changes apparently do not correlate with the higher porosity zone. Again, sedimentological, diagenetic, and/or recent weathering factors may be involved. Permeabilities again were low, with only one sample yielding greater than 1 mD.

Sample	Porosity (%)	Permeability (mD)	Sample	Porosity (%)	Permeability (mD)
Transcect 1: Imperial River, upper sandstone			**Transect 2: Imperial River, lower sandstone**		
8WZ1A	19.0	0.65	8WZ2A	10.0	0.02
8WZ1AA	14.0	0.21	8WZ2AA	10.0	0.03
8WZ1B	17.0	0.36	8WZ2B	11.0	0.01
8WZ1BB	14.0	0.26	8WZ2BB	12.0	0.03
8WZ1C	18.0	0.25	8WZ2C	10.0	0.02
8WZ1CC	15.0	0.15	8WZ2D	10.0	0.01
8WZ1D	18.0	0.50	8WZ2E	11.0	0.02
8WZ1E	19.0	1.58	8WZ2F	8.0	0.01
8WZ1H	19.0	0.52	8WZ2G	13.0	0.04
8WZ1I	18.0	0.38	8WZ2H	11.0	0.01
8WZ1J	18.0	0.34	8WZ2I	13.0	0.05
8WZ1K	14.0	0.10	8WZ2J	10.0	0.01
8WZ1M	19.0	0.40	8WZ2K	12.0	0.01
8WZ1N	18.0	0.52	8WZ2L	11.0	0.02
8WZ1O	19.0	0.48	8WZ2N	11.0	0.02
8WZ1P	17.0	0.42	8WZ2O	10.0	0.01
8WZ1Q	17.0	0.52	8WZ2P	11.0	0.01
8WZ1T	16.0	0.31	8WZ2Q	11.0	0.06
8WZ1U	16.0	0.27	8WZ2R	9.0	0.01
8WZ1V	17.0	0.33	8WZ2S	10.0	0.02
8WZ1W	14.0	0.33	8WZ2T	10.0	0.02
8WZ1X	16.0	0.19	8WZ2U	14.0	0.06
8WZ1Y	16.0	0.19	8WZ2X	12.0	0.03
8WZ1Z	14.0	0.16	8WZ2Y	13.0	0.03
Transect 1 average	**16.75**	**0.39**	8WZ2Z	12.0	0.06
			Transect 2 average	**11.0**	**0.02**
Transect 3: Katherine Creek					
8WZ3A	13.0	0.07	8WZ3K	14.0	0.04
8WZ3B	13.0	0.05	8WZ3M	13.0	0.02
8WZ3C	13.0	0.06	8WZ3O	14.0	0.08
8WZ3D	12.0	0.04	8WZ3P	13.0	0.06
8WZ3E	14.0	0.10	8WZ3Q	14.0	0.07
8WZ3F	18.0	0.46	8WZ3R	13.0	0.06
8WZ3G	19.0	0.48	8WZ3S	10.0	0.01
8WZ3H	19.0	0.93	8WZ3T	13.0	0.07
8WZ3I	18.0	0.29	8WZ3U	12.0	0.02
8WZ3J	15.0	0.06	8WZ3V	13.0	0.01
			Transect 3 average	**14.15**	**0.15**

Table 7.3.6. *Measured porosity and permeability from Imperial Formation outcrop samples taken along three sample transects near southeast Peel area. Samples in each transect were spaced approximately 5 m apart.*

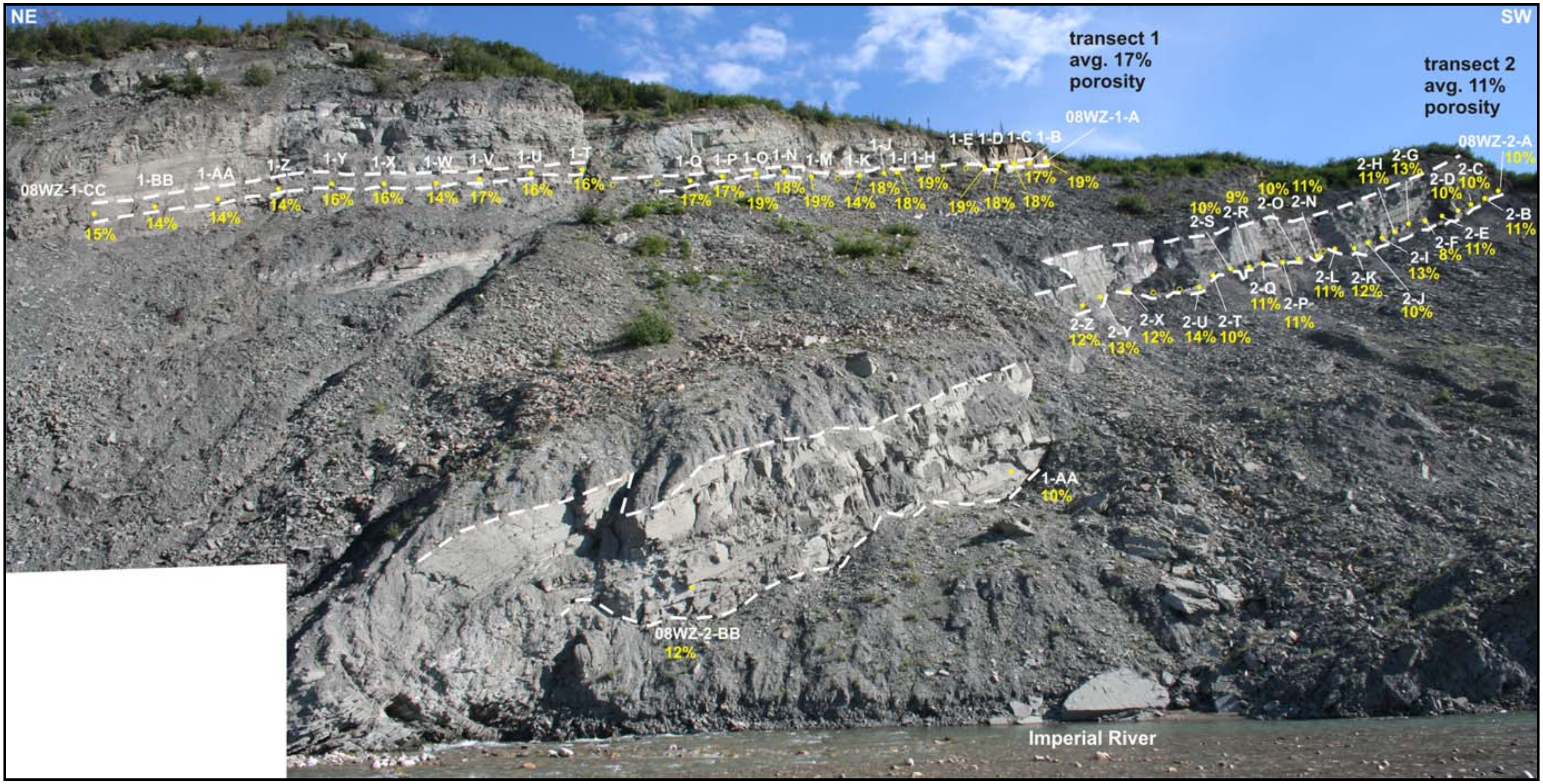

Figure 7.3.3. *View southwest of a portion of Imperial River section (Imperial Formation type section). The upper and lower sandstone units (dashed contacts) were sampled at approximately 5 m intervals, roughly parallel to the dip direction. Sample locations (locations as shown are approximate) and determined porosity are shown. Unfilled symbols indicate no sample. The upper bed (transect 1) averaged 17% porosity, the lower one (transect 2) averaged 11%. The upper sandstone is about 2 m thick, lower unit is approximately 8 m to 10 m thick.*

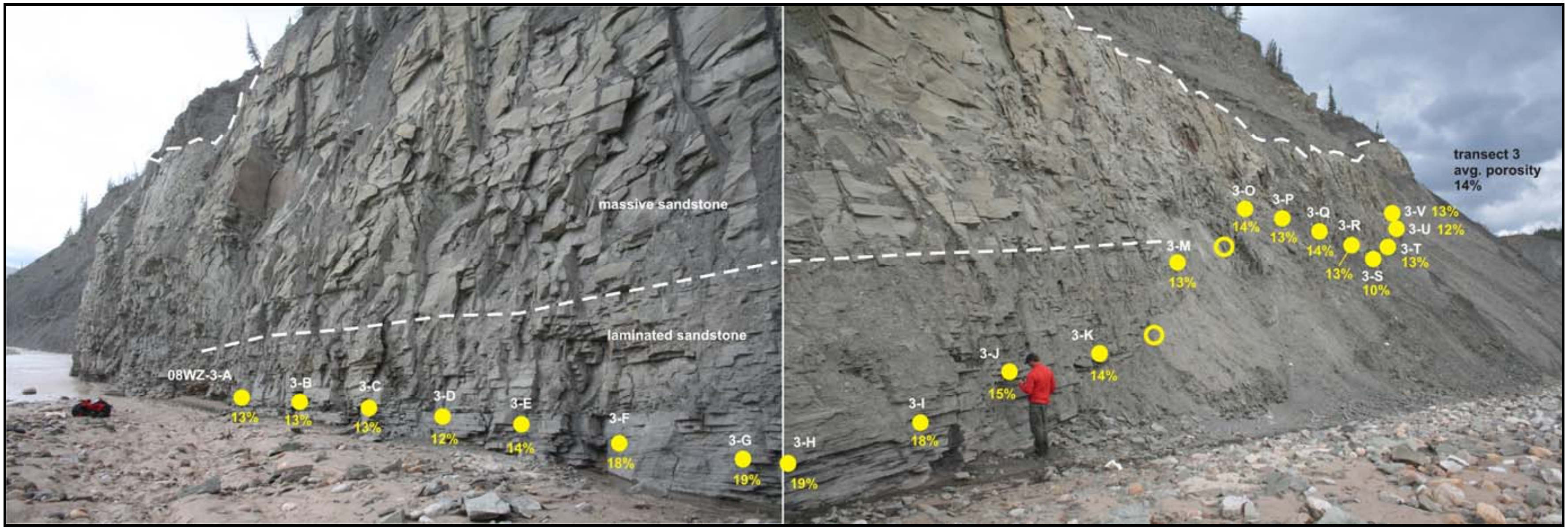

Figure 7.3.4. *View of the sample transect 3 along the northeast bank of Katherine Creek. This sandstone (dashed on upper contact, and between laminated and massive sub-units) was sampled at approximately 5 m intervals, roughly parallel to the strike direction. Sample locations (locations as shown are approximate) and determined porosity are shown. Unfilled symbols indicate no sample. The samples averaged 14% porosity. Geologist for scale. The view is from the northwest (left) to the southeast (right).*

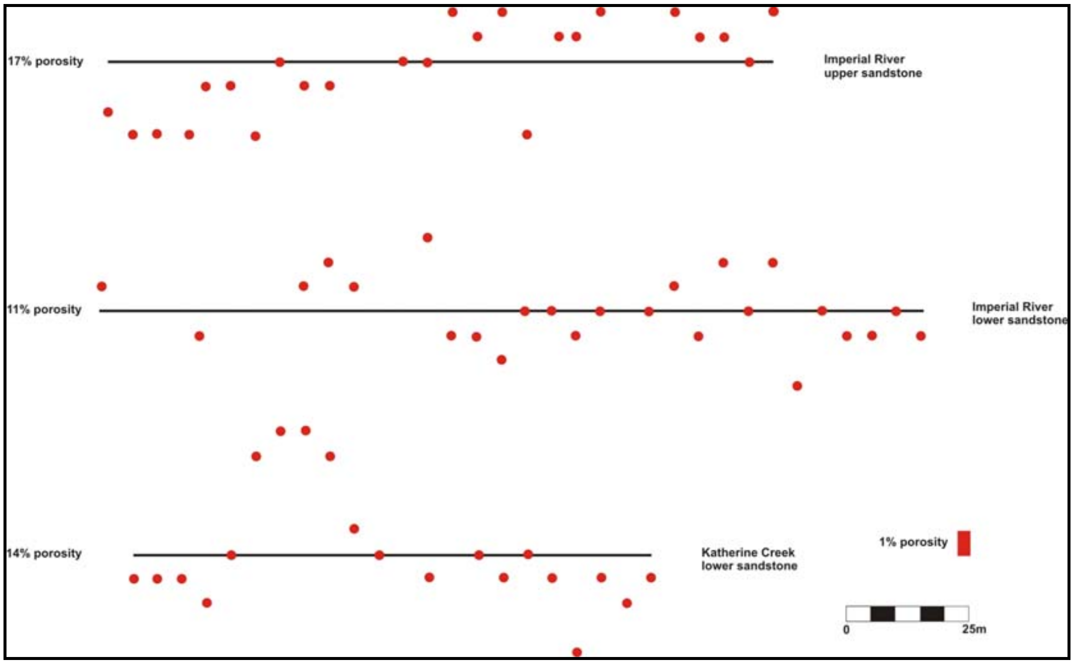

Figure 7.3.5. *Representation of porosities along three transects shown in figures 7.3.3 and 7.3.4. The red dots are individual sample porosities, plotted relative to the average for each transect (horizontal line). Note the gradual increase in porosities along the transect of the upper sandstone at Imperial River, compared to the less uniform variation in the lower sandstone bed. Note also the zone of relatively higher porosities along the Katherine Creek transect, which was sampled along the depositional strike, rather than along the depositional dip, as at Imperial River. Horizontal scale (m) and vertical scale (% porosity) are indicated.*

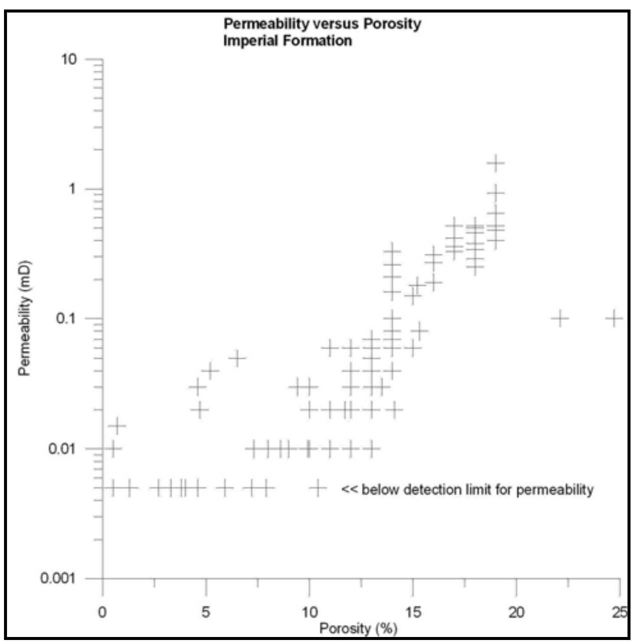

Figure 7.3.6. *Permeability versus porosity cross plot for all Imperial Formation samples analysed during the current study. A few anomalous permeability samples, probably due to fractures, are apparent. Note also that the two highest porosity samples are anomalous, and are off the trend. Generally, Imperial Formation sands can be considered tight.*

Several thin sections of Imperial Formation fine- to very fine-grained sandstone were examined. Typically, the fine sandstones are quartzose, well sorted but sub-angular, with abundant clay minerals. A preferential fabric was suggested in some samples by clay mineral and quartz grain alignment (Figure 7.3.7). In some samples, grains were rounded suggesting longer transport distances (Figure 7.3.8). Generally, porosity is assumed to be intergranular, but in many cases this was difficult to determine microscopically (Figure 7.3.9). The term microporosity may be applied in most instances. Fracture porosity was apparent in some thin sections (Figure 7.3.10), and minor fracture porosity was noted in the Canstrat log for Cranswick A-22 well (Canadian Stratigraphic Service Ltd., 1974). In some thin sections, porosity due to dissolution of grains was inferred (Figure 7.3.11). Clay minerals and local carbonate were common, and quartz overgrowths were possible (Figures 7.3.11, 7.3.12). Thin (up to 20 cm) fossiliferous carbonate beds interbedded with the sandstone and siltstone displayed intergranular, and some intra-organic porosity (Figure 7.3.13).

In western Peel Plateau and eastern Richardson Mountains, samples of Imperial Formation fine-grained sandstone showed: fused grain boundaries with quartz overgrowths; pore space infill by mud-sized grains and clay minerals; and calcite cement, all of which were assumed to negatively affect porosity and permeability (Allen and Fraser, 2008).

Figure 7.3.7. *Sample 07WZ-9B, typical Imperial Formation fine-grained quartzose sandstone. Note good sorting, angular to sub-angular grains, and apparent fabric reflected in the orientation of long axis of quartz grains. Plane polarized light, field of view is approximately 4.5 mm.*

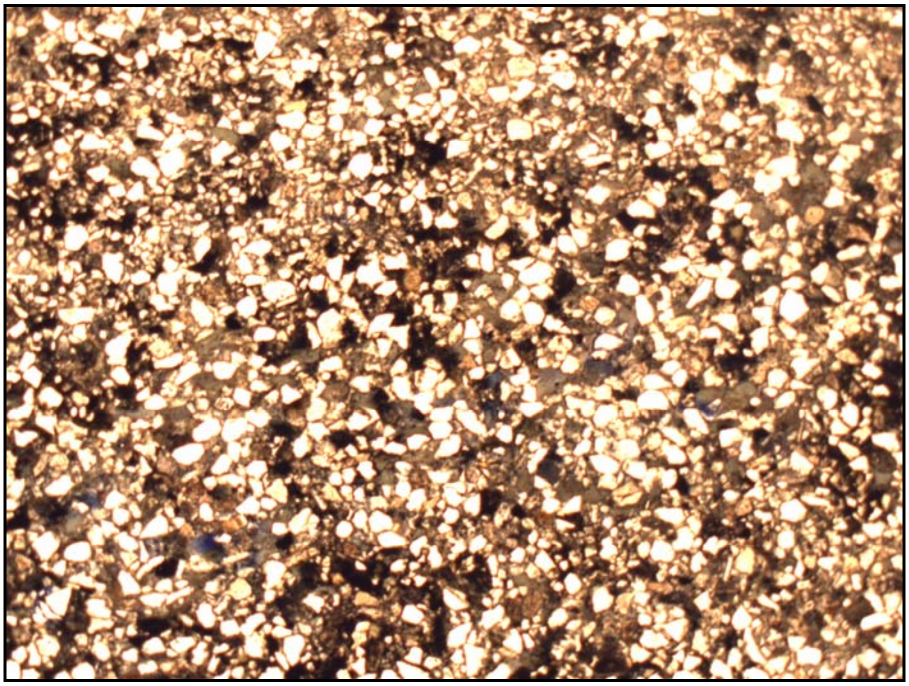

Figure 7.3.8. *Sample 07WZ-23G, fine-grained quartzose sandstone, Powell Creek. Grains are sub-angular to sub-rounded, compared to Figure 7.3.7 from further west on a tributary of Elbow Creek. This sample had 7.9% porosity; some intergranular porosity is apparent here. Note the band of higher porosity across the middle of the photo, possibly due to dissolution of grains. Plane polarized light, field of view is approximately 4.5 mm.*

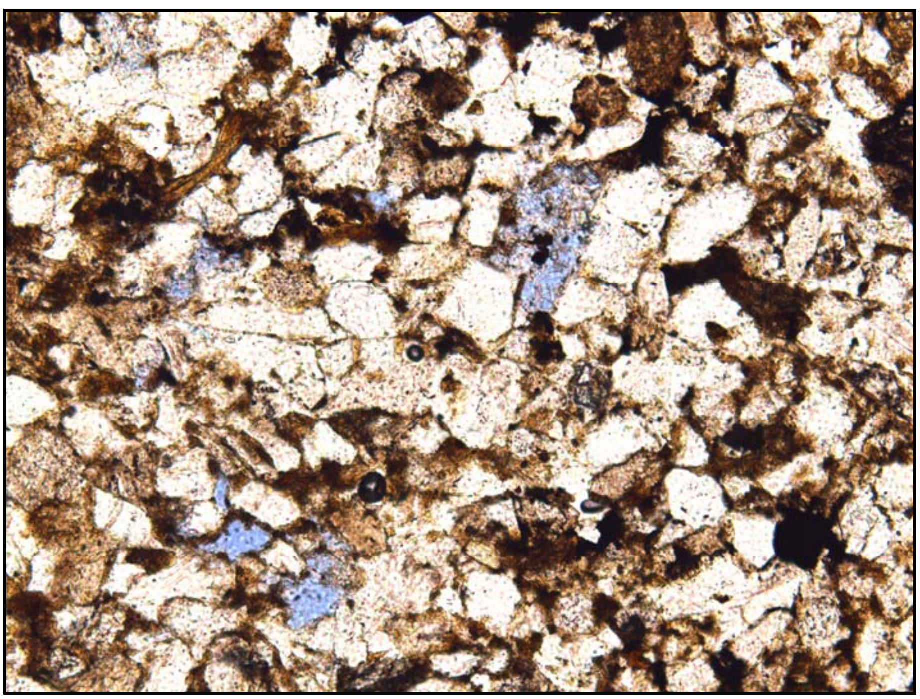

Figure 7.3.9. *Sample 07WZ-22B, fine-grained quartzose sandstone, from tributary of Elbow Creek. Grains are angular and sub-angular, possibly with some quartz overgrowths. Intergranular porosity is indicated by the blue epoxy. Note clay minerals as cement and lining pores. Plane polarized light, field of view is approximately 1.1 mm.*

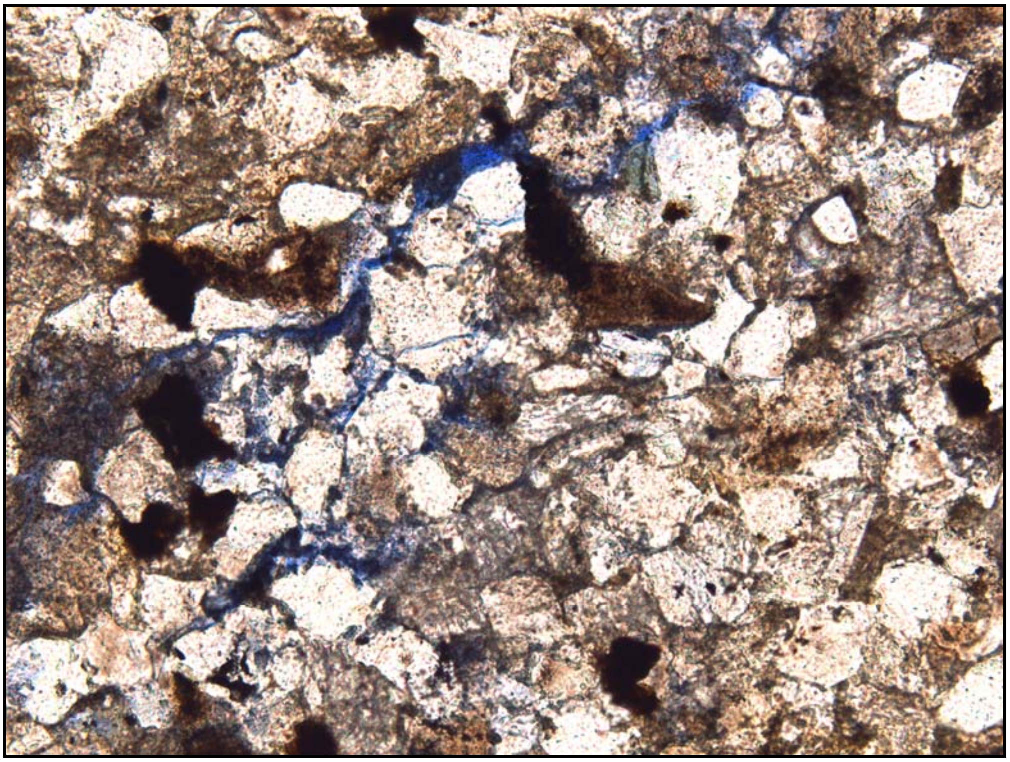

Figure 7.3.10. *Sample 07WZ-16B, some fracture porosity, from tributary of Arctic Red River. This sample had 4.6% porosity. Plane polarized light, field of view is approximately 1.1 mm.*

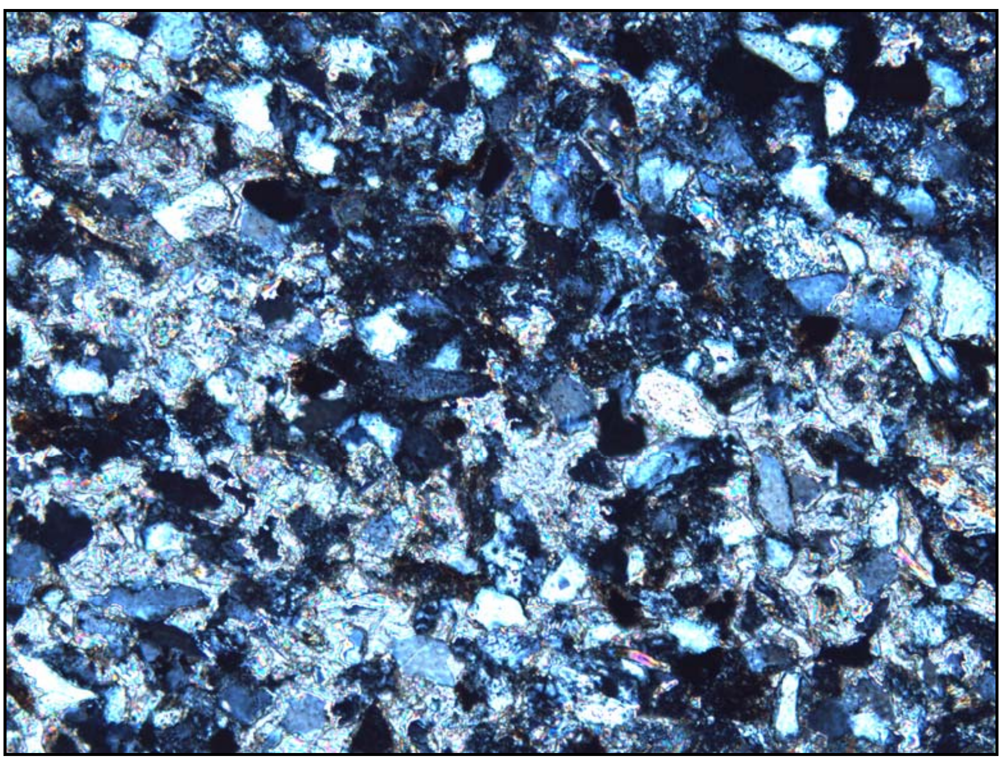

Figure 7.3.11. *Sample 07WZ-24G, calcareous fine-grained quartzose sandstone, Imperial River. Grains are angular and sub-angular, with carbonate cement. This sample had 10.4% porosity. Cross polarized light, field of view is approximately 1.1 mm.*

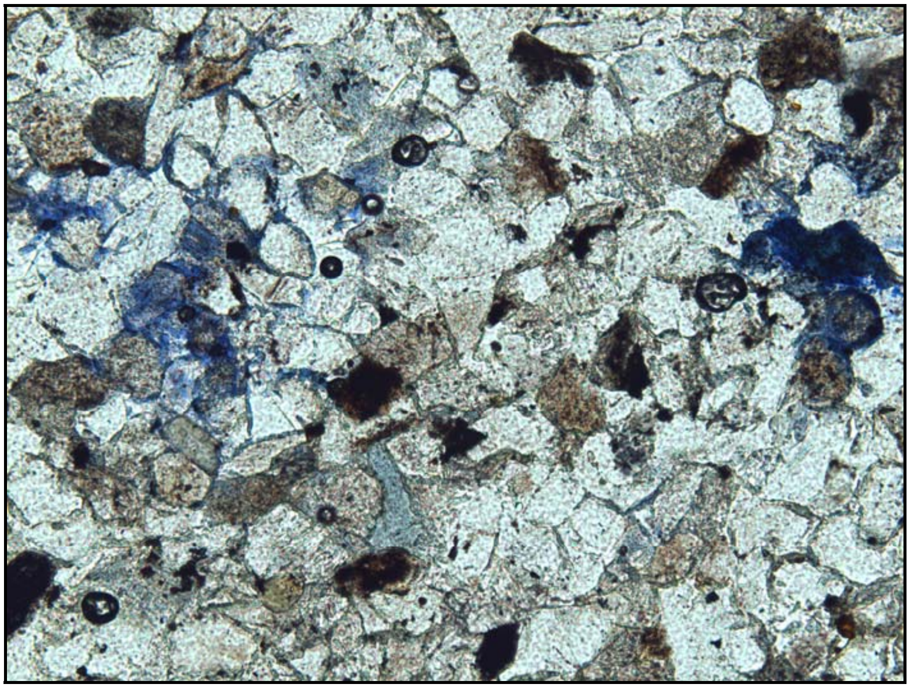

Figure 7.3.12. *Sample 07WZ-25C, calcareous fine-grained quartzose sandstone, Katherine Creek. Grains are angular and sub-angular, with carbonate and clay cement. This sample had 15.2% porosity, some intergranular pores are apparent. Plane polarized light, field of view is approximately 1.1 mm.*

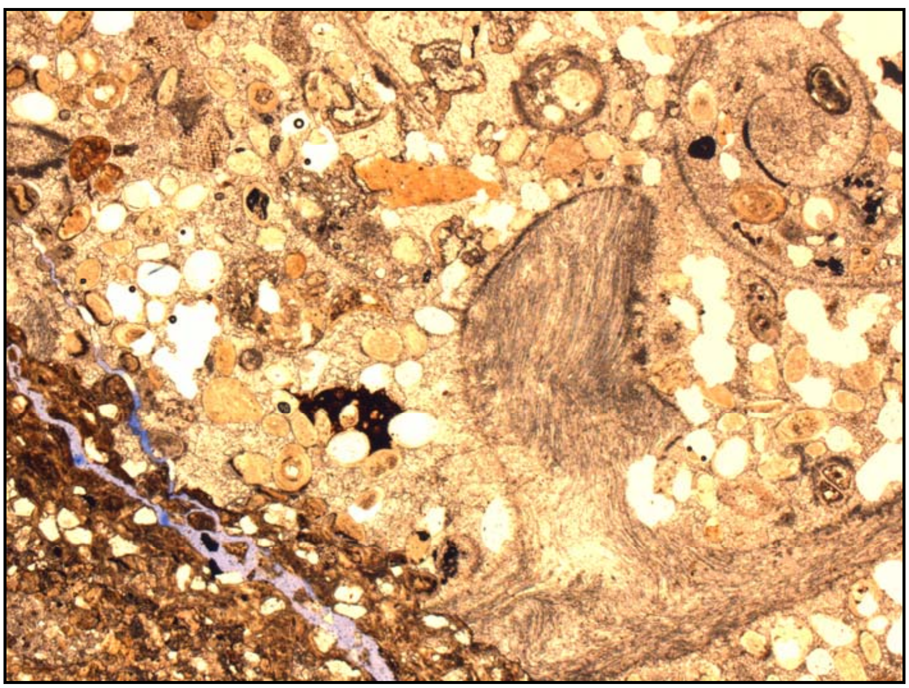

Figure 7.3.13. *Sample 07WZ-24A, rounded quartz grains floating in a fossiliferous peloidal packstone, Imperial River. Thin carbonate beds occur within the fine-gained quartz sandstones. This sample had 11.7% porosity, some intra-organic porosity is indicated here (the fracture seen here is probably an artifact of sample preparation). Plane polarized light, field of view is approximately 1.1 mm.*

Overall, Imperial Formation in southeastern Peel area, can be expected to contain intervals metres thick with 10% to 20% porosity and permeabilities less than 1 mD. Throughout most of Peel area, Imperial Formation can be considered to contain tight sands with 4% to 10% porosity. Fracturing might be expected to significantly improve permeability.

Source Rocks

From review of literature as well as field examination of outcrops and analyses during the current study, there are widespread, if moderate quality, source rocks within Imperial Formation. Pyle et al. (2008) compiled Rock-Eval and total organic carbon (TOC) analyses from Imperial Formation well and outcrop samples for Mackenzie Corridor, including Peel area. A histogram of the data (Figure 7.3.14) shows that most of the values are between 0.5% and 1% TOC. Many of the values are greater than 1% TOC. This data set compares well with samples collected during the current study (mainly from outcrops), in which the average for all analyses is 1.75% TOC. A histogram of TOC values is shown in Figure 7.3.15, and the Rock-Eval data is tabulated in Table 7.3.7.

An increase in TOC content of Imperial Formation shales, from east to west is evident as a weakly defined regional trend through the Peel area (Zantvoort, 2007; Figure 7.3.15).

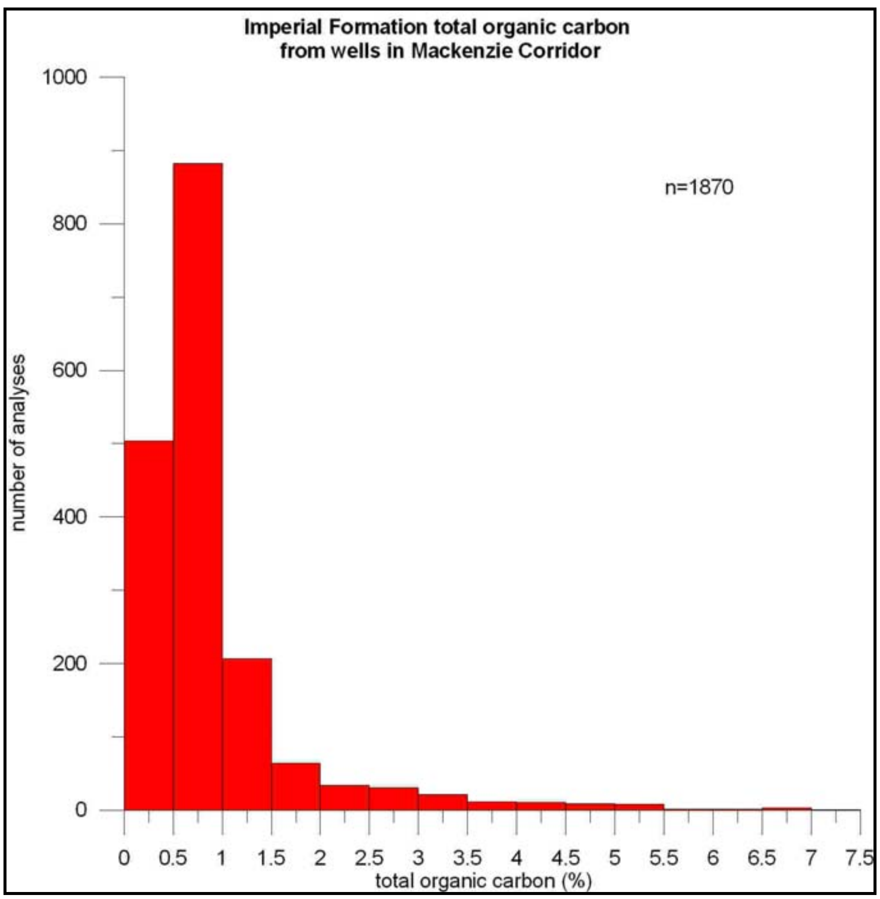

Figure 7.3.14. *Histogram of TOC analyses from well samples of Imperial Formation through Mackenzie Corridor. From data compiled in Pyle et al. (2008).*

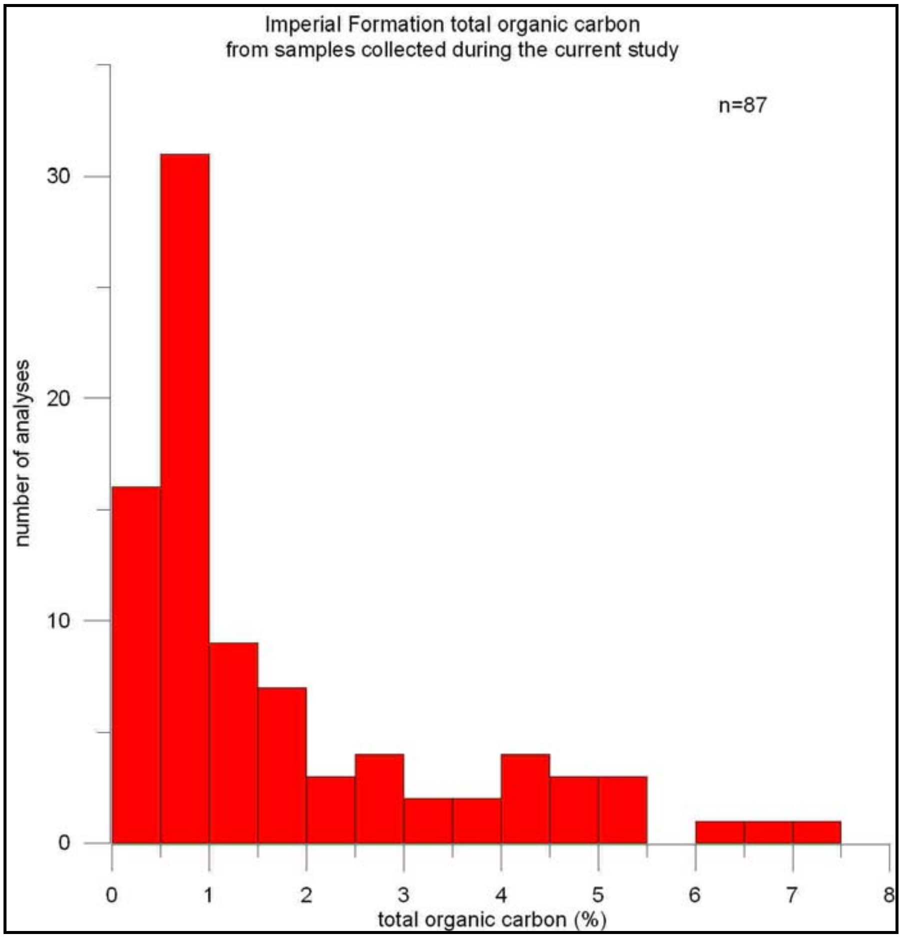

Figure 7.3.15. *Histogram of TOC analyses from samples of Imperial Formation collected during the current study. Total number of analyses is 87, and the mean value is 1.75%.*

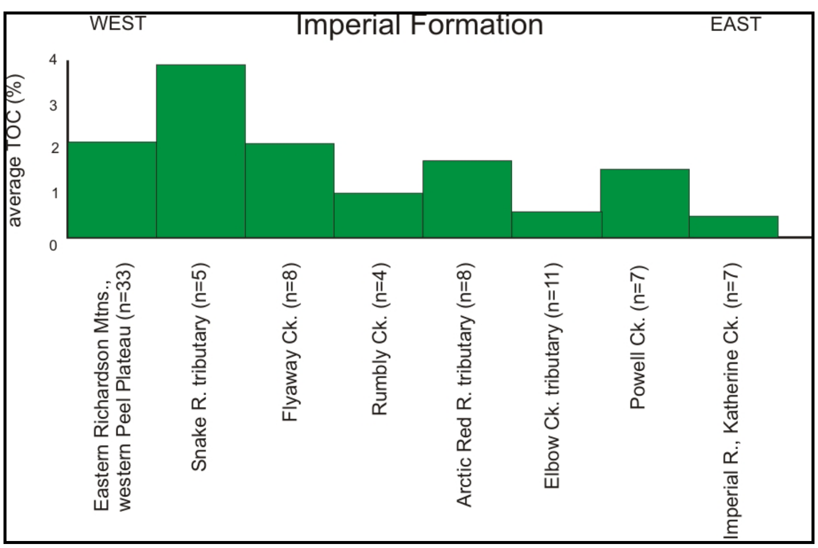

Figure 7.3.16. *Average TOC analyses from samples of Imperial Formation collected during the current study, grouped by sample location areas from west to east across Peel area. A general trend toward decreasing TOC, from west to east, is apparent.*

Sample	Formation	UTME	UTMN	S1	S2	PI	S3	Tmax	TOC	OI	HI	maturity
07TNT-RR-15A	Imperial	480166	7387921	0.09	0.15	0.60	0.04	577	0.75	20	12	--
07TNT-SR-41D	Imperial/Canol?	571634	7270745	0.01	0.04	0.13	0.13	607	1.39	9	3	--
07TNT-SR-41F	Imperial/Canol?	571634	7270745	0.01	0.04	0.16	0.15	607	1.87	8	2	--
07TNT-SRT-42A	Imperial	571448	7275031	0.01	0.06	0.16	0.24	608	4.86	5	1	--
07TNT-SRT-42B	Imperial	571441	7275024	0.01	0.06	0.12	0.35	607	5.47	6	1	--
07TNT-TET-22A	Imperial	477777	7399240	0.01	0.10	0.06	0.17	581	0.86	20	12	--
07TNT-TET-23A	Imperial	472740	7400219	0.00	0.02	0.12	0.23	605	0.57	40	4	--
07TNT-TR-01C	Imperial	482781	7370653	0.03	0.39	0.07	0.27	494	1.03	26	38	om
07TNT-TR-01D	Imperial	482807	7370647	0.02	0.44	0.04	0.26	496	1.22	21	36	om
07TNT-TR-01E	Imperial	482922	7370654	0.02	0.24	0.07	0.20	485	0.57	35	42	--
07TNT-TR-02B	Imperial	479871	7368934	0.01	0.07	0.09	0.24	602	0.99	24	7	--
07TNT-TR-33A	Imperial	492785	7379035	0.01	0.33	0.04	0.14	484	0.77	18	43	om
07TNT-TR-33C	Imperial	483012	7370833	0.01	0.22	0.04	0.30	483	0.72	42	31	--
07-WZ-12A	Imperial	359086	7263992	0.69	1.61	0.30	0.34	488	2.91	12	55	om
07-WZ-15A	Imperial	417818	7250699	0.01	0.17	0.07	0.42	527	0.67	63	25	--
07-WZ-15B	Imperial	417868	7250744	0.01	0.20	0.05	0.33	522	0.89	37	22	--
07-WZ-15C	Imperial	417899	7250797	0.02	0.17	0.08	0.18	513	0.61	30	28	--
07-WZ-17C	Imperial	308756	7277000	0.00	0.15	0.03	0.19	607	5.19	4	3	--
07-WZ-17D	Imperial	308742	7276977	0.01	0.14	0.05	0.27	609	4.91	5	3	--
07-WZ-17E	Imperial	308685	7276907	0.01	0.16	0.04	0.33	609	4.25	8	4	--
07-WZ-18A	Imperial	308905	7277667	0.00	0.05	0.08	0.23	392	0.73	32	7	--
07-WZ-18B	Imperial	309027	7277610	0.01	0.22	0.04	0.83	607	4.41	19	5	--
07-WZ-21B	Imperial	456504	7247327	0.02	0.18	0.08	0.17	466	0.34	50	53	--
07-WZ-21C	Imperial	456744	7247542	0.07	0.46	0.12	0.42	467	0.77	55	60	hm
07-WZ-21D	Imperial	456992	7247631	0.06	0.49	0.11	0.37	460	0.83	45	59	hm
07-WZ-21E	Imperial	457116	7247700	0.02	0.26	0.09	0.13	455	0.43	30	60	--
07-WZ-22C	Imperial	457271	7247846	0.02	0.15	0.12	0.16	457	0.27	59	56	--
07-WZ-22D	Imperial	457423	7247756	0.03	0.20	0.14	0.22	453	0.42	52	48	--
07-WZ-22E	Imperial	457537	7247824	0.03	0.25	0.11	0.19	456	0.49	39	51	--
07-WZ-23A	Imperial	510638	7239506	0.13	1.15	0.10	0.36	451	1.37	26	84	m
07-WZ-23C	Imperial	510855	7239574	0.05	3.47	0.01	0.66	442	2.52	26	138	m
07-WZ-23E	Imperial	510965	7239605	0.26	1.93	0.12	0.40	447	1.76	23	110	m
07-WZ-23F	Imperial	510961	7239698	0.03	0.32	0.08	0.33	443	0.58	57	55	m
07-WZ-23I	Imperial	511502	7239945	0.02	0.26	0.07	0.40	440	0.49	82	53	--
07-WZ-23J	Imperial	511634	7239957	0.02	0.25	0.07	0.37	440	0.47	79	53	--
07-WZ-24E	Imperial	553823	7221806	0.03	0.34	0.08	0.14	438	0.49	29	69	lm
07-WZ-24F	Imperial	553533	7221713	0.05	0.33	0.13	0.16	438	0.50	32	66	lm
07-WZ-25D	Imperial	570297	7214040	0.02	0.48	0.04	0.18	439	0.65	28	74	lm

Table 7.3.7. *Rock-Eval/TOC analyses for samples of Imperial Formation collected during the current study, including four samples from well cuttings. The samples with S2 values greater than 0.3, were considered to have meaningful Tmax values (i.e., slightly more conservative than the cut off recommended by Peters, 1986), have corresponding maturity (with respect to the oil window) noted in the right side column: im=immature, lm= low maturity, m=mature, hm= high maturity, om= overmature and post-mature. Samples 08WZ-4A and 4B (in bold) are oil stained, and discussed further in Chapter 10 (this volume).*

Sample	Formation	UTME	UTMN	S1	S2	PI	S3	Tmax	TOC	OI	HI	maturity
07-WZ-3A	Imperial	387828	7256205	0.00	0.07	0.05	0.20	524	0.27	74	26	--
07-WZ-3B	Imperial	388044	7256246	0.01	0.08	0.12	0.22	607	1.19	18	7	--
07-WZ-3C	Imperial	388299	7256054	0.02	0.07	0.18	0.15	457	1.67	9	4	--
07-WZ-4A	Imperial	389017	7255710	0.01	0.09	0.08	0.09	565	0.87	10	10	--
07-WZ-5B2	Imperial	404333	7278948	0.04	0.60	0.06	0.44	510	2.08	21	29	om
07-WZ-5C2	Imperial	404392	7278926	0.03	0.66	0.05	0.98	516	2.54	39	26	om
07-WZ-6A2	Imperial	405275	7266749	0.03	0.70	0.04	0.20	509	2.36	8	30	om
07-WZ-6C1	Imperial	402483	7263219	0.01	0.08	0.08	0.10	465	0.18	56	44	--
07-WZ-7A1	Imperial	359537	7263424	0.14	0.28	0.33	0.14	455	3.18	4	9	--
07-WZ-7A2	Imperial	359537	7263424	0.20	1.96	0.09	0.26	441	1.52	17	129	m
07-WZ-7B1	Imperial	359259	7263737	0.14	0.58	0.19	0.41	498	1.94	21	30	om
07-WZ-7B2	Imperial?	359259	7263737	0.14	1.22	0.10	0.31	442	1.25	25	98	m
07-WZ-8A	Imperial?	359044	7264291	0.33	1.72	0.16	0.13	469	3.24	4	53	hm
07-WZ-8B	Imperial	359050	7264480	0.51	4.87	0.09	0.17	466	4.53	4	108	hm
07-WZ-8C	Imperial?	359010	7264525	0.09	0.43	0.18	0.16	463	0.66	24	65	hm
07-WZ-9C	Imperial	456367	7246960	0.13	0.22	0.37	0.27	455	0.85	32	26	--
07-WZ-9D	Imperial	456429	7246940	0.17	0.42	0.28	0.07	456	1.38	5	30	m
08WZ-4-A	**Imperial**	**571404**	**7213955**	**1.73**	**1.69**	**0.51**	**0.22**	**360**	**0.61**	**36**	**277**	**stained**
08WZ-4-B	**Imperial**	**571404**	**7213955**	**0.04**	**0.16**	**0.19**	**0.21**	**441**	**0.2**	**105**	**80**	**stained**
D531540	Imperial	Hume R. D-53		0.11	0.64	0.15	0.29	444	0.82	35	78	m
F793170	Imperial	Clare F-79		0.14	0.59	0.20	0.25	459	0.98	26	60	m
L093260	Imperial	Hume R. L-09		0.08	0.76	0.10	0.24	444	1.00	24	76	m
O621540	Imperial	Hume R. O-62		0.11	0.70	0.13	0.45	442	1.08	42	65	m
TNT-PR-032A	Imperial	515914	7315451	0.05	0.31	0.15	1.44	480	0.99	145	31	om
TNT-PR-032B	Imperial	515914	7315451	2.48	2.93	0.46	0.23	431	3.94	6	74	im
TNT-PR-032C	Imperial	515914	7315451	1.06	2.82	0.27	0.30	438	5.07	6	56	lm
TNT-PR-035A	Imperial	518634	7317560	1.78	6.20	0.22	0.14	443	4.22	3	147	m
TNT-RR-020A	Tuttle/Imperial?	484113	7391184	0.04	2.22	0.02	0.15	430	2.33	6	95	im
TNT-RR-020B	Tuttle/Imperial?	484090	7391172	0.09	1.45	0.06	0.49	424	2.92	17	50	im
TNT-RR-020C	Tuttle/Imperial?	484090	7391172	0.06	1.00	0.06	0.19	423	1.94	10	52	im
TNT-RR-020F	Tuttle/Imperial?	484066	7391159	0.04	2.14	0.02	0.10	430	1.54	6	139	im
TNT-TR-007	Imperial	478543	7366649	0.01	0.07	0.07	0.35	594	0.76	46	9	--
TNT-TR-008	Imperial	478489	7366667	0.13	0.18	0.43	1.58	324	6.41	25	3	--
TNT-TR-009	Imperial	478545	7366689	0.01	0.06	0.11	0.27	606	1.11	24	5	--
TNT-TR-010	Imperial	478605	7366713	0.00	0.05	0.03	0.17	602	0.73	23	7	--
TNT-TR-011	Imperial	478711	7366788	0.02	0.04	0.37	0.88	428	6.98	13	1	--
TNT-TR-012A	Imperial	481330	7370081	0.02	0.44	0.04	0.46	607	7.03	7	6	om
TNT-TR-012D	Imperial	481404	7370113	0.00	0.11	0.04	0.20	546	0.62	32	18	--
TNT-TR-012F	Imperial	481439	7370117	0.00	0.12	0.03	0.78	555	0.77	101	16	--
TNT-TR-013A	Imperial	481618	7370239	0.01	0.16	0.07	0.35	540	0.80	44	20	--
TNT-TR-013B	Imperial	481469	7370231	0.01	0.14	0.04	0.49	554	0.73	67	19	--
TNT-TR-013E	Imperial	481778	7370230	0.01	0.13	0.05	0.17	540	0.64	27	20	--
TNT-TR-013F	Imperial	481790	7370212	0.00	0.06	0.06	0.08	539	0.33	24	18	--
WGZ-004-06	Imperial	510560	7239442	0.83	9.42	0.08	0.20	438	3.60	6	262	lm

Table 7.3.7. *Rock-Eval/TOC analyses for samples of Imperial Formation continued.*

Sample	Formation	UTME	UTMN	S1	S2	PI	S3	Tmax	TOC	OI	HI	maturity
WGZ-011-06	Imperial	417385	7251181	0.01	0.17	0.04	0.35	526	0.73	48	23	--
WGZ-016-06	Imperial	456532	7247207	0.02	0.19	0.12	0.16	470	0.40	40	48	--
WGZ-019-06	Imperial	457879	7247919	0.01	0.15	0.09	0.25	459	0.24	104	62	--
WGZ-024-06	Imperial	417960	7250400	0.07	0.56	0.11	0.25	575	4.44	6	13	om
WGZ-033B-06	Imperial	553766	7221988	0.01	0.22	0.03	0.21	436	0.45	47	49	--

Table 7.3.7. *Rock-Eval/ TOC analyses for samples of Imperial Formation continued.*

A pseudo-van Krevelen type cross plot of hydrogen and oxygen indices (HI versus OI), from data presented in Table 7.3.7 is shown in Figure 7.3.17. From this cross plot, it is apparent that Type III kerogen dominates, although there are some types I and II kerogen indicated. Thus it seems that the formation is largely gas prone, but certain shale interbeds contain oil-prone kerogen.

A plot of S2 versus TOC (Figure 7.3.18) was used to estimate an HI for Imperial Formation, after discounting inert carbon (e.g., Riediger et al., 2004). The slope of the line, fit by eye through the data, gives an HI of 147 (HI = S2/TOC *100), which is at the upper end of the gas only range (Peters, 1986).

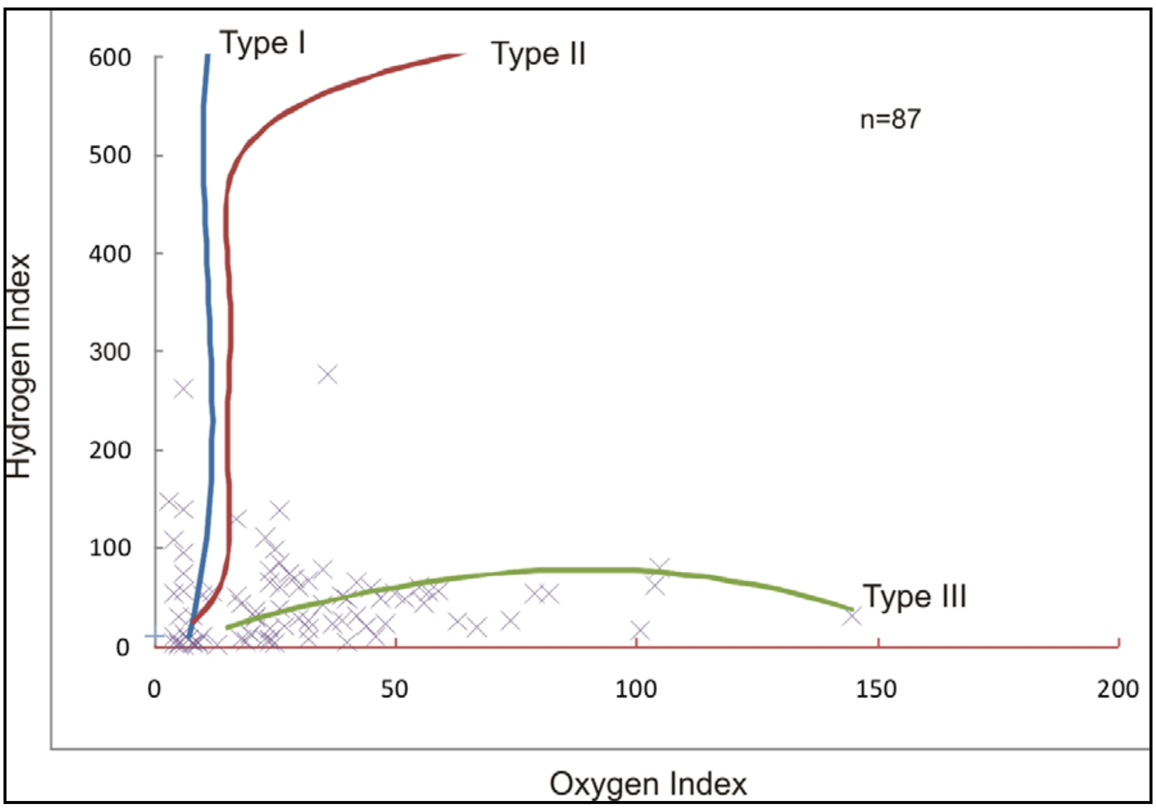

Figure 7.3.17. *Pseudo-van Krevelen cross plot of HI versus OI for Imperial Formation samples collected during the current study. Dominantly Type III (gas-prone) kerogen is indicated, with some Type I and Type II (oil-prone) kerogens as well.*

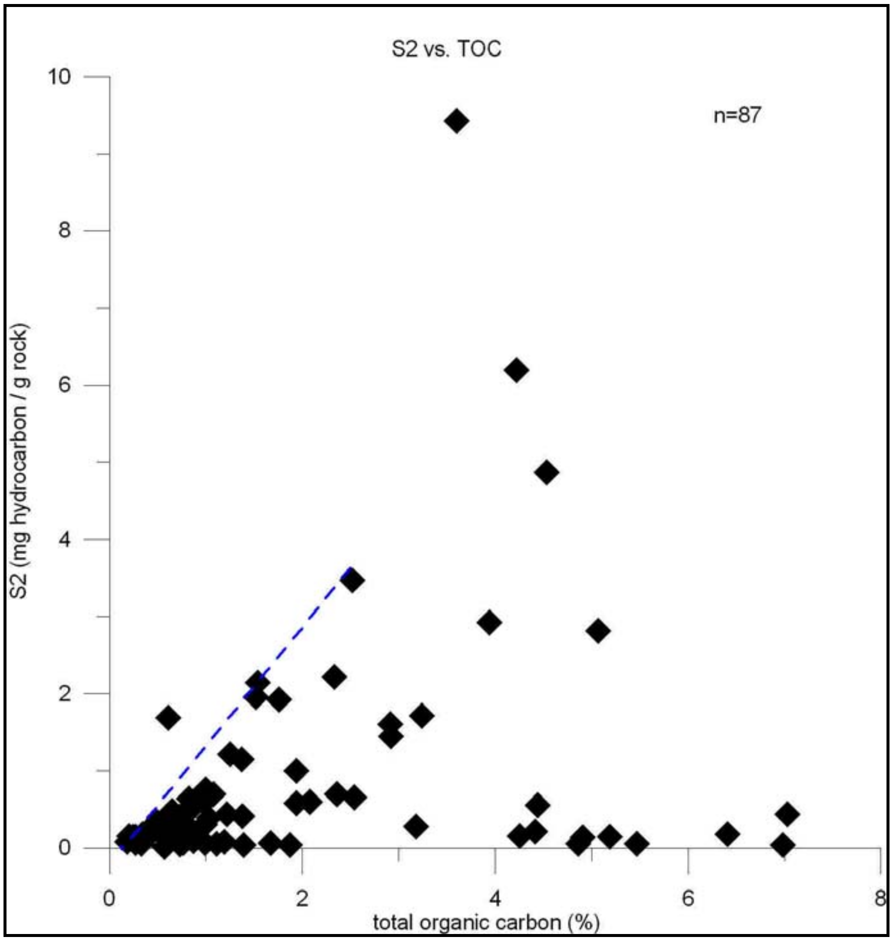

Figure 7.3.18. *Cross plot of S2 versus TOC. A line, fit by eye, at the limit of the data range, gives a slope equal to the HI of 147. The intercept of the line on the X axis indicates there is little inert carbon in the sampled sediments (about 0.2% organic carbon).*

Imperial Formation is generally mature to overmature in Peel area. Previously published vitrinite reflectance and equivalent vitrinite reflectance data for Imperial Formation in the Mackenzie Corridor (which includes Peel area) have been compiled by Pyle et al. (2008). This published data, plus Tmax data from samples collected during the current study, have been used to create an Imperial maturity map (Figure 7.3.1).

Palynology samples collected during the current study and analyzed at the Geological Survey of Canada in Calgary by Utting (2007a, 2008a) have also been classified according to thermal alteration index (TAI). A map of TAI is presented in Figure 7.3.19, for comparison with Figure 7.3.1. TAIs from palynology samples have yielded values ranging from 2- to 3+ / 4 which correspond to equivalent vitrinite reflectance values of 0.45% to 2% Ro (Utting et al., 1989). This is indicative of maturity conditions from the oil zone through to the dry gas zone, increasing in a general westward direction (Figure 7.3.17). TAI of Imperial Formation samples from western Peel Plateau and eastern Richardson Mountains indicate overmature conditions (TAI = 3+ to 4-, Utting, 2007b; 2008b; Allen and Fraser, 2008).

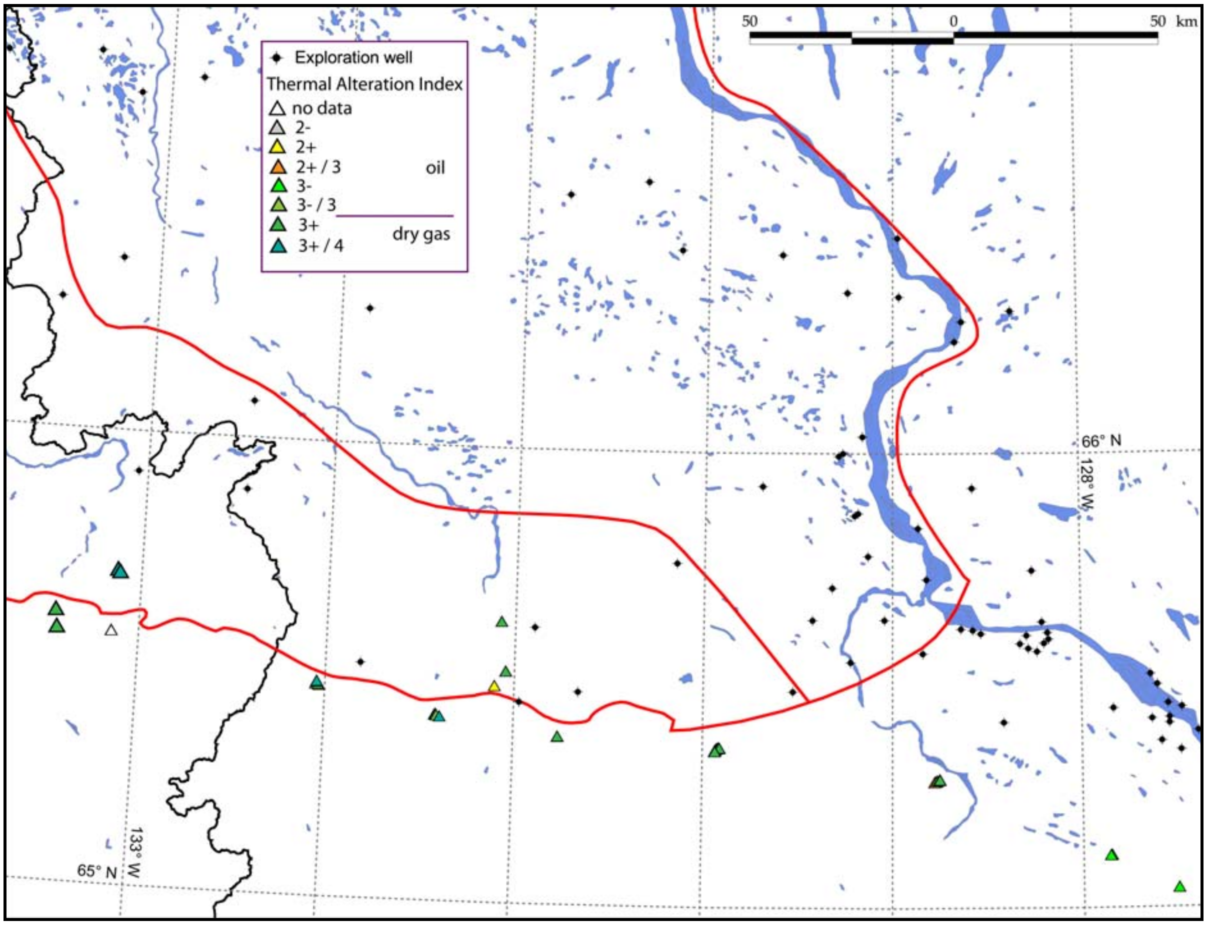

Figure 7.3.19. *Thermal alteration from Imperial Formation palynology samples as reported by Utting (2007a; 2008a; 2008b; 2008c). A general increase in maturity from east to west is apparent.*

To summarize, Imperial Formation is a fair source rock, with TOC values typically in the 0.5% to 1.5% range, with some higher values. Indications are that the kerogen types are dominantly gas prone. Imperial Formation is mature (within the oil window) through much of Peel Plain, and overmature (in the gas window) through much of Peel Plateau.

Seal and Overburden Rocks

Imperial Formation reservoirs may be sealed chiefly by intraformational shale and siltstone. Overlying shale might also form a seal; however, throughout much of Peel area, basal Cretaceous sandstone overlies Imperial Formation and makes a poor seal. Overlying Tuttle Formation sandstones in western Peel area might also be poor seals, but there are shales within the formation. Ford Lake shale is also a possible seal rock.

In northeast Peel area, Imperial Formation is at relatively shallow subcrop and covered by only thin Cretaceous sediments. The formation also rises to outcrop to the east, along the Mackenzie Valley. Of course the formation is also exposed at the Mackenzie and Richardson mountain fronts, and where it is involved in folds and faults of the Franklin Mountains (Figure 7.3.20). The top of Imperial Formation lies at depths of up to 1400 m below sea level along the central western edge of Peel area, and throughout Peel Plateau, the formation is mainly 400 m below sea level and deeper.

The Imperial Formation itself increases in thickness from an erosional zero edge in eastern Peel area, to 1900 m in the northeast (McPherson B-25 well; Figure 7.3.21). Thick Imperial Formation in northwest Peel area probably represents increased preservation of sediments from pre-Albian erosion, rather than being strictly a depocentre.

Traps

Both stratigraphic and structural traps in Imperial Formation are possible. Dixon et al. (2007) listed sandy turbidites in Imperial Formation as a possible reservoir rock, and stratigraphic traps associated with turbidite deposition (e.g., turbidite channels, fans and lobes, levees, etc.) are possible.

Hannigan et al. (2006) mention shelf and slope turbidite sandstone deposits in Imperial Formation that increase westward and northward through Interior Platform, and that some sandstone lenses may have developed sufficient porosity.

Pyle et al. (2008) note that possible traps include channelized sandstone or lateral pinch-outs of sandstone beds, inter-fingering relationships of Imperial and Tuttle formations, and minor folds and fault-bounded structures, particularly in the zone parallel to the Richardson Mountains. Pyle et al. (2008) also list unconformity-related traps as a possibility; however, because the widely distributed basal Cretaceous sandstone likely makes a poor seal, this type of play carries a high risk of failed top seal.

Structural traps (simple to complex or faulted anticlinal folds and domes) are possible at the margins of the Mackenzie, Richardson, and Franklin mountains. Lemieux et al. (2008) analyzed structural closures at the Imperial level from publicly available seismic maps from the southern part of Peel area. From the limited data, fault bounded structures up to 12 km by 22 km were indicated near the Whirlpool Fault zone on the Sans Sault Rapids map area (NTS 106 H). Smaller domal closures (typically a few km to 10 km in the long dimension) were identified from the Mackenzie River, west to the area between the Sainville and Cranswick rivers at the north edge of the Snake River map sheet (NTS 106 F).

Generation, Migration, and Accumulation

As discussed in Chapter 10 (this volume) Imperial Formation probably reached just into oil zone maturity in late Paleozoic time (under burial by Tuttle Formation) in western and central Peel area. Burial by Albian and later sediments (after a period of considerable uplift and erosion) increased maturity to well within the oil window in central and eastern Peel area, and into the dry gas zone in southwestern Peel area.

The organic rich shale and siltstone of Imperial Formation probably generated mostly gas in Albian and later time. Hydrocarbons could have migrated within the formation, into more porous sandstone lenses, whether in stratigraphic, structural, or combined traps. Migration could have occurred over considerable distances, along the depositional dip of regional clinoforms, to up-dip pinch outs.

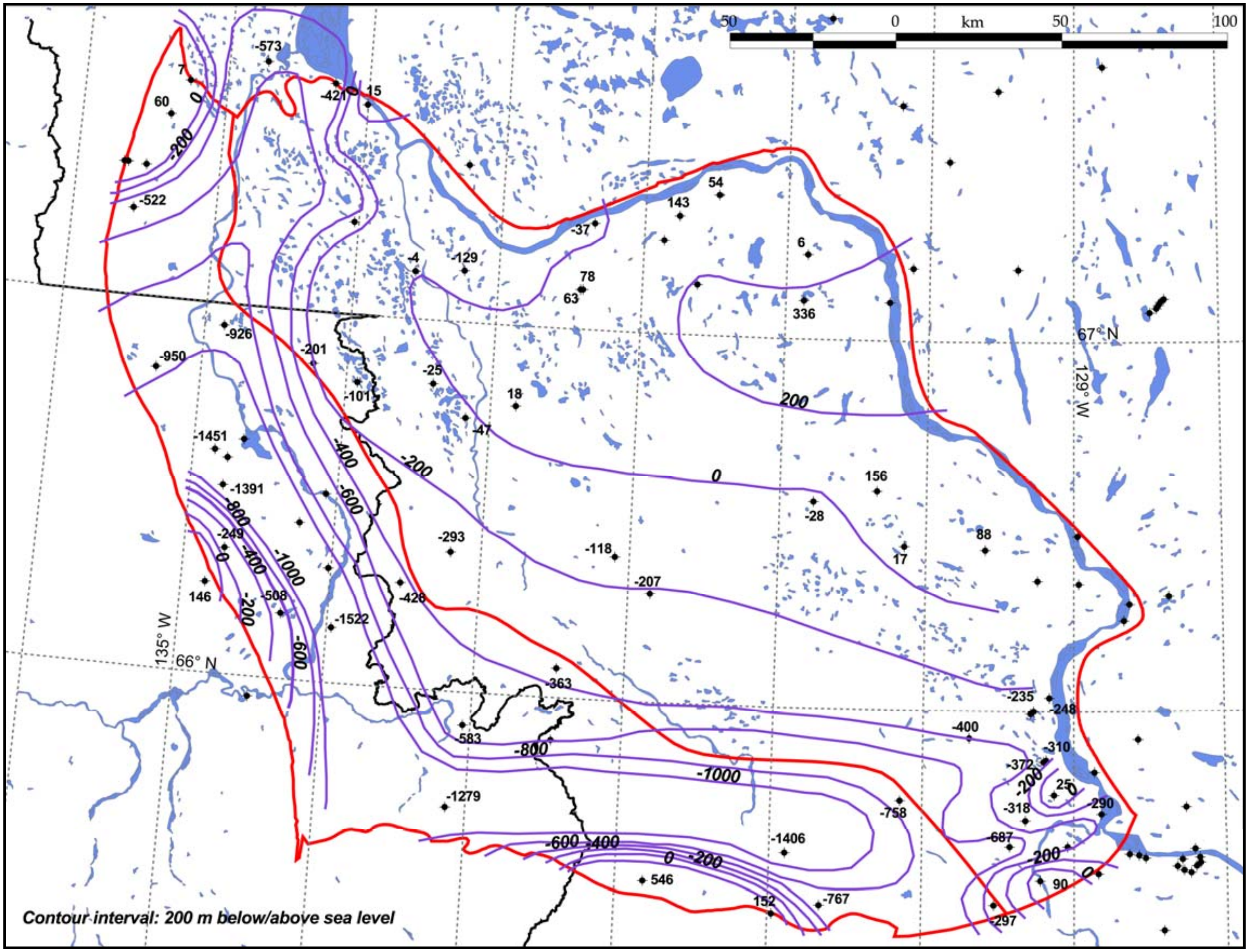

Figure 7.3.20. *Imperial Formation structure contours from well control. Well formation tops from Hogue and Gal (2008) and Fraser and Hogue (2007). The general trend of increasing depth toward the south and west is modified by structural uplifts adjacent to the Richardson, Mackenzie, and Franklin mountains.*

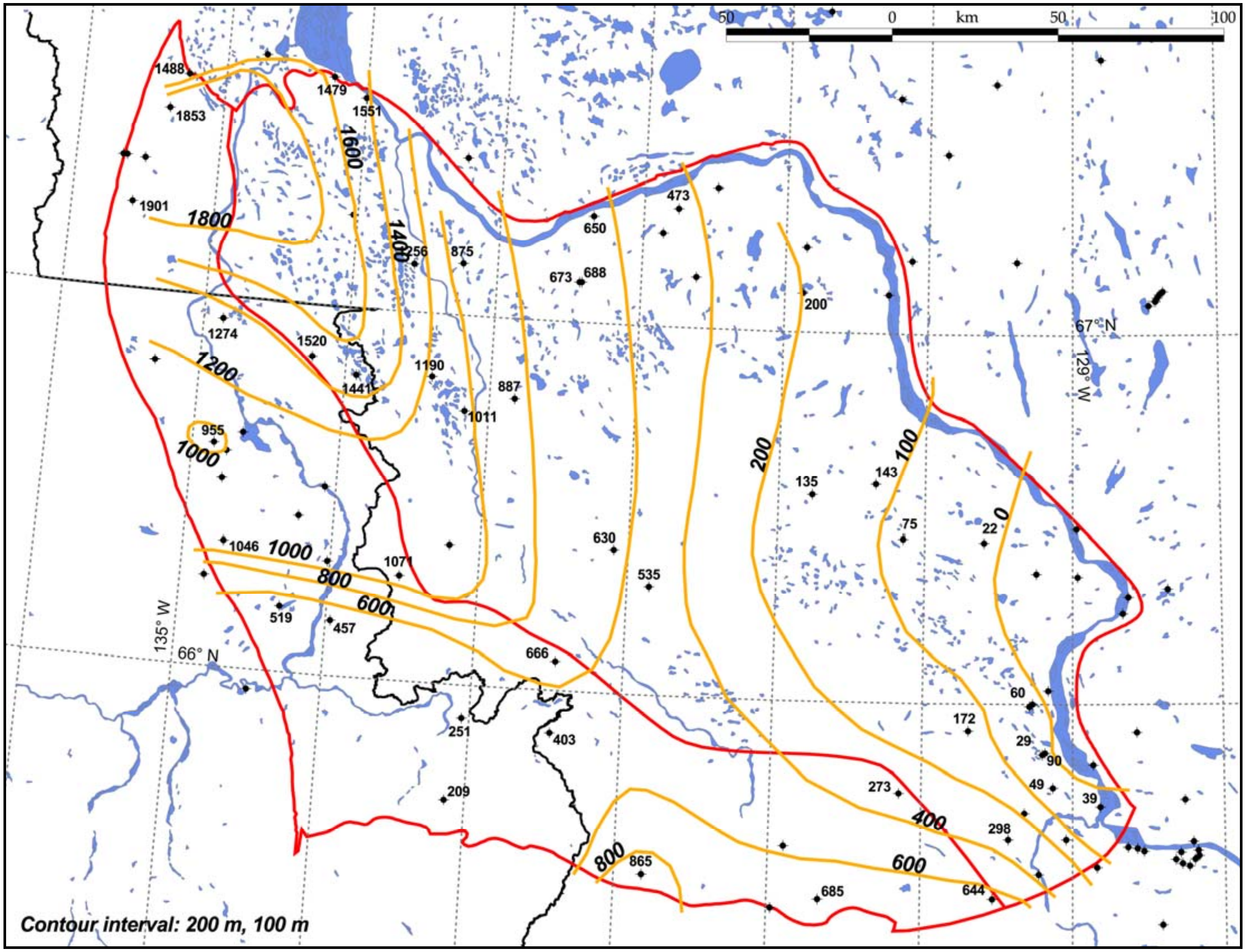

Figure 7.3.21. *Imperial Formation isopach map from well control. Well formation tops from Hogue and Gal (2008) and Fraser and Hogue (2007). There is a general trend toward increasing thickness toward the northwest.*

From oil stain data presented in Chapter 10, it is fairly certain that both upper Devonian (Canol Formation or Bluefish Member) and Cambrian-Ordovician (Mount Cap or Saline River formations) oil migrated through fine-grained Imperial Formation sandstones at Imperial River and Katherine Creek, southeast of Peel area. The older oil may have migrated in late Paleozoic time, shortly after Imperial deposition. The younger, Devonian oil probably migrated in the Late Cretaceous.

Zantvoort (2007) considered the eastern Imperial Formation sandstones to be the better potential reservoirs, which is borne out by the porosity data from Imperial River section. However, the formation here is generally at shallow depth to outcrop, and thus prone to breaching of reservoirs and degradation of pooled hydrocarbons.

Exploration Risks

Osadetz et al. (2005) grouped this play with Tuttle Formation in their Upper Paleozoic Clastics Play, which they estimated to contain about 15 x 10^9 m^3 of gas in place, in a dozen accumulations in the Yukon portion of Peel area. The Peel Plain portion of the play was considered to host more accumulations, and some of this potential can be considered to carry into Imperial Formation of Peel Plain on the NWT side of border, since Tuttle Formation thins out markedly to the east. Osadetz et al. (2005) did not find risk at the play level within Peel Plain, but at the prospect level there are many risks, chiefly associated with the poorly understood tectonic and diagenetic history, the long period of time required for preservation and the multiple chances for failure of various components of the petroleum system.

Play-scale risks for the Imperial Formation conceptual play throughout entire Peel area play include sufficient source rocks, reservoir quality and thickness, as well as stratigraphic trap formation (with closures). Pyle et al. (2008) note that the low permeability values (less than 0.1 mD) necessitate a greater understanding of joint and fracture distribution that might aid in hydrocarbon mobility. At the prospect level, preservation through pre-Cretaceous (and post-Cretaceous) uplift and erosion, breaching and leakage due to shallow depth, and insufficient seal are significant risks, particularly in eastern Peel area.

Overall, an Imperial Formation conceptual play is considered to have moderate potential in Peel area.

Unconventional Gas

An aspect not covered here is the potential for Imperial Formation to host accumulations of basin-centered or tight gas. The formation is thick in places, widespread, and has fair source rock potential in many areas. Intercalated fine-grained, weakly porous, and permeable sediments could host unconventional accumulations. More study of the petroleum geology and hydrodynamic systems of the Imperial Formation throughout the region would be needed to further assess this potential.

Acknowledgements

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Chapter 8 – Upper Devonian to Carboniferous Strata II – Tuttle Formation Play

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ABSTRACT

Upper Devonian to Lower Carboniferous Tuttle Formation has previously been identified as an oil and gas exploration target. During exploration in the 1960s and 1970s, six minor gas shows were documented in Tuttle Formation in Peel area. Although Tuttle Formation extends over most of Peel Plateau in the subsurface, it only crops out along the western and eastern flanks of the Richardson Mountains and possibly along the northern Mackenzie Mountains. Tuttle Formation consists of alternating packages of sandstone and shale deposited by turbidity currents. Rock-Eval pyrolysis indicates shale within Tuttle Formation has the potential to be a viable petroleum source rock; total organic carbon values typically range between 1 wt% to 2 wt% and shale contains kerogens of type II and III. Thermal maturity indicators suggest that Tuttle Formation is generally within the oil window. Sandstone and conglomerate in the formation are classified as negligible to very good reservoir rocks based on permeability and porosity analyses. This chapter combines surface data with subsurface data to evaluate the petroleum potential of the Tuttle Formation play.

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INTRODUCTION

Upper Devonian to Lower Carboniferous strata of the eastern Richardson Mountains and adjacent western Peel Plateau (Figure 1) consist of sandstone and conglomerate alternating with intervals of shale and siltstone. These strata comprise Canol, Imperial, and Tuttle formations, as well as Ford Lake Shale (Figure 2). Previously, the coarsest unit in this succession, Tuttle Formation, was examined for its potential as a hydrocarbon source and reservoir. Age equivalent strata in the region include portions of Imperial Formation and Ford Lake Shale, as well as a Carboniferous unit of largely fine-grained sandstone and minor shale that occurs along the northern flank of the Mackenzie Mountains (informal map unit 'M0' of Norris, 1982a; 1982b). Tuttle Formation, Ford Lake Shale, and 'M0' map unit are discussed here in terms of stratigraphy, palynology, and petroleum potential of Peel area with an emphasis on Tuttle Formation.

Tuttle Formation is distinguished from adjacent and time equivalent units by the presence of chert- and quartz-rich, coarse-grained sandstone and pebble conglomerate. Due to the presence of coarse-grained facies in Tuttle Formation, it has the best potential for hosting hydrocarbon reservoirs.

PREVIOUS WORK

Exploration History

Exploration for oil and gas was conducted in Peel area during the 1950s to 1970s. Oil and gas companies drilled wells, conducted 2D seismic surveys and photogeologic analyses, measured stratigraphic sections and completed targeted geologic mapping. Eighteen of the nineteen exploratory oil and gas wells that were drilled on the Yukon side of Peel area between 1965 and 1977 penetrated Tuttle Formation (Pugh, 1983). Various wireline geophysical logs for these holes are available to the public. At least 3000 line-km of 2D reflection seismic survey data were acquired in the Yukon Peel area between 1963 and 1976 (Oil and Gas Resources Branch, 2008). Approximately 500 line-km of seismic data are publicly available from the National Energy Board (NEB) in Calgary, Alberta, covering a small portion of the region and generally not spanning great distances.

A number of industry reports summarizing the results of oil and gas exploration are available at the NEB Frontier Information Office. An example includes a comprehensive lithological and environmental facies analysis of the Mississippian clastic wedge (Tuttle Formation) by Lutchman (1977) as part of the Lower Mackenzie Energy Corridor Study conducted by Geochem Laboratories and AGAT Consultants. The study involved examination of drill core, cuttings, and geophysical logs where available from boreholes.

In 1977, exploration activity in Peel area ceased due to the Berger Commission recommendations that a ten-year moratorium be placed on pipeline construction in the Mackenzie Valley (Morrell, 1995). Renewed energy industry interest in Peel area and northwest Canada in general is expected should either of the proposed natural gas pipelines (Alaska Highway Pipeline and Mackenzie Gas projects) be constructed, since infrastructure for the transportation of stranded resources will finally be in place.

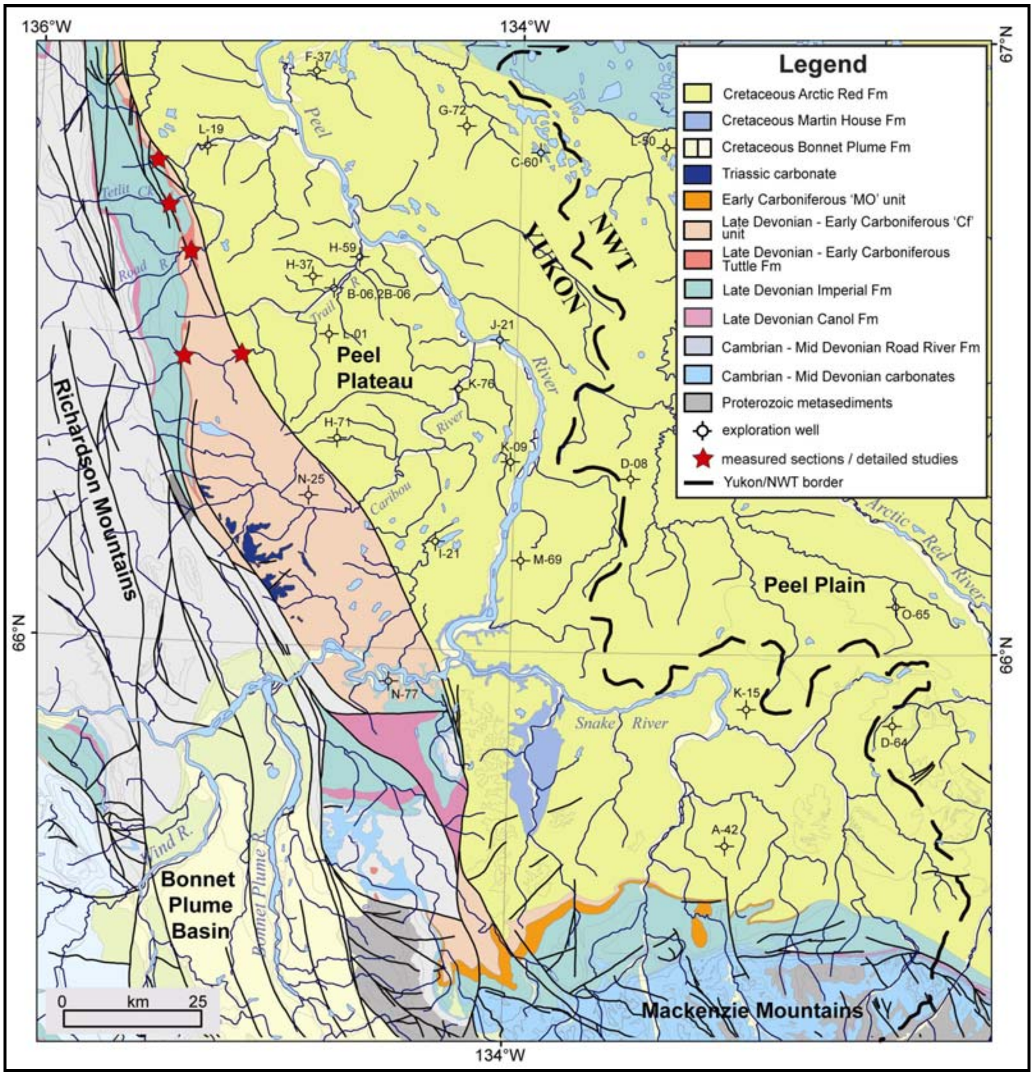


__Figure 1.__ Simplified geological map and legend for Peel Plateau and Plain, southern Richardson Mountains, and northern Mackenzie Mountains region (from Gordey and Makepeace, 2001).

Other Research

During the 1960s and 1970s, the Richardson Mountains, neighbouring Eagle Plain to the west, and Peel Plateau and Plain to the east were examined and mapped at a 1:250,000-scale by the Geological Survey of Canada (GSC) as part of *Operation Porcupine* (Norris, 1968; 1985). Norris (1968) provided a summary of early exploration and geological work on Devonian formations of the *Operation Porcupine* study area (northern Yukon Territory and Northwest Territories), including strata in Peel area. Geological bedrock maps produced from *Operation Porcupine* for the Yukon portion of Peel area include NTS map sheets 116 I (Eagle River), 106 L (Trail River), 106 K (Martin House), 106 E (Wind River), 106 F (Snake River) by Norris (1981a; 1981b; 1981c; 1982a; 1982b). These maps have contributed to an understanding of regional geology. Following the bedrock mapping phase, Norris (1985) presented a revised account of the Devonian geology of this same region including additional data acquired from field work.

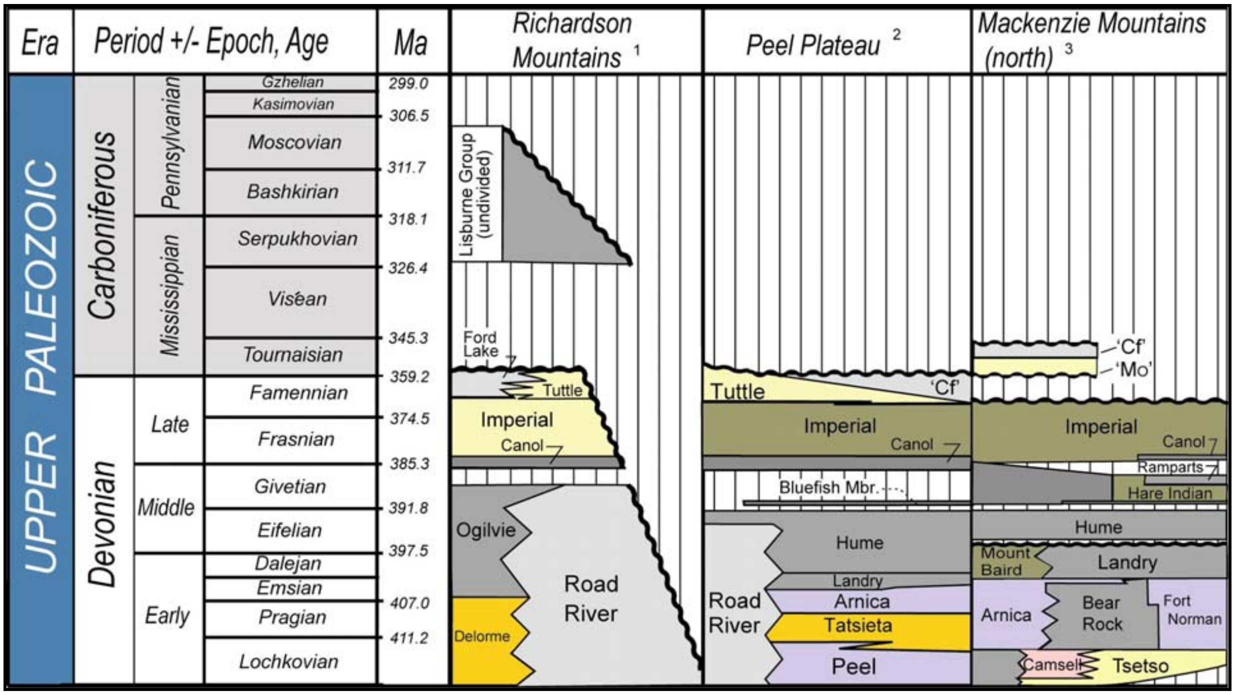


Figure 2. *Correlation chart illustrating the stratigraphic position of Tuttle Formation in the Richardson Mountains, Peel Plateau and northern Mackenzie Mountains. The stratigraphic position for Imperial Formation, Tuttle Formation and Ford Lake Shale (and equivalent 'Cf' map unit) have been modified from the original charts based on new palynological data (Utting, 2007; 2008a; 2008b). [1,3]Modified from Morrow et al. (2006); [2]modified from Pigage (2007). Ma = million years; time scale ages after Gradstein et al. (2004).*

A small number of topical studies were completed after the intense exploration of the 1950s to 1970s. Pugh (1983) published an extensive subsurface study of the Peel River map area that synthesized earlier work, including regional correlation of well logs and examination of drill cuttings. Braman and Hills (1992) completed palynological studies of Upper Devonian to Lower Carboniferous strata on Trail River (and other sections to the east including those on Imperial, Powell and Arctic Red rivers) and reported the ages of Imperial and Tuttle formations based on miospores collected from outcrop. A regional compilation incorporating *Operation Porcupine* and subsequent studies edited by D.K. Norris (1997a) includes pertinent reports on Devonian strata (D.K. Norris, 1997b) and Upper Devonian to Permian strata (Richards et al., 1997).

In 2000, a petroleum resource assessment of Peel Plateau was conducted by the NEB on behalf of the Yukon Government (National Energy Board of Canada, 2000). Geoscientific analysis was followed by systematic statistical analysis using Microsoft Excel 97 and Pallisade Corporations' @RISK add-in as part of the NEB's resource assessment methodology. Results concluded that there is potential for both oil and gas resources in Peel area.

Petrel Robertson Consulting Limited (2002) completed a regional geological and geophysical assessment of the central Mackenzie Valley, Northwest Territories, and Eagle Plain, Yukon, which also includes Peel Plateau and Richardson Mountains. Data used in the assessment were derived from logs, core tests, and geochemical data obtained from wells and seismic data.

A revised petroleum resource assessment that identified and employed statistical analysis to evaluate eight plays in three assessment regions of Peel Plateau and Plain of the Yukon Territory was published by Osadetz et al. (2005). Statistical analyses for plays and associated volumes were calculated by applying a play-oriented petroleum assessment method using the PETRIMES computer program (Lee and Tzeng, 1993). This assessment differed greatly from the NEB (2000) report with respect to oil potential; Osadetz et al. (2005) stated that oil resources could not be estimated given existing data.

GEOLOGIC FRAMEWORK

Peel Plateau and Plain are underlain by a westerly thickening wedge of Phanerozoic sedimentary rocks (up to 4.5 km thick) that unconformably overlies a poorly understood Proterozoic succession (Norris, 1997a). Phanerozoic strata in the region can be divided into three main depositional systems: 1) Cambrian to Upper Devonian carbonates and shales of the Mackenzie-Peel Shelf and Richardson Trough (Morrow, 1999); 2) an Upper Devonian to Carboniferous clastic wedge that was deposited in a foreland basin of the Yukon and Ellesmerian fold belts associated with the Frasnian to Tournaisian Ellesmerian Orogeny (Richards et al., 1997); and 3) Cretaceous marine shelf deposits that were deposited in the foreland basin of the Cordilleran Orogen (Dixon, 1992).

The southern Richardson Mountains border Peel Plateau to the west. The mountain range trends north and is an expression of the Richardson anticlinorium, which is a broad, north-plunging structure, bounded to the east by the Trevor fault and to the west by the Deception fault (Norris, 1997b). The anticlinorium is a structural inversion of the Richardson Trough that occurred during the Laramide Orogeny (Norris, 1997b). Upper Paleozoic stratigraphy for the Richardson Mountains is correlative to Peel Plateau and Plain (Figure 2).

Upper Paleozoic strata in Peel area of Yukon comprise an Upper Devonian to Lower Carboniferous succession of marine clastic deposits thousands of metres thick (Pugh, 1983; Richards et al., 1997). These strata include Upper Devonian Imperial Formation and Upper Devonian to Lower Carboniferous Tuttle Formation and their equivalents. Deposits of Imperial and Tuttle formations were transported mainly from a northern or northwestern orogenic source (Pugh, 1983; Norris, 1985). Upper Devonian to Mississippian Ford Lake Shale (Brabb, 1969) is interpreted as the basinal equivalent of Tuttle Formation and is mapped further south and west of Peel area (Pugh, 1983; Richards et al., 1997).

STRATIGRAPHY

Stratigraphic Nomenclature

Historically, in subsurface studies, Upper Devonian to Lower Carboniferous strata have been assigned either to Imperial Formation or to a ‘Mississippian’ unit in well history reports. In contrast, reconnaissance bedrock mapping and detailed stratigraphic studies during the 1960s and 1970s used limited outcrop control to attempt subdivision of these rocks into Imperial Formation, ‘Dus’, Tuttle Formation, ‘Cf’, and ‘M0’ map units (Norris, 1968; Norris, 1981b; 1981c; 1982a; 1982b). Long distances between ground control points, limited outcrop, and numerous faults contributed to uncertainty about regional correlations and stratigraphic relationships among these units.

Pugh (1983) formally defined Tuttle Formation, based on subsurface studies, as strata occurring between Imperial Formation and overlying Cretaceous strata. Strata on Trail River initially assigned to the Upper member of Imperial Formation (Norris, 1968) were reassigned to Tuttle Formation by Norris (1985). It is unclear how strata mapped at surface as ‘Dus’, ‘Cf’ and ‘M0’ fit into Tuttle Formation as defined by Pugh (1983). We herein recommend, based on outcrop observations, that Upper Devonian to Lower Carboniferous strata should be differentiated into ‘Cf’ map unit or Ford Lake Shale and ‘M0’ map units, distinguishable from Tuttle Formation. Inclusion of Ford Lake Shale as part of Tuttle Formation in the subsurface may be due to factors such as the lack of subsurface data in the area, as well as difficulty in recognizing units on seismic surveys or well logs. No detailed correlation has been made to date to address the inconsistency in Upper Paleozoic nomenclature between the surface and subsurface although this issue has been identified and is being addressed (cf. Lane et al., 2007).

Another example of a stratigraphy related dilemma in the region is the relationship between Tuttle Formation and ‘M0’ map unit (Norris, 1982a; 1982b). At surface, the two are lithologically distinct and are assigned to different ages. Coarse-grained clastics including sandstone and conglomerate of Tuttle Formation are typically poorly sorted and consist predominantly of subangular to subround quartz and chert grains. In contrast, the sandstone of the ‘M0’ map unit is well sorted, consists predominantly of subround to rounded quartz grains, and is commonly bioturbated. However, in the subsurface they both have been included in Tuttle Formation. Variations in lithology and sedimentology may have not been previously recognized, along with their important implications for depositional setting, facies, and lateral continuity of individual sandstone bodies. Thermal maturation also varies between the two units at surface. This may be a reflection of their proximity to the Richardson Mountains versus the Mackenzie Mountains, variable burial depths, or different organic compositions. Further examination of well cuttings and log signatures to determine if Tuttle Formation can be distinguished from the ‘M0’ map unit in the subsurface is required.

New palynological data have invalidated previously identified formation top picks in boreholes Cranswick Y.T. A-42 and Arctic Red Y.T. C-60 (see Figure 1 for well locations). In well A-42, the top of Martin House Formation is picked at 1104.6 m (3624 feet) and top of Tuttle Formation at 1170.4 m (3839.8 feet; Fraser and Hogue, 2007). The well consists almost entirely of shale with minor siltstone from the top to a depth of 1753 m (5750 feet), where sandstone is intersected. Palynological dating indicates strata between 1006 and 1737.4 m (3300 and 5700 feet) is Late Devonian age and that at 1219 (4000 feet) and 1707 m (5600 feet) is late Famennian age (Utting, 2008a; Table 1). The date assigned at 1006 m (3300 feet) does not correspond to the published well formation top picks of Martin House or Tuttle formations, and may more appropriately belong with Ford Lake Shale or Imperial Formation as strata in this interval are predominantly shale. To address this problem, additional palynological studies and examination of well cuttings should be completed.

In borehole C-60, wireline log signatures identify the Tuttle Formation top at 157 m (515 feet), and the top of Imperial Formation at 193 m (633 feet; Fraser and Hogue, 2007). Recent palynological studies on well cuttings assign strata previously included in Imperial Formation as Cretaceous with recycled Carboniferous spores to a depth of 204 m (670 feet; White, 2007; Table 1); the underlying shale and siltstone succession, assigned to Imperial Formation, from 231.6 m to 688.9 m (760 feet to 2260 feet) in C-60 is dated at mid-Famennian (Utting, 2008a).

However, interpretations based on cuttings should be used with caution when both caving and recycling are possibilities; it may be difficult to make an unequivocal age determination in these cases (White, 2007). Original well history reports did not identify a ‘Mississippian’ unit (or Tuttle Formation) in C-60. More work needs to be completed to confirm the presence of Tuttle Formation in borehole C-60.

In neighbouring Satah River Y.T. G-72 well, strata assigned to Tuttle Formation and dated as late Famennian (Utting, 2008a; Table 1) does not contain sandstone or conglomerate. The succession of shale and siltstone designated Tuttle Formation may actually be Imperial Formation or Ford Lake Shale, however further examination of well cuttings is needed to confirm this. Based on observations in boreholes C-60 and G-72 it is possible that Tuttle Formation shales out to the east and is not present as sandstone or conglomerate in these wells.

Unique Well Identifier (UWI)	Short Well Name	Depth (m)	Probable Age	T.A.I.	GSC Loc #	Reference
300A426550133000	Cranswick Y.T. A-42	1188.7	age not determined	3+/4-	C-430952	Utting, 2008a
300A426550133000	Cranswick Y.T. A-42	1219.2	late Famennian, Late Devonian	3+/4-	C-430953	Utting, 2008a
300A426550133000	Cranswick Y.T. A-42	1706.9	late Famennian, Late Devonian	3+/4-	C-430954	Utting, 2008a
300A426550133000	Cranswick Y.T. A-42	1737.4	Late Devonian	3+/4-	C-430955	Utting, 2008a
300C606650133450	Arctic Red Y.T. C-60	167.6-170.7	Barremian to Albian, Cretaceous	2- to 2+	C-430962	White, 2007
300C606650133450	Arctic Red Y.T. C-60	201.2-204.2	Cretaceous and Carboniferous, Carboniferous probably recycled	2- to 2+	C-430963	White, 2007
300F376700134450	Peel Y.T. F-37	112.8	Cretaceous with recycled Carboniferous	1+ to 2+	C-430933	White, 2007
300F376700134450	Peel Y.T. F-37	137.2	Barremian to late Albian, Cretaceous	1+ to 2+	C-430934	White, 2007
300F376700134450	Peel Y.T. F-37	170.7	late Famennian, Late Devonian	2	C-430935	Utting, 2008a
300F376700134450	Peel Y.T. F-37	198.1	late Famennian, Late Devonian	2	C-430936	Utting, 2008a
300F376700134450	Peel Y.T. F-37	347.5	late Famennian, Late Devonian	2	C-430937	Utting, 2008a
300F376700134450	Peel Y.T. F-37	381.0	mid-Famennian, Late Devonian	2	C-430945	Utting, 2008a
300F376700134450	Peel Y.T. F-37	527.3	mid-Famennian, Late Devonian	2	C-430938	Utting, 2008a
300F376700134450	Peel Y.T. F-37	643.1	mid-Famennian, Late Devonian	2	C-430939	Utting, 2008a
300F376700134450	Peel Y.T. F-37	670.6	mid-Famennian, Late Devonian	2	C-430940	Utting, 2008a
300F376700134450	Peel Y.T. F-37	887.0	mid-Famennian, Late Devonian	2	C-430941	Utting, 2008a
300F376700134450	Peel Y.T. F-37	932.7	mid-Famennian, Late Devonian	2	C-430942	Utting, 2008a
300G726700134000	Satah River Y.T. G-72	185.9	late Famennian (Strunian)	2	C-430903	Utting, 2008a
300G726700134000	Satah River Y.T. G-72	246.9	late Famennian (Strunian)	2	C-430904	Utting, 2008a
300G726700134000	Satah River Y.T. G-72	271.3	late Famennian (Strunian)	2	C-430905	Utting, 2008a
300H376640134450	Trail River Y.T. H-37	1289.3	late Famennian (Strunian)	2	C-430921	Utting, 2008a
300H376640134450	Trail River Y.T. H-37	1313.7	late Famennian (Strunian)	2	C-430920	Utting, 2008a
300H376640134450	Trail River Y.T. H-37	1478.3	late Famennian (Strunian)	2	C-430922	Utting, 2008a
300H376640134450	Trail River Y.T. H-37	1508.8	late Famennian, Late Devonian	2	C-430923	Utting, 2008a
300H376640134450	Trail River Y.T. H-37	1676.4	mid-Famennian, Late Devonian	2	C-430924	Utting, 2008a
300H376640134450	Trail River Y.T. H-37	1706.9	mid-Famennian, Late Devonian	2	C-430925	Utting, 2008a
300H376640134450	Trail River Y.T. H-37	1804.4	mid-Famennian, Late Devonian	2	C-430926	Utting, 2008a
300H596640134300	Peel R. Y.T. H-59	580.0	late Famennian, Strunian	2	C-473040	Utting, 2007
300H596640134300	Peel R. Y.T. H-59	587.8	late Famennian, Strunian	2	C-473041	Utting, 2007

Unique Well Identifier (UWI)	Short Well Name	Depth (m)	Probable Age	T.A.I.	GSC Loc #	Reference
300I216620134150	Peel R Y.T. I-21	33.5	early Tournaisian, Early Mississippian	2	C-430919	Utting, 2008a
300I216620134150	Peel R Y.T. I-21	48.8	early Tournaisian, Early Mississippian	2	C-430920	Utting, 2008a
300J216640134000	Peel River Y.T. J-21	332.2-335.3	Valanginian to Middle Albian, Cretaceous. Lower Carboniferous	1+ to 3-	C-430973	White, 2007
300J216640134000	Peel River Y.T. J-21	344.4-347.5	Carboniferous with caved Cretaceous		C-430974	White, 2007, Utting, 2007
300J216640134000	Peel River Y.T. J-21	614.9	late Famennian	2	C-473042	Utting, 2007
300J216640134000	Peel River Y.T. J-21	1199.7	age not determined	3?	C-473043	Utting, 2007
300K096620134000	Peel R Y.T. K-09	1339.9	latest Famennian? to earliest Tournaisian?	2	C-473044	Utting, 2007
300K156600133000	Taylor Lake Y.T. K-15	777.2	Famennian, Late Devonian	3/3+	C-430893	Utting, 2008a
300K156600133000	Taylor Lake Y.T. K-15	807.7	Famennian, Late Devonian	3/3+	C-430894	Utting, 2008a
300K156600133000	Taylor Lake Y.T. K-15	835.2	Famennian, Late Devonian	3/3+	C-430895	Utting, 2008a
300K156600133000	Taylor Lake Y.T. K-15	862.6	Famennian, Late Devonian	3/3+	C-430896	Utting, 2008a
300K156600133000	Taylor Lake Y.T. K-15	1005.9	late Famennian, Strunian	3/3+	C-430897	Utting, 2008a
300K156600133000	Taylor Lake Y.T. K-15	1042.4	age not determined	3/3+	C-430898	Utting, 2008a
300L016640134450	Peel R Y.T. L-01	1318.0	late Famennian (Strunian)	2	C-473045	Utting, 2007
300L016640134450	Peel R Y.T. L-01	1533.2	late Famennian (Strunian)	2	C-473046	Utting, 2007
300L016640134450	Peel R Y.T. L-01	1537.3	late Famennian (Strunian)	2	C-473047	Utting, 2007
300M696610133450	Peel River Y.T. M-69	457.2	mid-Cretaceous with recycled Lower Carboniferous	1+ to 2+	C-430911	White, 2007
300M696610133450	Peel River Y.T. M-69	883.9	mid-Cretaceous with recycled Lower Carboniferous	2 to 3-	C-430917	White, 2007
300N256620134450	Caribou Y.T. N-25	137.2	late Famennian (Strunian)	2	C-430883	Utting, 2008a
300N256620134450	Caribou Y.T. N-25	189.0	late Famennian (Strunian)	2	C-430885	Utting, 2008a
300N256620134450	Caribou Y.T. N-25	195.1	late Famennian (Strunian)	2	C-430886	Utting, 2008a

Table 1. *Probable ages of strata in wells previously assigned to Tuttle Formation (Pugh, 1983; Fraser and Hogue, 2007) based on recent palynological studies (with the exception of borehole Peel River Y.T. M-69 which were previously assigned to the Martin House Formation). Note that in boreholes Peel Y.T. F-37 and Peel River Y.T. J-21, some strata assigned to Tuttle Formation were dated as Cretaceous. T.A.I. = thermal alteration index.*

TUTTLE FORMATION

Definition

Upper Devonian to Lower Carboniferous strata have previously been described by several authors, including Norris (1968, 1985, 1997), Lutchman (1977), Pugh (1983), Braman and Hills (1992), Norris (1997a; 1997b), and Richards et al. (1997). In Eagle Plain, borehole Chevron North Parkin Y.T. D-61 drilled through 305 m of sandstone and conglomerate (from 1296.6 to 1604.5 m depth) which were called “Tuttle” in the 1972 D-61 well history report (Pugh, 1983). Norris (1981a; 1981b) mapped a succession of sandstone and chert pebble conglomerate overlying Imperial Formation informally as Tuttle formation prior to formalization of the formation by Pugh (1983). Pugh (1983) applied the term to an alternating succession of coarse- and fine-grained clastic rocks overlying Upper Devonian Imperial Formation and unconformably overlain by Mesozoic strata (and locally Ford Lake Shale) in an area flanking the eastern and western Richardson Mountains.

According to Pugh's (1983) definition, Tuttle Formation is distinguished from underlying Imperial Formation by the presence of kaolinite and quartz infill in the sandstone pores, thin orthoquartzite beds, vari-coloured chert conglomerate in the north, and finer grained, better sorted, and more quartzose sandstone in the south. It is also characterized by brown-black shale, carbonaceous fragments and local coal as well as the absence of carbonate cement. The base of Tuttle Formation is marked by the presence of the lowest conglomerate, lowest silicified beds, or lowest brown-black shale (Pugh, 1983). Norris (1985) stated that Pugh's definition encompasses informal units mapped by Norris (1981b; 1981c) as 'Dus' and 'Cf'.

In the field, the transition from Imperial to Tuttle formations is gradual. This study has recognized the base of Tuttle Formation as the first occurrence of visible chert grains and the presence of chalky white infill or kaolinite in the sandstone. The sandstone of underlying Imperial Formation is very fine- to fine-grained. Imperial Formation gradually increases in the percentage of sandstone as well as thickness of individual sandstone beds up section. At the point where sandstone beds reach their maximum abundance and grain size, it is generally coarse-grained, moderately to poorly sorted and contains visible chert clasts; and is assigned to Tuttle Formation. Fine-grained intervals associated with Tuttle sandstone are typically heterolithic, consisting of very thinly bedded shale, siltstone and very fine-grained sandstone.

Tuttle Formation may prove to be better defined as a coarse-grained member that is recognized by its resistant nature, occurrence of medium- to very coarse-grained sandstone and conglomerate, and ubiquitous presence of kaolinite. These coarse-grained intervals (up to 180 m) occur as individual resistant ribs separated by thick intervals (15 m to 150 m thick) of fine-grained siliciclastic rocks. The fine-grained rocks associated with the sandstone and conglomerate packages are mapped at surface as 'Dus', 'Cf', or Ford Lake Shale (Norris, 1981b; 1982a; 1982b). Lutchman (1977) subdivided coarse-grained strata between Imperial Formation and the Cretaceous succession, now included in Tuttle Formation, into M1 to M7 sandstone units, with M1 being the basal sandstone rib (e.g., borehole Pacific Peel Y.T. F-37; Figure 3). These units, containing sandstone and lesser conglomerate, were recognized in the subsurface by correlation of identifiable mechanical log characteristics combined with well cutting sample descriptions. Pugh (1983) illustrated that there is a conflict between correlations of sandstone intervals by Lutchman (1977) and palynological evidence.

In outcrop, Norris (1985) surmised that sandstone ribs exposed along Trail River correspond to M1 and M2 sandstone units of Lutchman (1977). The stratigraphically lowest sandstone rib exposed on Trail River is dated at late Frasnian to early Famennian (Utting, 2007). An additional sandstone body, approximately 10 km to the east on lower Trail River adjacent the mapped Trevor fault, is dated as Strunian (latest Famennian, Late Devonian) by Utting (2008b). Table 2 summarises dating based on palynological studies for selected outcrop samples.

Finer grained intervals (fines) between sandstone bodies typically have lithologies that can be distinguished from the underlying Imperial Formation and overlying Ford Lake Shale. The fines between sandstone ribs consist of interbedded shale, siltstone, and very fine-grained sandstone beds on a centimetre-scale, which are similar to those assigned to 'Dus' map unit. The fines of lower Imperial Formation and Ford Lake Shale lack this relationship of thin sandstone and shale interbeds ubiquitous in Tuttle Formation.

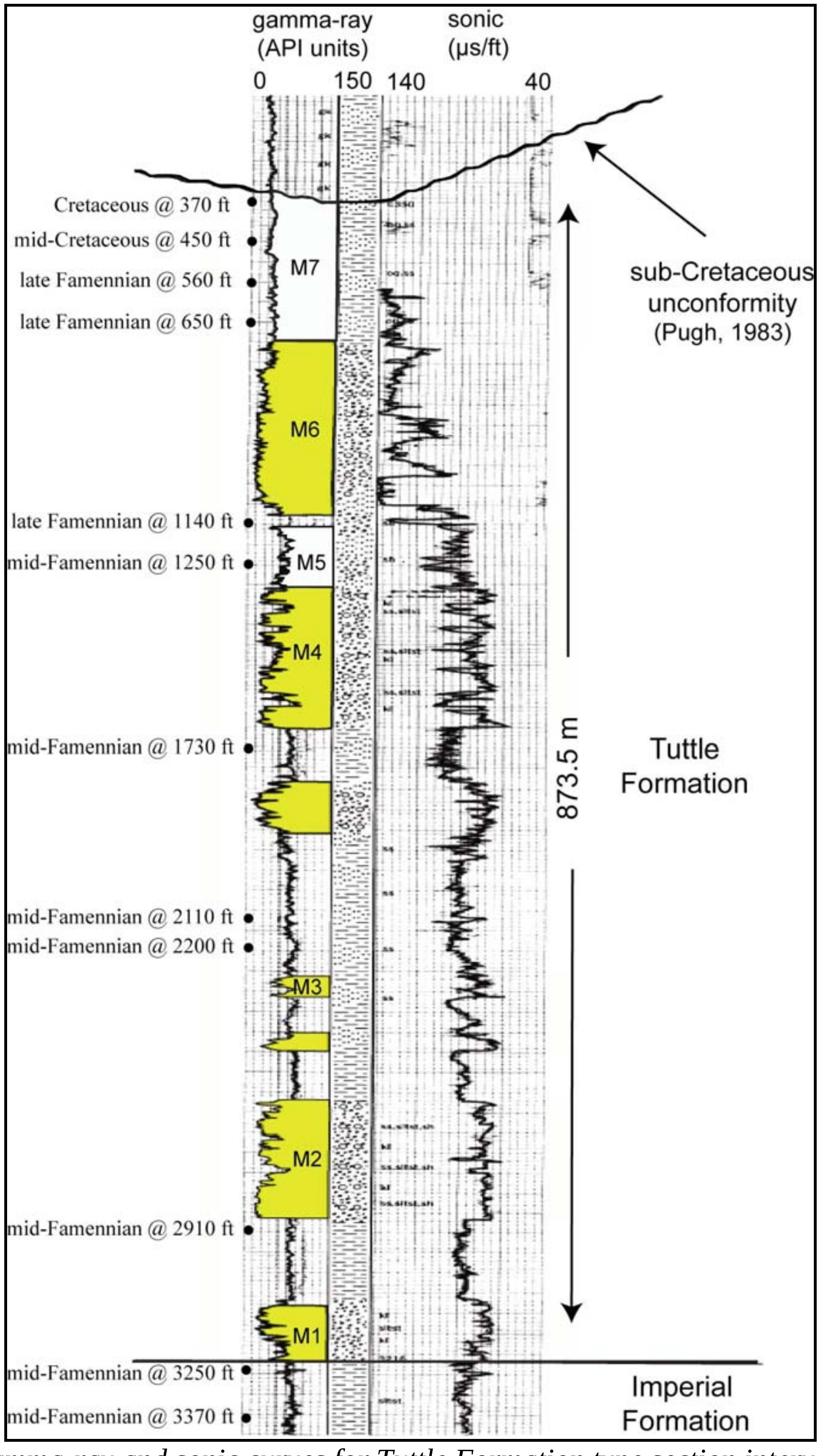


Figure 3. *Gamma-ray and sonic curves for Tuttle Formation type section interval (106.7 m to 980.2 m below kelly bushing) in the Pacific Peel Y.T. F-37 borehole (after Pugh, 1983). Yellow areas represent coarser grained intervals. Dates derived from palynomorphs are plotted adjacent to the gamma-ray curve (Utting, 2008a). M1 to M7 are designations assigned to sandstone bodies in the 'Mississippian clastic wedge' (Lutchman, 1977).*

Sample	UTM Easting	UTM Northing	Probable Age	Formation	T.A.I.	GSC C - Nos.	Reference
06TNT-TR-014A	483250	7371104	latest Frasnian to early Famennian	Tuttle	2	473054	Utting, 2007
06TNT-TR-014G	483250	7371104	Late Devonian	Tuttle	2	473055	Utting, 2007
06TNT-TR-015L	483479	7371292	latest Frasnian to early Famennian	Tuttle	2+	473056	Utting, 2007
06TNT-TR-016A	483552	7371310	not determined	Tuttle	2	473057	Utting, 2007
06TNT-TR-016-2	483570	7371318	Late Devonian	Tuttle	2	473058	Utting, 2007
06TNT-TR-017A	484937	7372301	Late Devonian	Ford Lake	2	473059	Utting, 2007
06TNT-RR-019E	483971	7391104	Late Devonian (late Famennian?)	Tuttle	2	473060	Utting, 2007
06TNT-RR-019K	483995	7391125	Late Devonian	Tuttle?	2	473061	Utting, 2007
06TNT-RR-020A	484113	7391184	Late Devonian	Tuttle?	2	473062	Utting, 2007
06TNT-RR-020C	484090	7391172	Late Devonian	Tuttle?	2	473063	Utting, 2007
06TNT-RR-020H	484059	7391144	Late Devonian, Famennian?	Tuttle?	2	473064	Utting, 2007
06TNT-RR-020V	484041	7391145	Late Devonian, Famennian	Tuttle	2	473065	Utting, 2007
06TNT-CC-026A	523198	7355395	not determined	Ford Lake	2	473066	Utting, 2007
06TNT-CC-026K	523167	7325671	not determined	Ford Lake	2	473067	Utting, 2007
06TNT-RR-028A	485951	7391245	Late Devonian, Famennian	Tuttle?	2	473068	Utting, 2007
06TNT-TR-029C	490861	7369955	Late Devonian, late Famennian	Tuttle	2	473069	Utting, 2007
06TNT-CR-031A	512994	7344407	late Famennian (Strunian)	Tuttle	2	473070	Utting, 2007
06TNT-PR-033A	529110	7314150	not determined	Ford Lake? Imperial?	3+ to 4-	473071	Utting, 2007
07TNT-TR-01H	483303	7370860	Late Devonian, early Famennian	Tuttle	2	473127	Utting, 2008b
07TNT-TR-01I	483303	7370860	Late Devonian, early Famennian	Tuttle	2	473128	Utting, 2008b
07TNT-TR-03E	492374	7371087	late Famennian (Strunian)	Tuttle	2	473129	Utting, 2008b
07TNT-TR-03F	492374	7371087	late Famennian (Strunian)	Tuttle	2	473130	Utting, 2008b
07TNT-TR-05H	493706	7371672	Late Devonian, late Famennian	Tuttle	2	473132	Utting, 2008b
07TNT-TR-06A	494385	7372527	Late Devonian, late Famennian	Tuttle	2	473133	Utting, 2008b
07TNT-TR-06C	494382	7372458	Late Devonian, late Famennian	Tuttle	2	473134	Utting, 2008b
07TNT-NTR-20A	479769	7404483	late Famennian (Strunian)	Tuttle	2	473137	Utting, 2008b
07TNT-NTR-20B	479713	7404507	late Famennian (Strunian)	Tuttle	2	473138	Utting, 2008b
07TNT-TET-21A	482352	7400500	Late Devonian	Tuttle	2	473139	Utting, 2008b
07TNT-TET-21B	482286	7400408	Late Devonian, late? Famennian	Tuttle	2	473140	Utting, 2008b
07TNT-CC-27A	526761	7327329	Late Devonian (late Famennian?)	Ford Lake	2	473143	Utting, 2008b
07TNT-TT-32A	492785	7379035	Late Devonian, late Famennian	Tuttle?	2	473144	Utting, 2008b
07TNT-ACH-34A	512804	7328585	not determined	Ford Lake	2+?	473147	Utting, 2008b
07TNT-ACH-34B	512907	7328592	Late Devonian, Famennian?	Ford Lake	2+?	473148	Utting, 2008b
07TNT-ACH-34C	512907	7328592	Late Devonian	Ford Lake	2+?	473149	Utting, 2008b
07TNT-M0R-39A	551078	7270060	Tournaisian, early Carboniferous	‘M0’	2	473150	Utting, 2008b
07TNT-SR-43B	571852	7279389	early Tournaisian, early Carboniferous	‘M0’	3 to 3+	473155	Utting, 2008b

Sample	UTM Easting	UTM Northing	Probable Age	Formation	T.A.I.	GSC C - Nos.	Reference
07TNT-M0R-46C	553978	7270171	early Tournaisian, early Carboniferous	'M0'	3	473156	Utting, 2008b
07TNT-M0R-46F	554160	7270376	early Tournaisian, early Carboniferous	'M0'	3	473157	Utting, 2008b
07TNT-SR-47E	571857	7279365	early Tournaisian, early Carboniferous	'M0'	3	473158	Utting, 2008b
07TNT-SR-47H	571852	7279389	early Tournaisian, early Carboniferous	'M0'	3	473159	Utting, 2008b
07TNT-SR-47I	571855	7279532	early Tournaisian, early Carboniferous	'M0'	3	473160	Utting, 2008b
07TNT-SR-47L	571840	7279585	early Tournaisian, early Carboniferous	'M0'	3	473161	Utting, 2008b
07TNT-SR-47M	571843	7279614	early Tournaisian, early Carboniferous	'M0'	3	473162	Utting, 2008b
07TNT-M0-50A	581624	7270239	early Tournaisian, early Carboniferous	'M0'	3	473163	Utting, 2008b

Table 2. *Probable ages based on recent palynological studies for select outcrop samples. T.A.I. = thermal alteration index.*

Type Section

Pugh (1983) described the Tuttle Formation type section as containing vari-coloured chert conglomerate, very poorly sorted quartz and chert sandstone, siltstone, and shale. The conglomerate is predominantly multi-coloured chert, including white, buff, grey, yellow, orange and pale green clasts. Most of the sandstone and shale beds are finely micaceous, with sandstone also containing kaolinite as a pore-filling cement. The top 100 m of the formation contains orthoquartzite beds.

The type section selected by Pugh (1983) for Tuttle Formation is found in the Pacific Peel Y.T. F-37 borehole (UWI 300F376700134450) which was drilled in 1972 in Peel area of Yukon (Figure 3). In F-37, Pugh (1983) assigned strata from 107 m to 981 m (351 feet to 3218.5 feet) below the kelly bushing to Tuttle Formation. This type section is problematic since only drill cuttings and wireline logs exist for this well. Pugh (1983) also suggested boreholes Peel River Y.T. L-19 and Peel R Y.T. I-21 as useful reference sections for Tuttle Formation. In addition, Tuttle Hill, on the west side of the Richardson Mountains, has been suggested as the type area of Tuttle Formation by Pugh (1983). Until recently, no palynological or other age determination studies were completed on borehole F-37. Strata between 54.9 m (180 feet) and 140.2 m (460 feet) were recently dated as Cretaceous based on palynological studies (White, 2007) indicating that the top of Tuttle Formation is deeper than originally proposed. According to this palynomorph study, the top of the formation lies between 137.1 m (450 feet) and 170.7 m (560 feet), rather than at 107 m (351 feet) where Pugh (1983) placed it.

Palynological work by Utting (2008a) assigned strata in well F-37 between 170.7 m and 347.5 m (560 feet and 1140 feet) to the late Famennian, and strata between 381 m and 1027.2 m (1250 feet and 3370 feet) to the mid-Famennian. In well F-37, Tuttle Formation overlies shale of Upper Devonian Imperial Formation. Its top has been eroded below the sub-Cretaceous unconformity, placing Cretaceous marine siliciclastic rocks directly over late Famennian strata of Tuttle Formation. The Tuttle Formation type section spans a thick succession of mid-Famennian to late Famennian strata (Utting, 2008a). Tournaisian-aged strata assigned to Tuttle Formation were penetrated in three other wells (I-21, Peel River Y.T. J-21, and Peel R Y.T. K-09) suggesting that younger Tuttle strata are not included in the type section.

Contacts

Some authors suggest the basal contact of Tuttle Formation with Imperial Formation is conformable (Pugh 1983), whereas others report that on Trail River, and possibly elsewhere, it is unconformable (Norris 1985; Braman, 1981). The lower Tuttle Formation contact with underlying Imperial Formation appears to be gradational, but diachronous, and likely intertongues with Imperial Formation (Pugh, 1983). A similar relationship occurs between Tuttle Formation and Ford Lake Shale. Field observations on the east flank of the Richardson Mountains (Norris, 1981b) suggest that Ford Lake Shale, at least in part, overlies Tuttle Formation and locally intertongues with the laterally equivalent Tuttle Formation (Norris, 1997).

Subsurface studies (e.g., Pugh, 1983; Lutchman, 1977) reported Tuttle Formation as unconformably overlain by Cretaceous strata which is recognized in the subsurface by high gamma-ray readings on logs (Dixon, 1997). Pugh (1983) stated that the near absence of glauconite distinguishes Tuttle Formation from overlying Cretaceous strata. At most localities, the top of Tuttle Formation is truncated by the sub-Mesozoic unconformity, with Cretaceous strata directly overlying Tuttle Formation. The presence of Ford Lake Shale has not been identified in the subsurface in Peel area.

Distribution and Thickness

Tuttle Formation occurs in Eagle Plain, the southern Richardson Mountains, Peel Plateau, and the western part of Peel Plain (Norris, 1981a; 1981b; 1981c; 1982a; 1982b; Pugh, 1983). Surface exposures of Tuttle Formation are limited almost exclusively to Yukon, where it crops out on the western and eastern flanks of the Richardson Mountains (Figure 4). Much of the research reported here involved studying surface exposures of Tuttle Formation on the east flank of the Richardson Mountains. Due to limited and non-continuous exposures and difficulty accessing the area, there is still limited understanding of Tuttle Formation and adjacent strata.

In the subsurface, Tuttle Formation has been documented in the western Peel Plateau and Eagle Plain. In Peel area, Tuttle Formation is recorded in 18 Yukon and eight Northwest Territories (NWT) boreholes (see Table 3 for thickness and depth of Tuttle Formation in the subsurface). Isopachs of Tuttle Formation based on well formation tops identified by Fraser and Hogue (2007) and including the Ford Lake Shale and 'M0' map units in Peel area, show a range in thickness from 0 m at the western and eastern erosional edges to a maximum of 1198.7 m in borehole Trail River Y.T. H-37 (Figure 5). Apparent stratigraphic thickness is reflected and indicates a thickening trend to the northwest.

Pugh (1983) interpreted a maximum thickness of over 1250 m and 1421 m for Tuttle Formation on the east and west sides of the Richardson Mountains anticlinorium, respectively. Norris (1985) suggested the depocentre of Tuttle Formation is within what is now the Richardson anticlinorium, before it was uplifted during the Laramide Orogeny, and Tuttle strata were subsequently removed by erosion. There has been significant post-Carboniferous erosion and any interpretation of the depocentre must take this into consideration.

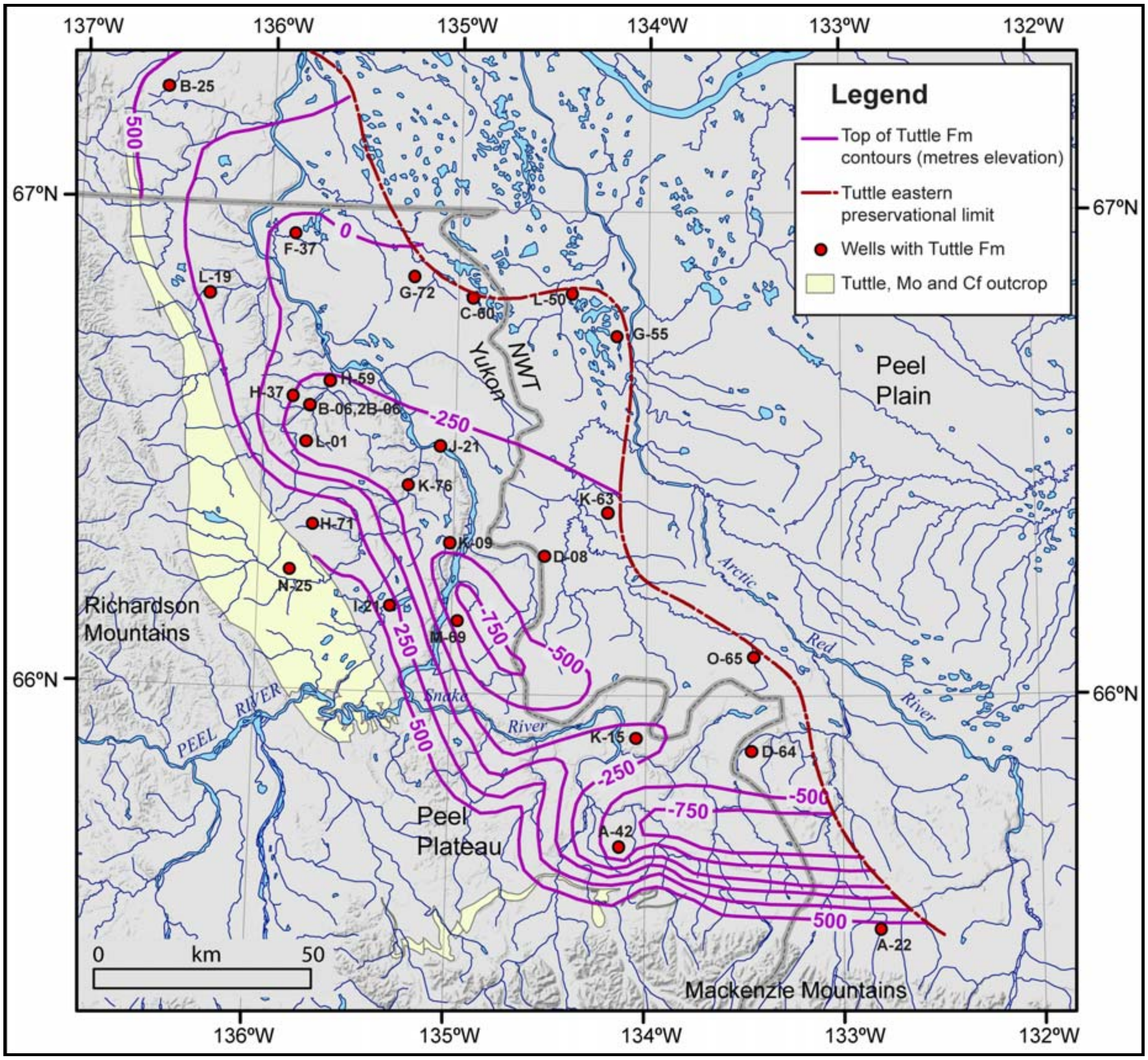


__Figure 4.__ Surface and subsurface distribution of Tuttle Formation including overlying 'Cf' and 'M0' map units in Peel area. Contours represent the elevation of the top of Tuttle Formation based on well data (Fraser and Hogue, 2007; Pugh, 1983). Yellow shading represents surface outcrop of Tuttle, 'M0' map unit, and overlying 'Cf' map unit. Wells (red circles) included here are those that intersect Tuttle Formation.

We identified some exposures (e.g., those at Trail River and Caribou River) mapped as 'Cf' (Carboniferous shale) that are lithologically more appropriately assigned to Tuttle Formation. On Trail River, a coarse-grained sandstone package occurs 10 km to the east of the mapped extent of Tuttle Formation, adjacent to the mapped Trevor fault. Sandstone beds near the mapped Trevor fault are flat-lying with approximately 9 m of thickness exposed. Norris (1981b) assigned this sandstone package to map unit 'Cf'. The present study assigns the sandstone to Tuttle Formation, however, which is consistent with the findings of Braman and Hills (1992) who assigned these strata a Tournaisian age based on palynological data. When these authors published their work it was common practice to include the lower Tournaisian in the Devonian Period. This sandstone package consists of poorly sorted sandstone with granules of grey and white weathered chert in a matrix of predominantly chert and quartz.

Unique Well Identifier (UWI)	Short well name	KB elevation(m)	Top Tuttle measured depth from KB (m)	Top Tuttle elevation (m)	Tuttle thickness (m)
300A226540131450	Cranswick A-22	768.4	138.4	630.0	84
300A426550133001	Cranswick Y.T. A-42	620.1	1170.4	-550.3	728.5
300B066640134450	Peel River Y.T. B-06	65.2	332.8	-267.6	>733.4
302B066640134450	Peel River Y.T. 2b-06	66.4	333.4	-267.0	>97.6
300B256720135301	Mcpherson B-25	492.3	82	410	943
300C606650133450	Arctic Red Y.T. C-60	92.0	157.0	-65.0	35.9
300D086620133300	Sainville River D-08	203.0	574	-371	356
300D646600132151	South Peel D-64	558.1	983.3	-425.2	108
300F376700134450	Peel Y.T. F-37	54.6	107.0	-52.4	873.5
300G556650133000	Arctic Red West G-55	44.6	75.3	-30.7	17
300G726700134000	Satah River Y.T. G-72	89.6	168.0	-78.4	122.7
300H376640134450	Trail River Y.T. H-37	393.2	646.0	-252.8	1198
300H596640134300	Peel R. Y.T. H-59	33.4	296.0	-262.6	>467.2
300H716630134300	Peel Y.T. H-71	513.0	31.1	481.9	730.9
300I216620134150	Peel R Y.T. I-21	381.2	3.9	377.3	885.3
300J216640134000	Peel River Y.T. J-21	45.7	341.0	-295.3	>878.2
300K096620134000	Peel R Y.T. K-09	349.5	830.3	-480.8	>724.2
300K156600133000	Taylor Lake Y.T. K-15	468.8	691.9	-223.1	360.3
300K636630133000	Sainville River K-63	138.7	413.4	-274.7	18
300K766630134000	Peel R Y.T. K-76	76.5	451.0	-374.5	>935.8
300L016640134450	Peel R Y.T. L-01	394.7	683.0	-288.3	1102.8
300L196650135150	Peel R Y.T. L-19	95.1	3.7	91.4	1041.5
300M696610133450	Peel River Y.T. M-69	291.7	934.0	-642.3	879.6
300L506650133150	Martin House L-50	88.0	106.7	-18.7	6.1
300N256620134450	Caribou Y.T. N-25	495.3	7.6	487.7	197.2
300O656610132150	Weldon Creek O-65	222.8	565.7	-342.9	20

Table 3. *Tuttle Formation tops (in metres) of wells that penetrate the unit in Peel area. Yukon tops after Fraser and Hogue (2007) and NWT tops after Pugh (1983). Note all wells did not penetrate the entire Tuttle Formation. KB = kelly bushing.*

Paleontology and Age

Strata assigned to Tuttle Formation are distinguished from underlying Imperial Formation by the first occurrence of conglomerate, silicified beds, or brown-black shale (Pugh, 1983). Palynological data presented in Pugh (1983) indicates that the base of Tuttle Formation is younger from north to south and time-transgressive over the interval from late Frasnian to early Famennian to very latest Famennian (Strunian). In the north, Lutchman's (1977) M1 to M7 sandstone designations in Peel R. Y.T. L-19 well were dated as late Frasnian or early Famennian to Strunian using palynomorphs; while to the south sandstones M1 to M7 in boreholes Peel River Y.T. B-06 and Peel River Y.T. H-59 are Strunian to Tournaisian (Late Devonian to Early Carboniferous) in age (unpublished palynological work of McGregor, 1968 and Barss, 1969 in Pugh, 1983).

The usage of the terms Strunian and Tournaisian have changed because the boundary between the Tournaisian and Famennian type series in Belgium did not coincide with the stage boundary of the Devonian and Carboniferous. The Tournaisian Series was formerly divided into three parts (Tn1, Tn2 and Tn3), with the lower part of Tn1 (Strunian stage) in the Upper Devonian. This has subsequently been changed so that the Tournaisian is now divided into a lower and upper stage (respectively, T1 = Hastarian and TII = Ivorian), and the Strunian stage is now placed at the top of the Famennian (Paproth et al., 1983).

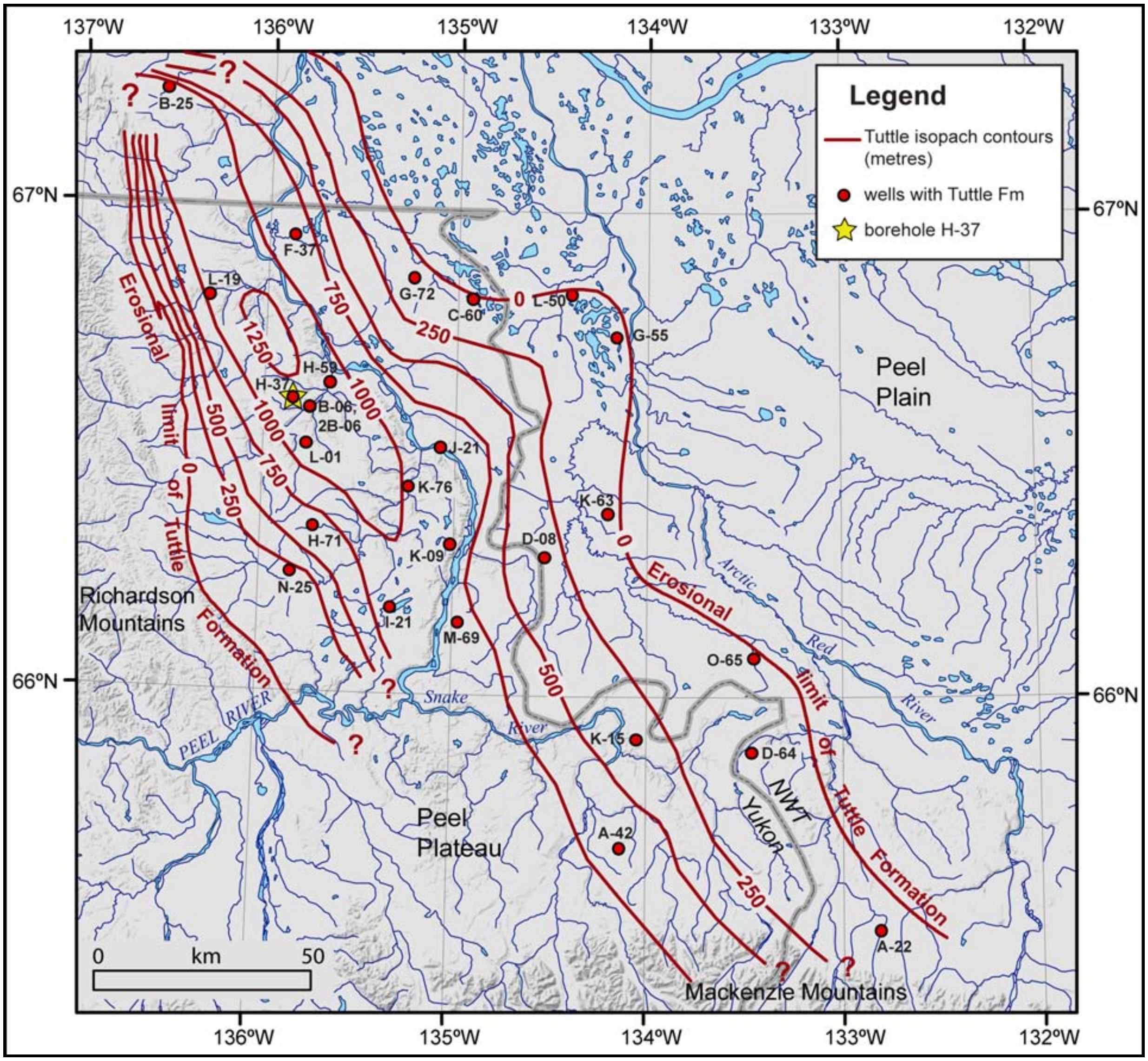


Figure 5. *Subsurface distribution of Tuttle Formation in Peel area. Contours represent thickness in metres based on well data (Fraser and Hogue, 2007; Pugh, 1983). Wells (circles) included here are those that intersect Tuttle Formation. Borehole H-37 contains the thickest known Tuttle section in Peel area at 1198.7 metres. Tuttle Formation is also found to the west of the Richardson Mountains.*

Additional palynological studies of Tuttle strata on Trail River confirmed that it is middle Famennian to late early Famennian (Braman, 1981). Hills et al. (1984) examined megaspore assemblages in Tuttle Formation on Road and Trail rivers and Tetlit Creek. They determined that there are two biozones in the succession on Trail River and Tetlit Creek, including an early to middle Famennian biozone and an early Tournaisian biozone.

Recent palynology studies have been conducted on 47 Tuttle Formation cutting samples from 15 wells in the Yukon's Peel area (Tables 1 and 2; Figure 6; Utting, 2007; 2008a; White, 2007). These subsurface investigations indicate that Tuttle Formation, as defined by Pugh (1983), ranges in age from mid-Famennian to early Tournaisian. It is possible, as stated by Pugh (1983), that there are younger unrecorded strata of Tuttle Formation. White (2007) identified recycled Carboniferous palynomorphs in Cretaceous strata in boreholes C-60, F-37, J-21, and M-69 (Table 1). Palynomorphs from an additional 26 outcrop samples of Tuttle Formation suggest that along the eastern flank of the Richardson Mountains, Tuttle strata can be assigned an age of late Frasnian to Strunian (Table 2; Figure 6). The oldest occurrence of Tuttle strata is on Trail River where poorly sorted medium- to coarse-grained sandstone and chert granule conglomerate beds are dated as latest Frasnian to early Famennian (Utting, 2007).

At the southern extent of Peel area along the northern Mackenzie Mountains, sandstone and shale mapped by Norris (1982a; 1982b) as the 'M0' map unit are dated at early Tournaisian (Utting, 2008b). In contrast, all strata identified as Tuttle Formation in outcrop were dated as latest Frasnian to Strunian. Also, strata assigned to Tuttle Formation by Pugh (1983) in boreholes A-42 and Taylor Lake Y.T. K-15 (nearest the mapped 'M0') was dated as Famennian (Utting, 2008a). Norris (1984) suggested that Ford Lake Shale, Tuttle Formation, and 'M0' may be correlative; however, more work is needed to assess this.

Lithology

Tuttle Formation

Tuttle Formation, based on Pugh's (1983) definition, and as observed in outcrop along the eastern flank of the Richardson Mountains, consists of alternating packages of coarse-grained clastic rocks including medium- to very coarse-grained chert- and quartz-rich sandstone and conglomerate, as well as finer grained intervals of siltstone and shale that are largely covered. The same relationship is recorded in the subsurface by examining well data. Coarse-grained intervals are resistant and comprise sandstone (Figure 7) with minor conglomerate consisting predominantly of chert and quartz.

Partial stratigraphic sections of Tuttle Formation were measured, but no complete section was observed in the field. Where Tuttle Formation crops out, strata are commonly folded and faulted. The best exposures of Upper Paleozoic strata occur on Trail River, Road River, and Tetlit Creek where partial detailed stratigraphic sections were measured (Appendix A). These sections describe individual bed thicknesses, grain size distribution, and sedimentary structures associated with sandstone and shale of Tuttle Formation and adjacent units. Sedimentary structures were often difficult to determine due to inaccessibility, lichen cover, cementation, and mud cover.

Sandstone is typically light olive grey to medium grey on the fresh surface and weathers medium grey, dark yellowish orange, or light brown. The composition of the sandstone is predominantly quartz (smoky grey) and vari-coloured (i.e., grey, black, yellow, green) or tripolitic chert (white)

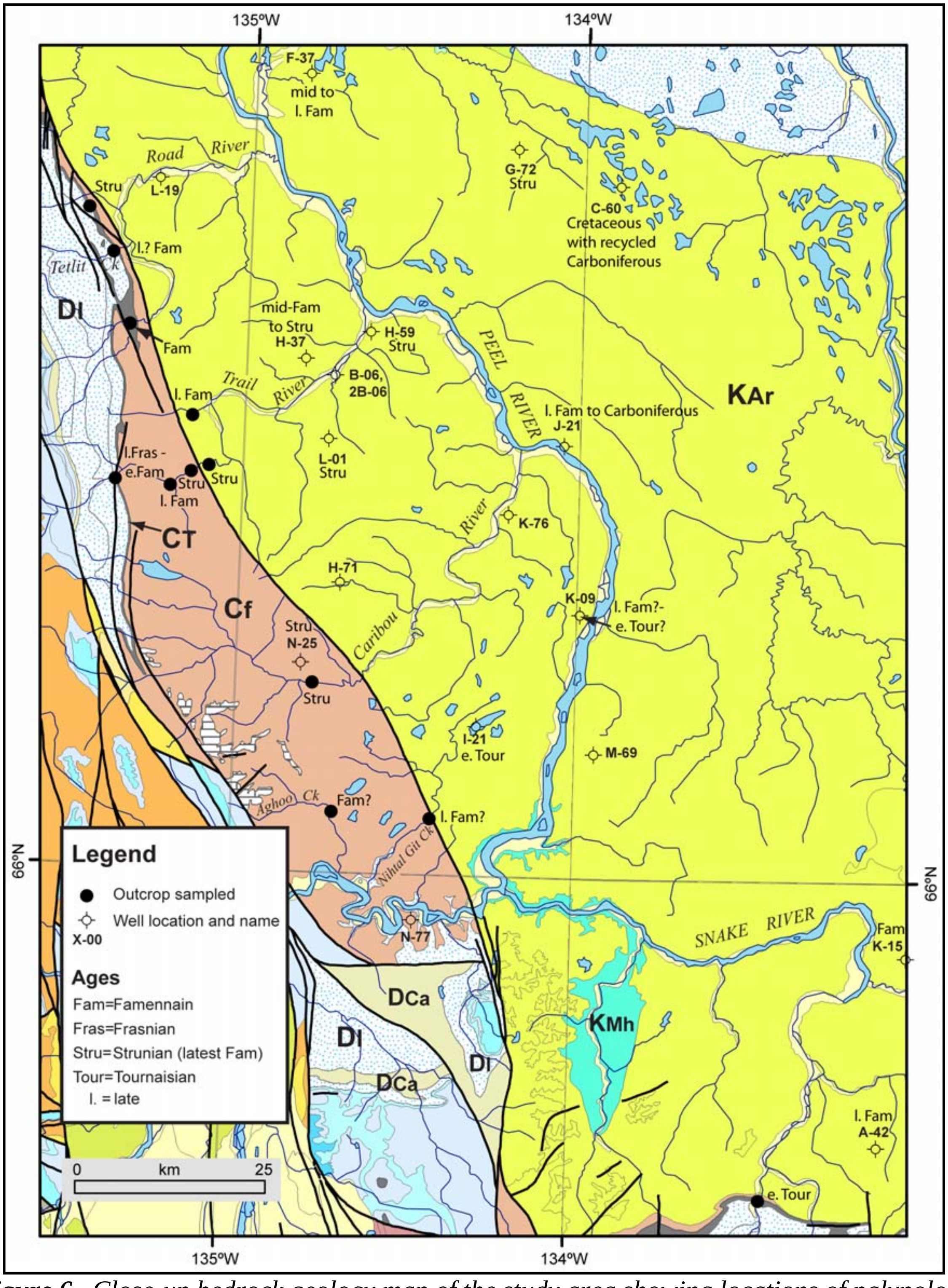


Figure 6. *Close-up bedrock geology map of the study area showing locations of palynology samples reported in Utting (2007, 2008a; 2008b) and White (2007) for strata identified as Tuttle Formation (based on formation tops by Fraser and Hogue, 2007). Map modified from Gordey and Makepeace, 2001. DCa = Canol Formation; DI = Imperial Formation; CT = Tuttle Formation; Cf = Ford Lake Shale; KAr = Arctic Red Formation; KMh = Martin House Formation.*

Figure 7. *Predominantly sandstone interval of Tuttle Formation exposed on Trail River; this outcrop is typical of Tuttle Formation. Stratigraphic thickness exposed is 55 m. Top of section is to the right. Rock hammer (30 cm long) circled for scale.*

grains, giving the rock a salt-and-pepper appearance (Figure 8a). Tripolitic weathering of chert refers to its light coloured, porous, friable, chalky appearance (after Neuendorf et al., 2005). The matrix consists of finer grained chert and quartz sandstone, with grains that are generally more rounded than the larger clasts. Between the sandstone grains, a white chalky material can locally be observed, which is likely a kaolinite pore-filling cement described by Pugh (1983) and Lutchman (1977). A very minor amount of mica has also been observed between sandstone grains. Sandstone textures range from fine- to very coarse-grained, with mainly moderate to poor sorting.

Graded sandstone beds comprise the most common lithofacies observed within coarse-grained intervals of Tuttle Formation (Figure 8b). Graded beds consists of coarse- to very coarse-grained sandstone with or without granules and pebbles at the base, grading to medium- to very fine-grained sandstone at the top. At the base of beds, the sandstone is poorly sorted, containing up to 20% subangular to subrounded very coarse sand grains, granules or pebbles (less than 1.7 cm in diameter). This basal zone is massive or cross-bedded. The top portions of fining-upward beds are lithologically similar to the base, and are either massive or parallel laminated. In the fine- to very fine-grained sandstone at the top, ripples were observed in laminations and beds up to 3 cm thick. The base of each bed is commonly marked by sole marks and/or load casts, and scours with up to 25 cm relief. Fining-upward beds tend to be stacked on top of one another and are locally separated by siltstone intervals less than 10 cm thick. Individual fining-upward beds average 60 cm thick, with 100 cm being the thickest observed bed. Further description of the coarse-grained facies of Tuttle Formation can be reviewed in Fraser and Allen (2007).

Other sedimentary structures common to Tuttle Formation sandstone beds include ripples, crossbeds, and rip-up clasts. Beds are tabular in geometry. Fossilized plant debris occurs as millimetre-size plant fragments on bedding planes, or as randomly oriented tree fragments. No in-situ plant remains were identified.

Figure 8a. *Typical poorly sorted sandstone of Tuttle Formation. Note the weathered chert clasts (white) which give rock a salt-and-pepper look.*

Figure 8b. *Graded granule conglomerate to fine-grained sandstone, typical of Tuttle Formation on Trail River.*

Conglomerate is not common in Tuttle Formation; however, it occurs as discrete beds up to 60 cm thick within sandstone-dominant intervals, and more commonly occurs in the northern part of the Trail River map area (106 L). Conglomerate is matrix- to clast-supported, consisting predominantly of granules and small pebbles with clasts averaging 1 cm across, though locally cobbles are observed. Pebbles are subangular to rounded and are predominantly vari-coloured chert (i.e., white, grey, black, yellowish-grey, light and dark green, and grey banded varieties) and quartz (Figure 9). Conglomerate beds range from continuous to lensoidal, and from structureless to exhibiting normal and reverse grading (Figure 9).

Figure 9. *Massive to normal or inversely graded, granule to small pebble conglomerate of Tuttle Formation, likely representing different flow events. This outcrop is exposed on a north-south trending ridge of Tuttle Formation, north of Road River. Hammer handle = about 20 cm.*

Fine-grained intervals of Tuttle Formation, up to 150 m thick, are composed of interlaminated shale, siltstone, and sandstone; giving the strata a "striped" appearance. Sandstone beds are light to medium grey and typically less than 3 cm thick. The sandstone is very fine-grained and quartz-rich. Some of these sandstone beds are cross-stratified and exhibit sole marks. No trace fossils were observed in Tuttle Formation. These sandstone beds are separated by 1 cm to 10 cm thick intervals of medium to dark grey shale and siltstone.

Ford Lake Shale

Assignment of strata to map unit 'Cf' and correlative 'CF' was inconsistent between map sheets (Table 4). In some map areas, 'Cf' overlies Tuttle Formation (Norris, 1981b) or 'M0' (Norris, 1982a); on other maps it is equivalent to Tuttle Formation (Norris, 1981a; 1984) or 'M0' (Norris, 1982b; 1984). In the Wind River area, Norris (1982b) separates the strata into 'Cf' and 'CF', stating that 'Cf' may include equivalents of 'M0', and 'CF' is Ford Lake Shale. Norris (1984) reassigned units he previously mapped as 'Cf' to the Ford Lake Shale.

NTS Map Sheet	Map Unit	Description	Relationship	Reference
Trail River 106 L	'Cf'	shale, silty, concretionary, dark grey; marine and nonmarine?	overlies Tuttle	Norris, 1981b
Snake River 106 F	'Cf'	shale, dark grey, silty, concretionary; marine and nonmarine	overlies 'M0'	Norris, 1982a
Wind River 106 E	'Cf'	shale, dark grey, silty, concretionary; marine and nonmarine; may include equivalents of 'M0'	equivalent to 'CF' and overlies 'M0'	Norris, 1982b
Wind River 106 E	'CF'	Ford Lake Shale - shale, dark grey, silty, concretionary; marine and nonmarine	equivalent to 'Cf' and overlies 'M0'	Norris, 1982b
Eagle River 116 I	'CF'	Fort Lake Shale – shale, greyish black, rusty weathering, nodular; sandstone, light grey, fine grained; marine	equivalent to Tuttle formation	Norris, 1981a
Various	'CF'	Ford Lake Shale – shale, calcareous, pyritic, marine	equivalent to Tuttle Formation and 'M0'	Norris, 1984

Table 4. *Summary of D.K. Norris' usage of 'Cf' and Ford Lake Shale ('CF') on bedrock maps.*

Ford Lake Shale, typically dark grey to black siliceous shale, is mapped only at surface in Peel area. This unit crops out on Caribou River, Aghoo Creek, Peel River, and tributaries in between (see Figure 6). It is generally flat-lying and exposed over large distances. Portions of the unit are highly siliceous and form resistant shale intervals that resemble sandstone bands from afar due to their resistant nature and white- to yellow-weathering residue (Figure 10a). Locally, these organic-rich black or olive grey shales are oxidized to a pale to moderate reddish-brown colour (Figure 10b).

The unit consists of siliceous black shale that weathers light bluish grey to light grey to yellowish grey. The shale breaks into plates measuring 3 mm to 2 cm thick and has a distinctive 'glass-like' sound when walked upon. The shale is locally petroliferous with oil-staining confirmed by the GSC Organic Geochemistry Lab in Calgary, Alberta. Plant impressions are commonly found on bedding surfaces. Also associated with this shale are siltstone, wafer-like shale, and sandstone. The siltstone is dark grey to olive grey, parallel-laminated, well indurated, and readily splits into 3 cm to 7 cm thick beds. The wafer-like shale is dark grey and papery with mm-size partings. The sandstone is very fine-grained, medium grey to olive grey, parallel-laminated and well indurated. Beds are up to 30 cm thick and petroliferous. Sandstone is not common in the unit.

Figure 10a. *Outcrop of black shale of the Upper Devonian 'Cf' map unit of Norris (1981b) or Ford Lake Shale on Nihtal Git Creek (aka Calamites Creek). The resistant bands are more siliceous shale than that of the recessive intervals. Exposure is approximately 120 m high.*

Figure 10b. *Shale typical of Ford Lake Shale as observed in Peel area. Locally, the shale is oxidized to a reddish-brown colour as shown here. Hammer is 30 cm long.*

Ford Lake Shale has not been distinguished in the subsurface in Peel area, although its presence is suspected in Peel area as a result of this study. Ford Lake Shale is likely present in borehole H-37, which contains red shale; and in borehole A-42, which contains a thick succession of Late Devonian shale and siltstone currently assigned to Tuttle Formation. More work is needed to confirm this stratigraphy in the subsurface.

'M0' Map Unit

Lower Carboniferous(?) sandstone and shale crops out along the northern front of the Mackenzie Mountains in the Wind River and Snake River map areas (106 E and 106 F). Norris (1982a; 1982b; 1984) mapped these clastic sediments as unit 'M0'. 'M0' map unit conformably to unconformably overlies Imperial Formation and is overlain conformably by a shale-rich unit mapped as 'Cf' by Norris (1982a; 1982b) or unconformably by Cretaceous strata, putting it at the same stratigraphic position as Tuttle Formation (Norris, 1982b; 1984). The total thickness of 'M0' map unit is difficult to determine due to its discontinuous exposure and folding and faulting in the region.

'M0' map unit has only been described on map legends of NTS sheets 106 E and 106 F (Norris, 1982a; 1982b) and on Norris' (1984) compilation map of the north which describes 'M0' as "sandstone, light grey, medium-grained; shale, dark grey; nonmarine?". More recently, Gordey and Makepeace (2001) included 'M0' map unit with Tuttle Formation. Figure 18 of Pugh (1983) and Figure 8.11 in Richards et al. (1997) suggest that Carboniferous strata, mapped as 'M0' along the northern front of the Mackenzie Mountains in the vicinity of Snake River, is fine-grained sandstone of Tuttle Formation.

Pugh's (1983) definition implies that 'M0' map unit is included in Tuttle Formation, but this is not explicitly noted. That study described thin orthoquartzite with quartz cement becoming more common southward, with finer grained, better sorted, and more quartzose sandstone to the south. The 'M0' map unit may be a southern extension of Tuttle Formation, where the sandstone is more mature (i.e., younger, better sorted, quartz-rich, fine-grained) than to the north.

On Snake River and neighbouring highlands to the east and west, 'M0' map unit crops out as resistant very fine- to fine-grained sandstone (Figures 11a, b), forming a narrowing of the river channel. The sandstone is quartz-rich with minor amounts of chert. Texturally, the sandstone is well-sorted with rounded grains. It consists of alternating intervals of rippled, lenticular, thinly bedded sandstone (Figure 11b); cross-bedded, thickly bedded sandstone; and minor shale. Horizontal and vertical burrows are commonly observed in the rippled sandstone (Figures 11c, d). Other features include coalified plant debris and stylolites draped with black organic(?) material. The percentage of fine-grained siliciclastic rocks increases up section in the Snake River section.

Thin section analysis reveals that the sandstone of 'M0' map unit is quartz-rich with minor, typically non-porous chert. The quartz grains are commonly fused together, and where present, a matrix commonly consists of carbonate with small amounts of mica and chlorite. Based on this study, 'M0' map unit exhibits features that are distinguishable from the "type" Tuttle Formation, including high quartz to chert ratios, substantial quartz cementation, low porosity and permeability values, the presence of carbonate cement, overall small grain size, presence of bioturbation, and well preserved sedimentary structures.

Figure 11a. *'M0' map unit (Carboniferous sandstone) of Norris (1982a; 1982b) on Snake River. Lighter coloured intervals consist of predominantly fine- to medium-grained cross-bedded sandstone; darker intervals are thinly bedded, rippled, very fine-grained sandstone.*

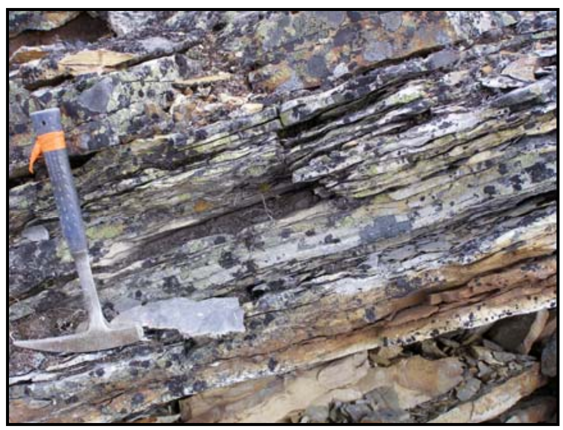


Figure 11b. *Close-up of the thinly bedded, rippled, very fine-grained sandstone. Hammer for scale.*

***Figure 11c.** Close-up of lined, horizontal burrows (*Palaeophycus?*) commonly noted in 'M0' map unit sandstone. Pencil tip for scale.*

***Figure 11d.** Close-up of burrows (*Planolites?*) on bedding surface of 'M0' map unit sandstone. Pencil tip for scale.*

DISCUSSION AND DEPOSITIONAL HISTORY

In the northernmost outcrop exposures of Tuttle Formation in Peel area (Chii Danaadaa Creek and slightly north of Vittrekwa River), the formation is predominantly conglomerate and sandstone. In a number of the exposures of Tuttle Formation, the depositional environment is difficult to ascertain due to heavy lichen cover, faulting, or lack of accessibility due to high water levels in the creeks and rivers and unstable cliff faces. Locally, conglomerate and sandstone beds appear to have eroded into underlying strata suggesting channel activity. Other notable features include preserved plant fragments, cross-stratification, and graded bedding. The best exposures of Tuttle Formation, as well as the most easily accessible, occur on Trail River and Tetlit Creek.

Lutchman (1977) suggested Tuttle Formation has a fluvio-deltaic origin based on study of drill core, well logs, and cuttings. Current field investigations support the interpretation of Hills and Braman (1978) that strata of Tuttle Formation on Trail River were deposited as turbidite currents or sediment gravity flows that began during deposition with Imperial Formation. The exposure where this is best observed occurs near the Imperial-Tuttle transition and is dated as latest Frasnian to early Famennian (Utting, 2008a). Supporting evidence here includes: the presence of repeated fining-upward sequences displaying partial Bouma sequences with divisions A through C being most common (Bouma, 1962); load casts, flutes, and tool marks on bases of beds; sharp erosional bases; parallel-sided sandstone beds that vary little in thickness; and large-scale soft sediment deformation features (i.e., intraformational slump folds). Bouma sequences in Tuttle Formation commonly consist of massive to cross-bedded granular conglomerate at the base (T_A), grading upwards to cross- or parallel-bedded, medium-grained sandstone (T_B), with fine- to very fine-grained sandstone (T_C), and locally shale or rippled siltstone at the top (T_{DE}; Figure 12).

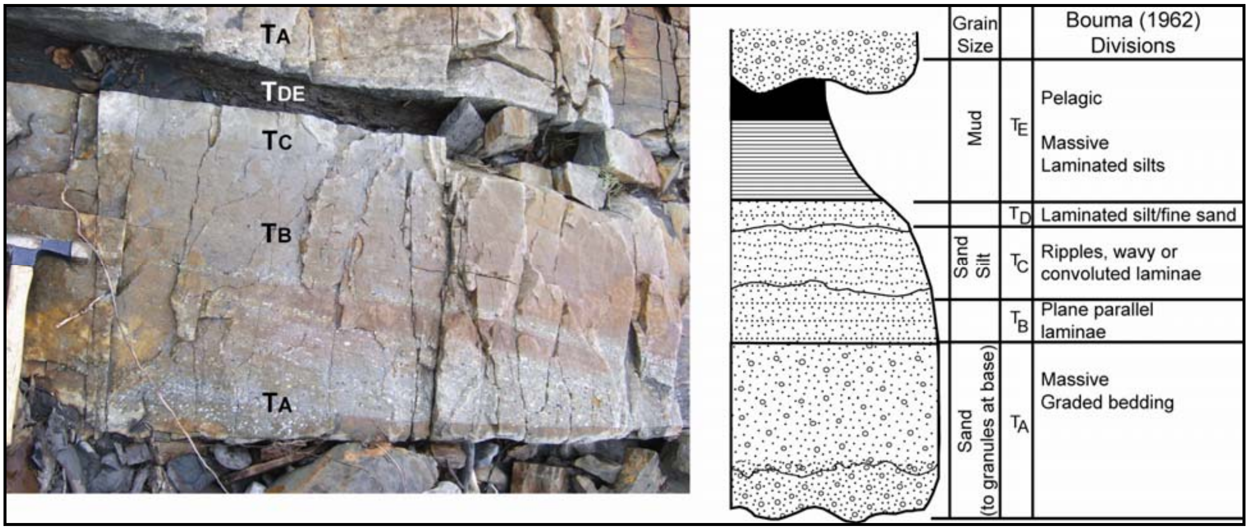


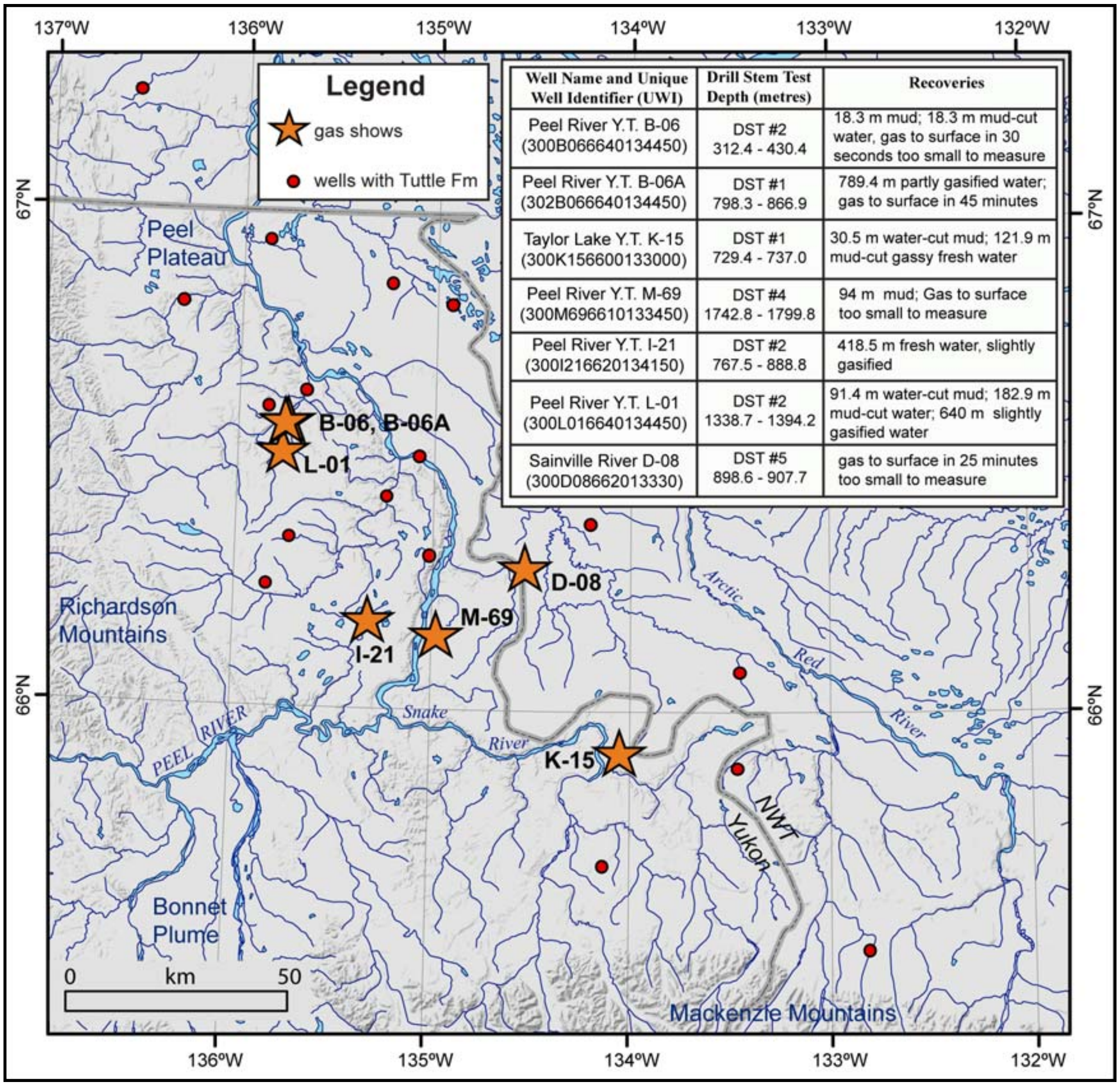
Figure 12. *Bouma sequence within Tuttle Formation, Trail River. These sequences, stacked on top of one another in the section, typically exhibit either massive or parallel- to cross-bedded granular sandstone (TA), grading into medium-grained sandstone with parallel- to cross-beds (TB), overlain by fine- to very fine-grained rippled sandstone (TC), and finally occasional mudstone (TDE). The cartoon above right is a "complete turbidite" modified from Walker (1979) and Bouma (1962). Hammer is 30 cm long.*

To the southeast, along the northern front of the Mackenzie Mountains, early Tournaisian (Utting, 2008a) sandstone above Imperial Formation mapped as 'M0' has been suggested to be correlative with Tuttle Formation (Pugh, 1983; Norris, 1984). Based on a limited number of exposures visited (Snake River and scattered outcrop on ridges to the east and west) these strata appear to have been deposited distal to Tuttle Formation. Well-sorted sandstone with subround to rounded grains of predominantly quartz with minor chert in 'M0' suggests this. The environment in which the sandstone was deposited suggests that energy levels were much lower than to the north allowing for the preservation of abundant fossilized burrow traces and ripple marks. Locally, coal was reported in 'M0' (Norris, 1984) although this was not confirmed in this present study.

PETROLEUM SYSTEMS

Tuttle Formation has historically been an exploration target in both Peel area and Eagle Plain. Here, minor gas has been detected from Tuttle Formation in six Yukon wells and one Northwest Territories well (Figure 13).

Previous petroleum resource assessments (NEB, 2000; Osadetz et al., 2005) of the northern Yukon's Peel area have suggested that gas is the most prospective hydrocarbon resource in the area with little to no potential for oil in Paleozoic clastics. Osadetz et al. (2005) suggest the succession of strata containing Tuttle Formation east of the Trevor fault constitutes a significant conceptual play for natural gas with the potential for a favourable stratigraphic component of entrapment. Recent field investigations have identified the presence of oil-stained sandstone in Tuttle Formation on Trail River, Yukon. Petroleum systems within Imperial Formation are discussed in Chapters 7 and 10 (this volume).



Well Name and Unique Well Identifier (UWI)	Drill Stem Test Depth (metres)	Recoveries
Peel River Y.T. B-06 (300B066640134450)	DST #2 312.4 - 430.4	18.3 m mud; 18.3 m mud-cut water, gas to surface in 30 seconds too small to measure
Peel River Y.T. B-06A (302B066640134450)	DST #1 798.3 - 866.9	789.4 m partly gasified water; gas to surface in 45 minutes
Taylor Lake Y.T. K-15 (300K156600133000)	DST #1 729.4 - 737.0	30.5 m water-cut mud; 121.9 m mud-cut gassy fresh water
Peel River Y.T. M-69 (300M696610133450)	DST #4 1742.8 - 1799.8	94 m mud; Gas to surface too small to measure
Peel River Y.T. I-21 (300I216620134150)	DST #2 767.5 - 888.8	418.5 m fresh water, slightly gasified
Peel River Y.T. L-01 (300L016640134450)	DST #2 1338.7 - 1394.2	91.4 m water-cut mud; 182.9 m mud-cut water; 640 m slightly gasified water
Sainville River D-08 (300D08662013330)	DST #5 898.6 - 907.7	gas to surface in 25 minutes too small to measure

Figure 13. *Map highlighting wells with reported gas shows (stars) in Tuttle Formation (Government of Canada, 1980).*

Structural Styles

This study did not address the structural geology in western Peel area; a synopsis of the structure here is presented by Osadetz et al. (2005). Regional structural elements to the east are discussed in Chapter 2 (this volume). Major structural elements of Peel Plateau include the Richardson Mountains to the west and the Mackenzie Mountains to the south. The eastern extent of the Richardson Mountains is marked by the Trevor fault which was mapped as a normal fault (Norris, 1981b; 1984) and then later, based on examination of seismic sections, interpreted as a westerly verging antithetic thrust above a larger east-verging fault (Osadetz et al., 2005). The structural style along the northern Mackenzie Mountains is complex and features several generations of faulting, resulting in repeated portions of the Upper Devonian stratigraphic succession in several places (Lemieux et al., 2007). A detailed structural study based on seismic interpretation and outcrop examination of Peel area adjacent to the Richardson and Mackenzie mountains would greatly enhance the understanding of hydrocarbon trapping potential.

Hydrocarbon Shows

No previous record of oil shows in Paleozoic strata are known from the literature, although solid hydrocarbon or bitumen are reported in borehole M-69 at 960.7 m (3152 feet) and 1586.2 m (5204 feet) in the M-69 well history report (Indian and Northern Affairs, 1974). Oil-stained sandstone samples were collected from Tuttle Formation on Trail River, Yukon near the mapped Trevor fault (UTM 492479, 7371153, NAD83, Zone 8). A total of five oil-stained samples collected from an active rock fall below an outcrop are stained dark brownish grey, are very porous (over 16%), and have strong petroliferous odours. This outcrop was mottled light grey and dark brownish-grey and was coated with a light yellow residue, but the authors were unable to access the cliff face and could not confirm if the outcrop was oil-stained. Grain size of the oil-stained samples ranges from fine- to coarse-grained sandstone, with moderate to poor sorting. Also, an oil-stained siltstone sample of Ford Lake Shale was collected from Aghoo Creek (UTM 512907, 7328592, NAD83, Zone 8). These samples were analysed at the GSC – Calgary's Organic Geochemistry Laboratory. Preliminary biomarker analyses of solvent extract results indicate that the oil stain on samples from Tuttle Formation and Ford Lake Shale is derived from a potential Upper Paleozoic marine source rock (K.G. Osadetz, pers. comm., 2008). Upper Paleozoic marine strata include Canol, Imperial, and Tuttle formations and Ford Lake Shale. The results indicate that these strata have excellent source rock potential based on source rock richness (HC yield >80 mg/g total organic carbon). In terms of source rock maturity, three Tuttle samples and the Ford Lake Shale sample are over 55% HC, confirming the presence of oil stains, while the other results indicate marginal maturity to within the main hydrocarbon generation stage (Table 5).

Sample #	%C Org	Ext Yield (mg/g)	HC Yield	%HC	PR/PH	Formation	Lithology
07TNTTR03A	0.57	1141.2	321.1	28.14		Tuttle	sandstone with oil stain
07TNTTR05D	1.44	1288.2	683.2	53.03		Tuttle	sandstone with oil stain
07TNTTR05F	0.62	1260.9	393.9	31.23		Tuttle	sandstone with oil stain
07TNTTR05J	1.55	1256.3	666.4	53.04		Tuttle	sandstone with oil stain
06TNTTR030A	1.48	1150	759.9	66.08		Tuttle	sandstone with oil stain
07TNTACH34B	3.29	318.2	255.1	80.16	1.53	Ford Lake Shale	siltstone

Table 5. *Results from biomarker analysis and corresponding solvent extract gross composition results. HC Yield = hydrocarbon yield; %HC = hydrocarbon percent (suggests source rock maturity); PR/PH = pristane/phytane ratio.*

In the vicinity of the mapped Trevor fault zone on Trail River, there is a very strong sulphur smell in the air over several kilometres that can be detected from a helicopter. Here, Tuttle Formation sandstone is locally coated with a yellowish-orange and white "popcorn-like" coating, particularly along fractures and joints. The rocks in the river are locally coated in a whitish-grey residue that may be indicative of petroleum seepage (K.G. Osadetz, pers. comm., 2008).

Source rock geochemistry

Source rock potential has been determined for outcrop and well cutting samples collected from Upper Paleozoic strata in the eastern Richardson Mountains, Peel Plateau, and northern Mackenzie Mountains. Analyses were conducted at the Organic Geochemistry Labs of GSC - Calgary on a Delsi Rock-Eval 6 unit equipped with a total organic carbon (TOC) analysis module to determine the type of kerogen, amount of organic carbon, and thermal maturity of these strata. Full results are published in Allen et al. (2008) and Allen and Fraser (2008). Figure 14 provides a summary of samples analysed for Rock-Eval/TOC from each unit as well as the number collected from subsurface (139) versus outcrop (70).

To understand whether hydrocarbon generation will occur, it is important to consider the amount and type of organic matter. TOC is a measure of the quantity of organic carbon within a rock, expressed as weight percent of rock (Peters et al., 2005). All results with low TOC values (i.e., < 0.3 wt%) or low S2 parameters (i.e., < 0.2 mg HC/g rock) have been removed from the interpretations below. If TOC is less than 0.3 wt% then all parameters have questionable significance and the analysis suggests no potential. The type of kerogen, or organic matter, present can be determined with parameters derived from Rock-Eval pyrolysis (i.e., hydrogen index [HI]). Identifying the type of organic matter present is important in determining if a rock is prone to generate oil and/or gas. S2 values below 0.2 mg HC/g rock have correspondingly unreliable T_{max} values due to the broad shape of the S2 peak (Peters, 1986).

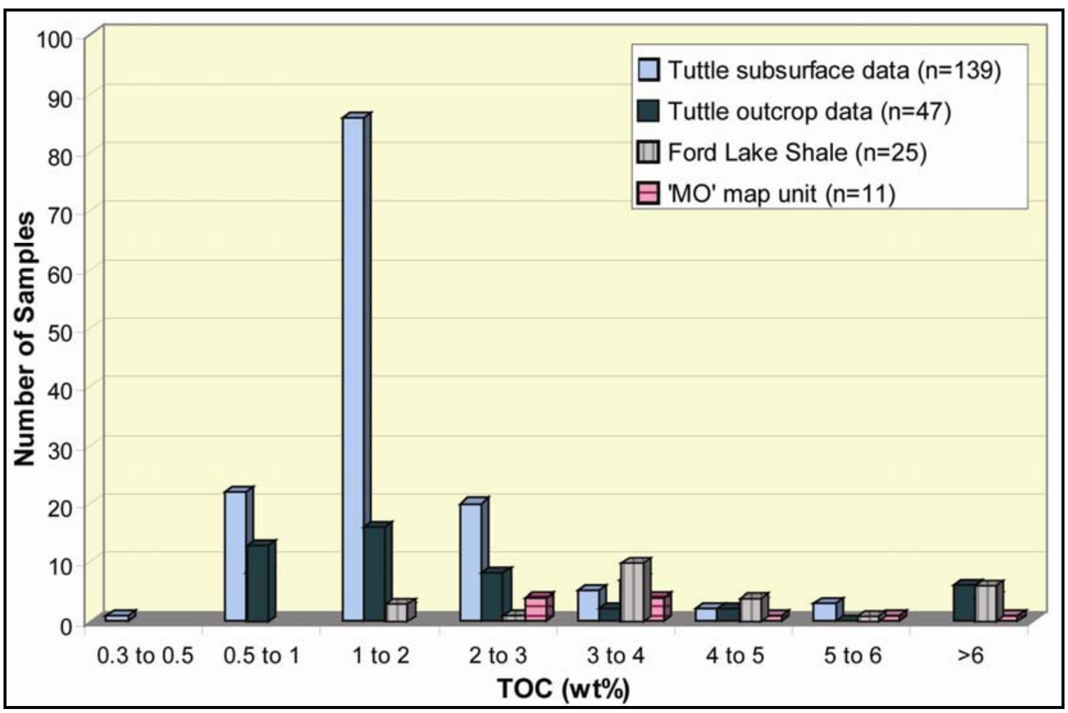


Figure 14. *Histogram of total organic carbon (TOC) values from shales of various formation/map units. Note that Tuttle Formation samples have been subdivided into those collected from well cuttings (subsurface) versus those collected from outcrop. Ford Lake Shale and 'M0' samples were collected from outcrop as those units are not recognized in the subsurface. Complete results for well samples are reported in Allen et al. (2008); those of outcrop samples are in Allen and Fraser (2008). n = number of samples.*

Tuttle Formation

Forty-seven surface and 139 subsurface samples of Tuttle Formation were submitted for Rock-Eval pyrolysis. Tuttle Formation strata range from 0.48 wt% to 40.25 wt% TOC, with most values between 1 to 2 wt% (Figure 14). Based on Rock-Eval results, Tuttle Formation contains predominantly type III, gas-prone kerogen with lesser type II, oil- and gas-prone kerogen, with HI values of 14 mg HC/g TOC to 458 mg HC/g TOC (Figures 15, 16). Tuttle strata on Road River are liptinite-rich with high amounts of sporinite and evidence of hydrocarbon fluid inclusions in some quartz fractures, which supports a type II kerogen type; bitumen, exudatinite, and resinite are also present, as well as reworked inertinite and pyrobitumen (Organic Geochemistry and Organic Petrology Laboratory [OGOPet Lab], pers. comm., 2007; Coal and Maceral and Vitrinite Reflectance Database [J. Reyes, analyst]; Geoscience Data Repository; Earth Sciences Sector; Natural Resources Canada). The unit demonstrates good to very good source rock potential for oil and/or gas. The oil-stained sandstone samples collected on Trail River have S1 values of 1.88 HC/g rock to 6.8 mg HC/g rock that are a reflection of free organic compounds, confirming the presence of oil and/or gas trapped in pores.

Ford Lake Shale

Twenty-five samples, collected from surface exposures of Ford Lake Shale, were analysed. The thick, black to dark grey shale succession yielded 1.46 wt% TOC to 12.17 wt% TOC, averaging 4.65 wt% TOC (Figure 14). Kerogen, based on Rock-Eval results, is determined to be type II or oil-prone, with HI values ranging from 26 mg HC/g TOC to 326 mg HC/g TOC (Figures 15, 16). Sixteen samples had S1 values of 1.12 mg HC/g rock to 5.07 mg HC/g rock. A representative sample of Ford Lake Shale from Aghoo Creek having an S1 value of 5.07 mg HC/g rock was confirmed to be oil-stained as reported above (Hydrocarbon Shows section).

‘M0’ map unit

‘M0’ map unit has only been identified at surface, where Norris (1982a; 1982b) mapped the unit on the northern flank of the Mackenzie Mountains. ‘M0’, though largely sandstone, has numerous thin shale interbeds from which 11 samples were collected and analysed at GSC - Calgary. TOC values for ‘M0’ range from 2.10 wt% to 11.31 wt% (average is 4.17 wt%), suggesting the strata are favourable in terms of source rock potential (Figure 14). The organic matter is type III, or gas-prone, based on HI values (40 mg HC/g TOC to 135 mg HC/g TOC; Figures 15, 16).

Thermal maturation

T_{max} values derived from Rock-Eval pyrolysis correspond to the oven temperature (ºC) at which the maximum amount of S2 hydrocarbons is generated (Peters, 1986). T_{max} can be used to estimate the level of thermal maturity of sedimentary sequences; however, caution should be used with samples that have S2 values below 0.2 mg HC/g rock (Peters, 1986) and these values have not been included in the interpretations below. T_{max} values for this study have been previously published in Allen et al. (2008) and Allen and Fraser (2008).

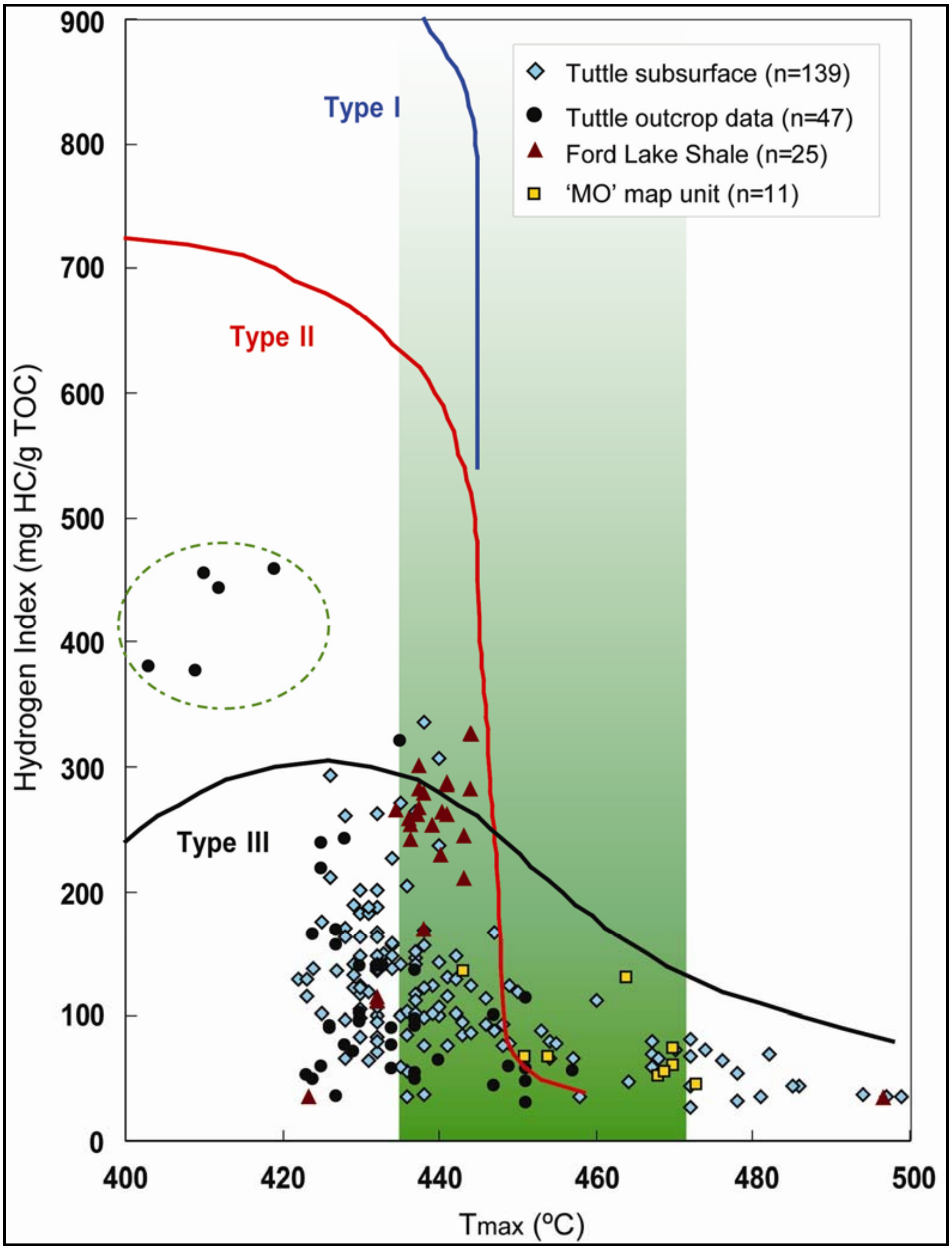


Figure 15. *Hydrogen Index versus T_{max} cross-plot for Tuttle Formation, Ford Lake Shale, and 'M0' map unit. This plot indicates that Tuttle Formation contains predominantly type III kerogen (gas-prone), Ford Lake Shale contains type II and III kerogens (oil- to gas-prone), and 'M0' contains type III kerogen (gas-prone). All fall within the oil window (green box) in terms of thermal maturity, although Tuttle Formation spans the spectrum of immature to overmature with respect to hydrocarbon generation. The circled samples with high HI values are the oil-stained samples collected from Trail River. Oil window parameters from Espitalité (1986). All samples with S2 values < 0.2 mg HC/g rock and TOC values < 0.3 wt% have been removed from the dataset. n = number of samples.*

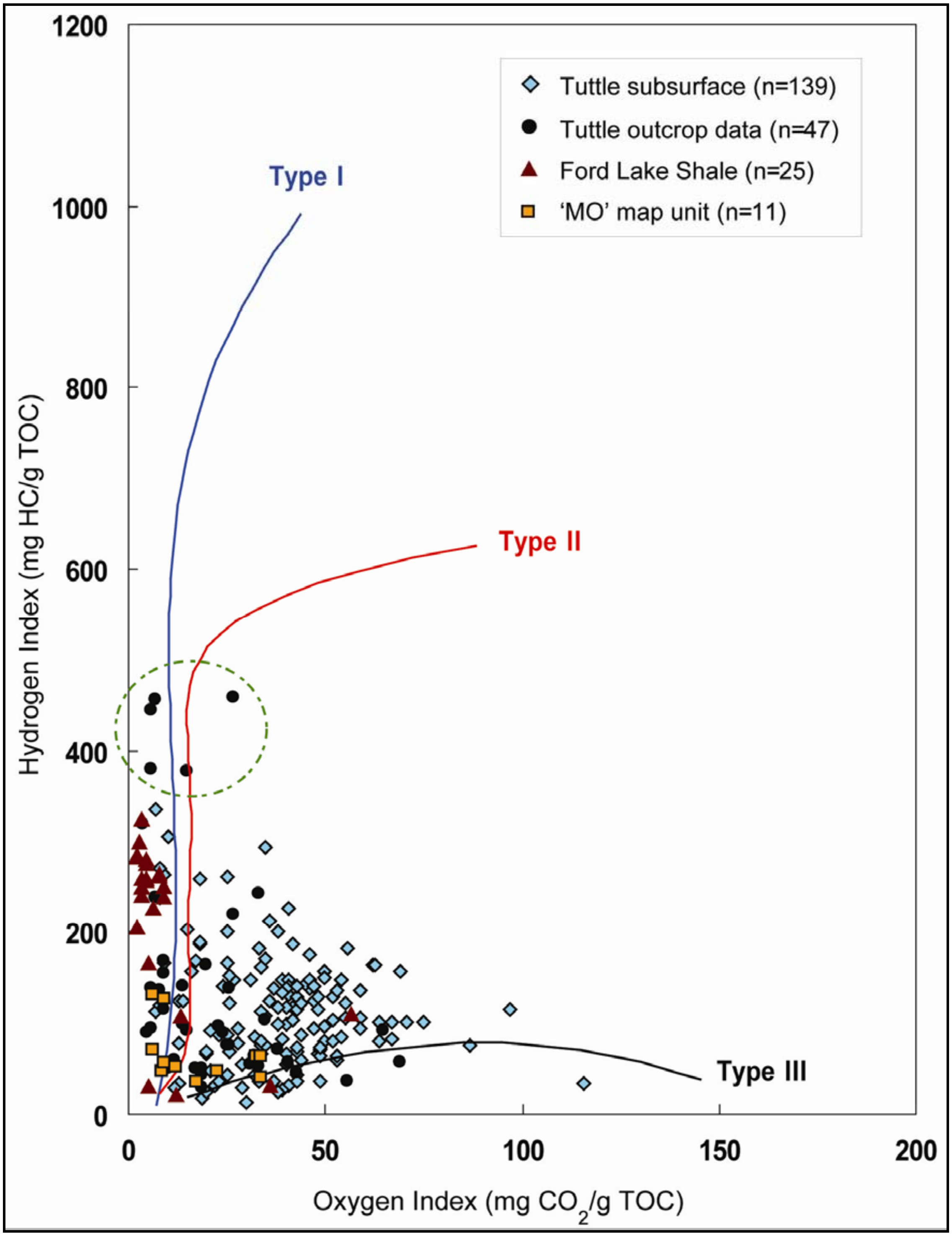


Figure 16. *Oxygen Index versus Hydrogen Index cross-plot indicating kerogen types of Tuttle Formation, Ford Lake Shale, and 'M0' map unit. Tuttle Formation is a range of types II and III (oil- to gas-prone), Ford Lake Shale is predominantly type II (oil- to gas-prone), and 'M0' map unit is largely type III (gas-prone). The circled samples with high HI values are the oil-stained samples collected from Trail River. All samples with S2 values < 0.2 mg HC/g rock and TOC values < 0.3 wt% have been removed from the dataset. n = number of samples.*

Thermal Alteration Indices (T.A.I.) and vitrinite reflectance values (%Ro) are also useful thermal maturity indicators. T.A.I. corresponds to maturity-induced colour changes in spores and pollen (Utting et al., 1989); %Ro values, a measure of thermal maturity shown by the optical properties of vitrinite, were determined by the Organic Geochemistry Lab at GSC - Calgary. Preliminary investigations suggest that at surface, there is a division in the thermal maturity of Tuttle Formation and Ford Lake Shale versus that of underlying Canol and Imperial formations (Figure 17). T.A.I. and vitrinite reflectance conducted on outcrop samples of Canol and Imperial formations suggest these units are in the dry gas zone in terms of thermal maturity. Overlying Tuttle Formation and Ford Lake Shale strata to the east and north are generally less thermally mature with T.A.I. values of 2 (Utting, 2008b) and are within the oil window. Tuttle strata to the southeast have reached a much higher thermal maturation (Figure 17).

In order to study this trend in more detail, subsurface well cutting samples were retrieved from 18 of the 19 wells in Yukon's Peel area for Rock-Eval/TOC analyses at approximately 30 m intervals (Allen et al., 2008). Rock-Eval derived T_{max} values indicate that Imperial Formation typically increases in thermal maturity with depth. The top of this formation generally falls within the oil window while lower Imperial strata are either approaching or within the dry gas generation zone. By contrast, Imperial Formation samples from outcrop (adjacent to faulting and mountains) are all within the dry gas zone suggesting that the apparent increase in maturity can be attributed, in part, to structure rather than directly to overburden thickness.

Tuttle Formation

At surface, T.A.I. values derived from palynology for all Tuttle Formation samples are 2 to 2+ (Utting, 2007; 2008b), suggesting ranges from thermally immature with respect to hydrocarbon generation to within the oil window (Tables 1, 3; Figure 17). These values are consistent with T_{max} values (403ºC to 460ºC) and vitrinite reflectance results (0.61 %Ro to 0.65 %Ro; OGOPet Lab, pers. comm., 2007).

In almost all wells examined, Tuttle Formation strata lie within the oil window based on T.A.I. values of 2 (Ro% equivalent of 0.55) with the exception of K-15 and A-42 wells, the only boreholes that lie east of Snake River in Yukon. Tuttle strata in borehole K-15 have a T.A.I. of 3/3+ (%Ro equivalent of 1.5) and in A-42 have a T.A.I. of 3+/4- (%Ro equivalent of 1.8), both in the dry gas zone (White, 2007; Utting, 2008a). To the east of these wells in the adjacent NWT, Tuttle strata in boreholes Cranswick A-22, South Peel D-64, and N. Ramparts A-59 also exhibit high maturity based on vitrinite reflectance data (L.P. Gal, pers. comm., 2008; Chapter 10, this volume). In this region, surface samples of Imperial Formation and overlying 'M0' are also thermally mature with respect to hydrocarbon generation (1.7 %Ro and 1.45 %Ro; OGOPet Lab, pers. comm., 2007). In borehole M-69, another well in the eastern portion of the research area, T_{max} values suggest that Tuttle Formation strata are postmature.

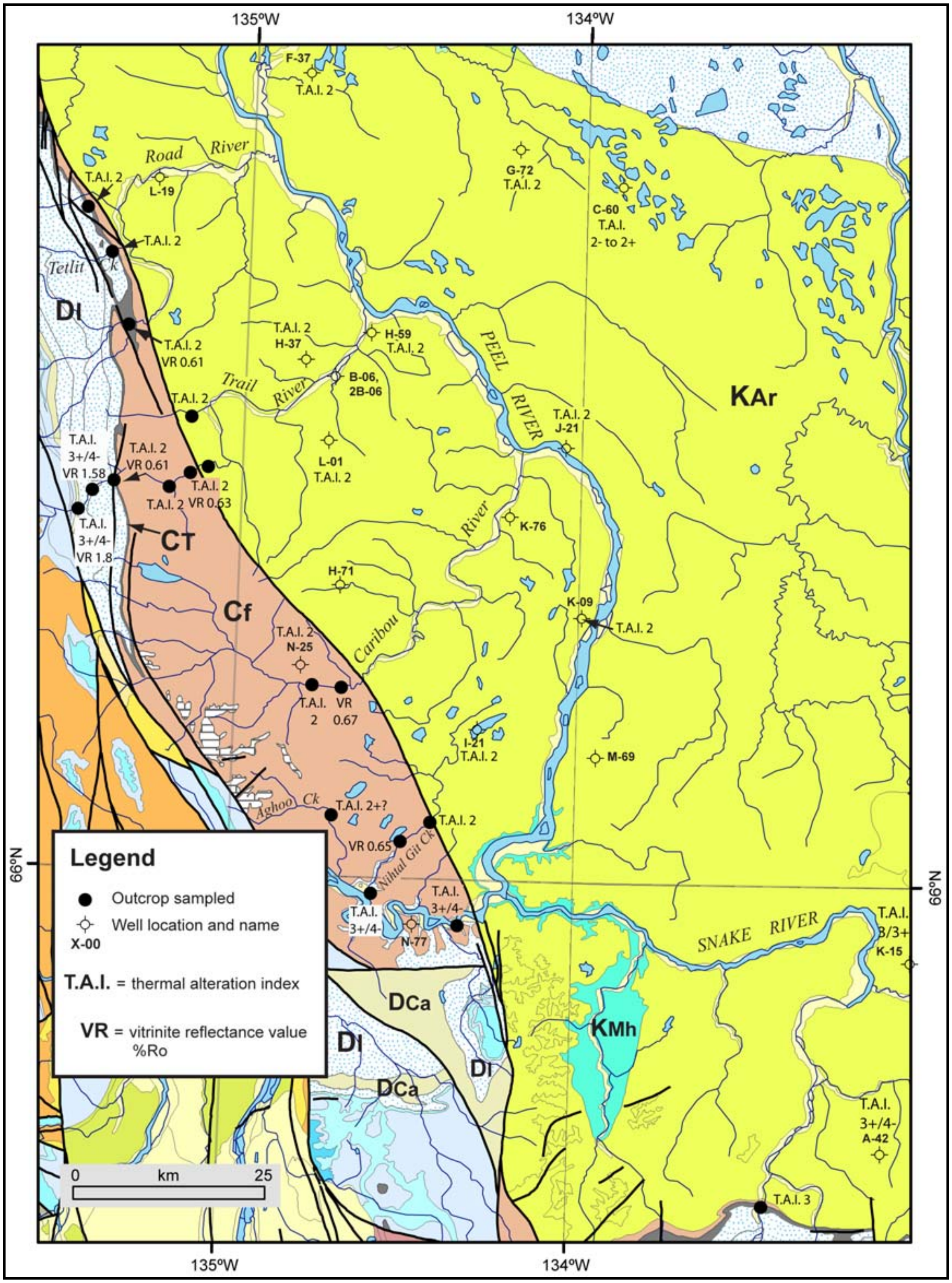


Figure 17. *Thermal maturation of Upper Paleozoic strata based on thermal alteration indices (Utting, 2007; 2008a; 2008b) and vitrinite reflectance (OGOPet Lab, pers. comm., 2007). Note the strata with the highest thermal maturity occur along the flanks of the Richardson and Mackenzie mountains and in the southeast. Map modified from Gordey and Makepeace, 2001. DCa = Canol Formation; DI = Imperial Formation; CT = Tuttle Formation; Cf = Ford Lake Shale; KAr = Arctic Red Formation; KMh = Martin House Formation.*

Ford Lake Shale

With the exception of two samples from Peel River, strata of Ford Lake Shale ranks within the oil window or is just entering the oil window, with T_{max} values ranging from 432ºC to 444ºC. These values are consistent with T.A.I results of 2 (%Ro equivalent of 0.55; Utting, 2007) and measured vitrinite reflectance values of 0.65 %Ro to 0.78 %Ro (OGOPet Lab, pers. comm., 2007; Tables 1, 3; Figure 17).

'M0' map unit

Shale of 'M0' map unit has T_{max} values of 443ºC to 480ºC, suggesting 'M0' is within the oil window to postmature with respect to hydrocarbon generation. T.A.I. values of 'M0' samples correspond to the T_{max} values. All 'M0' samples have a T.A.I. of 3 or a vitrinite reflectance equivalent of 1.45 %Ro which is at the boundary of the oil window and the dry gas zone (Utting, 2008b).

Reservoir rock potential

Sandstone and conglomerate samples were analysed for porosity and permeability at AGAT Laboratories, Core Services Division in Calgary using standard procedures (AGAT Laboratories, 2006; 2007). Samples collected represent a wide range of grain sizes from various Tuttle Formation outcrops and core, as well as sandstones of Imperial Formation and 'M0' map unit (see Allen and Fraser, 2008 for more in depth discussion of Imperial Formation samples). Samples submitted were analysed, when possible using 38.1 mm to 25.4 mm (1.5 inch to 1.0 inch) plugs. Porosity and permeability results have previously been published in Fraser and Allen (2007) and Allen and Fraser (2008).

Tuttle Formation

Outcrop samples

The coarse fraction of Tuttle Formation has a wide range of grain sizes ranging from fine-grained sandstone to small pebble conglomerate. Forty-six field samples, divided into six grain size classes, were analyzed for porosity and permeability; results are plotted on Figure 18. Porosity ranges from 2% to 26%, with permeability ranging between 0 mD and 127 mD. Reservoir potential, based on porosity and permeability, varies from negligible to very good using reservoir classes of Levorsen (2001). From this cross-plot, it is apparent that grain size does not significantly influence porosity and permeability values. Thin section analyses of Tuttle sandstones from outcrop show the presence of intergranular porosity as well as intragranular porosity within weathered chert grains. Oil-stained chert grains and what are likely small oil accumulations can be found in the pores of some sandstone samples (Figure 19). In samples with lower porosity, the quartz to chert ratio is higher, and primary porosity is often restricted by quartz overgrowths and infilled by clay minerals.

Outcrop-based predictions of subsurface reservoir quality have certain limitations; including differences in diagenetic history and pore system evolution between surface and subsurface samples, and recent outcrop diagenesis (leaching, cementation, sediment infill, etc.) that may enhance or destroy porosity and permeability otherwise present at depth (Tobin, 1997). Hence, these results are an approximation of subsurface reservoir quality for a frontier region with otherwise sparse subsurface data.

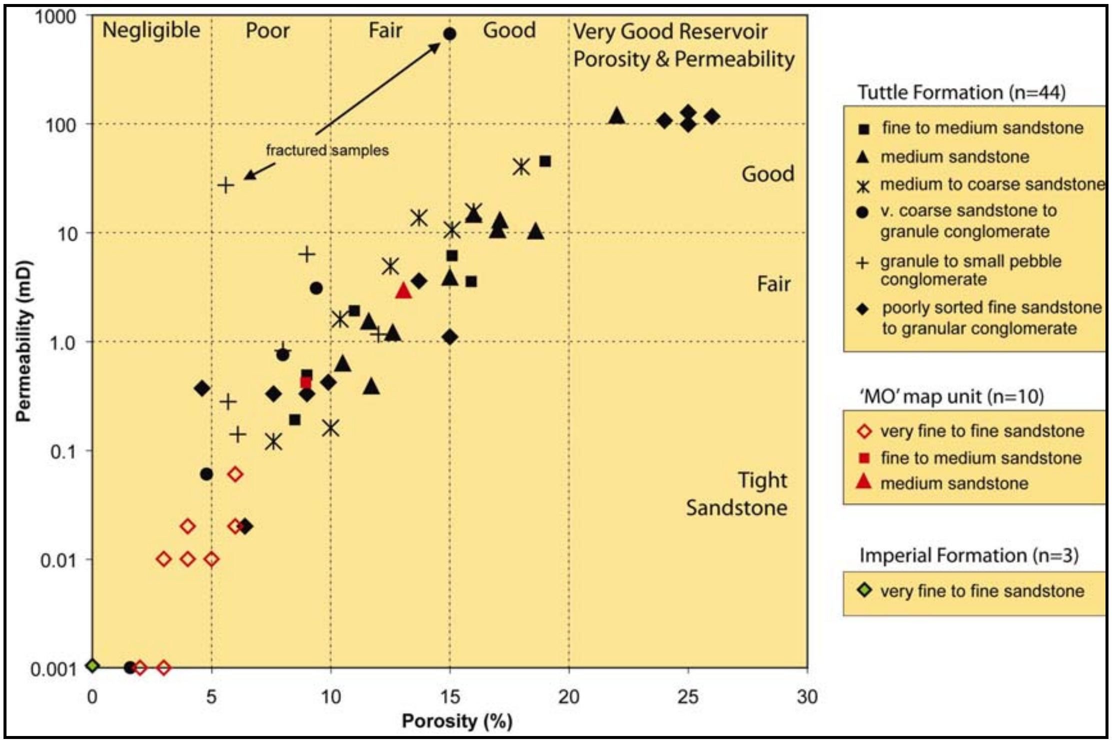


Figure 18. *Porosity/Permeability cross-plot for Imperial and Tuttle formations and 'M0' map unit samples. Data from AGAT Laboratories, conducted on 1.5 inch plug sandstone and conglomerate samples. Reservoir classes after Levorsen (2001). Tuttle Formation has the best reservoir prospects of these units. 'M0' map unit was less favourable, with negligible to fair reservoir potential. n = number of samples.*

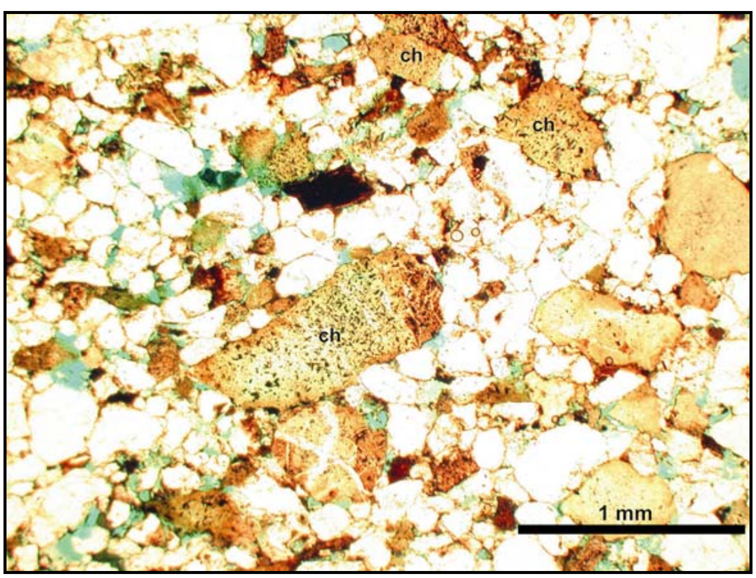


Figure 19. *Thin section photograph of chert- and quartz-rich Tuttle Formation sandstone from Trail River with 17% porosity and 13 mD permeability. Thin section is impregnated with blue epoxy to highlight porosity. Note the hydrocarbon-stained, porous chert grains (ch).*

Drill core samples

Six samples were taken from the coarse-grained fraction of Tuttle Formation from the Peel River Y.T. L-01 well, and one sample each from the K-09 and J-21 wells. Cored intervals in Peel wells are rare and these samples represent all cored intervals from Upper Paleozoic formations in Yukon Peel area wells. These samples were made into thin sections and impregnated with blue epoxy in order to examine lithology and porosity characteristics. Eight photographs were taken for each thin section, and an average porosity was determined for each sample. The eight Tuttle sandstone core samples were then analysed using imaging software to determine an area percent of the thin section that is porous (i.e., highlighted as blue when impregnated with epoxy).

The six sandstone samples analysed from the L-01 well were between depths of 4455.8 feet to 4483.2 feet (1358.1 m to 1366.5 m). Measured porosities of the samples range from 11.1% to 24%. Average grain size over this interval is fine- to medium-grained sandstone. In samples with lower porosity, primary porosity appears to be restricted by quartz overgrowths, calcite cement, and fused grain boundaries. Fused grain boundaries are more abundant between quartz grains, rather than between chert grains. Where chert grains are fused with one another, the contact does not appear to be as tight as a quartz-quartz contact, sometimes allowing a thin vein of porosity. In these zones of lower porosity, stylolites are observed locally. In areas of higher porosity, secondary porosity plays an important role, particularly due to the weathering of chert grains (Figure 20). Chert grains weather both around their margins, as well as within their boundaries. The dissolution of these grains, combined with any primary porosity, appears to provide a well-connected pore distribution system, thereby enhancing permeability.

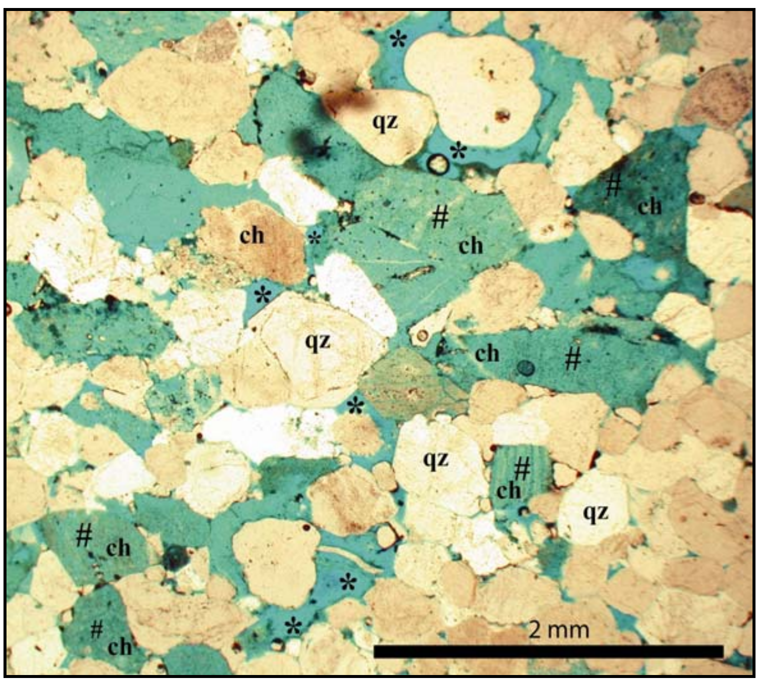


Figure 20. *Stained thin section of poorly sorted, massive sandstone from borehole L-01 (4458 foot level). Sandstone of Tuttle Formation exhibits both intergranular (*) and intragranular (#) porosity, the latter observed most frequently in tripolitic chert (ch). The main constituents are tripolitic chert and quartz (qz), giving the sandstone and other coarse fractions a salt-and-pepper appearance. Thin section is impregnated with blue epoxy to highlight porosity.*

Fine-grained sandstone from the K-09 well was sampled at a depth of 4391.5 feet (1338.5 m). Porosity for this sample measured 7.9%, and is mainly secondary from the dissolution of chert grains. Porosity both within and between chert grains is present. In some cases, entire chert grains have been weathered, resulting in large pore spaces. This sample is generally well-compacted with fused boundaries between quartz grains. Porosity in this sample has been slightly reduced by calcite cement.

One fine-grained sandstone sample was analyzed from the J-21 well at a depth of 2020.7 feet (615.9 m). Porosity from this sandstone was < 3%. This sandstone was very well-compacted with an abundance of fused grain boundaries between chert and also between quartz grains. The small amount of porosity observed is associated with weathering of chert grains. This secondary porosity appears to be greatly reduced due to both calcite and siderite cement found within and between chert grains. This sample has a higher quartz to chert ratio than the other subsurface samples, and quartz overgrowths also play a role in porosity reduction.

From observation of both outcrop and subsurface samples, porosity within Tuttle Formation is both intragranular and intergranular, both greatly influenced by the presence of weathered chert. Where this chert is present in higher amounts, secondary porosity is increased and the effects of quartz cementation are diminished. This investigation shows that the presence of tripolitic chert in Tuttle Formation greatly enhances its reservoir capabilities.

‘M0’ map unit

The coarse fraction of ‘M0’ map unit is typically very fine- to fine-grained sandstone. Ten field samples were analyzed for porosity and permeability with samples ranging from very fine- to medium-grained sandstone. Analyses conclude that reservoir characteristics of ‘M0’ are generally negligible to poor, with only one sample classified as fair (Figure 18). This cross-plot indicates that grain size appears to influence reservoir characteristics; medium-grained sandstone has better reservoir prospects. Porosity values ranged from 2% to 13%, with permeability ranging from 0 mD to 2.6 mD. Thin sections of ‘M0’ sandstone display generally well-compacted quartz-rich sandstone with fused grain boundaries and minor porosity. Primary porosity, where present, is often reduced by quartz overgrowths, clay minerals, and/or calcite cement.

CONCLUSIONS

Upper Devonian to Lower Carboniferous Tuttle Formation contains prospective petroleum source and reservoir rocks. Tuttle Formation consists of intercalated sandstone, conglomerate, and shale. Sandstone and conglomerate of Tuttle Formation have variable porosity and permeability, indicating a range in reservoir rock quality from negligible to very good. The shale component is a 1 wt% to 2 wt% TOC potential source rock within the oil window in terms of thermal maturity. Oil has recently been confirmed in sandstone samples collected from Trail River. Historically, gas shows were encountered in Tuttle Formation while drilling. Further investigations are needed to more clearly understand the structure of the region and implications related to the petroleum system, both along the Richardson and Mackenzie mountains.

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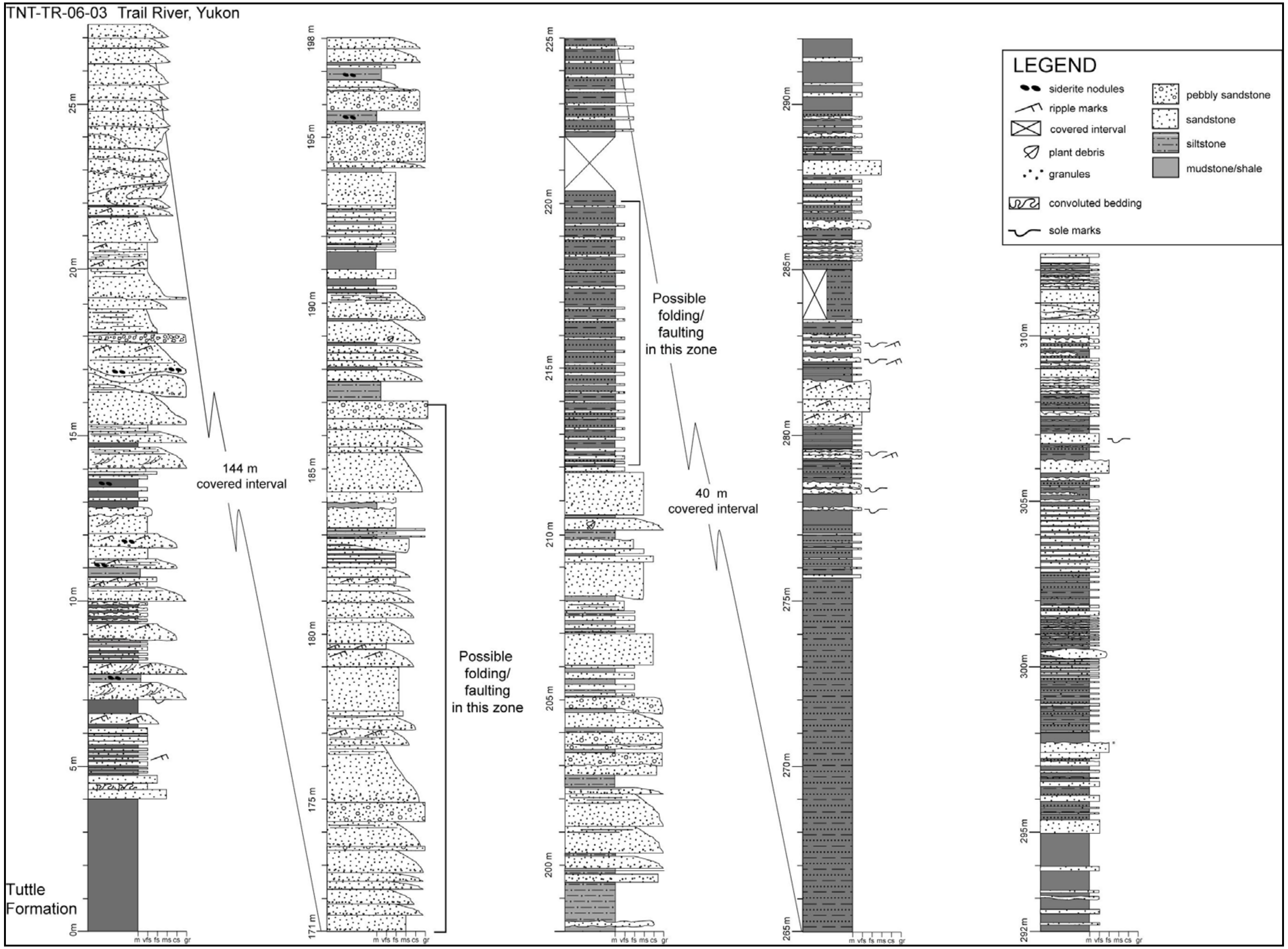
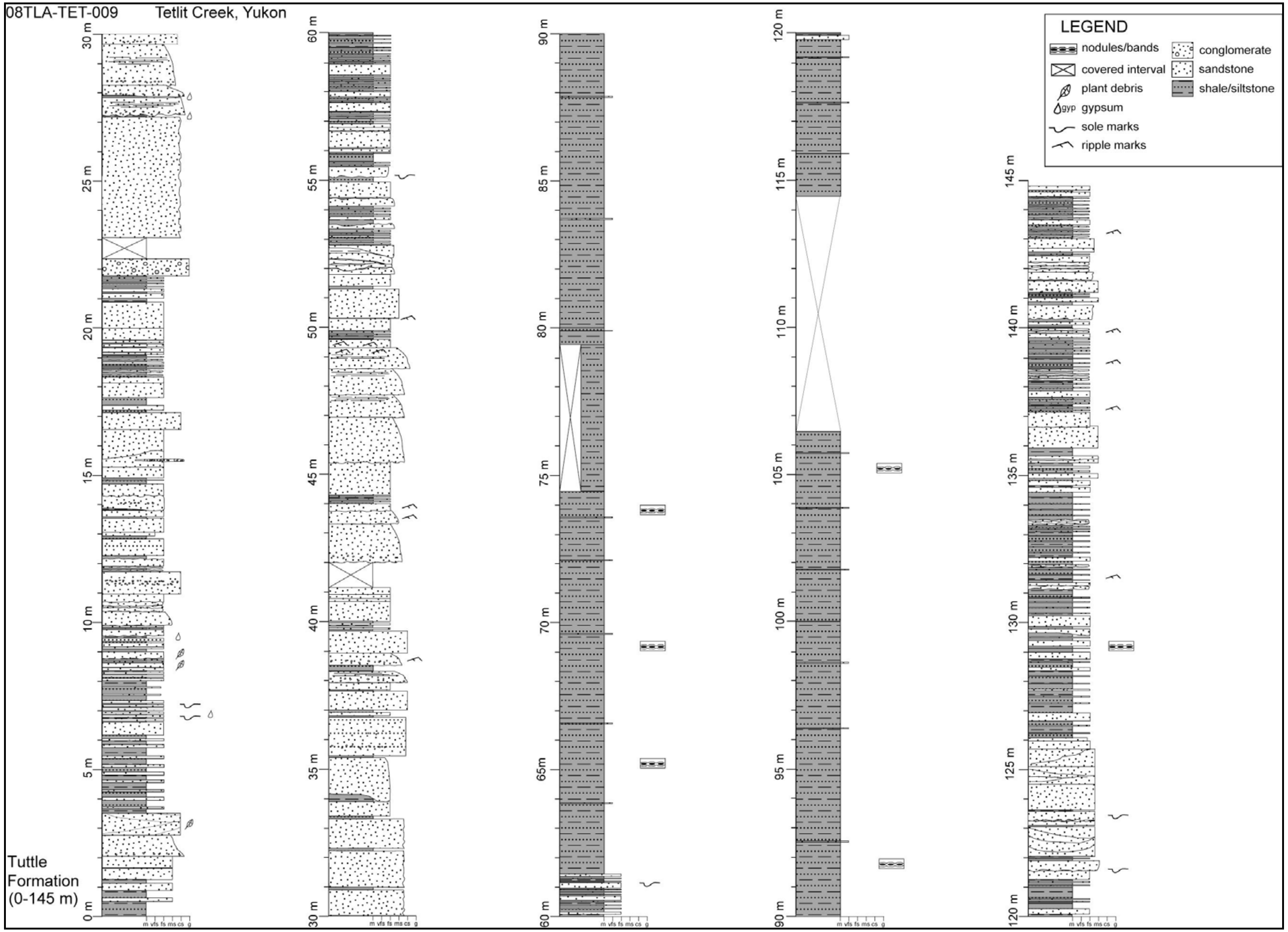
APPENDIX A



Stratigraphic section of Tuttle Formation strata measured on Trail River, Yukon starting at 483250, 7371104 (NAD 83). The first shale interval measured is dated as latest Frasnian to early Famennian and strata above are assigned to the Late Devonian with no further constraint on age determinable from the samples (Utting 2007). The entire section was measured on the northern side of Trail River and coincides with the uppermost portion of the section measured by Norris (1968) on Trail River map sheet (106 L/6).

APPENDIX B



Stratigraphic section of Tuttle Formation strata measured on Tetlit Creek, Yukon starting at 480401, 7399167 (NAD 83). The entire section was measured on the southern side of Tetlit Creek map sheet (NTS 106L/1).

Chapter 9 – Cretaceous Strata and Basal Cretaceous Sandstone Play

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ABSTRACT

Based on new foraminiferal biostratigraphy, Cretaceous strata of the Peel Plateau and Plain regions are sub-divided into two unconformity bound successions. An Albian succession comprises Martin House and Arctic Red formations. A Cenomanian-Turonian succession comprises Slater River and Trevor Formations.

Martin House Formation is informally sub-divided into three units: (1) Tukweye member; (2) basal marine sandstone; and (3) upper Martin House Formation sandstone. The name of Tukweye member is informally proposed here for geographically restricted non-marine deposits at the base of Martin House Formation. Fluvial sandstone and floodplain mudstone, sandstone, and minor coal are preserved along an approximately north-trending corridor interpreted as a paleovalley that records the drainage pattern prior to base level rise. Regional relative sea level rise resulted in deposition of the basal marine sandstone from near the Richardson Mountains to Keele Arch. Facies of the basal marine sandstone indicate a west to east transition from offshore to barrier bar, lagoon, and tidal flat. The eastern culmination of this lateral facies change was the emergent shoreline on the edge of Keele Arch, a paleohigh. Following overall transgressive deposition of the basal marine sandstone and an overlying approximately 20 m thick shale interval, sandstones of upper Martin House Formation were deposited by westward prograding shorefaces, indicated by a westward sandstone to shale transition. The interpretation of Keele Arch as a paleohigh during deposition of Martin House and lower Arctic Red formations is consistent with seismic reflectors from Martin House Formation and lower Arctic Red Formation that onlap Keele Arch.

Arctic Red Formation is a shale-dominant succession that tapers from up to 1000 m thick in the western part of the study area to 0 m over part of Keele Arch, in part due to a westward-deepening basin geometry during deposition. Sans Sault Member is interpreted as a shoreface

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sandstone containing hummocky cross-stratification that occurs within Arctic Red Formation in the eastern portion of the study area.

Slater River Formation, newly recognized within Peel area, refers to a Cenomanian shale interval up to 500 m thick that was previously mapped as the upper portion of Arctic Red Formation. The base of this succession is postulated, based on outcrop and well log correlation, to correlate to an angular unconformity interpreted from seismic data. The unconformity truncates strata eastward, in part accounting for the eastward tapering geometry of underlying Arctic Red Formation.

Trevor Formation is an over 700 m thick succession of 18 classic offshore to shoreface parasequences. Clinoforms at the base of Trevor Formation dip eastward indicating that the shelf was established by west to east progradation, which would have sourced sediment from the montane regions to the west and directly opposite to the westward-deepening Albian basin geometry. The unconformity at the base of the Cenomanian-Turonian succession therefore separates two quite distinct depositional systems.

Three conceptual Cretaceous plays are identified. The Tukweye member incised valley play is defined by a Tukweye member fluvial sandstone reservoir, Martin House or Arctic Red formations shale seal, and Arctic Red Formation source. The play is geographically restricted to the poorly defined distribution of Tukweye member. The reservoir for the basal Cretaceous sandstone play is the basal marine sandstone of Martin House Formation, which is regional in distribution, but of favourable thickness east of Arctic Red River. The source and seal is Arctic Red Formation. A Trevor Formation tight sandstone play is geographically restricted to areas where total Cretaceous strata exceed 1 km in thickness. In Peel area the youngest exposed rocks are Trevor Formation, and therefore potential reservoirs are quite shallow; this represents a high preservation risk.

9.1 INTRODUCTION

Cretaceous strata represent a large portion of the map area of Peel Plateau and Plain regions (Peel area; Figure 9.1.1). Prior to this study, these Cretaceous strata had not been subject to detailed sedimentology, key stratigraphic questions remained (e.g., Trevor Formation did not have a type section but rather a type area), and the age of stratigraphic units was not well defined.

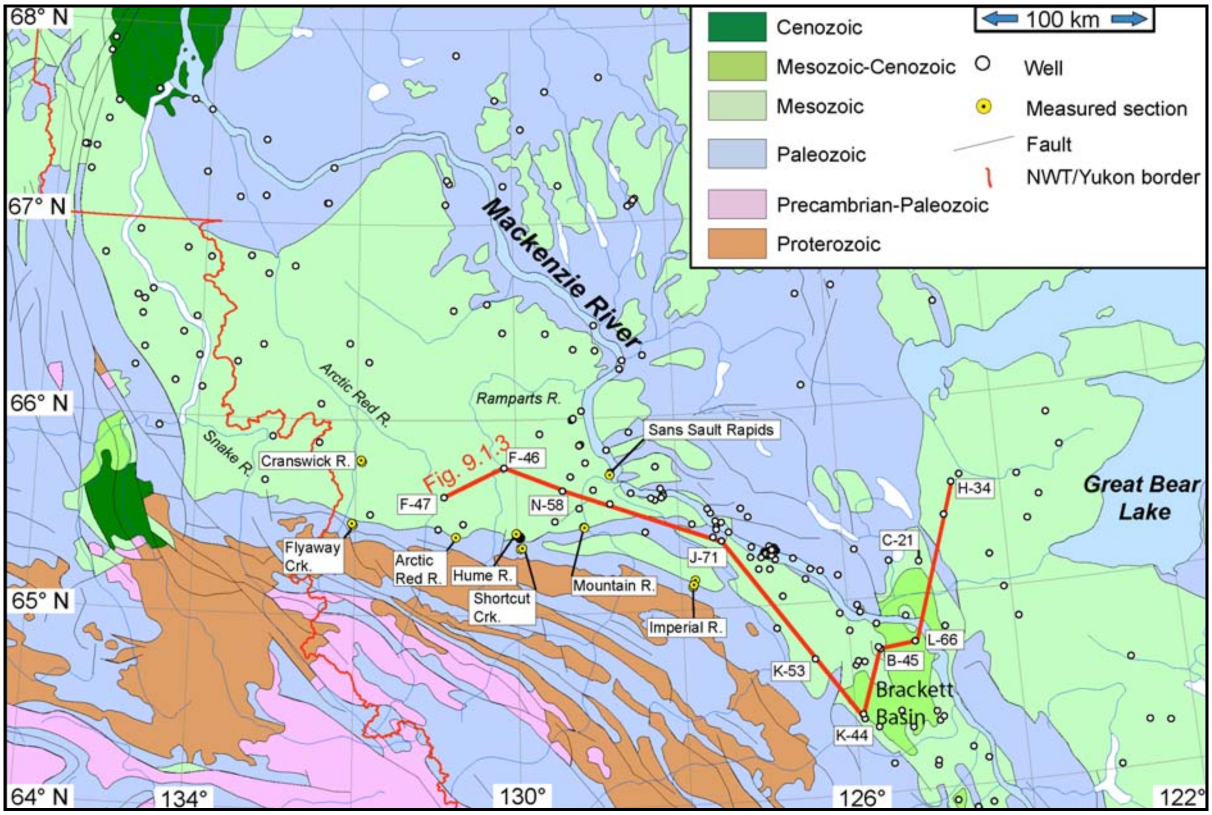

Figure 9.1.1. *Geological map of the study area (geology after Wheeler et al., 1997), showing pertinent wells and outcrop locations. Cross-section line corresponds to the regional cross-section of Figure 9.1.3.*

In Peel area Cretaceous deposits are subdivided into four formations (Figure 9.1.2). At the base of the succession, Martin House Formation is a transgressive sandstone-dominated interval generally less than 50 m thick (Figure 9.1.3). We informally designate non-marine deposits of Martin House Formation as Tukweye member (section 9.3). Arctic Red Formation comprises shale up to 600 m thick and includes very minor interbedded sandstone intervals of the Sans Sault Member that are generally less than 10 m thick. Slater River Formation is newly proposed for the region, consisting of an up to 500 m thick shale interval that unconformably overlies shale of Arctic Red Formation (section 9.2). Trevor Formation conformably overlies Slater River Formation and is an interbedded sandstone and mudstone interval up to 800 m thick.

In this chapter we present stratigraphic revisions based on biostratigraphy (section 9.2), report on detailed sedimentology (section 9.3), provide a stratigraphic synthesis based on outcrop, well logs, and seismic data (section 9.4), and explore the petroleum geology of Cretaceous strata in Peel area (section 9.5).

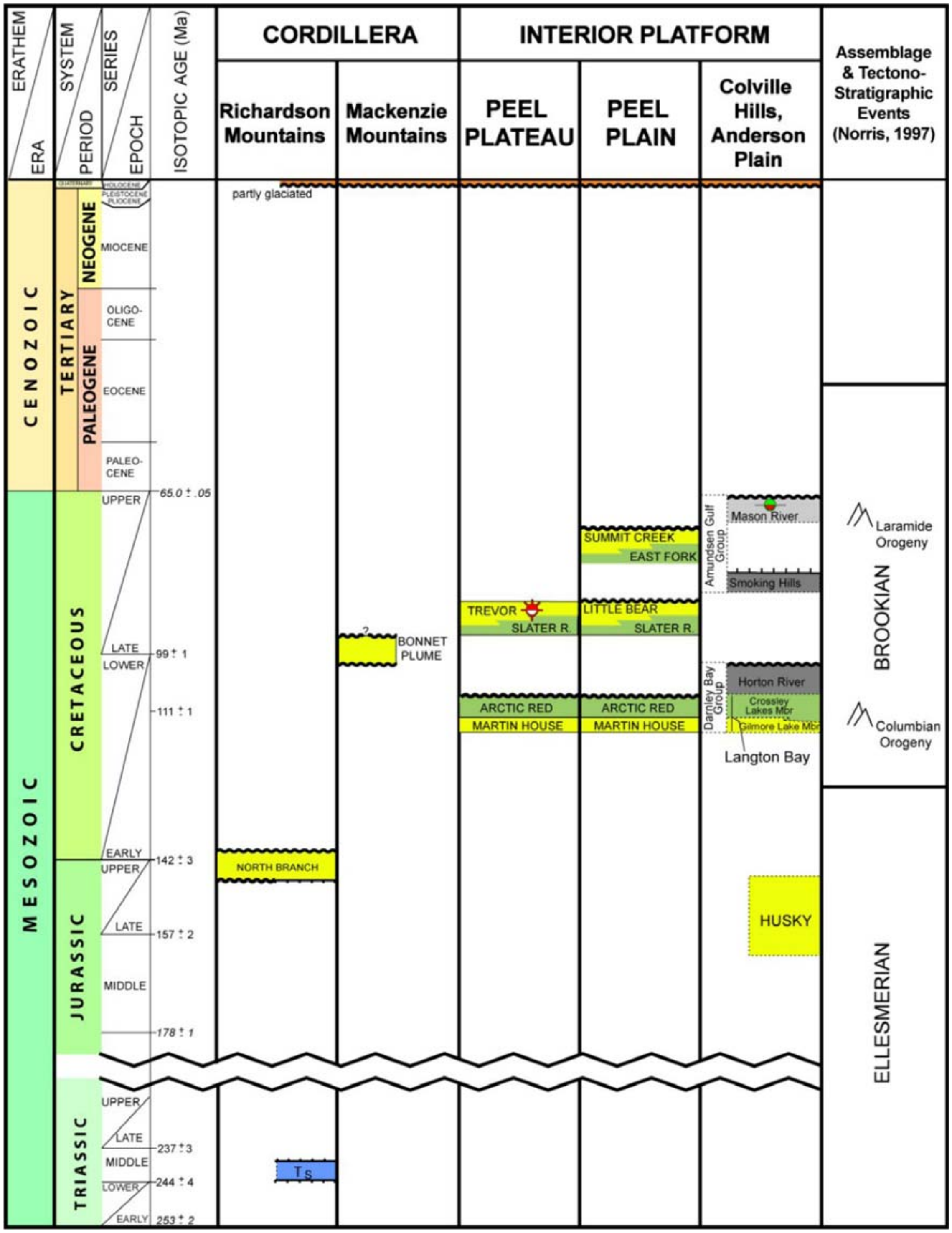

Figure 9.1.2. *Stratigraphy of Peel Plateau and Plain regions of northern Northwest Territories. Timescale after Okulitch (2004); stratigraphic data after Norris (1983, 1997) and Jones and Gal (2007).*

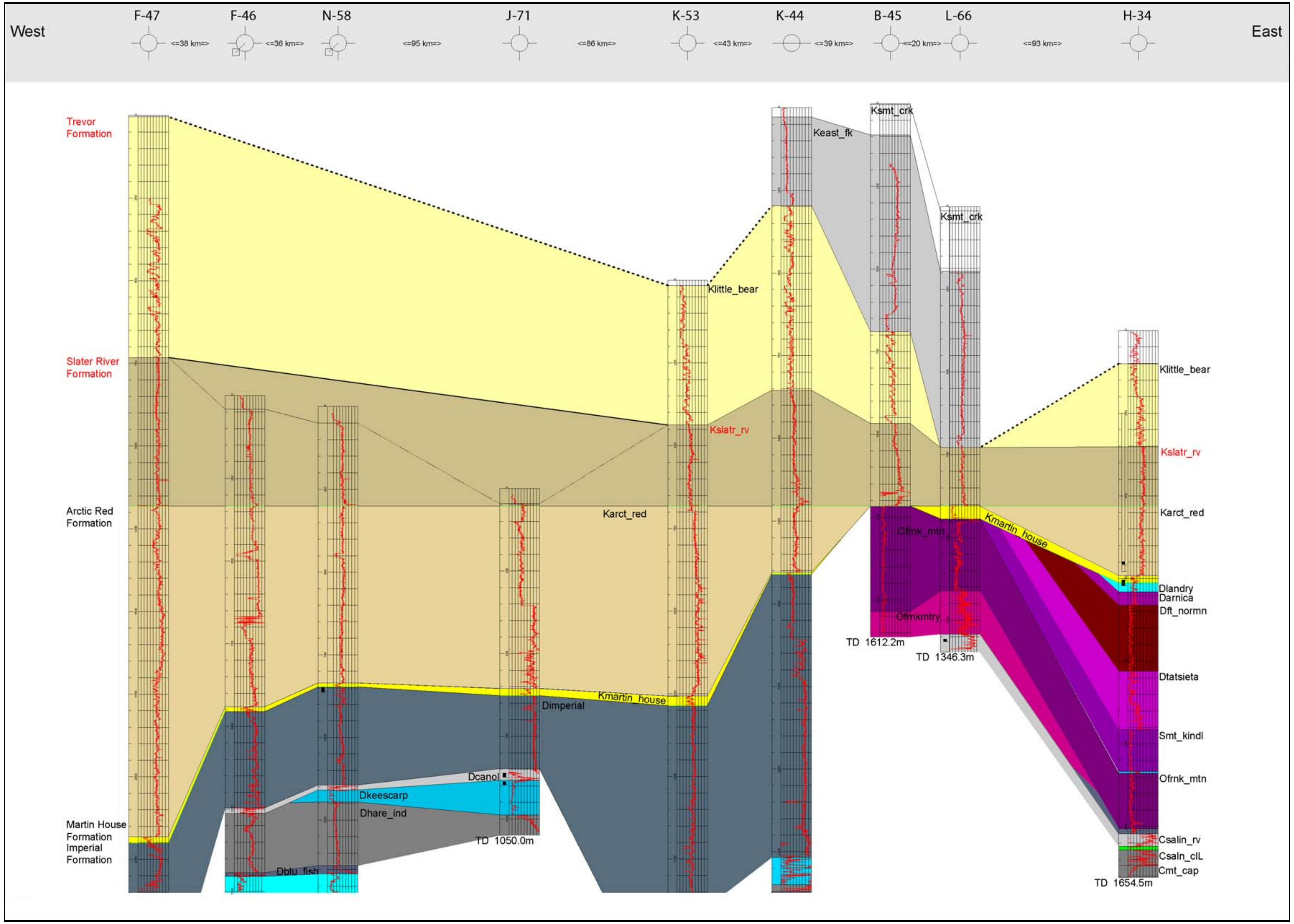

Figure 9.1.3. *Regional stratigraphic correlations using subsurface data. See Figure 9.1.1 for well locations. Lower Paleozoic rocks underlie the sub-Cretaceous unconformity at Keele Arch (wells B-45 and L-66). Trevor Formation is correlated to Little Bear Formation. Datum is a regional high gamma-ray stratigraphic marker at the base of Slater River Formation (section 9.2).*

9.1.1 Previous Work: Lithostratigraphy

Prior to this study, Cretaceous strata of Peel area have been subdivided into three formations. Martin House Formation was initially proposed by Mountjoy and Chamney (1969) for Albian marine sandstones and siltstones overlying the sub-Cretaceous unconformity from the Snake and Peel River areas in Yukon Territory. Yorath and Cook (1981) and Aitken et al. (1982) referred to equivalent strata in Peel area as basal sandstone of Arctic Red Formation. Dixon (1999) extended the geographical range of Martin House Formation to include the basal Cretaceous sandstone of Peel Plateau and Plain. Martin House Formation is not present along Keele Arch structure (section 9.2; Cook, 1975).

Non-marine deposits at the base of Martin House Formation are intersected in only a few wells, including cored intervals at Hume River I-66 and East Hume River N-10 (section 9.3). Industry reports informally referred to this unit as Gilmore Lake member (e.g., Chevron Canada Resources, 1989). Dixon (1999) correlated Martin House Formation non-marine deposits to Gilmore Lake Member of Langton Bay Formation of the Anderson Plain region, but the unit remained unnamed in Peel area.

Shale-dominated Arctic Red Formation is distributed throughout Peel area, and most of Mackenzie Plain except for a few locations where the sub-Cenomanian unconformity overlies the Paleozoic (e.g., East Mackay B-45 and Brackett Lake C-21 wells; Figure 9.1.3). Sandstones within Arctic Red Formation outcropping at Sans Sault Rapids on the Mackenzie River are named Sans Sault Member (Dixon, 1999).

Originally Mountjoy and Chamney (1969) described Arctic Red Formation as being overlain by Trevor Formation. Discovery of a regionally recognizable radioactive marker within upper Arctic Red Formation supports the separation of the overlying strata as a distinct unit. The same marker is known from the Mackenzie Plain region within basal Slater River Formation (Dixon, 1999). Consequently we propose this terminology for correlative strata in Peel area that are bounded by a pisolitic marker bed occurring directly below the radioactive marker and a distinct pebble bed at the top. For a detailed discussion of the introduction of Slater River Formation see section 9.2.

Trevor Formation was originally named by Mountjoy and Chamney (1969) to describe sandstone interbedded with shale, above Arctic Red Formation, at the southwest margin of Peel Plateau. Within the subsurface of Peel area only Arctic Red F-47 well intersects Trevor Formation and there are no cored intervals. Dixon (1999) suggested a questionable unconformity within Trevor Formation in Peel Plateau region which is now confirmed as the base of Slater River Formation as proposed here (section 9.2). Little Bear Formation as described from the Mackenzie Plain region (Dixon, 1999) is partly correlative to Trevor Formation in Peel area.

9.2 BIOSTRATIGRAPHY

D. Thomson, C.J. Schröder-Adams, and T. Hadlari

Abstract

Cretaceous strata in the Northern Interior Plains are widespread and their interbasinal lithostratigraphic correlations indicate several regional disconformities that require biostratigraphic confirmation. This study proposes a new zonation based on benthic foraminifera utilizing the reference section for Arctic Red and Trevor formations located along Hume River in Peel area. Five zones are recognized, using where possible, zonal markers from previously established biostratigraphic frameworks to facilitate regional correlation with surrounding Western and High Arctic regions. The Early Albian *Quadrimorphina albertensis* Zone is found in Martin House and lower Arctic Red formations and is well established in other Arctic regions. The upper part of Arctic Red Formation is correlated with the newly established Middle to Late Albian *Gaudryina canadensis* Zone. The top of this zone is marked by an erosional horizon followed by a nearly barren interval. This interval is characterized by the occurrence of fish teeth, *Inoceramus* prisms, algal cysts, and a single occurrence of *Textularia alcesensis*, suggesting an Early Cenomanian age. The Late Cenomanian *Gaudryina irenensis* Zone extends through the lower part of the Trevor Formation giving way to the Turonian *Pseudoclavulina hastata* Zone in the upper Trevor Formation.

Southeast of Peel area in Mackenzie Plain, a disconformity separates Albian Arctic Red Formation from ?late Cenomanian-Turonian strata, there named Slater River Formation. In order to recognize the significant disconformity associated with the loss of Albian foraminifera, the use of Slater River Formation is proposed to describe the strata bounded by the erosional horizon and the first pebble bed marking the base of the interbedded mudstones and sandstones of the overlying Trevor Formation.

9.2.1 Introduction

Cretaceous strata in the Northern Interior Plains are widespread and their stratigraphic correlations, including outcrop and core data, indicate several regional disconformities (Dixon, 1993; 1999). Detailed biostratigraphic work supporting regional correlations is still needed. This study investigates foraminiferal biostratigraphy of the Cretaceous in Peel area, where strata have poorly constrained ages. Biostratigraphic correlations for this region, based on a foraminiferal zonation previously proposed for Martin House, Arctic Red, and Trevor formations (Mountjoy and Chamney, 1969; Chamney, 1978) remain somewhat tentative. Uncertainties are caused by: a) the framework containing zonal markers that seem to be facies dependant and therefore do not allow full integration with neighbouring regions; and b) the type section being a composite section where the position of the basal unconformity separating Cretaceous strata from the underlying Paleozoic is unknown. Yorath and Cook (1981) described a more complete section of correlative strata along Hume River and its tributaries that contains, in ascending order, the basal Paleozoic unconformity, Martin House Formation – equivalent strata, Arctic Red and Trevor formations; and proposed this locality as a reference section. This study involved measuring and sampling this reference section for foraminiferal analysis. This section focuses on biostratigraphy and a new foraminiferal zonation for Peel area is proposed and correlated with existing zonations from Western and High Arctic regions. Foraminiferal biofacies analysis and paleoenvironmental interpretations will be published elsewhere.

Previous Work

The type section for Martin House and Arctic Red formations is a composite section located in the area of Snake and Peel rivers (Mountjoy and Chamney, 1969). Outcrop in that area contains nearly horizontal strata making the top of sections inaccessible for sampling. In addition, the basal unconformable contact with underlying Paleozoic strata is not exposed at the type section. An Aptian to Early Albian age was assigned to Martin House Formation and a Middle-Late Albian age to Arctic Red Formation (Mountjoy and Chamney, 1969; Chamney, 1978). Trevor Formation was described from the Cranswick River area. In the absence of a continuous section, the age of Trevor Formation was determined to span the latest Early to Late Albian using sparse and tentative macrofossil and microfossil data. Therefore, it was believed that Arctic Red and Trevor formations were time correlative (Mountjoy and Chamney, 1969; Chamney, 1978).

Subsequent studies including further mapping by Yorath and Cook (1981) and Aitken et al. (1982) resulted in a revised stratigraphy of Peel area (Dixon, 1999). An Aptian to late Middle or early Late Albian age was assigned to Arctic Red Formation and a Turonian age to Trevor Formation. These authors did not separate Martin House Formation from Arctic Red Formation. Throughout northern Canada a regionally significant disconformity separates Albian from Upper Cretaceous strata (Dixon, 1993). It was expected that an event of such extent would be present in Peel area. Consequently, Dixon (1999) placed this disconformity within Trevor Formation based on the stratigraphic section measured by Yorath and Cook (1981) along Hume River. Southeast of the project area, in Mackenzie Plain, a disconformity separates Albian Arctic Red strata from ?Upper Cenomanian-Turonian Slater River strata. Slater River Formation is considered time equivalent to Trevor Formation of Peel area (Dixon, 1999). Fossil-derived ages for Slater River Formation are poorly constrained, spanning the Middle Albian to Turonian (Yorath and Cook, 1981). This long range stems from the close proximity of this formation to Keele Arch, which results in a diachronous base influencing the biostratigraphic range of Slater River strata. Dixon (1999) shortened the age by suggesting a Cenomanian to Turonian age for Slater River Formation based on dinoflagellate occurrences.

Foraminiferal assemblages from Cretaceous strata of Alaska (Bergquist, 1966; Tappan, 1962), the Beaufort-Mackenzie area (McNeil, 1996), the Arctic Islands (Sliter, 1981; Wall, 1983) and the southern Western Interior Basin (Caldwell et al., 1993; Caldwell et al., 1978; McNeil and Caldwell, 1981; Mellon and Wall, 1956; Stelck and Leckie, 1990) provide useful biostratigraphic frameworks for this study. Most zonal markers are agglutinated taxa (Figure 9.2.1) that tend to range longer than calcareous species. The Arctic Slope, Eastern Sverdrup Basin and Beaufort-Mackenzie area have several zonal marker species in common, with two zones representing the Albian (Figure 9.2.1). In contrast, Chamney (1978) proposed six zones and numerous subzones for the same interval in the Snake and Peel rivers region, the locality of the Martin House and Arctic Red formations type section (Figure 9.2.1).

Less uniformity among zonal markers exists for the Cenomanian to Turonian interval in the North. Continuous sedimentation over the Albian/Cenomanian boundary was inferred only for the Arctic Slope of Alaska, where Tappan (1962) established the Cenomanian *Gaudryina* *irenensis/Trochammina rutherfordi* Zone. The Upper Cretaceous is not represented in the Snake River and Peel River areas (Figure 9.2.1); consequently no comparisons to the work of Chamney (1978) can be drawn.

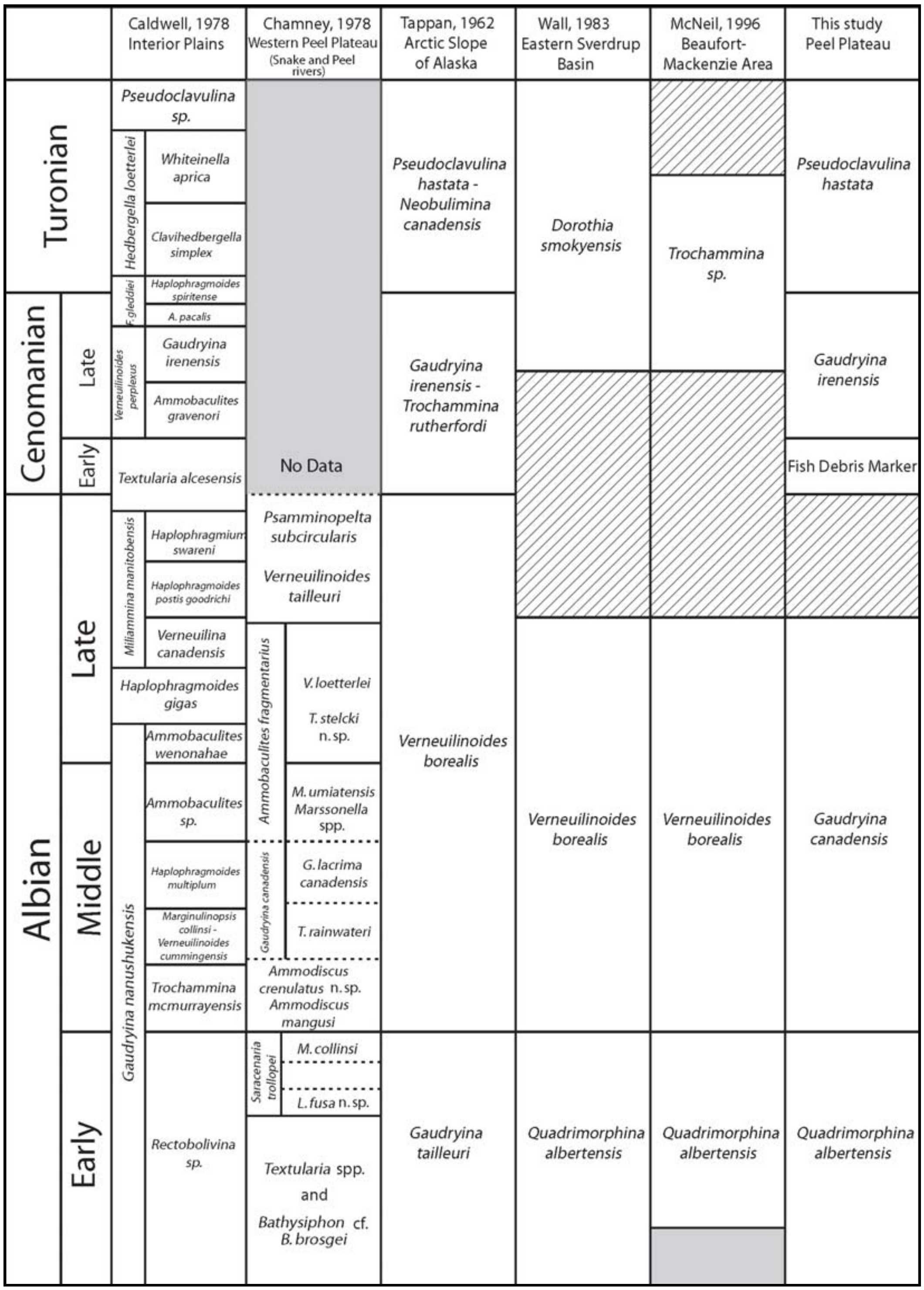

Figure 9.2.1. *Foraminiferal biostratigraphic frameworks previously proposed from north and south of the study area. New zonation for Peel Plateau is shown on the far right.*

9.2.2 Foraminiferal Zonation

Where possible, established zonal markers were used in the new foraminiferal stratigraphic framework proposed here. A total of five zonal markers were identified spanning Early Albian to Turonian time (Figure 9.2.2; Appendix A). Each zonal marker is associated with an assemblage of partly longer ranging species that show increased abundance within the zone, most likely as a response to favourable paleoenvironmental conditions (Figure 9.2.3).

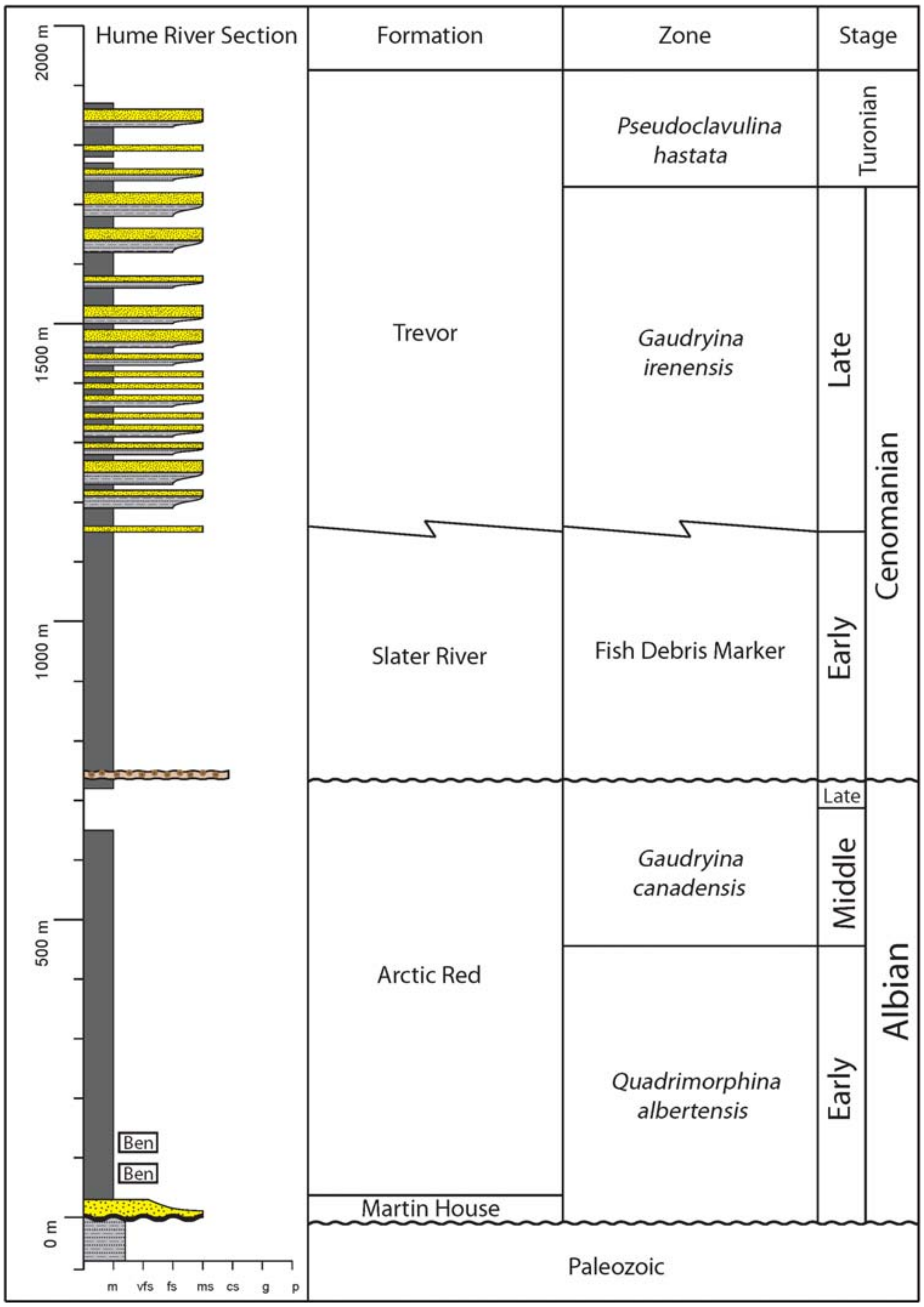

Figure 9.2.2. *New foraminiferal zonation for Peel Plateau correlated with simplified lithology and new stratigraphic framework for Hume River reference section.*

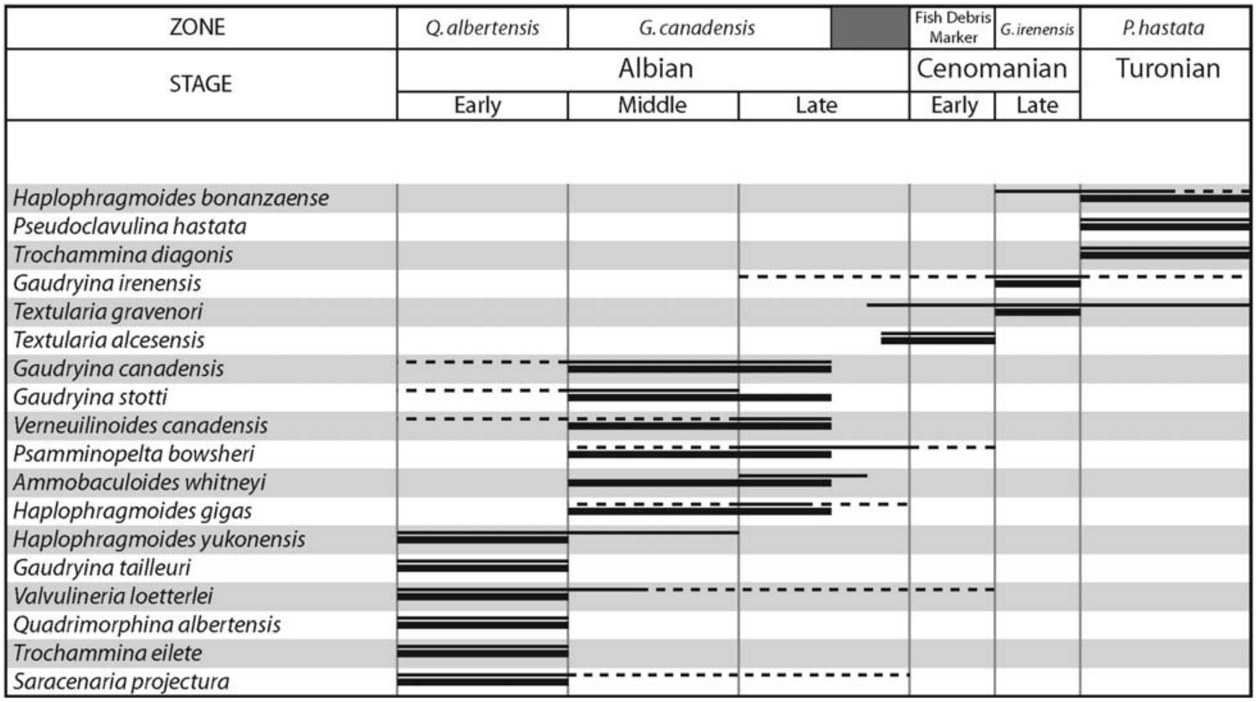

Figure 9.2.3. *Reported ranges (thin line) of selected foraminiferal species from Cretaceous strata of Alaska (Bergquist, 1966; Tappan, 1962), the Beaufort-Mackenzie area (McNeil, 1996; Sliter, 1981; Wall, 1983), the Arctic Islands (Sliter, 1981; Wall, 1983); the southern Western Interior Basin (Caldwell et al., 1993; Caldwell et al., 1978; McNeil and Caldwell, 1981; Mellon and Wall, 1956; Stelck and Leckie, 1990); and this study (thick line).*

***Quadrimorphina albertensis* Zone**

In the Hume River section the *Quadrimorphina albertensis* Zone occurs in lower Arctic Red Formation (Figure 9.2.2). Samples of underlying Martin House Formation were barren of foraminifera. However, this zone is extended down to Martin House Formation based on foraminifera recovered in equivalent strata exposed along Imperial River (McNeil, 2007).

The *Quadrimorphina albertensis* Zone was first described by Wall (1983) for the Eastern Sverdrup Basin. It was dated as Early Albian based on associated ammonites (Wall, 1983). This zone is at least partly correlative with the Early Albian *Gaudryina tailleuri* Zone described for the Arctic Slope of Alaska (Bergquist, 1966; Sliter, 1981; Tappan, 1962). The upper boundary of this zone is drawn at the last occurrence of *Quadrimorphina albertensis* and overall loss of calcareous faunal elements. Diagnostic taxa of this zone include: *Quadrimorphina albertensis* Mellon and Wall 1956, *Haplophragmoides yukonensis* Chamney 1978, *Gaudryina tailleuri* (Tappan) 1957, *Valvulineria loetterli* (Tappan) 1940, *Saracenaria projectura* Stelck and Wall 1956, and *Conorboides umiatensis* (Tappan) 1957.

Diagnostic taxa from Martin House Formation at Imperial River include *Valvulineria loetterlei, Gaudryina tailleuri*, and *Conorboides umiatensis* (McNeil, 2007), all faunal elements of the *Quadrimorphina albertensis* Zone. The calcareous zonal marker species might be linked to the transgression associated with the basal shales of Arctic Red Formation.

***Gaudryina canadensis* Zone**

The newly proposed *Gaudryina canadensis* Zone extends through the upper part of Arctic Red Formation (Figure 9.2.2). This zone contains numerous diagnostic species described from the Middle to Late Albian *Verneuilinoides borealis* Zone (Bergquist, 1958a; Tappan, 1962). Although no specimens of *Verneuilinoides borealis* were retrieved, the authors consider these two zones to be time equivalent. The upper boundary of this zone is defined by a disconformity and a coinciding loss of nearly all Albian species. A pisolitic marker bed defines this horizon in outcrop (Figures 9.2.2, 9.2.4). This discontinuity can be recognized in seismic profiles and on wireline logs by a high kick in gamma ray values, which is interpreted as a marine flooding surface overlying the erosional horizon (section 9.4).

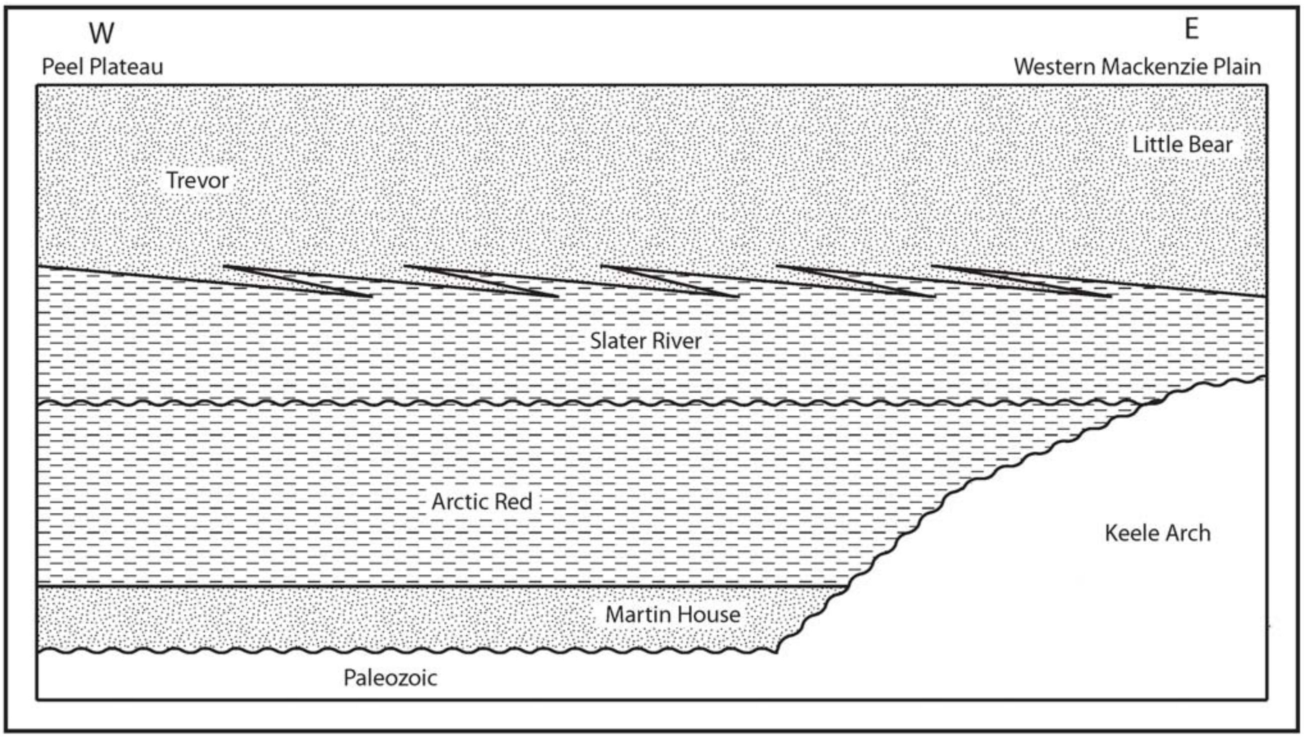

Figure 9.2.4. *Diagrammatic cross-section showing relationship of strata in Peel area with that in western Mackenzie Plain.*

For the southern part of Western Interior Plains, the Middle to Late Albian interval is characterized by three foraminiferal zones (Caldwell et al., 1978; 1993). These include, in ascending age, the *Gaudryina nanushukensis*, *Haplophragmoides gigas*, and the *Miliammina manitobensis* zones. The *Miliammina manitobensis* is further subdivided into the *Verneuilina canadensis, Haplophragmoides postis goodrichi,* and the *Haplophragmium swareni* subzones. The *Gaudryina canadensis* Zone, as proposed here, includes faunal elements of all these zones with the exception of the subzonal markers *Haplophragmoides postis goodrichi* and *Haplophragmium swareni.* The lack of these marker species suggests that the uppermost part of the latest Albian strata is missing in this section (Figures 9.2.1, 9.2.2, 9.2.3), as also documented on a regional scale by Dixon (1993). Diagnostic taxa of the *Gaudryina canadensis* Zone include: *Gaudryina canadensis* Cushman 1943, *Gaudryina stotti* Chamney 1978, *Verneuilinoides* *canadensis* (Cushman) 1927, *Psamminopelta bowsheri* Tappan 1957, *Ammobaculoides whitneyi* (Cushman and Alexander) 1930, and *Haplophragmoides gigas* (Cushman) 1927.

Fish Debris Marker Zone

The *Gaudryina canadensis* Zone is overlain by a nearly barren interval that spans approximately 450 metres of section. The interval is bounded by disconformities with the pisolitic marker bed at the base and a transgressive chert pebble lag at the top (Figure 9.2.2). These strata are characterized by the occurrence of fish teeth, *Inoceramus* prisms, and algal cysts. These are typical elements of Early Cenomanian strata basin-wide (Schröder-Adams et al., 1996). An Early Cenomanian age is also supported by a single occurrence of *Textularia alcesensis*, a marker for a zone spanning the Albian/Cenomanian boundary in NE British Columbia and NW Alberta (Stelck et al., 1958; Caldwell et al., 1978; Figure 9.2.3). In Mackenzie Plain, this nonconformity separates Albian Arctic Red Formation from ?Upper Cenomanian-Turonian strata, there named Slater River Formation (Dixon, 1999). In Peel Plateau we propose the name Slater River Formation for the stratal package, bounded by distinct disconformities, between Arctic Red and Trevor formations (Figures 9.2.2, 9.2.4). Due to the lack of age-diagnostic faunal elements, its age is determined by the underlying and overlying foraminiferal zones and is placed within the Early Cenomanian.

***Gaudryina irenensis* Zone**

The *Gaudryina irenensis* Zone extends through the lower part of Trevor Formation (Figure 9.2.2). This zone was first described by Bergquist (1958a) in characterizing the Cenomanian of Northern Alaska. A Cenomanian designation of this species was followed by Tappan (1962). From the Peace River district a *Gaudryina irenensis* Subzone was described, narrowing the age designation to Late Cenomanian (Caldwell et al., 1978; Stelck and Wall, 1955; Figure 9.2.1). In Peel area, the base of the zone is identified by a sudden reappearance of foraminifera, a common phenomenon throughout the Western Interior Plains associated with Upper Cenomanian strata (Schröder-Adams et al., 1996). Some species identified within this interval have reported ranges into the Turonian (Figure 9.2.3); however, a Late Cenomanian age is preferred for this zone. Diagnostic taxa for the *Gaudryina irenensis* Zone include: *Gaudryina irenensis* Stelck and Wall 1955 and *Textularia gravenori* Stelck and Wall 1955.

***Pseudoclavulina hastata* Zone**

The *Pseudoclavulina hastata* Zone extends throughout upper Trevor Formation (Figure 9.2.2). In Alaska this zone was first described for Turonian strata by Bergquist (1958b) and later recognized by Tappan (1962). The base of this interval is gradational with the underlying *Gaudryina irenensis* Zone, with some species ranging from the Cenomanian into the Turonian. This zone represents the highest stratigraphic interval sampled in this study. Diagnostic taxa for *Pseudoclavulina hastata* Zone include: *Haplophragmoides bonanzaense* Stelck and Wall 1954, *Pseudoclavulina hastata* Cushman 1927, and *Trochammina diagonis* (Carsey) 1926.

9.2.3 Discussion

Revisiting the reference section of Arctic Red Formation provided increased resolution of the depositional history and revealed significant sedimentary discontinuities. Within the formation, as originally defined, a foraminiferal faunal turnover was discovered that coincides with a major erosional surface defined by the pisolitic marker bed (Figure 9.2.4). This horizon is marked by the nearly complete loss of the Albian foraminiferal assemblage. Consequently, a revision of the lithostratigraphic framework calls for a separation between the strata above the disconformity and Arctic Red Formation (Figure 9.2.2). A major flooding surface above the pisolitic marker bed results in a distinct increase in gamma ray values. A similar log marker has been used by Dixon (1999) for regional correlations of wells in Mackenzie Plain and is placed at or near the base of Slater River Formation. This allows for correlations westwards into Peel area where we propose the use of Slater River Formation to describe the strata bounded by the pisolitic marker bed and the first pebble bed marking the base of the interbedded mudstones and sandstones of the overlying Trevor Formation (Figures 9.2.2, 9.2.4). Our biostratigraphic framework for the Peel Plateau suggests a Cenomanian age for Slater River Formation and a Late Cenomanian to Turonian age for Trevor Formation, in contrast to Dixon (1999) who proposed a Cenomanian/ Turonian age for Slater River Formation.

9.2.4 Summary

A new foraminiferal biostratigraphic framework is proposed for Peel area. Five zones are recognized, using zonal markers from established frameworks where possible. The Early Albian *Quadrimorphina albertensis* Zone is identified in lower Arctic Red Formation with faunal elements extending into underlying Martin House Formation. The Middle to early Late Albian interval within upper Arctic Red Formation is marked by the *Gaudryina canadensis* Zone. The disconformable boundary to overlying Slater River Formation is indicated biostratigraphically by a nearly complete loss of Albian benthic foraminifera. Missing zones of latest Albian assemblages typical for the Western Interior Plains suggest erosion or non-deposition during Late Albian time. The presence of fish remains, *Inoceramus* prisms, algal cysts, and lack of foraminifera that mark the Fish Debris Zone, suggests an Early Cenomanian age for Slater River Formation. The overlying Trevor Formation spans Late Cenomanian to Turonian time and is characterized by the Late Cenomanian *Gaudryina irenensis* and Turonian *Pseudoclavulina hastata* zones. The new integration of Slater River Formation into the stratigraphic framework of Peel area requires re-examination of that formation in its type area.

Acknowledgements

The authors thank George Dix for helpful discussions and Peter Jones for his assistance with SEM analysis. The Northwest Territories Geoscience Office generously supported D. Thomson's and C. Schröder-Adams' field participation. Schröder-Adams also thanks NSERC for her Discovery Grant.

APPENDIX A

Plate 1. *Photomicrographs and SEM images of representative foraminiferal species from the five foraminiferal zones (see below) of Peel Plateau. Scale bar is 100 µm long.*

***Quadrimorphina albertensis* Zone**
1-2. *Quadrimorphina albertensis* Mellon and Wall 1956, umbilical view. Sample 07-Peel-06, lower Arctic Red Formation.
3-4. *Haplophragmoides yukonensis* Chamney 1978. Sample 07-Peel-26, middle Arctic Red Formation.
5-6. *Gaudryina tailleuri* (Tappan) 1957. Sample 07-Peel-08, lower Arctic Red Formation.
7-8. *Valvulineria loetterli* (Tappan) 1940. Figure 7, spiral view; sample 07-Peel-26. Figure 8, umbilical view; sample 07-Peel-26. Both specimens from middle Arctic Red Formation.
9-10. *Saracenaria projectura* Stelck and Wall 1956. Sample 07-Peel-05, lower Arctic Red Formation.

***Gaudryina canadensis* Zone**
11-12. *Gaudryina canadensis* Cushman 1943. Sample 07-Peel-38, upper Arctic Red Formation.
13-14. *Gaudryina stotti* Chamney 1978. Sample 07-Peel-34, upper Arctic Red Formation.
15-16. *Verneuilinoides canadensis* (Cushman) 1927. Sample 07-Peel-37, upper Arctic Red Formation.
17-18. *Psamminopelta bowsheri* Tappan 1957. Sample 07-Peel-38, upper Arctic Red Formation.
19-20. *Ammobaculoides whitneyi* (Cushman and Alexander) 1930. Sample 07-Peel-38, upper Arctic Red Formation.
21-22. *Haplophragmoides gigas* Cushman 1927. Sample 07-Peel-37, upper Arctic Red Formation.

Fish Debris Marker Zone
23-24. *Textularia alcesensis* Stelck and Wall 1958. Sample 07-Peel-54, Slater River Formation.

***Gaudryina irenensis* Zone**
25-26. *Gaudryina irenensis* Stelck and Wall 1955. Sample 07-Peel-100, lower Trevor Formation.
27-28. *Textularia gravenori* Stelck and Wall 1955. Sample 07-Peel-108, lower Trevor Formation.

***Pseudoclavulina hastata* Zone**
29-30. *Pseudoclavulina hastata* Cushman 1927. Sample 07-Peel-113, upper Trevor Formation.
31-32. *Haplophragmoides bonanzaense* Stelck and Wall 1954. Sample 07-Peel-117, upper Trevor Formation.
33-36. *Trochammina diagonis* (Carsey) 1926. Figures 33 and 36, spiral view; Figure 34, umbilical view; Figure 35, aperture view. Sample 07-Peel-116, upper Trevor Formation.

9.3 SEDIMENTOLOGY

T. Hadlari, D. Thomson, and C.J. Schröder-Adams

Martin House and Arctic Red formations have been interpreted as a transgressive marine sandstone and regressive mudstone, respectively (see Dixon, 1999). Detailed sedimentology of Trevor Formation has been lacking; however, Dixon (1999) suggested that Trevor Formation comprises a series of shoreface or delta-front cycles based on seismic data coupled with upward-coarsening cycles interpreted from well logs. The shoreface interpretation was confirmed by field observations undertaken as part of the Peel Project (Hadlari, 2006).

9.3.1 Martin House Formation

In this study Martin House Formation is subdivided into an informal non-marine member (Tukweye member), a basal marine sandstone, and upper sandstone intervals. The unnamed non-marine member has been informally referred to as Gilmore Lake member in industry reports (e.g., Chevron Canada Resources, 1989), which is a member of Langton Bay Formation. In section 9.4. (Stratigraphy) we propose to informally designate the unnamed non-marine member as Tukweye member of Martin House Formation.

The term “basal Cretaceous sandstone” is widely used in well reports from the area, often synonymously with Martin House Formation (e.g., Petro-Canada, 1984) but also where the age, and therefore correlation, is not constrained. “Basal Cretaceous sandstone” is not a proper stratigraphic term, but from a reservoir perspective it does have utility in referring to the basal sandstone of Martin House Formation apart from siltstones and interbedded shale, and so “basal marine sandstone” is herein employed for the lowermost marine sandstones of Martin House Formation.

Tukweye member

Non-marine deposits of Martin House Formation, here informally named Tukweye member (section 9.4), are restricted to a relatively small geographic area, an approximately north-trending corridor from the Shortcut Creek section to wells Ramparts River F-46, Hume River I-66, East Hume River N-10, and Hume River A-53 (Figure 9.3.1).

At Shortcut Creek the Tukweye member is represented by an approximately 6 m thick upward-fining, trough cross-bedded, pebbly, coarse-grained sandstone. Wood fragments are common. Above the sandstone are thin laminae of coal. This association is interpreted to be a fluvial sandstone and floodplain, which is truncated by a transgressive surface and overlain by a lag and bioturbated sandstone interpreted as marine.

Drill core from Hume River I-66 well intersects a stratigraphic succession from Imperial Formation through the full thickness of Tukweye member to the top of Martin House Formation marine sandstone (Figure 9.3.2). Above the sub-Cretaceous unconformity interbedded shale, carbonaceous shale with abundant root traces, thin coal beds and laminae, and sandstone laminae and ripple cross-laminae are interpreted as floodplain deposits (Figure 9.3.3).

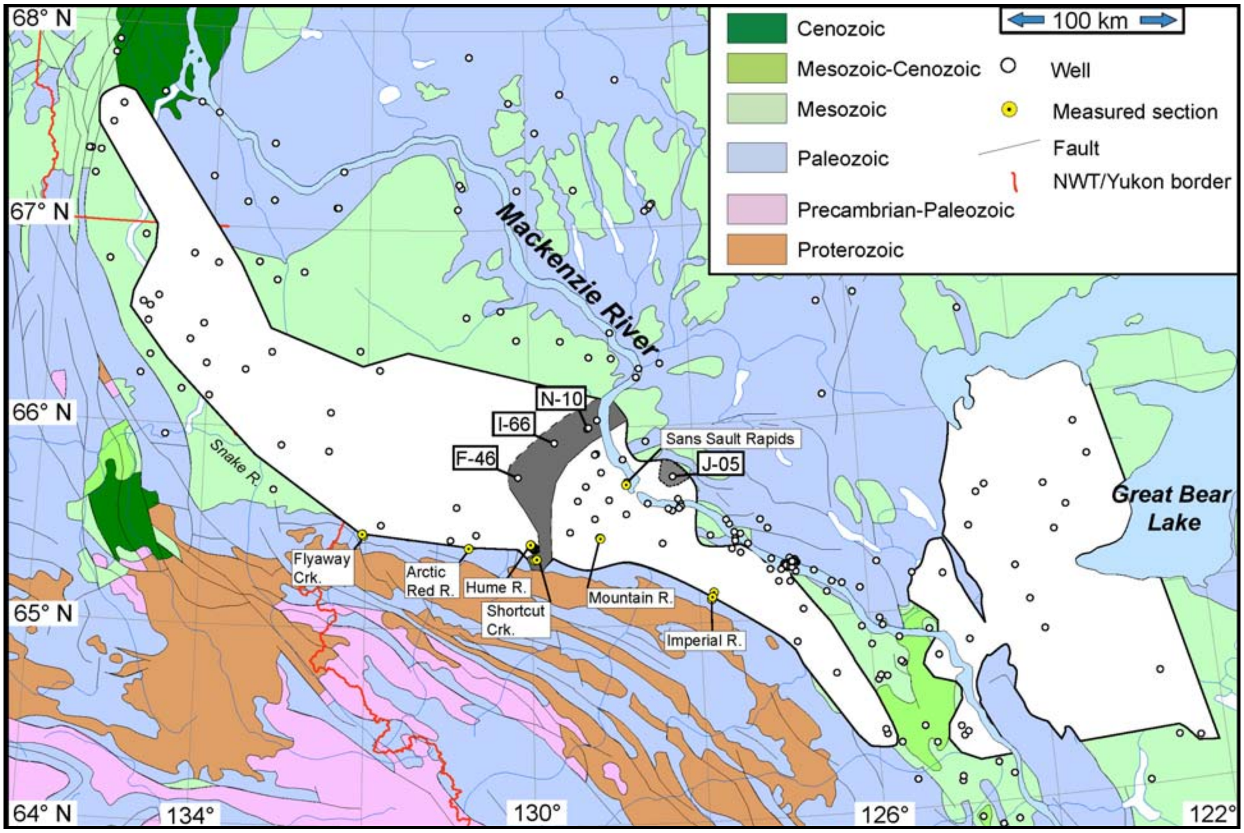

Figure 9.3.1. *The distribution of Martin House Formation based on well logs (shown in white) is superimposed on the bedrock geology; there are discrepancies between the datasets, probably due to the lack of outcrop near well locations. The grey area shows the distribution of Tukweye member, interpreted as an approximately north-trending paleovalley.*

Interval 484.45 m to 477.6 m contains trough cross-stratified, medium- to coarse-grained sandstone that contains coaly laminae and no bioturbation. Similar to the sandstone at Shortcut Creek, cross-bedded sandstone in well I-66 is interpreted to be fluvial. Martin House Formation above the fluvial sandstone is a transgressive succession from a lag through lower shoreface storm deposits to offshore mudstone of Arctic Red Formation (Figure 9.3.2).

Although coal is not well developed in Hume River I-66, there is a 1.5 m thick coal bed in East Hume River N-10 (Figure 9.3.3).

The association of floodplain and fluvial deposits geographically restricted to an approximately north-south trending corridor is interpreted as an incised paleovalley that records deposition during the first stages of base level rise.

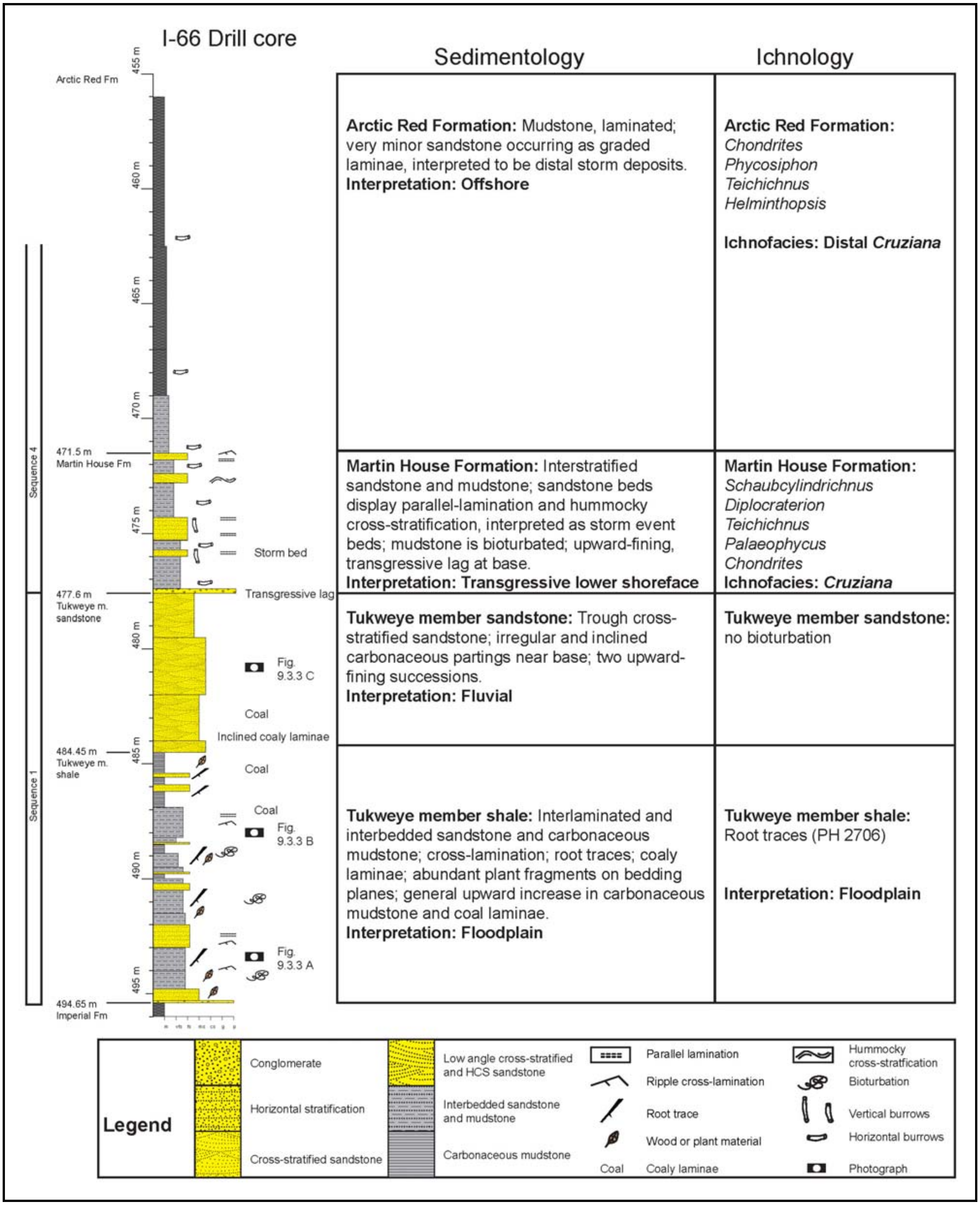

***Figure 9.3.2.** Measured section of Tukweye member from drill core of well Hume River I-66.*

Figure 9.3.3. *Photographs of Tukweye member from Hume River I-66 drill core: (A) root traces from floodplain facies; (B) coal laminae; (C) medium- to coarse-grained, trough cross-stratified sandstone interpreted as fluvial; and (D) 1.5 m thick coal bed from East Hume River N-10 drill core.*

Basal marine sandstone

The basal marine sandstone of Martin House Formation is present almost everywhere that Martin House and Arctic Red formations are distributed (Figure 9.3.4). It is thickest in the middle of the study area and thins to zero both over Keele Arch and to the northeast at Rat Pass K-35 well (Figure 9.3.5). Description of sedimentology will focus on drill core from Sainville River D-08 and outcrop sections from Flyaway Creek, an unnamed tributary of Arctic Red River, Mountain River, and Imperial River (Figure 9.3.6). The Imperial River section was measured by Laudon (1950). The upper part of the basal marine sandstone is a transgressive succession consisting of a basal lag overlain by shoreface storm deposits which grade into offshore mudstone as seen in the Hume River I-66 well. The surface below the lag at the base of this succession is interpreted as a transgressive ravinement surface. The following sedimentological description will focus on the deposits below the transgressive ravinement surface. Trace fossil interpretations follow (Pemberton et al., 1992; 2001).

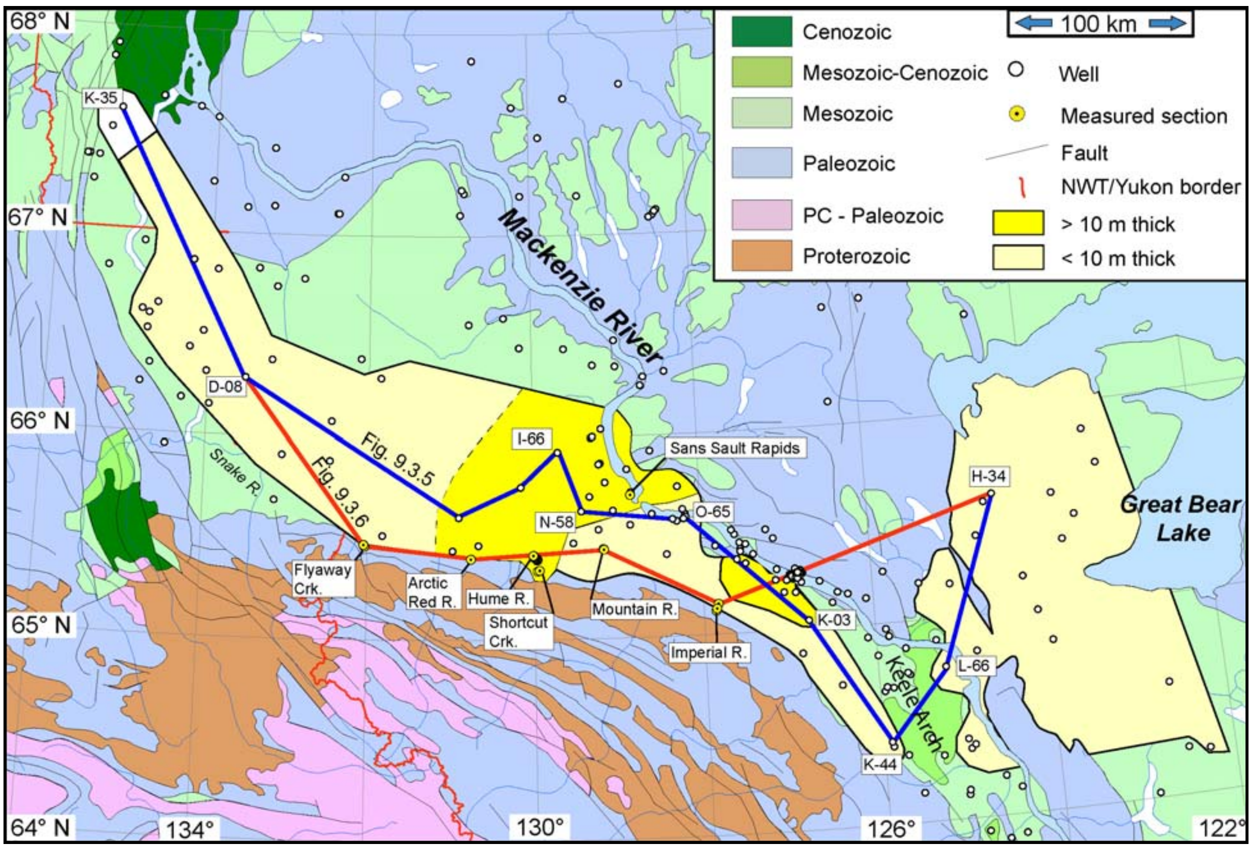

Figure 9.3.4. *Simplified isopach of the basal marine sandstone of Martin House Formation. Light yellow is less than 10 m thick, bright yellow is greater than 10 m thick. West of Keele Arch the northern and southern boundaries are erosional edges underlain by Paleozoic rocks. The basal marine sandstone grades to shale westward, reaching a zero thickness at well K-35. Martin House Formation was not deposited on Keele Arch, which is interpreted as a paleohigh. Area east of Keele Arch is not contoured.*

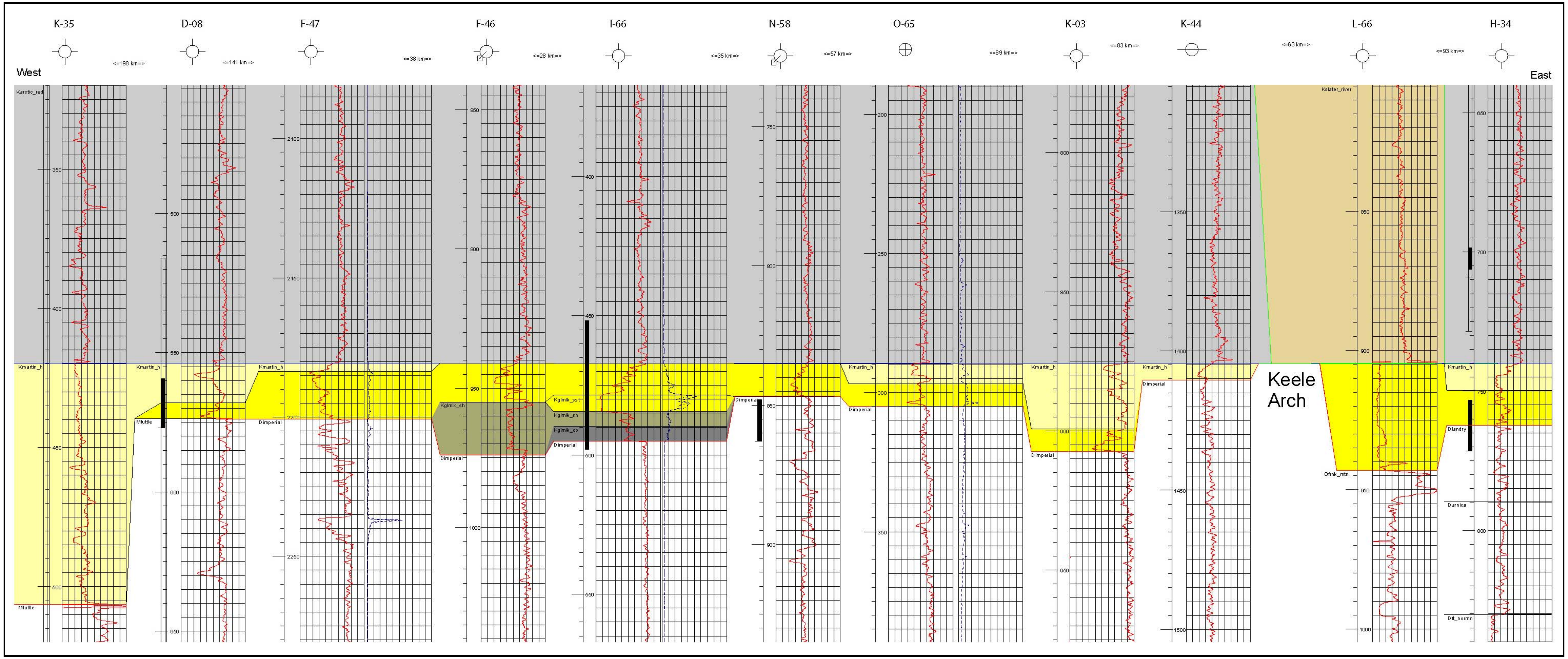

Figure 9.3.5. *Lithostratigraphic correlation of Martin House Formation. The basal marine sandstone is bright yellow. Datum is the base of Arctic Red Formation. Locations are indicated on simplified isopach map (Figure 9.3.4).*

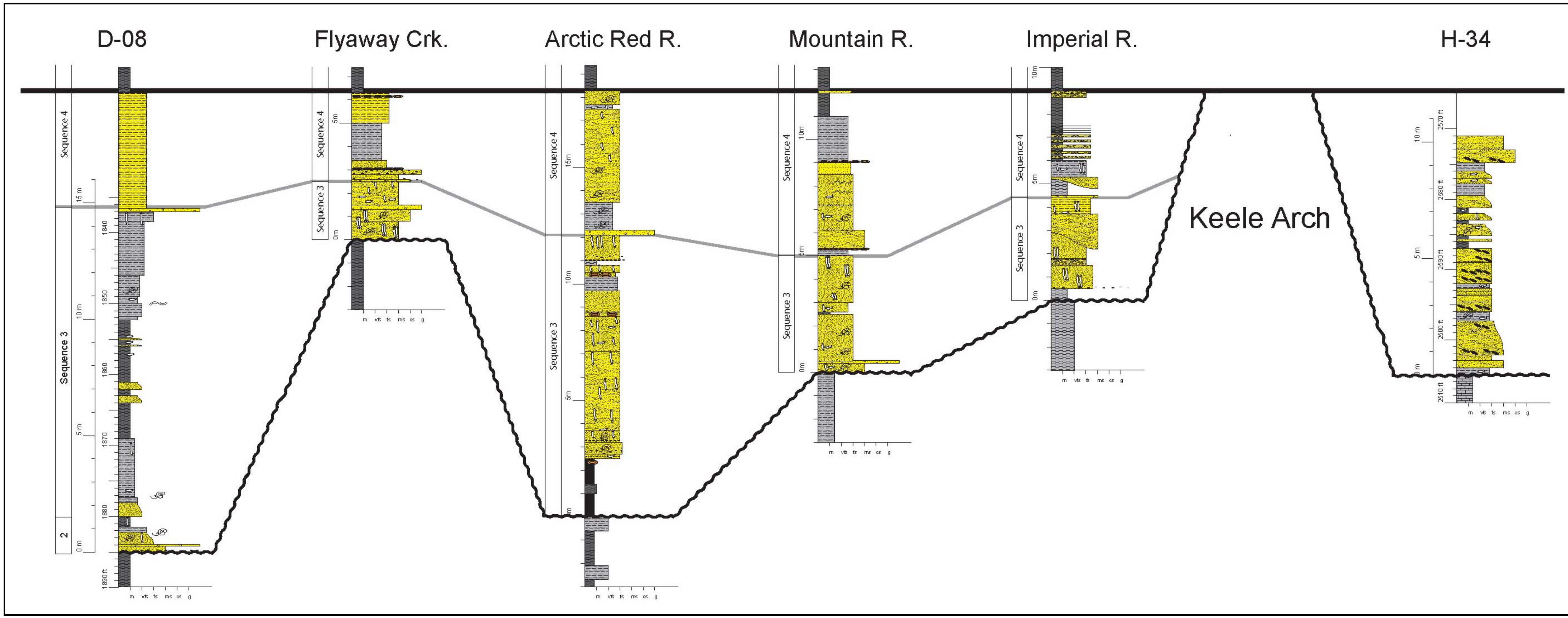

Figure 9.3.6. *Measured sections of the basal marine sandstone and Martin House Formation from drill core and outcrop. Locations are indicated on simplified isopach map (Figure 9.3.4).*

Section: Sainville River D-08 Drill Core

Sainville River D-08 well is located in the western part of the study area where the basal marine sandstone is less than 10 m thick (Figure 9.3.4). The cored interval of Martin House Formation in well D-08 is a shale-dominant succession that fines upward from a basal pebbly bed and subsequently coarsens upward to a pebble conglomerate overlying an erosional surface at the top (Figure 9.3.7).

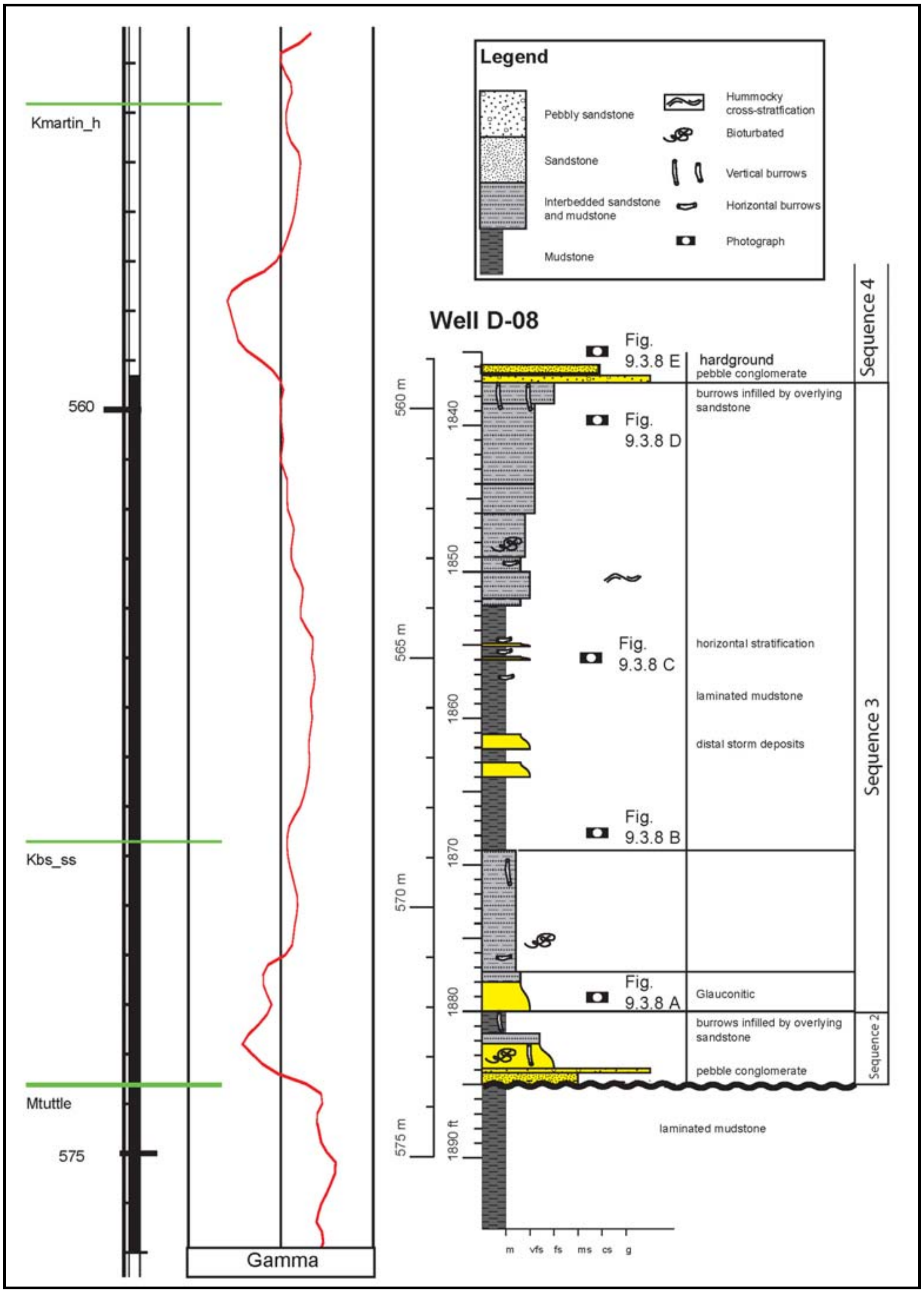

Figure 9.3.7. *Measured section of drill core from well Sainville River D-08.*

The pebble conglomerate above the sub-Cretaceous unconformity is interpreted as a transgressive lag. This is overlain by bioturbated sandstone and mudstone of marine origin. The mudstone is overlain by a firm ground surface at 1880 feet indicated by a *Glossifungites* ichnofacies suite containing *Diplocraterion* and *Thalassinoides* burrows in mudstone infilled with sandstone from the overlying bed (Figure 9.3.8). Overlying this surface is an upward fining succession grading from sandstone to mudstone. Interbedded sandstone and mudstone is bioturbated, displaying traces of the *Cruziana* ichnofacies indicative of a lower shoreface to offshore setting. This lower succession is interpreted as a transgressive interval and grades into an upward-coarsening succession of mudstone, to mudstone interbedded with thin beds of sandstone, to interbedded small-scale hummocky cross-stratified and horizontally stratified sandstone and mudstone. This succession is interpreted to record offshore to distal lower shoreface deposition and therefore a fall in relative sea level.

The upper erosional surface is interpreted as a ravinement surface formed during the transgression that in most sections, particularly in the western portion of the study area, demarcates the top of Martin House Formation and base of Arctic Red Formation. Above the ravinement an upward-fining trend is interpreted from the gamma-ray log (Figure 9.3.7).

In summary, the basal marine sandstone is very thin at Sainville River D-08 well, and below the thin transgressive sandstone at the top of Martin House Formation, the depositional setting is interpreted as distal lower shoreface and offshore.

Section: Arctic Red River Tributary (Monument Creek)

The basal marine sandstone of Martin House Formation is thickest near Arctic Red River as indicated by the isopach and the section (approximately 15 m) measured along a tributary of Arctic Red River (Figure 9.3.4). The basal marine sandstone consists of two sandstone intervals (Figure 9.3.9).

Directly above the sub-Cretaceous unconformity the lowermost deposits of Martin House Formation are mudstone and claystone 2.5 m thick. Sharply overlying the mudstone is the lower sandstone interval, which consists of intensely bioturbated trough cross-stratified sandstone. At the base of the sandstone *Thalassinoides* and *Diplocraterion* burrows penetrate the underlying mudstone and are infilled with sandstone, interpreted to represent a firmground *Glossifungites* surface (Figure 9.3.10). The sandstone itself is intensely bioturbated, containing *Diplocraterion* and *Skolithos* of the *Skolithos* ichnofacies. Sedimentary structures are generally destroyed, although some trough cross-stratification is preserved. The association of *Skolithos* ichnofacies and trough cross-stratified sandstone is interpreted to represent an upper shoreface setting.

The lower sandstone interval is truncated at the top by complex association of pebble lag, glauconitic sandstone, and a *Glossifungites* surface below a granular cross-stratified sandstone bed. The upper sandstone is the typical transgressive lower shoreface to offshore succession with a ravinement surface at the base that is present in other sections (Figure 9.3.6).

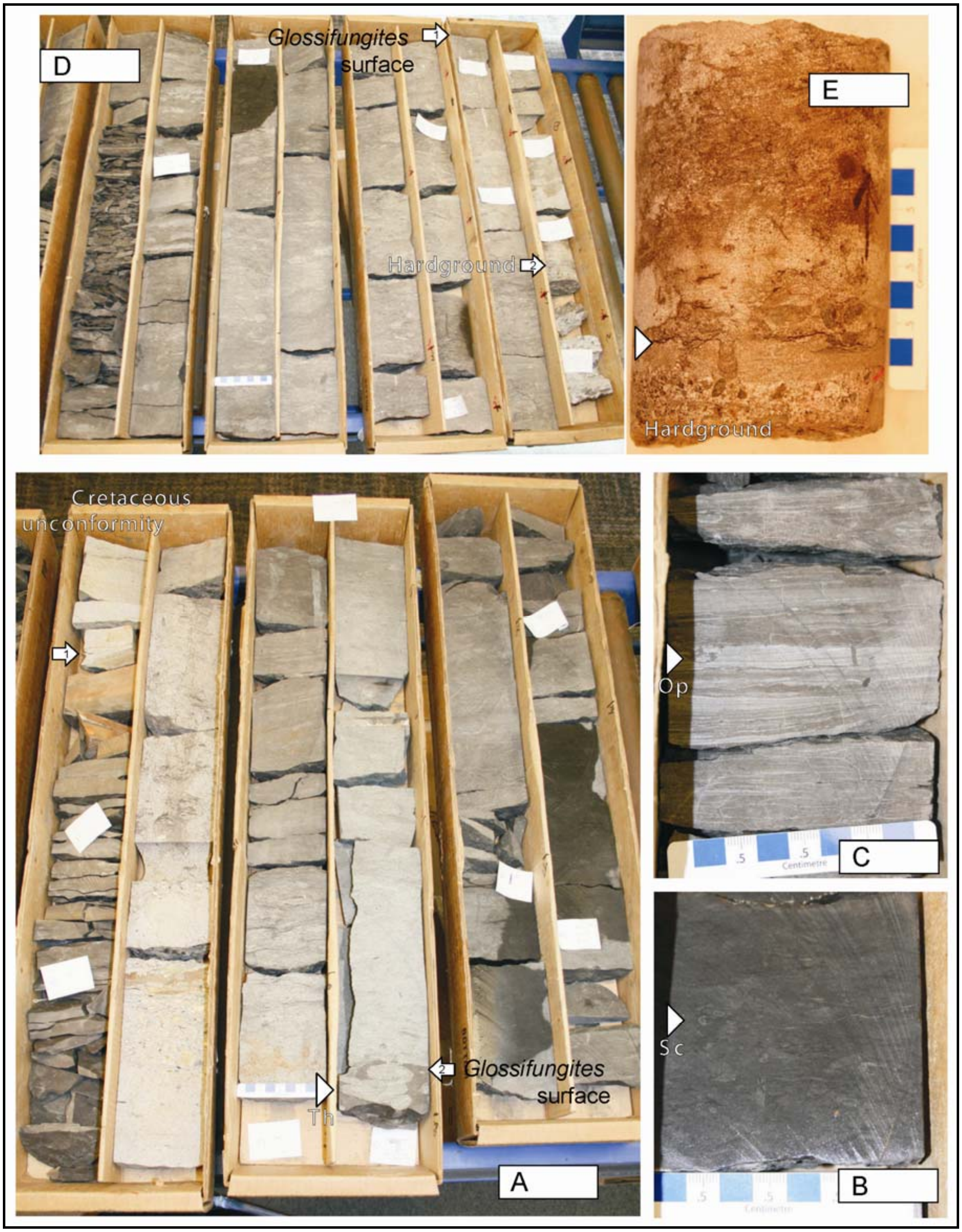

Figure 9.3.8. *Photographs of Martin House Formation from core of Sainville River D-08 well: (A)* Glossifungites *surface at the base of a transgressive succession (see Figure 9.3.7); (B) Traces, including* Schaubcylindrichnus*, within offshore facies; (C) distal storm bed burrowed by* Ophiomorpha*; (D) upper part of drill core showing* Glossifungites *surface overlain by a transgressive lag; and a marine hardground (E).*

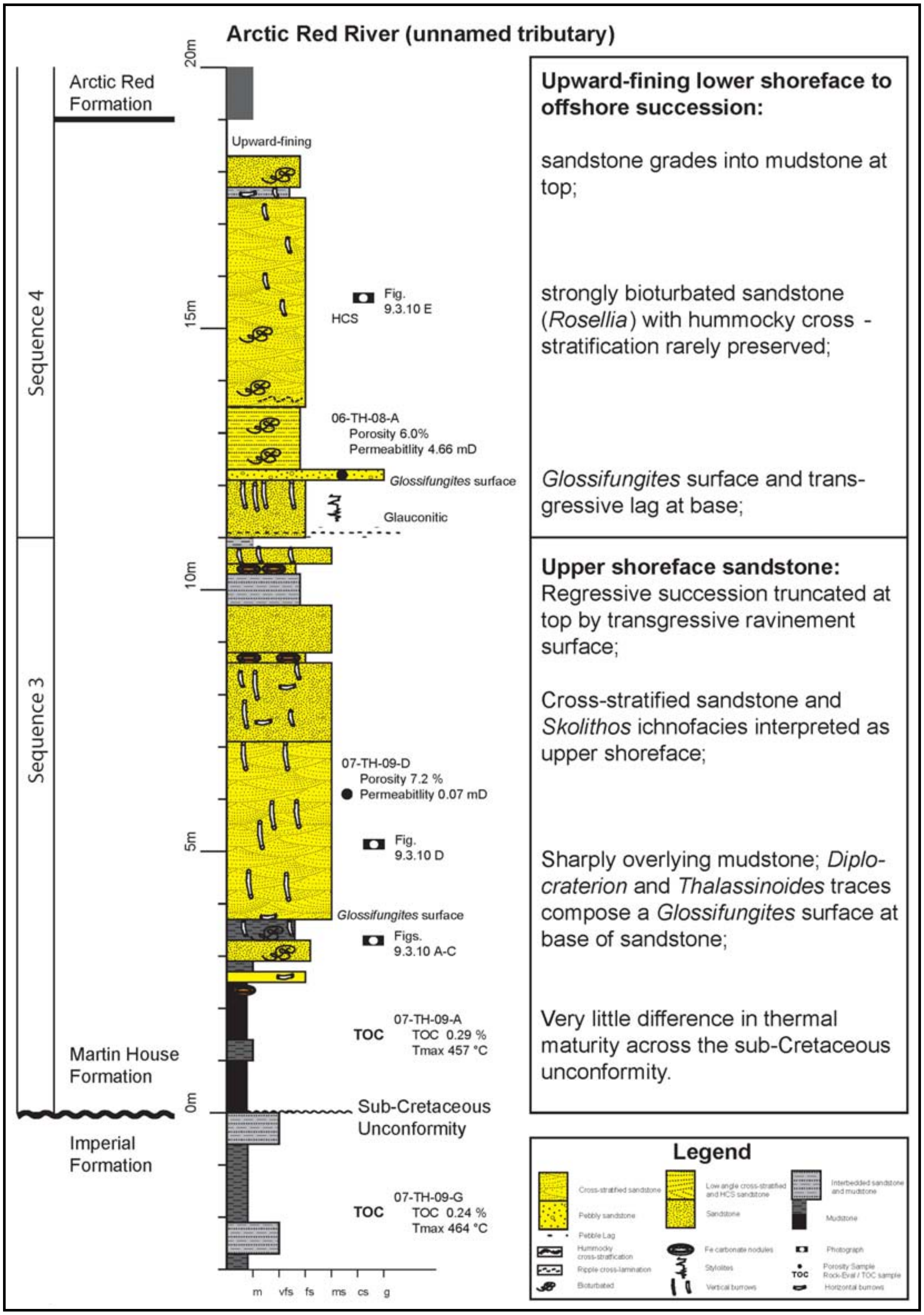

Figure 9.3.9. *Measured section from an unnamed tributary of Arctic Red River (see Figure 9.3.4). The lower portion is a regressive succession which is truncated by a transgressive lag and overlain by a transgressive succession from lower shoreface sandstone to offshore mudstone of Arctic Red Formation. Note that the Rock-Eval/TOC data indicate Tmax values of Martin House Formation (457°C) and Imperial Formation (464°C) are very close.*

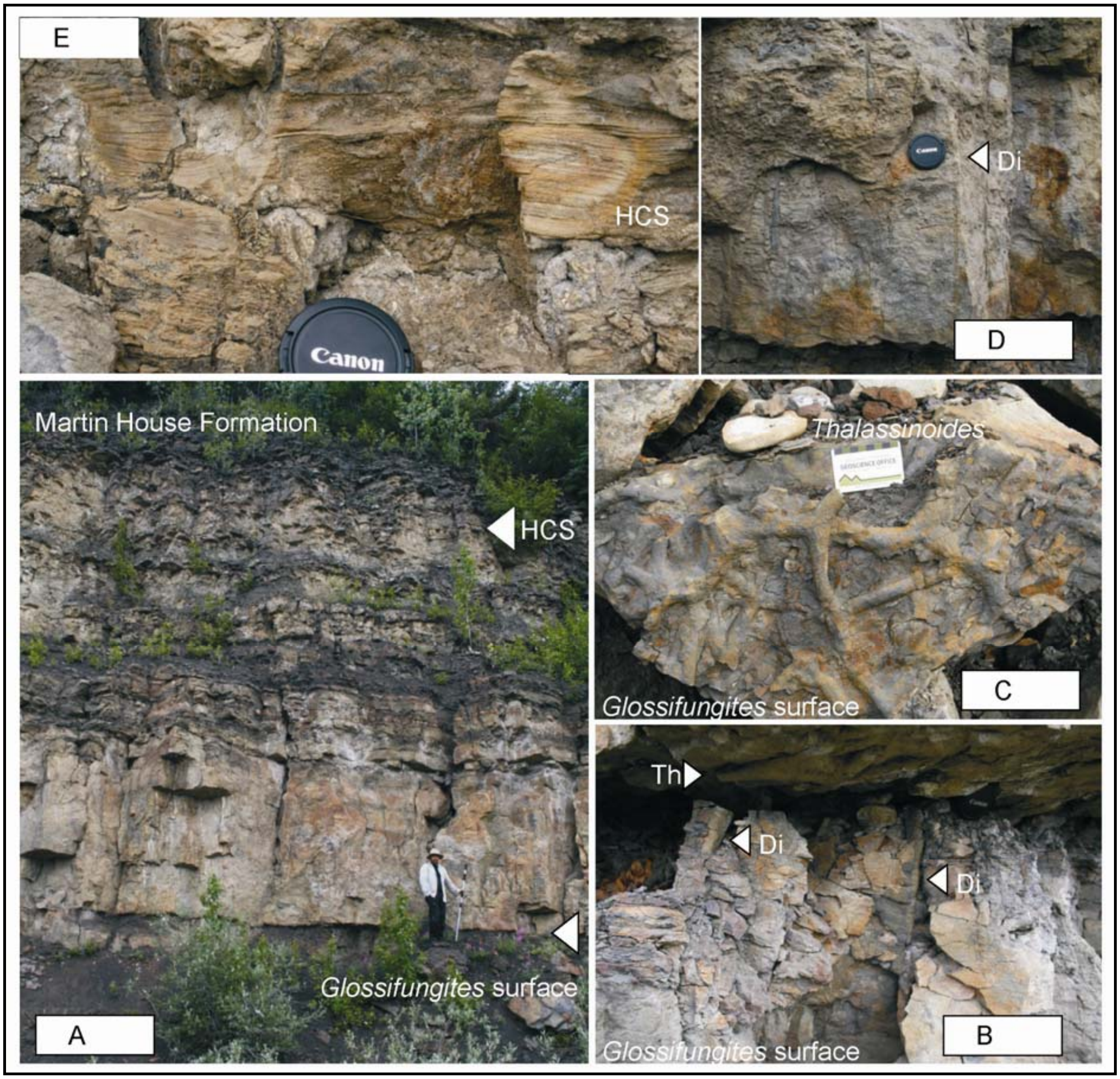

***Figure 9.3.10.** Outcrop photographs of Martin House Formation from the unnamed tributary of Arctic Red River: (A) outcrop showing two sandstone intervals (geologist for scale); (B)* Diplocraterion *and (C)* Thalassinoides *compose a* Glossifungites *surface at the base of lower sandstone; (D) vertical burrows, such as* Diplocraterion*, dominate the bedded sandstone of the lower interval; and (E) Hummocky cross-stratification preserved within bioturbated lower shoreface deposits of the upper sandstone interval.*

Section: Mountain River

At Mountain River, Martin House Formation is subdivided into two intervals (Figure 9.3.11). The lower interval is characterized by extensively developed bioturbation in interlaminated sandstone and mudstone, indicating a low energy environment. Traces include *Planolites* but are dominated by *Teichichnus* (Figure 9.3.12). The intense bioturbation further indicates a relatively quiescent depositional setting, and the low diversity is suggestive of a stressed marine environment. This location is shoreward of upper shoreface deposits at Arctic Red River, consequently the depositional setting is interpreted as a lagoon that was protected from the open ocean by a barrier bar complex near Arctic Red River.

The second interval is an upward-fining succession of storm deposits, interpreted to represent transgression from lower shoreface to offshore (Figure 9.3.11). The base of the interval is correlated with the transgressive ravinement surface at Sainville River D-08 well and Arctic Red River section (Figure 9.3.6).

Section: Imperial River

The basal marine sandstone at Imperial River is subdivided into two intervals separated by an erosional surface (Figure 9.3.13).

At the base of the lower interval moderately to intensely bioturbated, predominantly sandstone with mudstone laminae is interbedded with non-bioturbated sandstone containing hummocky cross-stratification and ripple cross-lamination. The bioturbated sandstone contains a diverse suite of traces including *Rosellia* (Figure 9.3.14), *Teichichnus*, *Planolites,* and *Diplocraterion* composing a *Cruziana* ichnofacies. The association of storm deposits with an open marine *Cruziana* ichnofacies is interpreted to record a lower shoreface depositional setting.

The middle of the lower interval is non-bioturbated, trough cross-bedded sandstone with lenticular geometry, and is interpreted as a channel sandstone body (Figure 9.3.14). Within the channel sandstone a single mudstone bed was observed containing *Planolites* burrows, possibly indicating a marginal marine setting. Above the channel sandstone is an 80 cm thick heterolithic interval of interlaminated sandstone and mudstone. The heterolithic interval is weakly bioturbated with both horizontal and vertical burrows, contains ripple cross-lamination, and lenticular bedding; an association of structures interpreted to indicate a tidal flat depositional setting. The succession from the channel sandstone to the heterolithic unit is therefore interpreted as a tidal channel overlain by tidal flat deposits. In summary, the lower interval is therefore a succession of facies representing lower shoreface, tidal channel and tidal flat that were deposited during relative sea level fall (regressive succession; Figure 9.3.13).

A transgressive ravinement surface at the base of the upper interval is overlain by sandstone with hummocky cross-stratification (Figure 9.3.14) interbedded with mudstone, interpreted as lower shoreface storm deposits, that fine upward to mudstone interpreted as offshore deposits.

The basal marine sandstone at Imperial River is a sandstone unit where the lower beds were deposited during relative sea level fall and the uppermost beds are transgressive with a basal ravinement surface overlain by lower shoreface sandstone that grades to offshore mudstone.

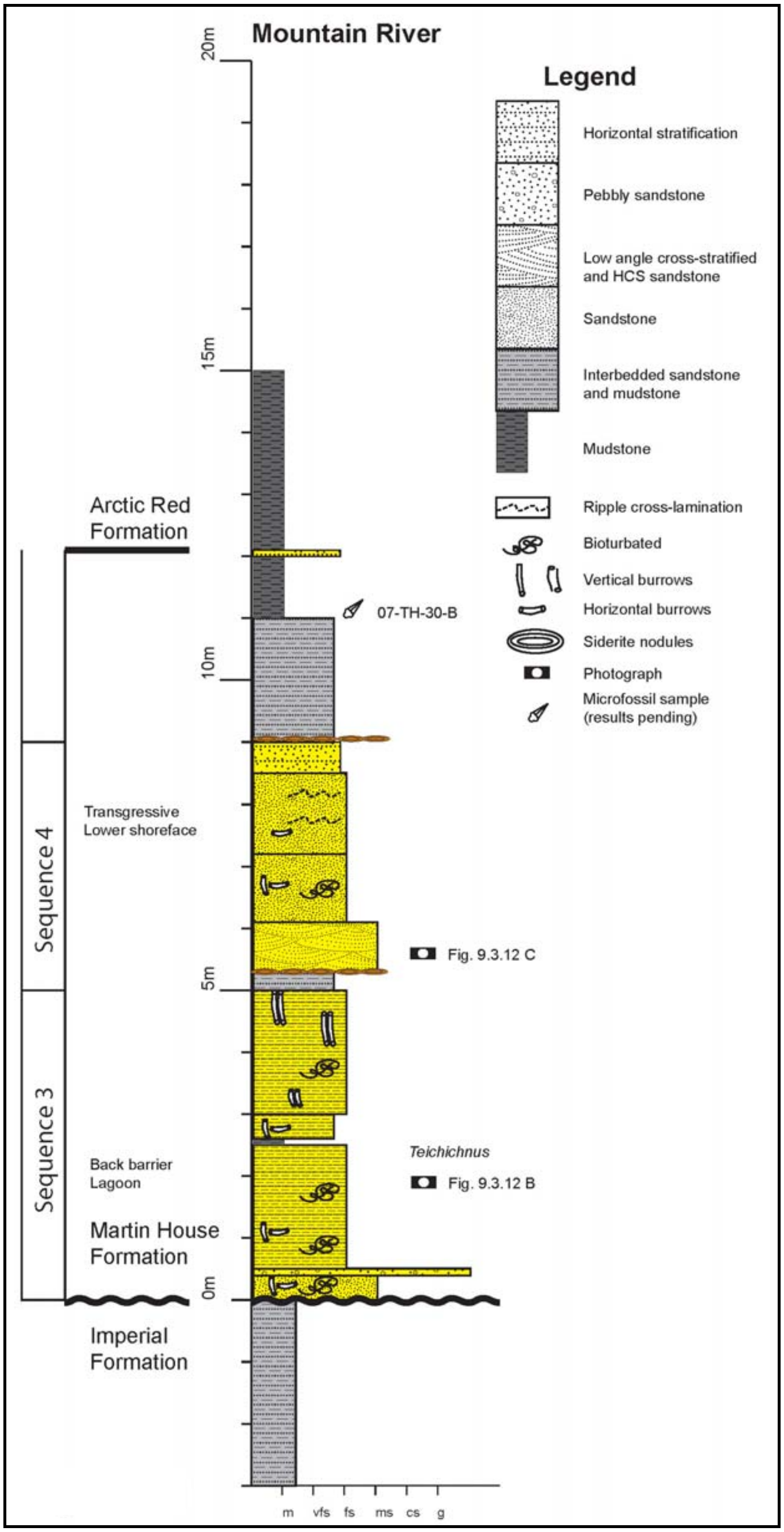

Figure 9.3.11. *Measured section of Martin House Formation at Mountain River. The lower interval is interlaminated sandstone and mudstone with very strong to intense bioturbation, interpreted to record a protected back-barrier lagoonal environment.*

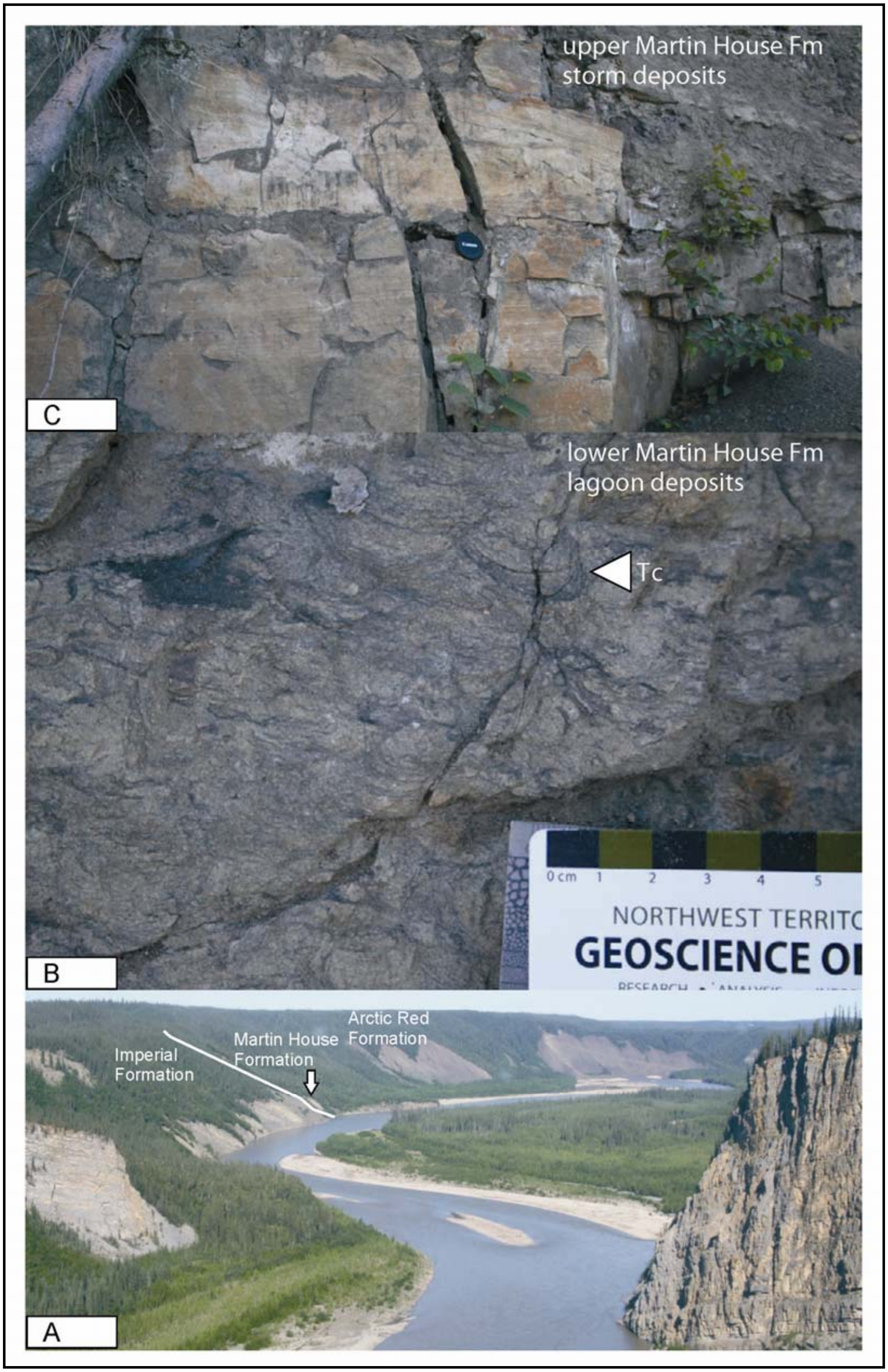

Figure 9.3.12. *Outcrop photographs from Mountain River: (A) outcrop location view facing north; (B)* Teichichnus-*dominated sandstone and mudstone from lagoonal deposits; and (C) low-angle cross-stratified storm deposits from upper sandstone interval (see Figure 9.3.11).*

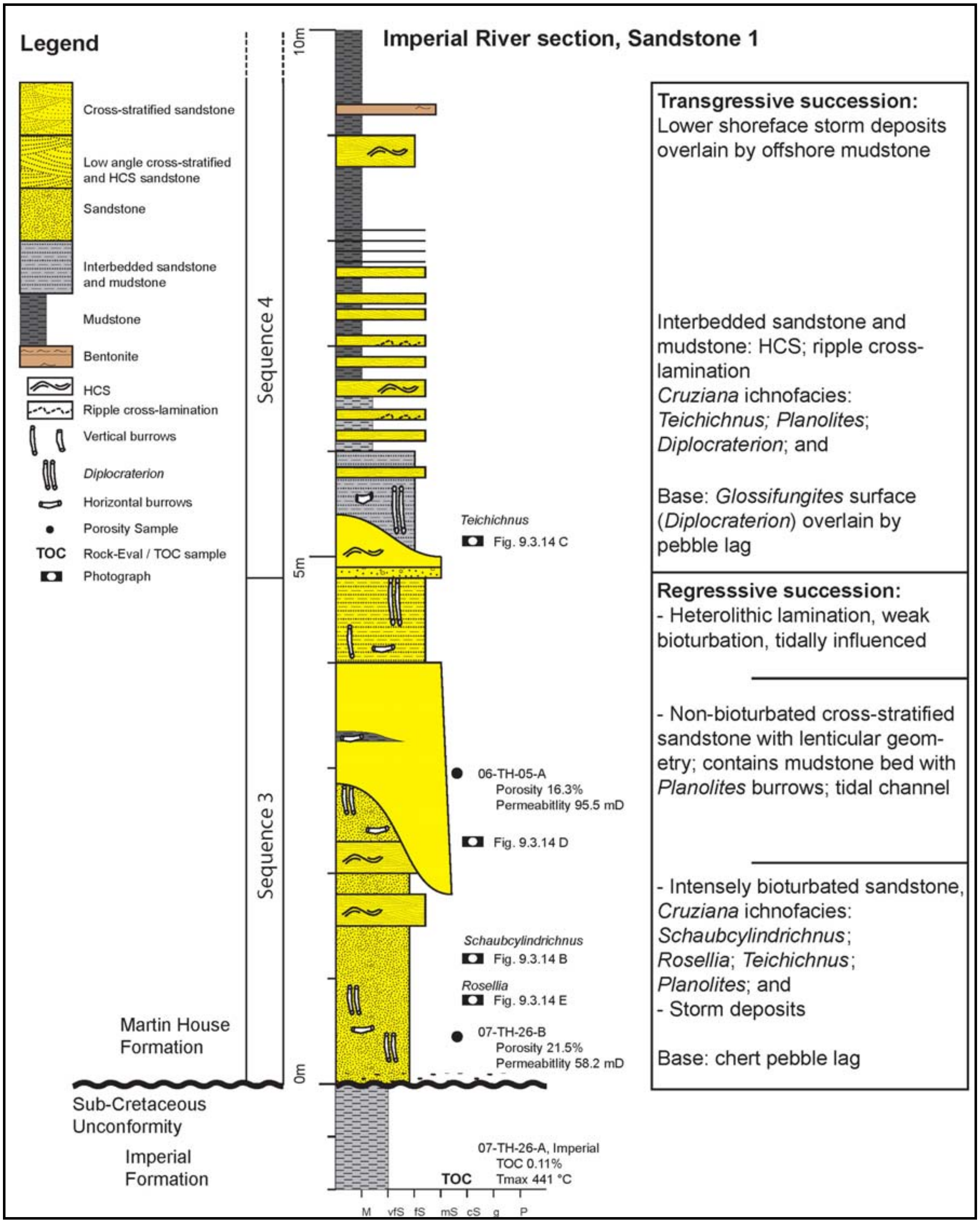

Figure 9.3.13. *Measured section of basal marine sandstone from Imperial River. The lower part is regressive and the upper part is transgressive.*

Figure 9.3.14. *Outcrop photographs of Basal Sandstone from Imperial River: (A) basal marine sandstone is labeled Sandstone 1; (B)* Schaubcylindrichnus *and (C)* Teichichnus *from lower shoreface deposits; (D) trough cross-stratified sandstone interpreted as tidal channel; and (E)* Rosellia *from lower shoreface deposits.*

Upper Martin House Formation Sandstones

In the eastern part of the study area approximately 20 m of mudstone separates the basal marine sandstone from overlying metre-scale sandstone units. In well logs, such as those from well K-03, the sandstone units appear to be the upper part of regressive successions (Figure 9.3.5), comparable to the outcrop at Imperial River (Figure 9.3.14).

At Imperial River there are two sandstone intervals above the basal marine sandstone separated by mudstone. In Figure 9.3.15 Sandstone 2 (30 m to 37 m) is broadly upward coarsening from interbedded hummocky cross-stratified sandstone and mudstone to amalgamated sandstone with hummocky cross-stratification near the base and swaley cross-stratification near the top. The succession of structures is interpreted to record a shoaling-upward succession of storm deposits. In this respect, the prograding shoreface indicated by Sandstone 2 represents the culmination of relative sea level fall following the transgression recorded at the top of the basal marine sandstone (Sandstone 1; Figure 9.3.15).

The top of Sandstone 2 is sharply overlain by mudstone, which in turn is gradationally overlain by the upward coarsening Sandstone 3; this succession is interpreted to record rapid relative sea level rise followed by shoreface progradation and relative sea level fall.

9.3.2 Arctic Red Formation

Arctic Red Formation conformably overlies Martin House Formation. At Imperial River, Arctic Red Formation overlies shoreface sandstones of upper Martin House Formation. West of Imperial River, Arctic Red Formation overlies the basal marine sandstone of Martin House Formation.

In outcrop few structures are apparent in the recessively weathered exposures of brown mudstone other than siderite concretions and rare, faint and indistinct laminae of fine-grained sandstone. The lowest part of Arctic Red Formation is intersected in core from well I-66, where moderately to intensely bioturbated mudstone with diffuse sand grains preserve a diverse suite of traces including *Schaubcylindrichnus*, *Helminthopsis*, *Chondrites*, *Teichichnus*, and *Planolites* composing a distal *Cruziana* ichnofacies, indicative of an open marine depositional setting.

Sans Sault Member

East of Hume River, such as at Imperial River, Mountain River, and Sans Sault Rapids on the Mackenzie River (Figure 9.3.4), 5 m to 10 m thick sandstone intervals occur within Arctic Red Formation.

At Mountain River and Imperial River, an approximately 5 m thick sandstone unit occurs in Arctic Red Formation, estimated from maps to be approximately 400 m to 500 m above Martin House Formation. This unit has a gradational base and sharp top. Sedimentary structures include parallel lamination and hummocky cross-stratification interpreted as storm deposits. The sandstone is therefore interpreted to have been deposited by a progradational shoreface.

At Sans Sault Rapids a sandstone interval similar to the one at Imperial and Mountain rivers outcrops on the north side of the Mackenzie River. The upper and lower contacts are not exposed but this sandstone unit has been termed Sans Sault Member of Arctic Red Formation (Dixon, 1999). This is correlated with the sandstones at Imperial River and Mountain River.

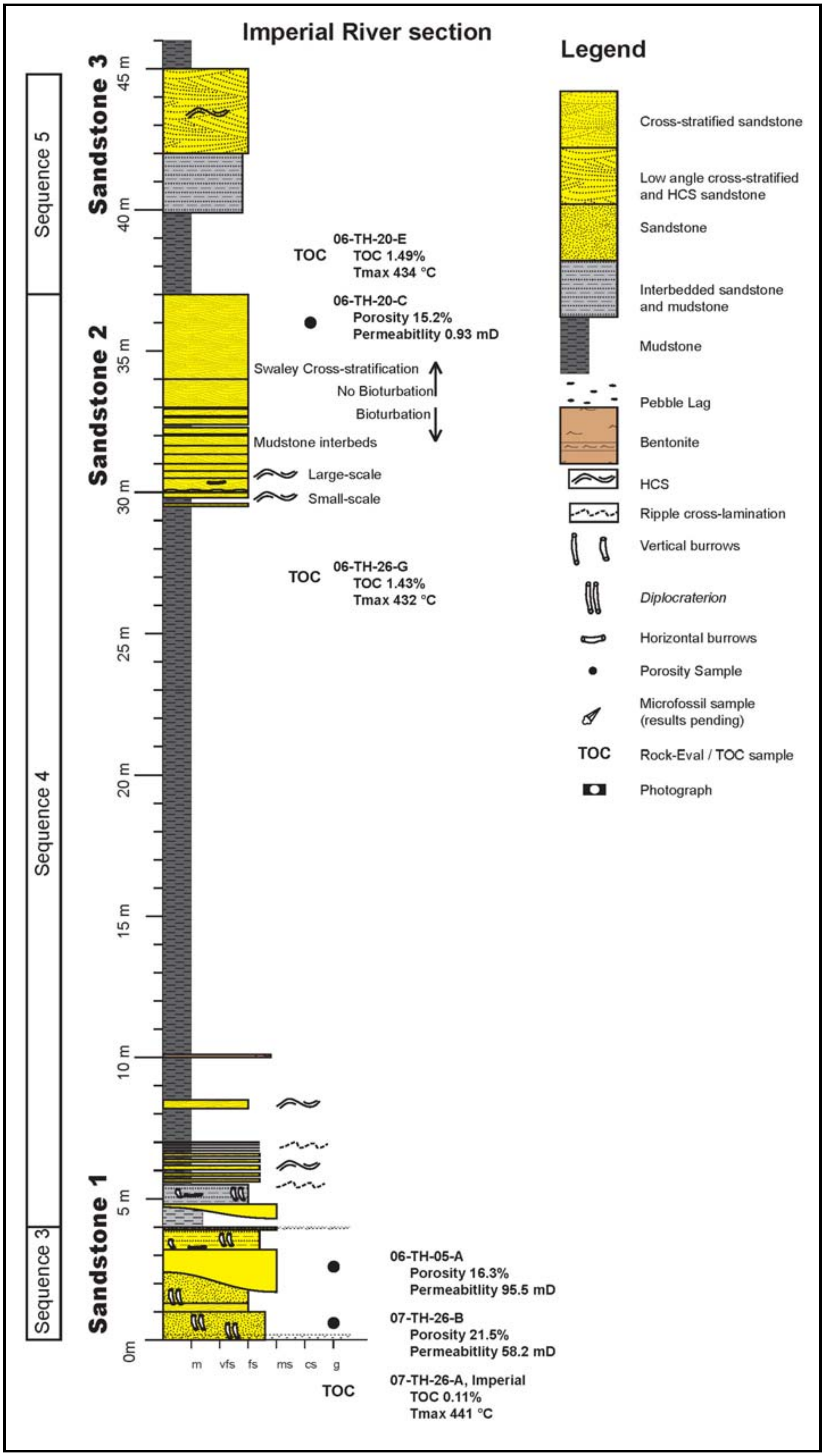

Figure 9.3.15. *Measured section of Martin House Formation from Imperial River. Sandstone 2 and 3 are typical progradational shoreface deposits.*

9.3.3 Slater River Formation

In Peel area, Slater River Formation is exposed in very few outcrops and is not intersected in any drill cores. The best exposure is at Hume River where a newly proposed mudstone interval of Slater River Formation underlies sandstone of Trevor Formation (see section 9.2).

Slater River Formation comprises brown- and reddish brown-weathering, poorly indurated mudstone and lesser siltstone with dark grey fresh surfaces. In the 50 m below Trevor Formation very rare thin beds and laminae of fine-grained sandstone contain ripple cross-lamination.

9.3.4 Trevor Formation

Trevor Formation is an interval of up to 800 m thick interstratified sandstone and mudstone at the 10 m to 100 m scale. It is not intersected by any drill core and is best exposed at Hume River and Cranswick River (Figure 9.1.1). Description of Trevor Formation sedimentology will employ a facies approach, and is mainly based on the Hume River section (Figures 9.3.16, 9.3.17). The Hume River section has been measured previously and recommended as a reference section for Trevor Formation (Yorath and Cook, 1981).

Facies

Trevor Formation is sub-divided into four facies: mudstone, interbedded sandstone and mudstone, amalgamated sandstone beds, and horizontally stratified sandstone (Figure 9.3.18). Hummocky cross-stratification (HCS) is sub-divided into small-scale (10 cm to 20 cm thick beds, wavelength 10 cm to 30 cm) and large-scale (>30 cm thick beds, wavelength 1 m to 3 m). These facies typically compose upward coarsening successions from mudstone to interbedded sandstone and mudstone to amalgamated sandstone facies (Figure 9.3.17).

Mudstone Facies

The mudstone facies is composed of interbedded mudstone, siltstone, and very minor sandstone (A in Figure 9.3.18). Mudstone is clay-rich, but not well indurated and lacks a pronounced fissility. Beds of mudstone are up to 20 cm thick. Siltstone and silty mudstone beds are less than 10 cm thick. Sandstone is uncommon, contains ripple cross-lamination and symmetrical ripples, and is very fine- to fine-grained. Macrofossils are rare, but include bivalves and coalified wood fragments. Trace fossils, though absent in lower parts of some parasequences, include 1 mm to 5 mm diameter horizontal sandstone-filled burrows.

The mudstone facies records suspension-dominated deposition of clay and silt generally below storm wave base. Sandstone with wave ripple-cross lamination indicates that the substrate, albeit rarely, was subject to wave currents. Since storm generated currents were rare and deposition from suspension was the primary mode, this facies is interpreted to represent an offshore depositional environment.

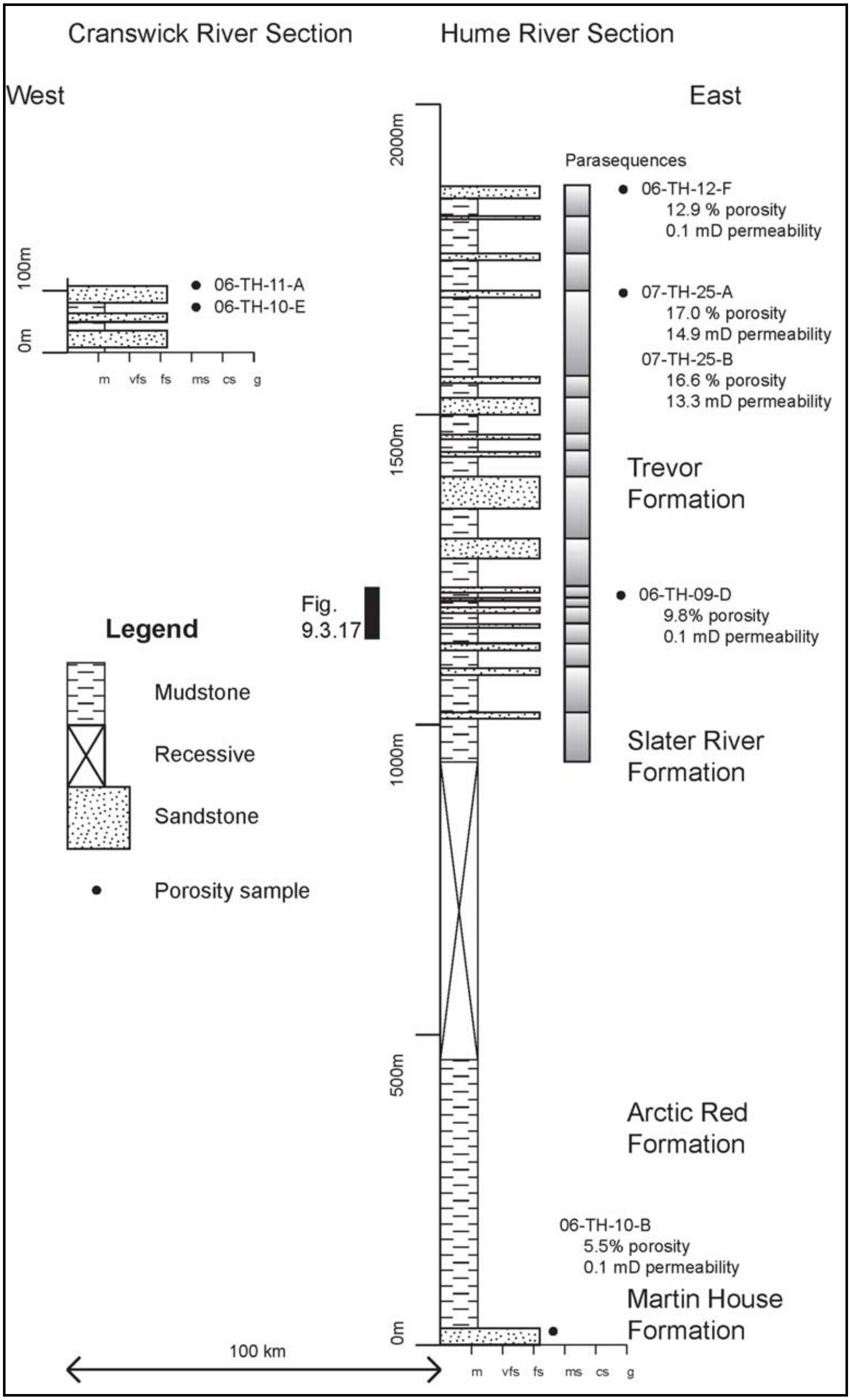

Figure 9.3.16. *Measured sections of Trevor Formation from Cranswick River and Hume River (locations on Figure 9.1.1).*

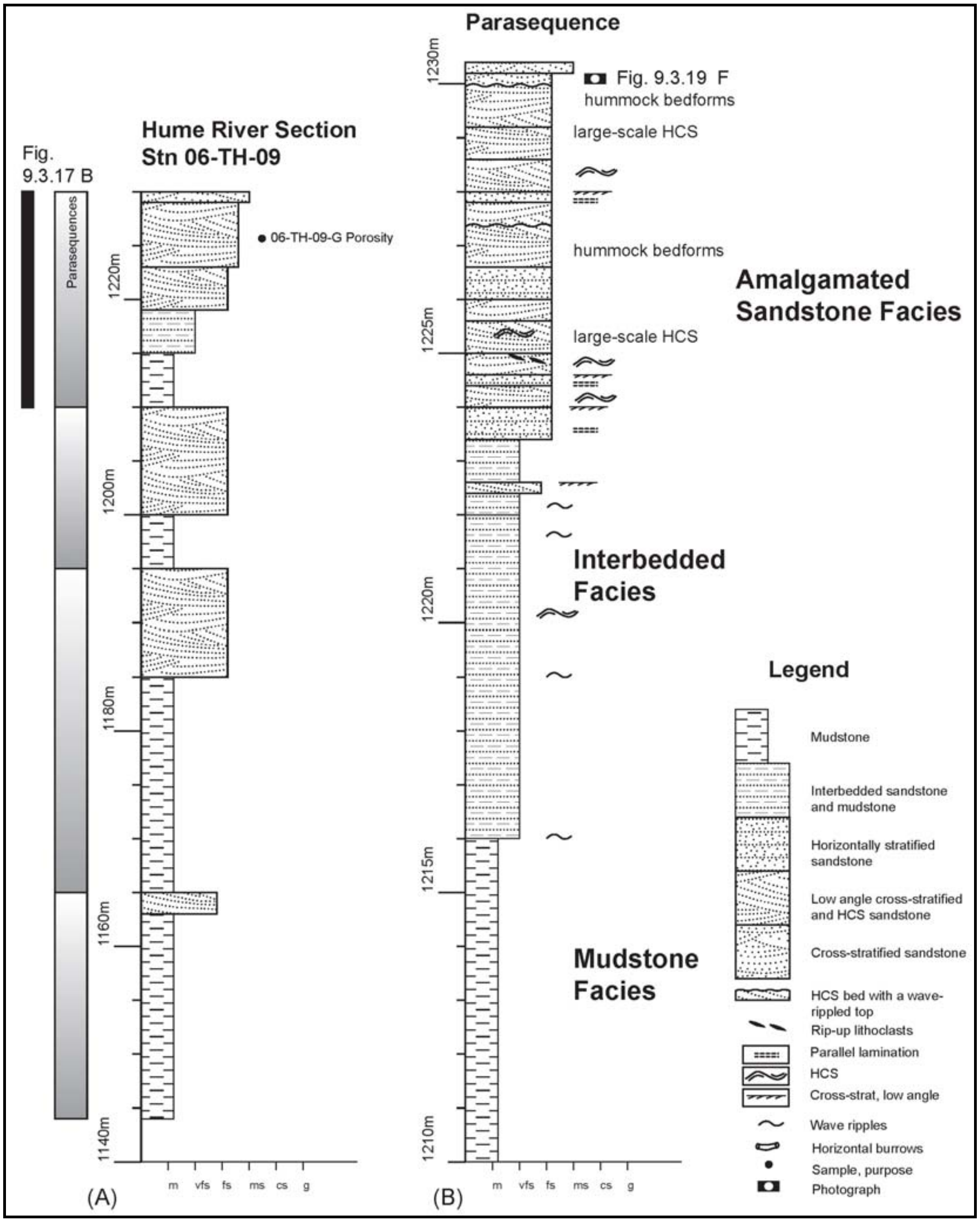

Figure 9.3.17. *Part of the Hume River measured section showing that the sandstones of Trevor Formation compose the tops of upward coarsening and upward shoaling successions interpreted as parasequences.*

Interbedded Sandstone and Mudstone Facies

Interbedded sandstone and mudstone facies is composed of cross-stratified sandstone with thin interbeds and laminae of mudstone (A in Figure 9.3.19). Typically, 60 cm to 150 cm intervals of interlaminated mudstone and ripple cross-laminated sandstone alternate with thin beds of sandstone (B in Figure 9.3.18). In general, this facies represents a gradation from mudstone facies to amalgamated sandstone facies, reflected by an upward decrease in thickness of mudstone interbeds and thickening of the sandstone beds.

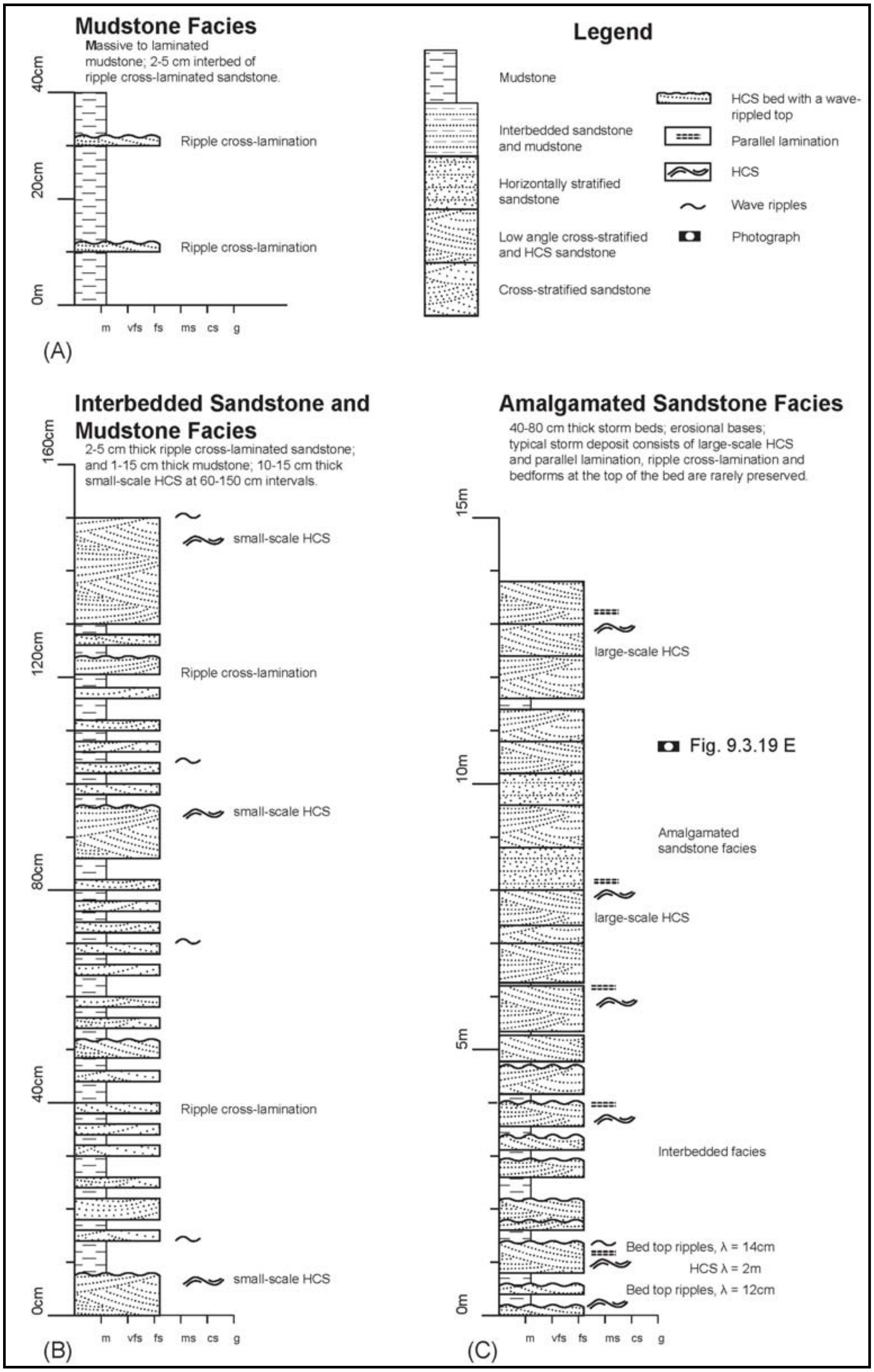

***Figure 9.3.18.** Facies of Trevor Formation.*

Very fine- to fine-grained sandstone displays small-scale HCS, ripple cross-lamination (e.g., B in Figure 9.3.19), and symmetrical ripple bedforms. Individual beds are 5 cm to 30 cm thick and vary in thickness laterally; some are discontinuous. A typical succession of sedimentary structures is: very low-angle cross-stratification, HCS, undulatory and parallel lamination, overlain by ripple cross-lamination with symmetrical ripple bedforms preserved at the top of the bed. Near the gradational transition to the amalgamated sandstone facies, up to 70 cm thick beds locally contain HCS with wavelengths of up to 2 m (C, D in Figure 9.3.19).

Ripples are generally symmetrical with 2D and 3D planforms. Cross-lamination associated with the 2D planform commonly has a preferred climbing direction. Interlaminated sandstone and mudstone contain horizontal, vertical, and 3D burrows. Beds of HCS are generally not bioturbated.

Sedimentary structures such as HCS and wave-ripple cross-lamination are indicative of wave generated currents. The typical succession of structures observed is interpreted to represent deposition from a waning storm (e.g., Walker and Plint, 1992). 3D symmetrical ripples and 2D symmetrical ripples with a preferred climbing direction are interpreted as combined flow ripples (Arnott and Southard, 1990; Dumas et al., 2005). Lateral thickness variation and discontinuity of beds indicate that this environment was relatively starved of sand-grade sediment, with influx occurring during storm events. Background sedimentation is recorded by interlaminated mudstone and sandstone. Characterized by storm deposits, the interbedded sandstone and mudstone facies is interpreted as transitional between offshore and a wave-dominated lower shoreface.

Amalgamated Sandstone Facies

Erosionally based 20 cm to 50 cm thick beds of fine-grained sandstone comprise the amalgamated sandstone facies (C in Figure 9.3.18; E in Figure 9.3.19). Sedimentary structures in typical vertical succession include large-scale HCS and undulatory to parallel lamination. Very low-angle cross-stratification is common. Ripple cross-lamination is rarely preserved at the top of beds. Bedding plane exposures exhibit primary current lineation and large-scale hummocks (F in Figure 9.3.19).

Although HCS is the most common form of cross-stratification, included in this facies are swaley cross-stratified (SCS) beds at the base that pass upward into plane and ripple cross-stratified beds (Figure 9.3.20).

The succession of facies from HCS through to wave-ripple cross-lamination records a waning-storm deposit. Parallel laminae with primary current lineation displayed on bedding planes are interpreted as upper flow regime plane beds (Allen, 1964). In contrast to the storm deposits of the interbedded facies, in the amalgamated facies the upper interval of ripple-cross lamination was usually eroded during subsequent storm events. As a result the predominant sedimentary structures are HCS, parallel lamination, and low-angle cross-stratification with minor SCS. Superimposed beds and absence of interbedded fines suggest that high energy storm currents were too frequent and strong to preserve mud-grade sediment. The amalgamated storm deposits thus form continuous sandstone sheets. The depositional environment is interpreted as a high energy storm-dominated middle shoreface (e.g., Leckie and Walker, 1982).

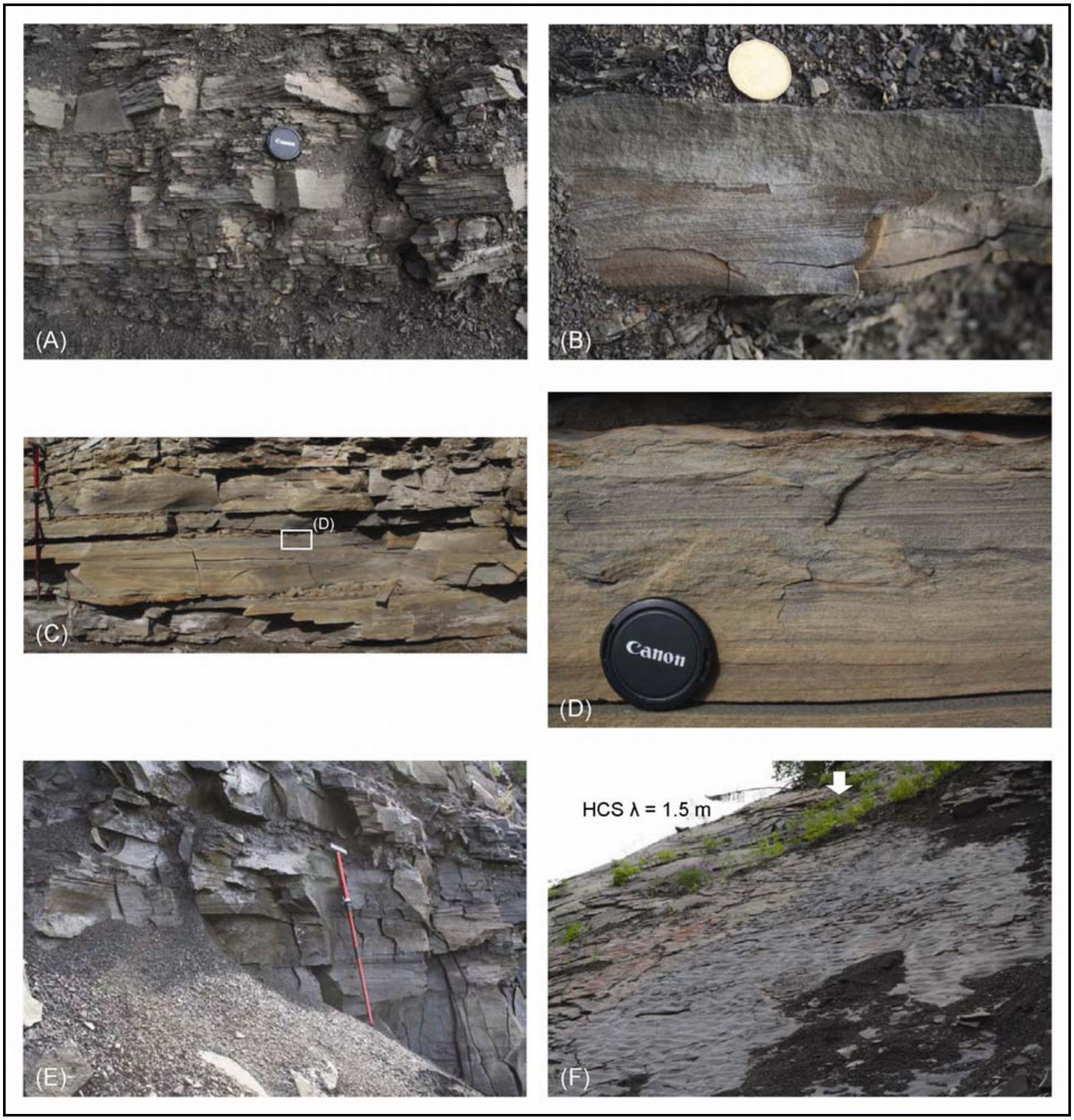

Figure 9.3.19. *Outcrop photographs of Trevor Formation sandstones at Hume River: (A) interbedded facies; (B) small-scale hummocky cross-stratification; (C, D) cyclic deposition of parallel lamination and ripple cross-lamination interpreted as storm events; (E) amalgamated sandstone facies; and (F) hummock bedforms preserved at the top of an amalgamated sandstone body.*

Horizontally Stratified Medium-grained Sandstone

Parallel-laminated, horizontally stratified medium-grained sandstone occurs in intervals greater than 5 m thick. Cross-stratification is very rare, restricted to infill of erosional scours. This facies was only observed near the top of Trevor Formation at Cranswick River.

In other sandstone facies of Trevor Formation the absence of cross-bedding is attributable to the fine-grained nature of the sand; however, dunes are expected to form in medium-grained sand (Southard and Boguchwal, 1973; 1990). Deposition of horizontally stratified facies was therefore dominated by upper flow regime plane beds where successive high energy events obliterated lower energy, probably fair-weather, deposits. For this reason, predominance of parallel lamination and absence of cross-bedding is considered evidence of a storm-dominated upper shoreface (Walker and Plint, 1992).

Discussion

The predominant sedimentary structures observed in Trevor Formation within the Peel Plateau are low-angle cross-stratification, HCS, SCS, parallel lamination, and symmetrical ripples. HCS with wavelengths up to 3 m indicate that long period waves were generated in a basin with sufficient fetch or size. The presence of upper-flow regime plane beds attest to the high velocities produced by these wave-generated currents. Although the velocities are not comparable to plane beds formed by unidirectional currents because experiments in fine-grained sand have shown that when a weak unidirectional component is added to a strong oscillating current, the stability field for plane beds decreases dramatically with respect to current velocity (Arnott and Southard, 1990). Therefore the prevalence of parallel lamination within Trevor Formation storm deposits is attributed to combined flow currents, consistent with the presence of combined flow ripples. The absence of cross-bedding formed by dunes is attributed to the grain size of the sand, since ripples in fine-grained sand transform directly into upper-flow regime plane beds with increasing stream velocity (Southard and Boguchwal, 1973; 1990).

Parasequences

Eighteen parasequences (cf. Van Wagoner et al., 1990; Arnott, 1995) are identified in the upper Hume River section (about 800 m thick) and five parasequences in the approximately 100 m thick Cranswick River section; correlation of these intervals is uncertain (Figure 9.3.16). A typical parasequence (Figure 9.3.17), bounded by flooding surfaces, is composed of a facies succession from mudstone, to interbedded sandstone and mudstone, to amalgamated sandstone. Offshore mudstone facies is typically 20 m to 60 m thick. In some instances, parasequences fine upward from the basal flooding surface and then coarsen upward in transition to interbedded sandstone and mudstone facies. The transitional lower shoreface facies of interbedded sandstone and mudstone is typically 5 m to 15 m thick. Middle shoreface amalgamated sheets of sandstone are 5 m to 10 m thick (e.g., B in Figure 9.3.17). Shoreface sandstones are generally fine-grained, but single beds of sandstone at the top may be coarse-grained or even pebbly, and are interpreted as transgressive lags. These parasequences record pulses of relative sea level rise followed by shoreface progradation into a mud-rich basin.

Figure 9.3.20. *Anatomy of a storm deposit from base to top: (A) swale bedforms overlain by (B) horizontal parallel lamination with primary current lineation; (C, D) 3D ripple cross-lamination; and (E) symmetrical 2D ripple bedforms that produced relatively simple climbing ripple cross-lamination.*

Trevor Formation Summary

Facies that compose Trevor Formation are offshore mudstone, lower shoreface interbedded sandstone and mudstone, middle shoreface amalgamated sandstone sheets, and upper shoreface storm-dominated sandstone. A typical lower to middle shoreface storm-deposit consists of very fine- to fine-grained, hummocky cross-stratified sandstone that passes upward into undulatory lamination, parallel lamination, and ripple cross-lamination. Concomitant bedforms include hummocks, primary current lineation, as well as 3D and 2D ripples. The depositional environment is interpreted to be a storm-dominated offshore to marine shoreface system.

This work supports the proposition by Dixon (1999) that Trevor Formation comprises a series of progradational shoreface cycles. In the study area, Trevor Formation consists of a progradational succession of offshore to middle shoreface parasequences typically 30 m to 60 m thick. It gradationally overlies offshore mudstone facies of Slater River Formation and represents basin scale progradation of fine-grained sand into a mud-rich marine basin.

9.4. STRATIGRAPHY AND BASIN GEOMETRY

T. Hadlari, D. Thomson, C.J. Schröder-Adams, B.C. MacLean, and Y. Lemieux

Based on foraminiferal analysis of samples from a measured section at Hume River (section 9.2), a significant stratigraphic revision wherein Cretaceous strata are subdivided into two unconformity bounded successions is presented: (1) sandstone of Martin House Formation and overlying shale of Arctic Red Formation are broadly of Albian age; and (2) shale of Slater River Formation and interstratified sandstone and shale of Trevor Formation are Cenomanian-Turonian in age.

9.4.1 Albian Succession: Martin House and Arctic Red Formations

Martin House Formation

West of Keele Arch, Martin House Formation overlies the sub-Cretaceous unconformity and is distributed everywhere that Cretaceous rocks are preserved (Figure 9.4.1). Martin House Formation is not present along Keele Arch structure and both thickens and grades to shale westward (Figures 9.3.5, 9.3.6). Martin House Formation is subdivided into three parts: 1) unnamed non-marine deposits referred to as Gilmore Lake member in industry reports (e.g., Chevron Canada Resources, 1989), informally proposed here as Tukweye member; 2) basal marine sandstone; and 3) upper Martin House Formation sandstones.

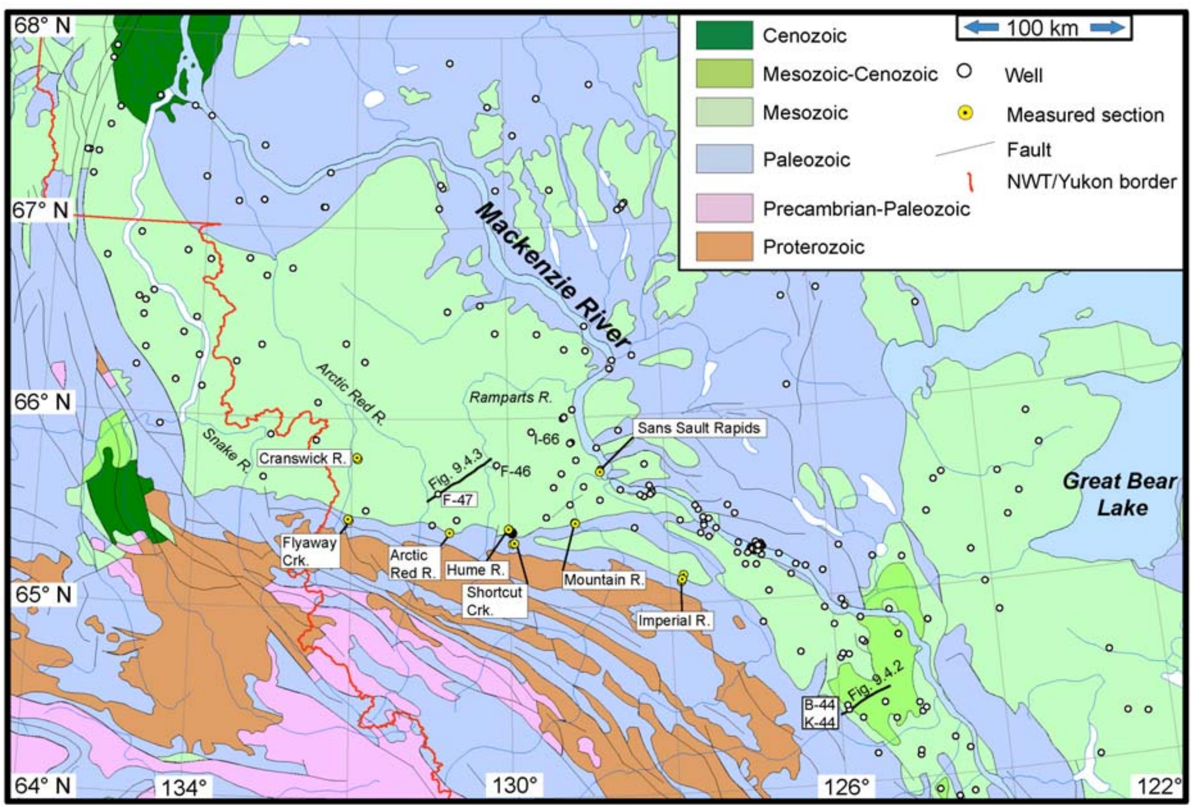

Figure 9.4.1. *Geological map showing the location of seismic lines and the regional cross section of Figure 9.1.3.*

Non-marine Deposits: Tukweye member

Non-marine deposits at the base of Martin House Formation are intersected by relatively few wells in a geographically restricted area, including cored intervals at wells I-66 and N-10 (Figure 9.3.1). Fluvial deposits were only observed in outcrop at Shortcut Creek. Although the distribution is defined by only few points, there is a general north-south trend. An appealing modern analog is the Mackenzie River which traverses a north-trending valley parallel to the northern Cordillera.

Within industry reports these non-marine rocks are informally called Gilmore Lake member (e.g., Chevron Canada Resources, 1989), which is a member of the Langton Bay Formation of Anderson Plain (Dixon, 1999). We propose a new informal designation of Tukweye member for the distinctive and geographically restricted non-marine deposits of Martin House Formation after Tukweye Lake, which lies northeast of well I-66 west of Mackenzie River. The best stratigraphic section is the cored interval of well I-66 which contains the full thickness of Martin House Formation from the sub-Cretaceous unconformity through floodplain and fluvial deposits of Tukweye member to the basal marine sandstone of Martin House Formation and offshore mudstone of Arctic Red Formation (Figure 9.3.2).

Basal marine sandstone

As discussed in section 9.3 the basal marine sandstone is composed of two depositional sequences that record two pulses of relative sea level rise and fall. Facies of the lowermost sequence illustrate a basin to shoreward transition from west to east (Figures 9.3.5, 9.3.6). These facies are therefore consistent with the interpretation that Keele Arch was a paleohigh (Cook, 1975). A westward deepening basin represents a significant change from northward directed drainage during deposition of Tukweye member and is interpreted to represent greater subsidence to the west during formation of the Albian foreland basin to the Columbian Orogeny (Figure 9.1.2).

Upper Martin House Sandstones

The upper Martin House Formation sandstones interpreted as shoreface deposits at Imperial River are correlated with sandstones from wells in the eastern part of the study area in proximity to Keele Arch (e.g., wells J-71 and K-03; Figure 9.3.5). Well log correlations indicate that these sandstones grade westward into shale (Figure 9.3.5), and so the geometry of a westward deepening basin continued throughout deposition of Martin House and lower Arctic Red formations.

Arctic Red Formation

Arctic Red Formation shales are distributed throughout Peel Plateau and Plain regions wherever Cretaceous deposits occur, and most of Mackenzie Plain except for a few locations on Keele Arch where the sub-Cenomanian unconformity overlies Paleozoic strata (e.g., wells B-45 and L-21; Figure 9.1.3).

Sans Sault Member sandstones within Arctic Red Formation are generally less than 10 m thick and interpreted to be typical lower to middle shoreface deposits. The distribution of Sans Sault

Member is limited to areas east of Hume River such as Sans Sault Rapids, Mountain River, and Imperial River (Figure 9.4.1). This distribution is interpreted to illustrate that eastward-shoaling and westward-deepening basin geometry continued throughout Arctic Red Formation deposition.

Further evidence for Keele Arch as a paleohigh within a westward deepening basin is indicated by seismic data. Line A293 is oriented approximately east-west intersecting both well K-44 and Keele Arch (Figure 9.4.1). Reflectors near the base of the Albian succession (Martin House and Arctic Red formations) onlap the sub-Cretaceous unconformity eastward (Figure 9.4.2), indicating that: (1) the absence of Martin House Formation over Keele Arch is a depositional relationship, not erosional, and consistent with facies interpretations; and (2) Keele Arch was a paleohigh throughout at least the lower part of Arctic Red Formation deposition, also consistent with facies interpretations.

9.4.2 Cenomanian-Turonian Succession: Slater River and Trevor Formations

Slater River Formation

Slater River Formation is newly proposed for Peel area based on biostratigraphy of the Hume River section (section 9.2), which indicates a Cenomanian age. At the base of Slater River Formation a distinctly high gamma-ray shale (section 9.2) is interpreted to record a major flooding event characteristic of lower Slater River Formation (Dixon, 1999). The high gamma-ray shale is correlated from Hume River to Arctic Red F-47 well (Figure 9.1.3). Seismic correlations show that the base of Slater River Formation in Arctic Red F-47 well correlates to an angular unconformity that truncates strata of Arctic Red Formation (Figure 9.4.3).

The sub-Slater River Formation unconformity increasingly truncates underlying strata eastward, enhancing the eastward-tapering cross-sectional geometry of the Albian succession (Figure 9.1.3). For example on Keele Arch at East Mackay B-45 well, the sub-Slater River Formation unconformity directly overlies Paleozoic rocks, eroding the entire Albian succession, if it was deposited. An increasing erosional truncation eastward is interpreted to indicate relative uplift of Keele Arch prior to regional transgression at the base of Slater River Formation. During uplift a northerly trending arch structure is inferred because east of Keele Arch, Martin House and Arctic Red formations are preserved (Figure 9.1.3).

Trevor Formation

Outcrop of Trevor Formation was identified only at Cranswick River and Hume River. Within Peel area, only the Arctic Red F-47 well intersects Trevor Formation but there are no cored intervals. The reference section at Hume River is critical for biostratigraphic control, and a Cenomanian-Turonian age has been assigned, which indicates correlation with Little Bear Formation of Mackenzie Plain (Figure 9.1.3).

Following regional transgression and deposition of up to over 200 m of Slater River Formation shale, parasequences of Trevor Formation record falling relative sea level and input from a new siliciclastic source. Clinoforms interpreted from seismic line A15 at the top of Slater River Formation and base of Trevor Formation dip eastward indicating that the newly established shelf deepened and migrated to the east (Figure 9.4.3). An eastward-deepening basin geometry is thus opposite to the geometry during Albian time. The sub-Slater River unconformity therefore separates two distinctly different depositional systems. An eastward prograding shelf at the base of the Trevor Formation indicates that the shoreface systems also prograded from west to east, bringing westerly derived sediment, most likely from the Cordillera, to the region.

9.4.3 Summary

Cretaceous strata in Peel area are subdivided into two large-scale unconformity bounded successions: (1) Martin House and Arctic Red formations broadly of Albian age; and (2) Slater River and Trevor Formations of Cenomanian-Turonian age.

The Tukweye member of Martin House Formation records deposition within a poorly defined but generally north trending paleovalley during the earliest phase of base sea level rise. Overall transgressive marine sandstones and shales of Martin House Formation were deposited in a westward-deepening basin in which Keele Arch was a paleotopographic high, indicated by onlapping geometry of Martin House and lower Arctic Red formations onto Paleozoic rocks of Keele Arch. Arctic Red Formation records further submergence and offshore shale deposition across the region. Sandstones of Sans Sault Member in the eastern part of the study area indicate that Keele Arch was a paleotopographic high throughout most of Arctic Red Formation deposition.

From foraminiferal biostratigraphy of the Hume River section, Thomson et al. (section 9.2) demonstrate that a disconformity exists between Albian Arctic Red Formation and Cenomanian Slater River Formation. Identification of a high gamma shale at the base of Slater River Formation allows regional correlation to well logs. From seismic line A15 the disconformity at the base of Slater River Formation is interpreted as an angular unconformity that erosionally truncates strata eastward. This erosional truncation is postulated to be the result of renewed uplift of Keele Arch prior to regional transgression at the base of Slater River Formation. Within the same seismic line are east-dipping clinoforms at the base of the Trevor Formation that are interpreted to represent a shelf that prograded eastward, an interpretation suggesting that sandstones of Trevor Formation were derived from a western sediment source. The sub-Cenomanian unconformity therefore separates strata deposited within different basin configurations.

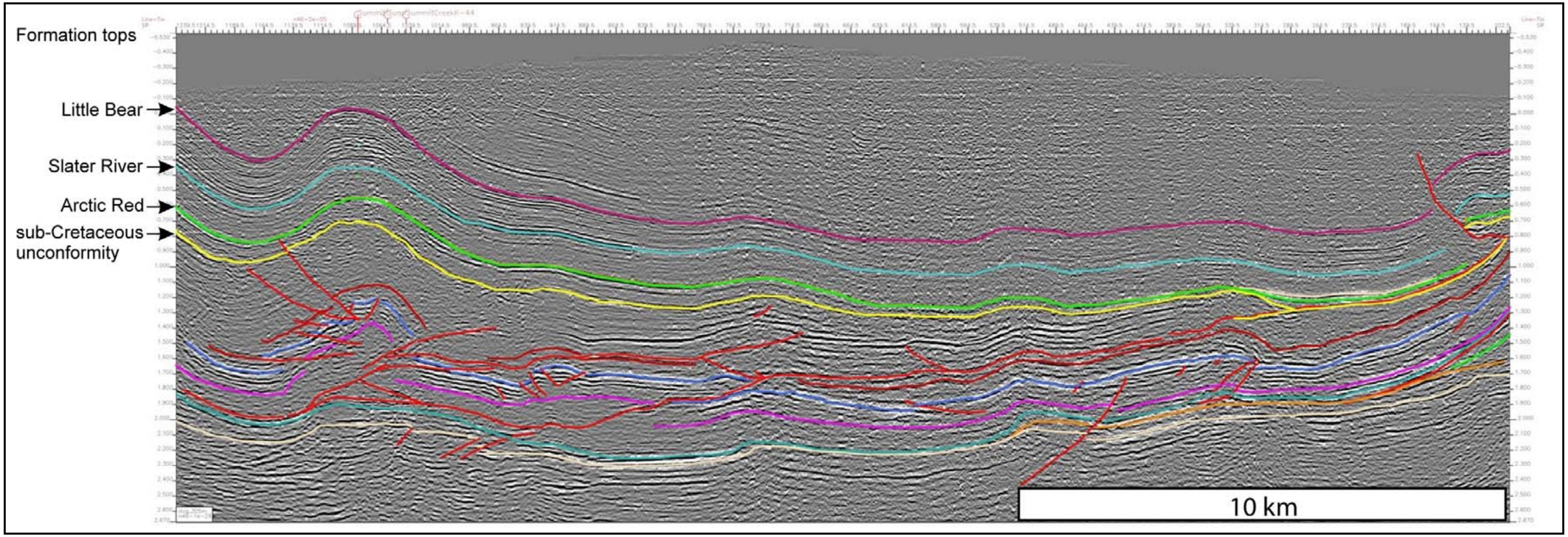

Figure 9.4.2. *Interpreted seismic section A239. Reflectors within Arctic Red Formation onlap the sub-Cretaceous unconformity eastward, interpreted to indicate that Keele Arch was a paleotopographic high.*

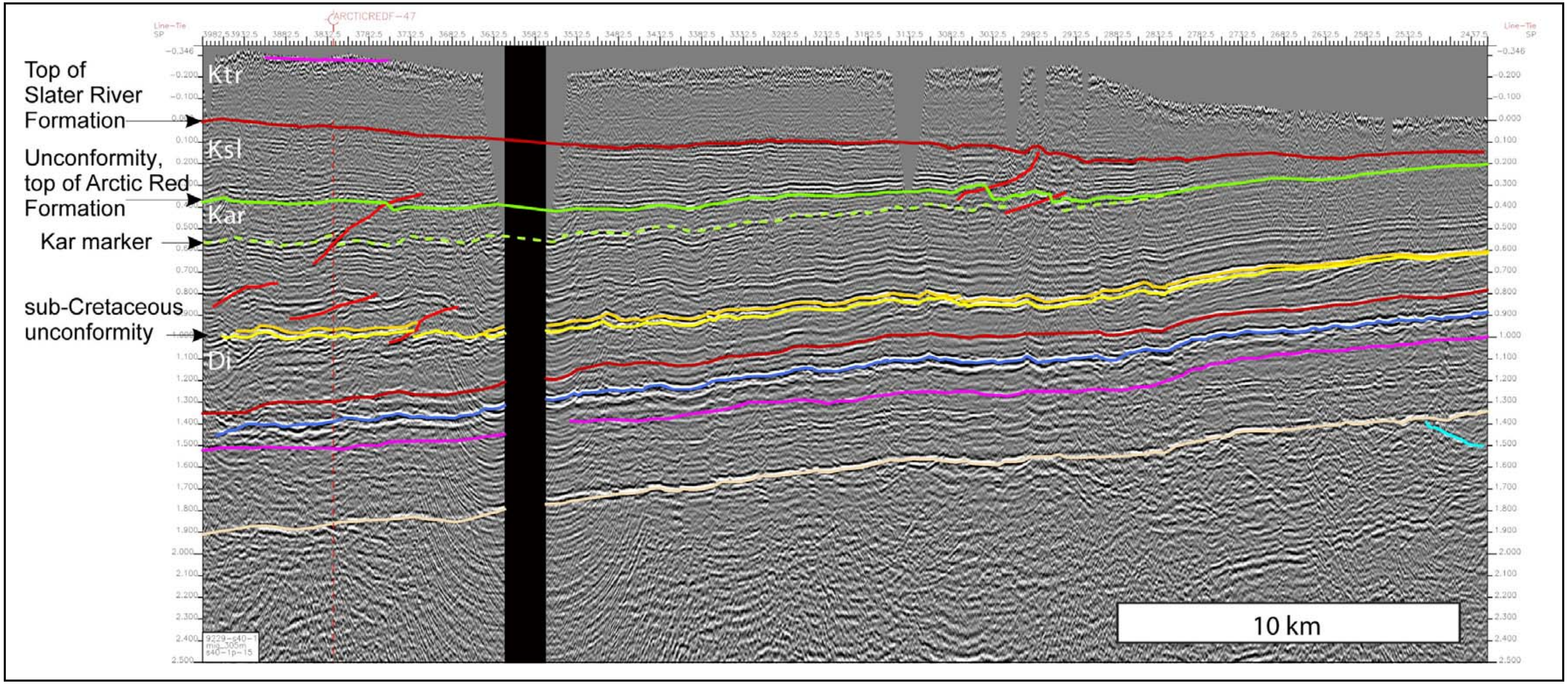

Figure 9.4.3. *Interpreted seismic section A15. Horizontal reflectors of Trevor Formation sandstone overlie eastward-prograding clinoforms within upper Slater River Formation shale. Offlap relations for some topset-foreset pairs within upper Slater River Formation and lowermost Trevor Formation indicate eastward progradation. The unconformity at the base of Slater River Formation truncates Arctic Red Formation, removing section eastward. Correlation with well Arctic Red F-47 (gamma-ray log not shown) places the high gamma-ray marker (section 9.2) within the prominent horizontal reflectors above the unconformity.*

9.5. PETROLEUM GEOLOGY

T. Hadlari, L.P. Gal, D. Thomson, and C.J. Schröder-Adams

This section examines the potential of a Cretaceous petroleum system in the Peel Plateau and Plain regions. Intervals through Cretaceous strata have not encountered oil or gas shows and there are very few cored intervals, so the data presented are mainly derived from outcrop samples.

9.5.1 Source Rocks

Potential Cretaceous source rocks are shales of Martin House, Arctic Red, Slater River, and Trevor formations.

Shale intervals within Martin House Formation are relatively thin. The thickest shale intervals are west of Arctic Red River where the basal marine sandstone grades into shale and north and east of Imperial River where up to 20 m of mudstone lie between the basal marine sandstone and upper Martin House sandstones (Figure 9.3.15). Analysis of samples by Rock-Eval/TOC pyrolysis indicates that TOC values for Martin House Formation shales are less than 1.5% (Table 9.5.1). On HI/OI (Hydrogen Index/Oxygen Index) plots Martin House Formation shales fall within the range of type III kerogen (Figure 9.5.1); terrestrial input is consistent with the inferred relatively shallow marine depositional environment.

Arctic Red Formation is shale dominant, up to over 500 m thick (tapering eastward toward Keele Arch; Figure 9.1.3), and has TOC values generally less than 2% , although some are higher, up to 3.54% (Table 9.5.1). HI/OI plots indicate both type I/II kerogen (HI up to 213) and type III (Figure 9.5.1). Based on the large thickness of shale and the presence of both marine and terrestrial organic matter, Arctic Red Formation has potential to produce oil and gas.

Slater River Formation has consistently higher TOCs than Arctic Red Formation (Table 9.5.1). The kerogen type appears to be only type I/II, with a maturity trend from HI 299 to values less than HI 100 (Figure 9.5.1). A stratigraphic thickness of over 300 m is consistent from the Arctic Red F-47 well and Hume River section to the Summit Creek K-44 well (see Figure 9.1.3). Slater River Formation thus has the best source rock potential of Cretaceous strata; however, the regional distribution is controlled by the thickness of Cretaceous strata preserved.

Shales of Trevor Formation have TOC values generally less than 2%. The kerogen type is difficult to interpret from an HI/OI plot because both HI and OI values are generally less than 50. Furthermore, the distribution of the formation is quite limited.

Sample	Formation	UTM 9 Easting	UTM 9 Northing	Location	S1	S2	S3	PI	S2/S3	Tmax (°C)	TOC (%)	HI	OI
Trevor Formation													
06-TH-12-C	Trevor	453061	7255421	Hume River	0.01	0.32	0.47	0.03	0.68	451	1.48	22	32
06-TH-12-B	Trevor	453161	7254872	Hume River	0.04	1.2	0.24	0.03	5.00	441	1.71	70	14
07-PEEL-116	Trevor	453116	7255542	Hume River	0.01	0.39	0.36	0.03	1.08	436	1.25	31	29
07-PEEL-108	Trevor	453085	7255439	Hume River	0.01	0.49	0.61	0.02	0.80	443	1.78	28	34
07-PEEL-102	Trevor	453392	7255187	Hume River	0.01	0.4	0.57	0.02	0.70	448	1.45	28	39
07-PEEL-95	Trevor	453349	7255086	Hume River	0.02	1.43	0.61	0.01	2.34	437	2.2	65	28
07-PEEL-83	Trevor	453323	7254634	Hume River	0.05	0.78	0.28	0.07	2.79	441	0.99	79	28
07-PEEL-75	Trevor	453567	7254390	Hume River	0.01	0.65	0.37	0.02	1.76	439	0.92	71	40
Slater River Formation													
07-PEEL-69	Slater River	453692	7254320	Hume River	0.02	0.77	0.17	0.02	4.53	438	0.89	87	19
07-PEEL-62	Slater River	453875	7254094	Hume River	0.03	0.95	0.44	0.03	2.16	444	1.6	59	28
07-PEEL-58	Slater River	453835	7253953	Hume River	0.09	2.03	0.51	0.04	3.98	436	1.73	117	29
07-PEEL-51	Slater River	454515	7253811	Hume River	0.15	7.09	0.23	0.02	30.83	428	2.69	264	9
07-PEEL-50	Slater River	454522	7253803	Hume River	0.17	6.99	0.09	0.02	77.67	426	2.34	299	4
07-PEEL-48	Slater River	454562	7253756	Hume River	0.21	1.64	0.91	0.11	1.80	421	2.34	70	39
07-PEEL-47	Slater River	454546	7253788	Hume River	0.09	1.7	0.17	0.05	10.00	424	2.07	82	8
07-PEEL-46	Slater River	454554	7253764	Hume River	0.05	1.29	0.32	0.04	4.03	433	1.96	66	16
07-PEEL-45	Slater River	454554	7253772	Hume River	0.1	2.44	0.14	0.04	17.43	434	1.76	139	8
07-PEEL-43	Slater River	454714	7253800	Hume River	0.06	0.64	0.4	0.08	1.60	436	1.46	44	27
07-PEEL-40	Slater River	454721	7253803	Hume River	0.01	0.19	1.71	0.03	0.11	454	0.93	20	184
Arctic Red Formation													
07-PEEL-39	Arctic Red	454721	7253828	Hume River	0.04	0.47	0.52	0.07	0.90	435	1.22	39	43
07-PEEL-29	Arctic Red	455237	7253683	Hume River	0.06	1.36	0.26	0.04	5.23	429	1.75	78	15
07-PEEL-23	Arctic Red	455364	7253233	Hume River	0.39	5.42	0.4	0.07	13.55	434	2.54	213	16
07-PEEL-20	Arctic Red	455402	7253109	Hume River	0	0.29	0.16	0.02	1.81	440	0.88	33	18
07-PEEL-14	Arctic Red	455403	7252983	Hume River	0.04	0.65	0.19	0.06	3.42	445	1.28	51	15
07-PEEL-09	Arctic Red	455420	7252808	Hume River	0.09	0.63	0.21	0.13	3.00	449	1.01	62	21
07-PEEL-04	Arctic Red	455367	7252710	Hume River	0.11	0.87	1.2	0.11	0.73	447	1.38	63	87
07-PEEL-03	Arctic Red	455388	7252719	Hume River	0.12	1.19	0.58	0.09	2.05	450	1.77	67	33

Table 9.5.1. *Data table of Rock-Eval/TOC analyses of Cretaceous samples.*

Sample	Formation	UTM 9 Easting	UTM 9 Northing	Location	S1	S2	S3	PI	S2/S3	Tmax (°C)	TOC (%)	HI	OI
07-TH-11-B	Arctic Red	455417	7252831	Hume River	0.2	4.72	0.26	0.04	18.15	448	3.54	133	7
07-TH-10-E	Arctic Red	455326	7252668	Hume River	0.06	0.88	0.91	0.07	0.97	446	1.16	76	78
07-TH-10-D	Arctic Red	455326	7252668	Hume River	0.06	0.67	0.45	0.09	1.49	448	0.85	79	53
06-TH-04-C	Arctic Red	455393	7253310	Hume River	0.1	1.81	0.34	0.05	5.32	442	2.08	87	16
06-TH-03-A	Arctic Red	492076	7258261	Mountain River	0.04	1.05	0.17	0.03	6.18	440	1.55	68	11
07-TH-27-B	Arctic Red	554941	7225703	Imperial River	0.01	0.48	0.13	0.03	3.69	432	0.84	57	15
06LP-19-10	Arctic Red	507891	7287663	Sans Sault	0.01	0.25	0.25	0.05	1.00	440	0.44	57	57
06LP-19-08	Arctic Red	507827	7287534	Sans Sault	0.01	0.24	0.16	0.04	1.50	438	0.57	42	28
07LG-11-B	Arctic Red	312621	7273857	Snake River	0	0.11	0.04	0.24	2.75	594	2.35	10	5
Martin House Formation													
07-TH-09-A	Martin House	418504	7254314	Arctic Red River	0.01	0.13	0.33	0.06	0.39	457	0.29	45	114
07-PEEL-02	Martin House	455380	7252727	Hume River	0.07	0.78	0.67	0.09	1.16	447	0.94	83	71
07-PEEL-01	Martin House	455376	7252735	Hume River	0.02	0.15	0.13	0.11	1.15	452	0.28	54	46
06-TH-20-E	Martin House	554108	7223314	Imperial River	0.08	1.54	0.3	0.05	5.13	434	1.49	103	20
07-TH-26-G	Martin House	554162	7223351	Imperial River	0.02	0.54	0.42	0.03	1.29	432	1.43	38	29
Imperial Formation													
07-TH-09-G	Imperial	418522	7254295	Arctic Red River	0.01	0.12	0.24	0.07	0.50	464	0.24	50	100
07-TH-10-A	Imperial	455292	7252652	Hume River	0.01	0.13	0.21	0.04	0.62	454	0.26	50	81
07-TH-26-A	Imperial	554210	7223133	Imperial River	0	0.05	0.31	0.08	0.16	441	0.11	45	282

Table 9.5.1. *Data table of Rock-Eval/TOC analyses continued.*

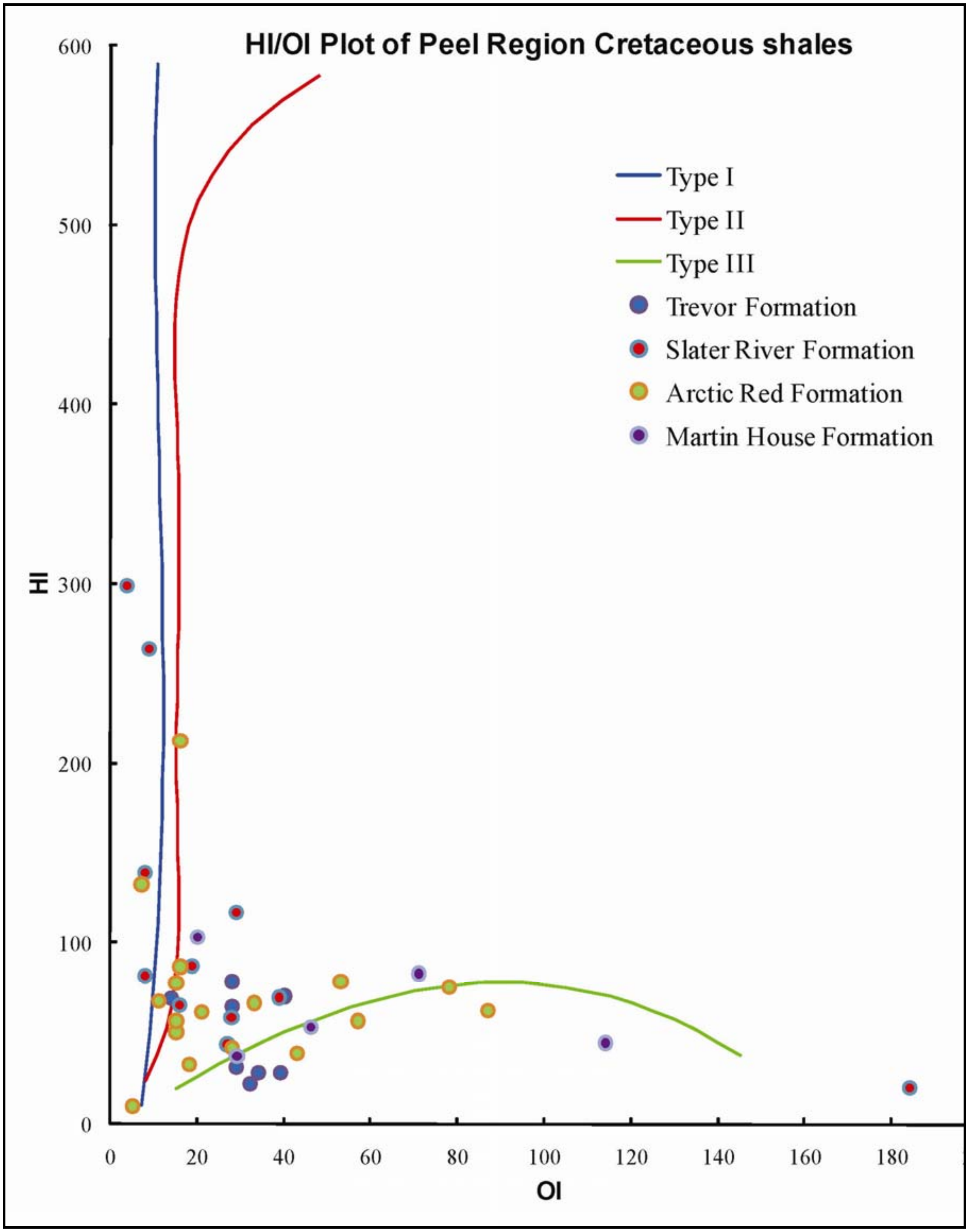

Figure 9.5.1. *Hydrogen Index (HI) vs. Oxygen Index (OI) from Rock-Eval pyrolysis data. Martin House and Trevor formations have type III kerogen trends. Arctic Red Formation has both type I/II and type III kerogen. Slater River Formation has the highest HI values and only type I/II kerogen.*

9.5.2 Thermal Maturity

Virtually all Cretaceous samples have Tmax values bracketing the oil window between 430°C and 450°C (Table 9.5.1). Previously compiled data indicate Cretaceous strata are within the oil window in most of Peel area, and in the gas window in western areas (Figure 9.5.2). There is a clear trend of increasing maturity from east to west of samples from lowermost beds in the Cretaceous succession (Figure 9.5.3), which is also seen from Paleozoic samples (Chapter 10, this volume), and is consistent with a general westward thickening of Cretaceous strata across the study area. Where samples of Imperial Formation were collected from directly below the sub-Cretaceous unconformity, Tmax values are slightly higher but probably within the range of analytical error (Figure 9.5.3). Because the thermal maturity of the lowermost Cretaceous and underlying Paleozoic rocks are so similar, peak thermal maturity was probably achieved following deposition of Cretaceous rocks. Furthermore, if rocks of Trevor Formation are thermally mature as the data appear to indicate, then a significant amount of rock has since been eroded. Maximum estimates of total Cretaceous stratal thickness are 1 km of Albian strata (Arctic Red and Martin House formations), 1 km of Cenomanian-Turonian strata (Slater River and Trevor formations), 1 km of Santonian-Maastrichtian (?) strata (East Fork and Summit Creek formations), and an unknown amount of Tertiary strata. The age of the youngest deposits would put the timing of peak burial in the latest Cretaceous or early Tertiary.

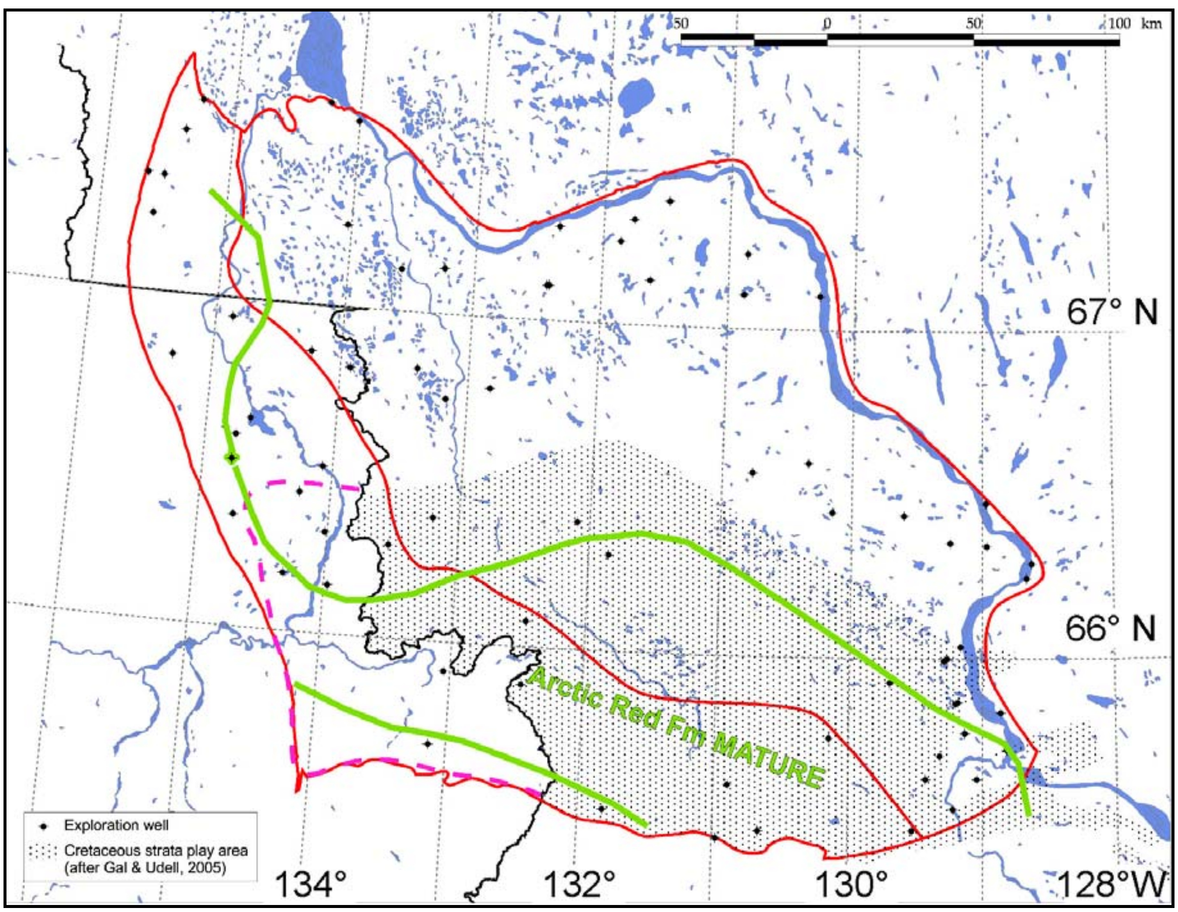

Figure 9.5.2. *Thermal maturity map of Arctic Red Formation.*

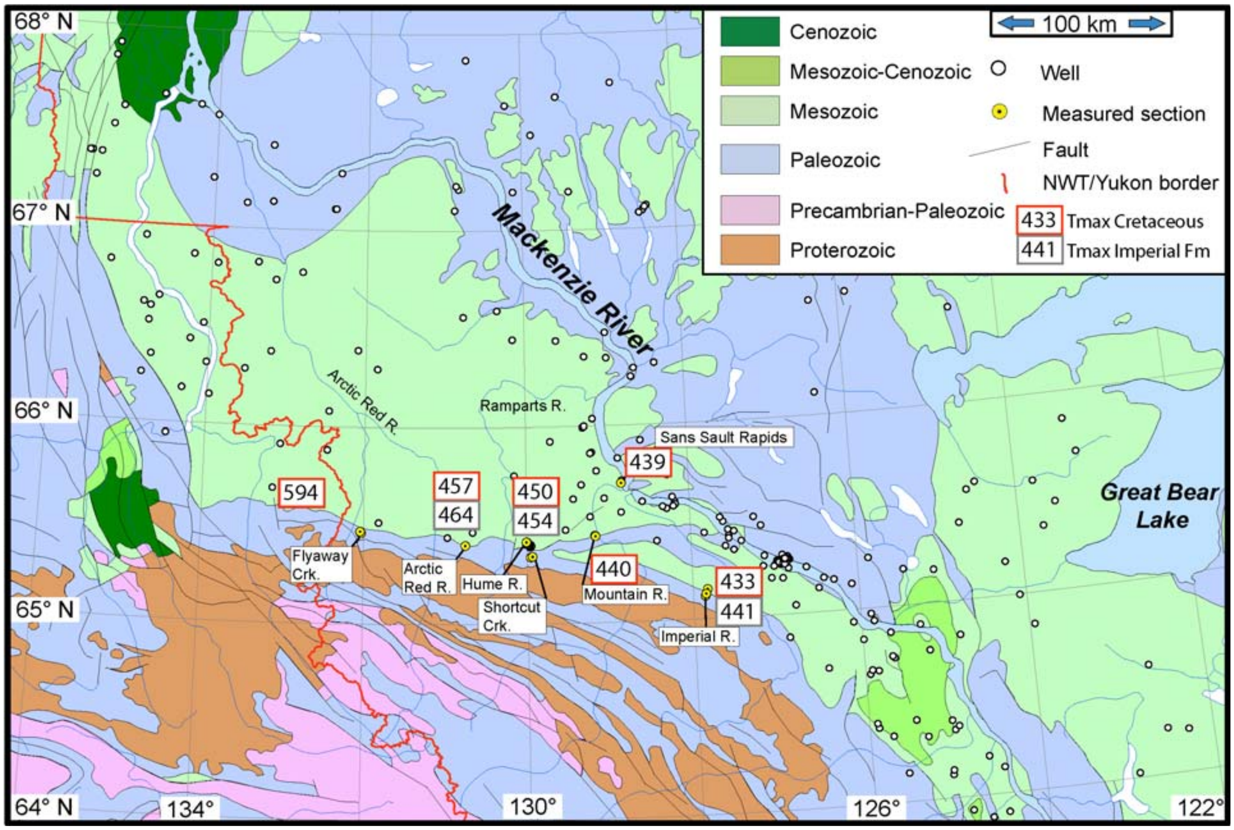

Figure 9.5.3. *Geologic map showing Rock-Eval/TOC Tmax values for the base of the Cretaceous succession from either Martin House Formation or Arctic Red Formation. Where Imperial Formation was sampled immediately below the sub-Cretaceous unconformity, those data are shown for comparison with base-Cretaceous data; note that they are similar.*

The Rock-Eval/TOC data are not without problems. When Tmax values are plotted against the Hume River section, Tmax of Arctic Red Formation decreases from about 450°C to less than 430°C over 500 m of section, which is a large decrease over a relatively thin package of rock (Figure 9.5.4). Tmax values from the base of Slater River Formation are quite scattered before leveling off around 440°C in Trevor Formation. The pattern could indicate contamination of upper Arctic Red and lower Slater River formations, and perhaps the prominent horizontal reflectors at the base of Slater River Formation coincide with a hydrodynamic boundary (Figure 9.4.3).

9.5.3 Reservoir Rocks

Potential reservoir rocks are sandstones of Martin House Formation, Arctic Red Formation, and Trevor Formation.

Tukweye member of Martin House Formation has poorly defined, but limited, geographic distribution (Figure 9.3.1). Outcrop samples of Tukweye member fluvial sandstones were not analysed; however, measured porosity and permeability results are available from the Hume River I-66 well report (Chevron Canada Resources, 1989; Table 9.5.2). From an almost 10 m thick interval of trough cross-stratified, medium- to coarse-grained sandstone, permeability exceeds 17.7 mD (millidarcies), up to 298 mD, and porosity ranges from 8.4 to 12.9%. These good reservoir characters are manifested in well logs by a low gamma-ray and relatively high resistivity signature (Figure 9.3.5).

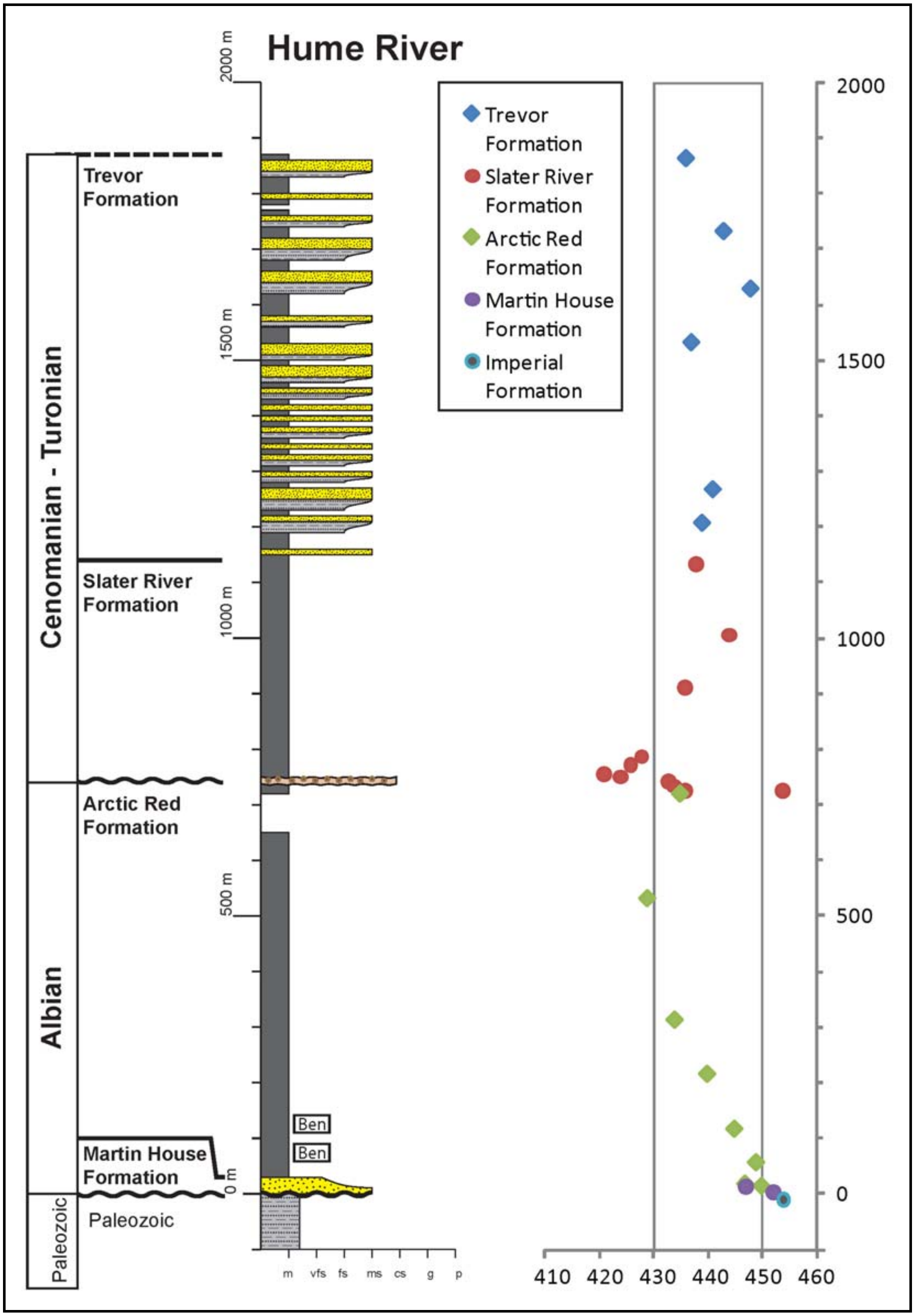

Figure 9.5.4. *Thermal maturity (Tmax) plotted against stratigraphic level within Hume River section.*

Sample	Formation	Location	Permeability Kmax (mD)	Porosity (%)
Trevor Formation				
06-TH-11-A	Trevor	Cranswick River	0.26	9.9
06-TH-10-E	Trevor	Cranswick River	0.16	8.9
06-TH-12-F	Trevor	Hume River	0.08	12.7
06-TH-09-D	Trevor	Hume River	0.06	9.8
07-TH-25-A	Trevor	Hume River	14.90	17.0
07-TH-25-B	Trevor	Hume River	13.30	16.6
Arctic Red Formation				
06-TH-03-D	Arctic Red	Mountain River	3.24	14.4
06-TH-03-C	Arctic Red	Mountain River	0.02	5.4
Martin House Formation				
06-TH-08-A	Martin House	Arctic Red River	4.66	6.0
07-TH-09-D1	Martin House	Arctic Red River	0.07	7.2
07-TH-09-D2	Martin House	Arctic Red River	0.06	7.4
07-TH-10-B	Martin House	Hume River	0.06	5.5
06-TH-20-C	Martin House	Imperial River	0.93	15.2
06-TH-05-A	Martin House	Imperial River	95.50	16.3
07-TH-26-B	Martin House	Imperial River	58.20	21.5
Tukweye member (Hume River I-66 well report; Chevron Canada Resources, 1989)				
Depth (m)		**Well**		
477.36	Tukweye mbr	I-66	153.00	11.6
478.04	Tukweye mbr	I-66	150.00	12.2
478.60	Tukweye mbr	I-66	84.10	11.2
478.78	Tukweye mbr	I-66	101.00	12.9
479.13	Tukweye mbr	I-66	116.00	12.9
479.81	Tukweye mbr	I-66	94.00	10.3
480.11	Tukweye mbr	I-66	137.00	12.0
480.24	Tukweye mbr	I-66	98.10	11.1
480.95	Tukweye mbr	I-66	126.00	10.2
481.23	Tukweye mbr	I-66	87.30	10.7
481.36	Tukweye mbr	I-66	134.00	11.1
482.28	Tukweye mbr	I-66	90.90	10.0
482.55	Tukweye mbr	I-66	36.20	9.2
482.60	Tukweye mbr	I-66	57.90	9.2
483.43	Tukweye mbr	I-66	17.70	8.7
483.62	Tukweye mbr	I-66	54.20	8.4
483.75	Tukweye mbr	I-66	152.00	10.6
483.90	Tukweye mbr	I-66	82.50	10.4
484.04	Tukweye mbr	I-66	52.20	10.0
484.47	Tukweye mbr	I-66	298.00	11.0

Table 9.5.2. *Table of measured porosity and permeability data.*

The basal marine sandstones of Martin House Formation are distributed almost everywhere Cretaceous strata are present between Arctic Red River and Keele Arch (Figure 9.3.4). At Imperial River an interpreted tidal channel sandstone sample yielded 95.5 mD permeability and 16% porosity and an intensely bioturbated lower shoreface sandstone yielded 58.2 mD and 21.5% porosity. These excellent results were not found in the Hume River and Arctic Red River sections west of Imperial River (< 5 mD; < 8% porosity). Petrographic comparison of medium-grained sandstones at Arctic Red River and Imperial River show that the early diagenetic histories of quartz overgrowths, minor intergranular quartz cement, and minor sutured grain boundary features are identical. Pore spaces in the sandstone from Arctic Red River are filled with clay, which leaves an open question as to whether this was a product of recent exposure at surface, in which case the subsurface correlative sandstones (interpreted barrier bar deposits) could be expected to have much better porosity and permeability than indicated.

At Mountain River, the basal marine sandstone is slightly less than 10 m thick and the lower part comprises strong to intensely bioturbated, interstratified sandstone and mudstone (Figure 9.3.11). The interstratified sandstone and mudstone is very friable and so intact samples could not be cut for thin section or tested for porosity/permeability, but hand sample inspection indicates that the porosity could be quite good.

Progradational shoreface sandstones of upper Martin House Formation at Imperial River yielded good porosity, 15%, but low permeability, 0.93 mD. Unlike the regional distribution of the basal marine sandstone, these units have local distribution and are generally less than 5 m thick.

Sandstones of Trevor Formation are fine- to very fine-grained. Porosity ranges from 9% to 17% with generally low permeability, less than 14.9 mD. There are 18 sandstone units ranging from 5 m to 15 m thick within an 800 m interval of Trevor Formation at Hume River. Although there is a relatively large amount of sandstone in the measured section, Trevor Formation is geographically restricted to an area where preserved Cretaceous strata exceed 1 km in thickness (Figure 9.5.5).

9.5.4 Tukweye member Incised Valley Play

For the Tukweye member incised valley play, the reservoir is Tukweye member fluvial sandstone which is generally restricted to a north-trending corridor (Figure 9.3.1), although there are other fluvial sandstones in the region, such as at Hanna River J-05 well (35 m thick). Arctic Red Formation is both the source rock and seal. At the base of the Cretaceous succession thermal maturity data indicate that there was sufficient burial to generate hydrocarbons (Tmax 439°C to 457°C; Figure 9.5.3). Fluvial sandstones are not distributed throughout the entire Tukweye member area, indicating that discrete channels could compose a stratigraphic trap, which would predate any hydrocarbon generation from Cretaceous sources.

Preservation is a major risk because the inferred trend of the paleovalley is parallel to the structural dip direction. A structural trap would be better, such as if a Late Cretaceous Laramide structure were formed prior to peak thermal maturity in the Late Cretaceous/Early Tertiary.

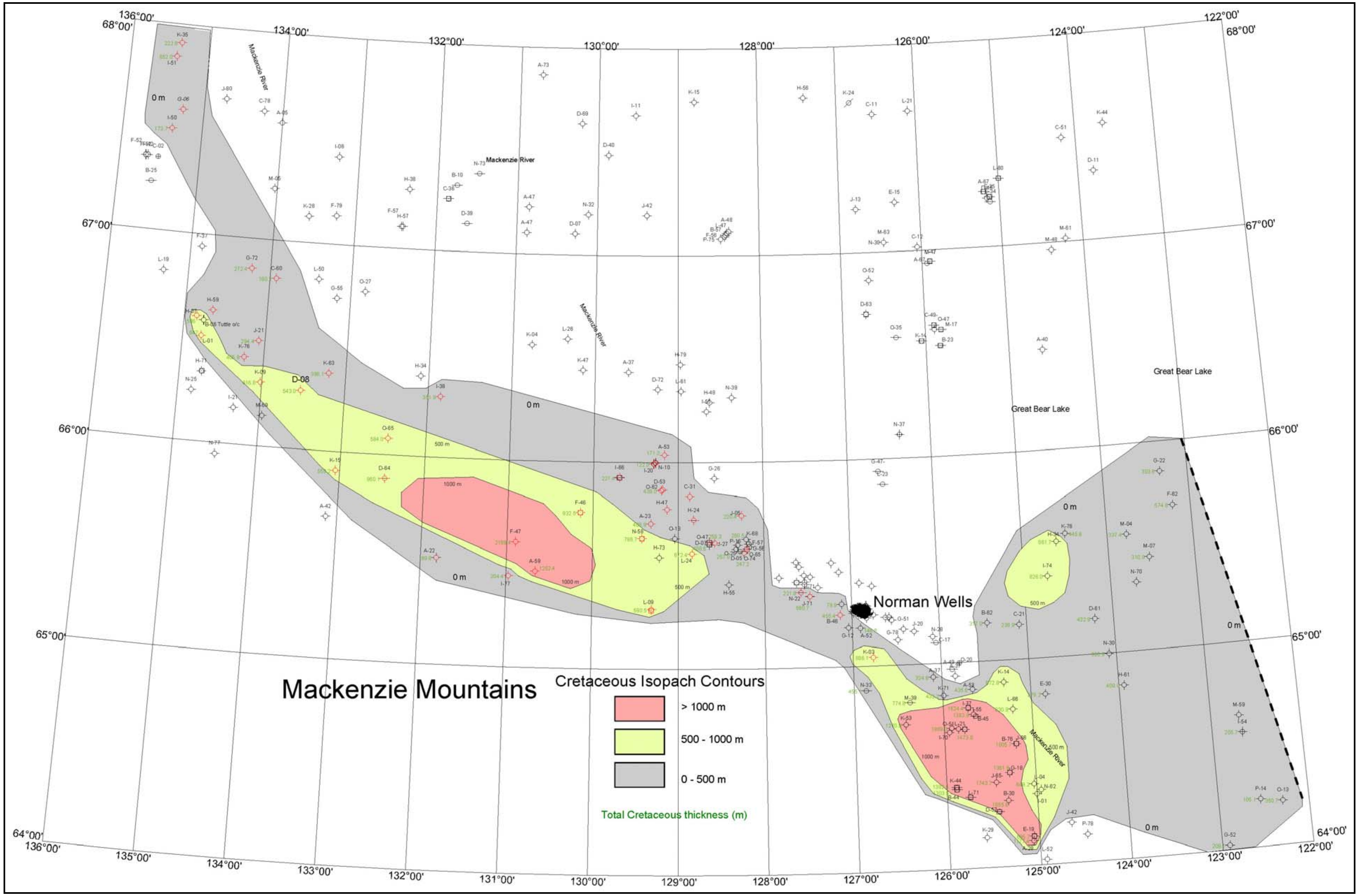

Figure 9.5.5. *Isopach map of Cretaceous strata. Strata thicken abruptly north of the Mackenzie Mountain front and then thin more gradually northward to zero. The geometry is a function of the south-vergent detachment at the front of the Mackenzie Mountains.*

9.5.5 Basal Cretaceous Sandstone Play

The reservoir for the basal Cretaceous sandstone play is the basal marine sandstone of Martin House Formation. Arctic Red Formation is both source rock and seal. Thermal maturity is favourable (Tmax 433°C to 457°C; Figure 9.5.3). The consistent regional distribution of the sandstone could enable lateral fluid migration, making a purely stratigraphic trap unfavourable. Unless, for example, barrier bar or tidal flat deposits were compartmentalized by shale, a structural trap would be preferable. Martin House Formation occurs at the base of Cretaceous strata over a large area, so the presence is fairly predictable; but in terms of preservation, the best trap would be a structure parallel to the strike of the mountain front in which deformation and later erosion has not progressed to the point of breaching.

9.5.6 Trevor Formation Tight Sandstone Play

The best source rock for a Trevor Formation play is Slater River Formation; Trevor Formation shale is less prospective. The reservoir is fine-grained sandstones of Trevor Formation. The seal is interbedded shale within Trevor Formation. If the shoreface sandstones are bounded by shale (compared to other parasequences, on the order of 20 km laterally; e.g., Hampson and Storms, 2003), then a stratigraphic trap is possible. Because Trevor Formation is limited to areas where the Cretaceous succession exceeds 1 km in thickness near the mountain front (Figure 9.5.5), trap preservation is dependent upon a favourable structural setting, if not actually developed as a structural trap. Another preservation risk is that Trevor Formation is generally shallow or at surface. The area west of Norman Wells where the thickest Cretaceous succession is preserved contains a relatively few number of wells (Figure 9.5.5) and so this part of the isopach map is not well defined. There is, however, a very good correspondence between the Cretaceous isopach and an isostatic gravity anomaly map for the same area (Figure 9.5.6), where areas with relatively thick Cretaceous strata are characterized by a low gravity signature.

9.5.7 External Factors

For each play a Cretaceous source rock has been identified, but there are two other high potential source rocks within Peel area: Devonian Canol Formation and Bluefish Member of Hare Indian Formation. Peak thermal maturity of Devonian rocks was probably achieved during maximum burial in the latest Cretaceous to possibly Early Tertiary which may account for the preservation of oil in Ramparts Formation at Norman Wells.

There are two stratigraphic relationships that could enable hydrocarbon migration from Devonian source rocks to Cretaceous reservoirs. First, due to the inclined geometry of sandstone units within Imperial Formation, considered to be parallel to clinoforms interpreted from seismic data (Hadlari et al., in press), it is quite likely that hydrocarbons generated from source rocks below Imperial Formation could migrate up-dip to sandstone reservoirs of Martin House Formation, particularly where Imperial Formation is relatively thin. Second, due to the geometry of Paleozoic rocks (tilted and probably faulted) below the sub-Cretaceous unconformity there are locations proximal to Keele Arch where Martin House Formation directly overlies (e.g., Brackett Lake C-21 well; Figure 9.1.1) or is in very close proximity to Canol Formation, and possibly the Bluefish Member (e.g., Figure 9.1.3). These scenarios allow for both oil and gas to migrate to Cretaceous, probably Martin House Formation, reservoirs.

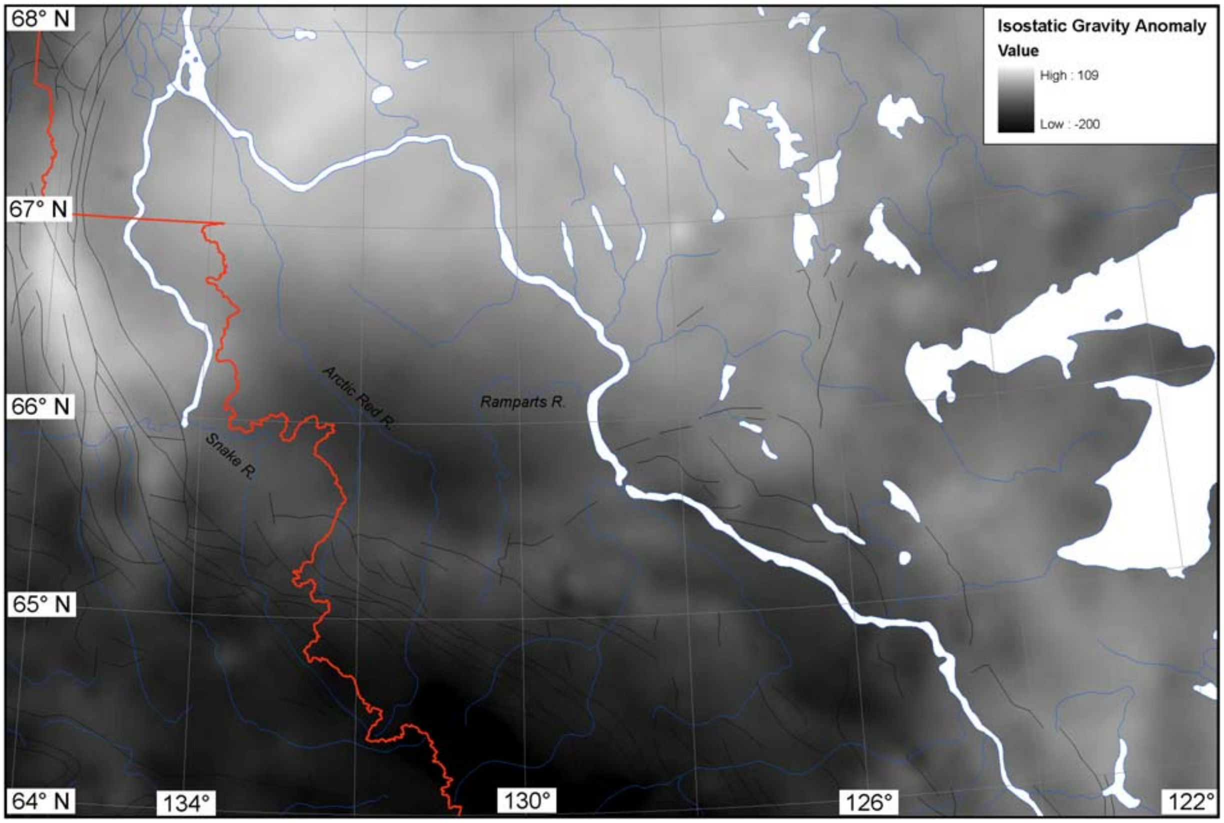

Figure 9.5.6. *Isostatic gravity anomaly map of Peel Plateau and Plain regions (Geological Survey of Canada, 1999).*

9.5.8 Summary

In Peel area the best potential Cretaceous source rocks are shales of Arctic Red and Slater River formations. Arctic Red Formation has TOC values ranging from poor (0.44%) to good (3.54%) with both type I/II and type III kerogen. Slater River Formation has slightly better TOC values of fair (0.89%) to consistently good (>1.5% to 2.69%), and type I/II kerogen (HI up to 299). Rock-Eval pyrolysis data indicate that thermal maturity for most Cretaceous rocks is within the oil window, with most Tmax values between 430°C and 450°C.

Potential reservoir rocks are fluvial sandstones of Tukweye member, transgressive marine sandstones of Martin House Formation, and progradational shoreface sandstones of Trevor Formation. Tukweye member fluvial sandstones measured from approximately 10 m of drill core from well I-66 have porosities from 8.4% to 12.9% and permeability from 17.7 mD to 298 mD. Martin House Formation sandstone samples from outcrop at Imperial River have yielded excellent porosities and permeabilities (16% porosity, 95.5mD; 21.5% porosity, 58.2 mD), which have not been duplicated at other outcrop localities. Martin House Formation sandstones at Imperial River and Arctic Red River have similar diagenetic cements, except that pore spaces from Arctic Red River sandstone are filled with clay. Trevor Formation sandstones are fine-grained and the best measured porosity and permeability values of 16.6% to 17% and 13.3mD to 14.9mD are lower than Martin House Formation sandstones.

Within Peel area, conceptual plays considered to have the highest exploration potential involve Martin House Formation reservoirs and Arctic Red Formation source rocks and seals. The Tukweye member incised valley play requires the identification of fluvial sandstones bounded by floodplain shales below and Arctic Red Formation shales above. The reservoir of the Basal Cretaceous sandstone play is transgressive marine sandstone of Martin House Formation extending from near Arctic Red River north and east to Keele Arch. Both plays could be stratigraphic but they probably require a structurally favourable setting, such as a strike-parallel Laramide anticline or fault that predates maximum burial in latest Cretaceous to early Tertiary. Both plays could benefit from local stratigraphic relationships that would enable hydrocarbons to migrate from Canol Formation and possibly Bluefish Member to Martin House Formation traps.

Acknowledgements

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Chapter 10 – Petroleum Systems Elements

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ABSTRACT

New and existing data coupled with new models indicate the potential for several effective and conceptual total petroleum systems in Peel Plateau and Plain (Peel area). Gas seeps, oil stained outcrops, bitumen occurrences, and petroleum shows in exploration wells both indicate and characterize the petroleum systems and their prospectivity in Peel area. The shows are linked to several conceptual plays, named after the formation or member hosting the show, which were discussed in the preceding stratigraphic-themed chapters of this volume. Here, the conceptual plays are characterized, modeled, and analyzed within a petroleum systems framework, where the known or potential petroleum source rock is considered the primary element.

Solvent extracts from oil stained samples collected for this study provide crude oil compositional data and interpretations (by K.G. Osadetz, Geological Survey of Canada - Calgary) that indicate the presence of two distinct oil types in southeastern Peel area: a "Norman Wells-type" oil potentially sourced from upper Devonian rocks and a "Colville Hills-type" oil potentially sourced from middle Devonian or older, likely Cambrian-Ordovician rocks. Stratigraphic and geochemical analyses indicate that the primary potential source rocks in Peel area are Canol Formation and Bluefish Member, which are inferred to be the source for the "Norman Wells – type" crude oil. Mount Cap or Saline River formations are considered to be potential source rocks in the Cambrian-Ordovician section. Crude oils from the same source rocks migrated into several potential reservoir strata.

Several known, hypothetical, or speculative petroleum systems are potentially important in Peel area. These include: a known Cambrian petroleum system (Mount Cap – Mount Clark), a hypothetical Cambrian-Devonian petroleum system (Road River – Ronning), a known middle to upper Devonian petroleum system (Horn River – Ramparts), two hypothetical (and probably interrelated) upper Paleozoic petroleum systems (Tuttle – Tuttle and Imperial – Imperial), and a known Cretaceous petroleum system (Arctic Red – Martin House).

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One-dimensional burial history models helped determine the timing of petroleum generation events in each of these petroleum systems. Generally in western Peel area, the models indicate that late Paleozoic burial by Imperial and Tuttle formations caused most potential Paleozoic source rocks to enter the oil window. Subsequent burial by thick successions of Albian and younger rocks caused the petroleum source rocks to enter the dry gas generating field. In eastern Peel area, some of these Paleozoic source rocks (for example, Horn River Group) did not enter the middle oil window until burial by Albian and younger siliciclastics.

The thermal maturity data indicate that much of the inferred Cretaceous succession has been eroded. The implications of uplift and erosion for petroleum accumulation preservation during the early Mesozoic (pre-Albian) and post-Cretaceous (and/or Tertiary) hiatuses are expected to be negative. However, the timing of late Cretaceous to early Tertiary petroleum generation and migration are inferred to be positive factors for the entrapment of petroleum in Late Cretaceous-Tertiary Laramide structures.

10.1 INTRODUCTION

L.P. Gal

This chapter is an analysis and discussion of conceptual petroleum plays in Peel area within a framework of petroleum systems (Dow, 1974; Magoon, 1988). The goals of this chapter are to: 1) present a compilation of petroleum occurrences in Peel area; 2) present new compositional data from oil stained rocks collected during this study; 3) present and discuss one-dimensional burial history models that assess the possible timing of petroleum generation relative to trap formation; and 4) identify and characterize known and hypothetical petroleum systems in Peel area, associating the conceptual plays presented in preceding chapters with the petroleum system of which they are a part.

10.2 PETROLEUM OCCURRENCES AND SHOWS

L.P. Gal

A first-order indication of the petroleum potential of Peel area is the existence of oil stained outcrops, bitumen occurrences, surface oil and gas seeps, reported gas in seismic shotholes, gas kicks in exploration wells, mud gas recorder anomalies, drill stem test (DST) and flow test results (Figure 10.2.1). Surrounding Peel area are regions with known accumulations of petroleum; notably the Norman Wells oil field to the southeast, natural gas and oil in the Colville Hills to the east, oil in the Eagle Plains to the west, and oil and gas in the Mackenzie Delta to the northwest.

10.2.1 Oil Stained Outcrops

Oil stained outcrops have been noted by early explorers throughout southeastern Peel Plain and the Mackenzie Plain (e.g., Collins and Scherp, 1965). Oil stained rocks are present in the stratigraphic section from Mount Kindle Formation up into the Cretaceous rocks, at locations near the Mackenzie and Franklin mountain fronts such as: Mountain River where it crosses the Imperial anticline crest, Powell Creek, Carcajou Ridge, Stratigrapher Cliffs, Loretta Canyon, and Katherine Creek. In addition, well history reports often mention oil stained core or cuttings, or a fluorescent cut in the cuttings. Examples of oil stained cores examined during the current study are found in Pierce and Jones (2009). Kunst (1973) and Pugh (1983) have compiled some oil stain occurrences. New occurrences in western Peel Plateau in Tuttle Formation were examined and analyzed by Allen et al. (2008a). New analyses of oil stained rocks from just southeast of Peel area are discussed in section 10.3.

10.2.2 Bitumen Occurrences and Oil Impregnated Rocks

Bitumen “dykes” have been reported adjacent to western Peel area in Road River Group rocks by Stelck (1944) on Peel River and Riddell (1969) along Vittrekwa River. Jeletzky (1960) reported oil impregnated Cretaceous sandstones along Stony Creek in the Richardson Mountains. North of Peel area, a massive bitumen “sill” within Imperial Formation occurs near Rengleng River (Figure 7.3.2 in Chapter 7, this volume; Norris and Cameron, 1986; Pyle et al., 2007).

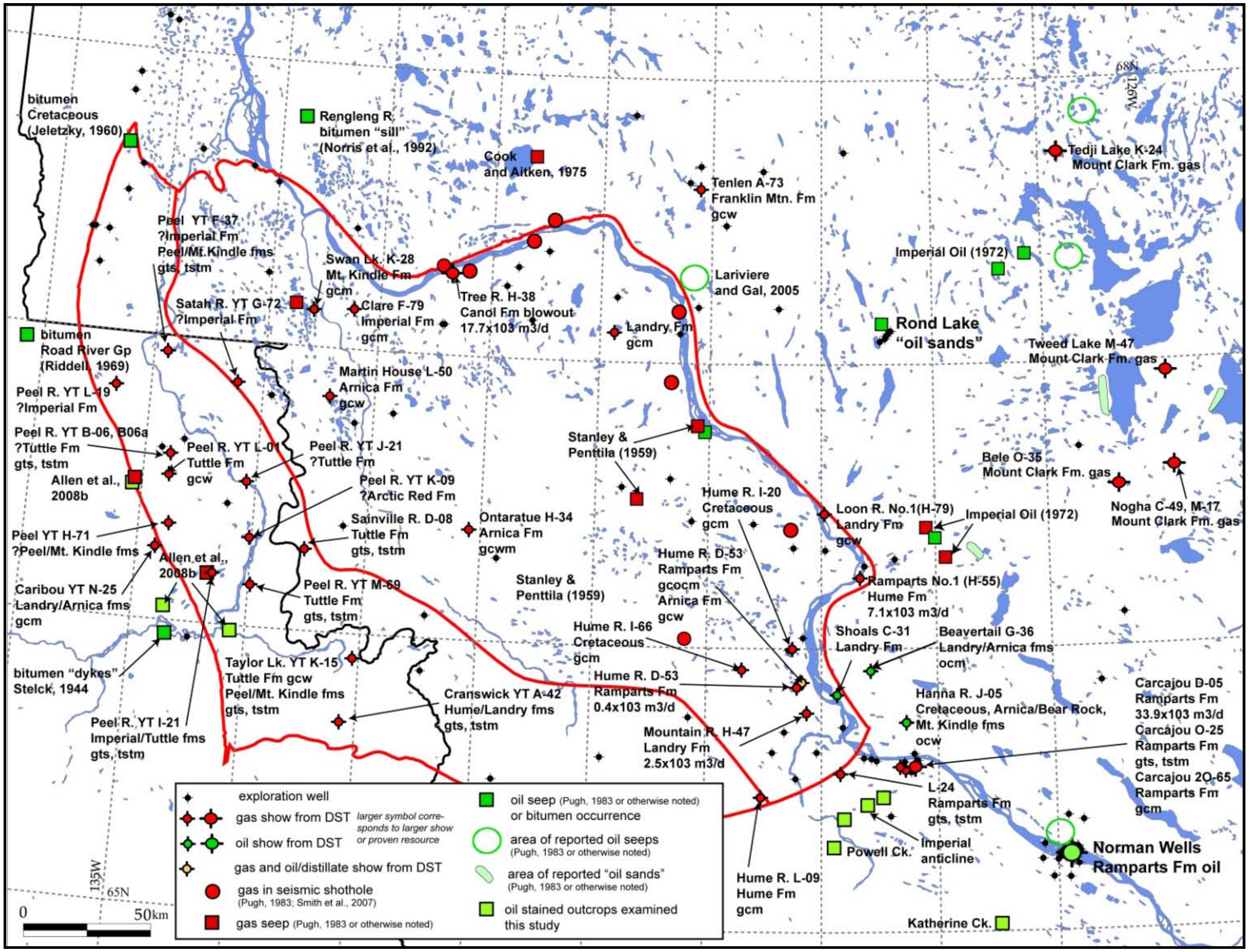

Figure 10.2.1. *Summary map of hydrocarbon indications in wells and outcrop of Peel area. Shows and seeps, etc., are compiled from a number of sources, as indicated on this figure and in the text. Question marks are used where there are conflicting reports. DST results are compiled from individual well history reports and the database of GeoLOGIC Systems Ltd. Geoscout™ program. Abbreviations from DST results are as follows: gts = gas to surface; tstm = too small to measure; gcw = gas cut water; gcm = gas cut mud; ocm = oil cut mud; ocw = oil cut water; gcocm = gas cut, oil cut mud; gcwm = gas cut water, gas cut mud.*

Bitumen has been noted quite commonly as minor occurrences in well history reports throughout Peel area (e.g., Williams, 1969; Franklin Mountain Formation in Stony I-50 well); examples from core are illustrated in Pierce and Jones (2009).

The oil impregnated sandstones at Rond Lake have long been known (Williams, 1960; Janicki, 2001) as have those at Lac Belot, Lac du Bois, and Lac Jacques (Williams, 1969; Pugh, 1983). At Rond Lake a thin veneer of poorly consolidated Cretaceous sandstone are saturated in oil; the underlying Ramparts Formation and Bear Rock breccias are oil stained as well (Williams, 1960).

10.2.3 Oil Seeps

The oil seeps along the Mackenzie River and Bosworth Creek near Norman Wells are also well known (Janicki, 2001), and led to the discovery at Norman Wells. Areas of reported oil seeps east of Peel area have been mapped by Pugh (1983). Devlan Exploration Inc. reported oil seeps near the junction of the Thunder and Mackenzie rivers in northeast Peel area (see Lariviere and Gal, 2005). Gal (2005) mapped oil seeps reported in geological and geophysical reports submitted by field parties to the government (e.g., Stanley and Penttila, 1959; Campbell and Sproule, 1960; Imperial Oil Enterprises Ltd., 1972).

10.2.4 Surface Gas Seeps and Seismic Shothole Gas

Gas seeps have been reported by industry field parties (e.g., Stanley and Penttila, 1959; Imperial Oil Enterprises Ltd., 1972); including in the Ontaratue River area in central Peel Plain (Campbell and Sproule, 1960). Compilations of locations have been mapped by Kunst (1973), Pugh (1983), and Gal (2005). Cook and Aitken (1975) mapped a gas seep on the east side of Travaillant Lake north of Mackenzie River, and Norris (1981, 1997) reported a seep at Swan Lake in northwest Peel area.

Gas shows from seismic shothole drilling have been mapped in Peel area by Pugh (1983) and compiled in a comprehensive database by Smith et al. (2007). Allen et al. (2008a) reported new gas seeps at the western edge of Peel Plateau; and indirect evidence for gas seepage in Tuttle Formation was presented by Allen and Fraser (2007).

10.2.5 Petroleum Indications during Drilling and Testing of Exploration Wells

Based on well history reports, a number of wells in Peel Plateau have recovered small amounts of gas (too small to measure) chiefly from Tuttle Formation; but also Cretaceous, Imperial, Landry/Arnica, and Delorme Group/Mount Kindle formations (Figure 10.2.1). In western Peel Plain traces of gas in fluids recovered on DSTs have been reported from Imperial, Arnica, and Mount Kindle formations. A blowout of sweet gas, estimated to flow at 17,700 m^3/d (0.5 Mmcf/day) from Canol Formation, occurred at 721 m depth while drilling the Tree River H-38 well (Imperial Oil Enterprises Ltd.,1967; Morrell, 1995).

In central and eastern Peel Plain, a few wells have yielded traces of gas from Arnica and Landry formations on DST (e.g., Ontaratue H-34, Grandview Hills No. 1 A-47, and Loon River No.1 H-79 wells).

In southeastern Peel area, there have been a number of gas and oil traces from DSTs and some modest shows: the Ramparts No.1 (H-55) well had a flow of gas from Hume Formation, estimated at 7,100 m^3/day (251,000cf/day; Soul, 1960), Mountain River H-47 flowed gas from Landry Formation at 2,500 m^3/day (88,000 cf/day; Holmes and Koller, 1972), and Hume River D-53 flowed gas on a Ramparts DST estimated at 400 m^3/day. Further gas traces (too small to measure) were reported in well history reports of: Hume River A-53 (Ramparts and Arnica formations) and Hume River L-09 (Hume Formation).

There was a small recovery of 39.2° API oil from Landry Formation in Shoals C-31 well (Evans, 1966). Just east of Peel area, specks of oil in fluids recovered on DST were reported in the Hanna River J-05 and Beavertail G-26 wells.

Gas detector anomalies were reported from Cretaceous and older strata in several of the Hume River and Mountain River wells drilled by Chevron in the 1990s, which were the most recent wells drilled in the Peel area (Chapter 1, this volume).

Just southeast of Peel area around the mouth of Carcajou River, there have been a number of tests and gas shows, the most significant of which was the Carcajou D-05 well, spudded in 1984 by AT&S Exploration Ltd., and classified as a suspended Ramparts Formation gas show. The well kicked gas while pulling a core from Ramparts Formation at 546 m, and sour gas (6 ppm H_2S) flared at an estimated $140x10^3$ m^3/day (almost 5 Mmcf/day; Dudus, 1985). 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 (Dudus, 1985).

10.3 COMPOSITIONAL TRAITS OF RECENTLY IDENTIFIED OIL STAINS

L.P. Gal

10.3.1 Sample Location and Characteristics

Eight samples were collected during the current study, having been determined visually, and by their petroliferous odour, to be oil stained. The samples include: four samples of Hume and Ramparts formations collected at Powell Creek; two samples of Imperial Formation collected at Katherine Creek, southeast of Peel area; and two samples of Arnica and Fort Norman formations sampled from Imperial anticline. Sample locations are shown in Figure 10.2.1 and noted in Table 10.3.1. Field location photos are shown in Figures 10.3.1, 10.3.2, and 10.3.3. Additional oil stain chemistry data from new samples of Tuttle and Ford Lake formations are discussed in Chapter 8 (this volume) and Allen et al. (2008a).

10.3.2 Source of Compositional Data

Samples were analyzed at the Organic Geochemistry Laboratory at the Geological Survey of Canada (GSC) in Calgary by solvent extraction, gas chromatography, and gas chromatography - mass spectrometry (GCMS). Gross composition of these samples, are tabulated below (Table 10.3.1). Figure 10.3.4 is a ternary petroleum composition plot of the samples. The following analyses and interpretations of sample chemistry were provided by K.G. Osadetz of GSC - Calgary (pers. comm.; 12 August, 15 September, 14 November, 2008; 25 March, 2009).

Sample # (GSC #)	TOC (%)	Extract Yield (mg)	Petroleum Yield (mg)	%HC	Prystane: phytane	Formation	Lithology	Location, UTM coordinates (NAD 83, Zone 9)
07LG-12-A (X10866)	0.20	1252.1	418.2	33.4	0.5	Fort Norman	dolostone	Imperial anticline; 514451E, 7261766N
07LG-12-B (X10867)	0.12	541.6	59	10.9	0.82	Arnica	dolostone	Imperial anticline; 514721E, 7261847N
07LG-15-B (X10868)	0.05	355.1	61.1	17.21	0.77	Hume	limestone	Powell Creek; 510447E, 7239090N
07LG-15-C (X10869)	**3.58**	**117.3**	**42.8**	**36.54**	**0.7**	**Ramparts**	**limestone**	Powell Creek; 510469E, 7239377N
07LG-15-D (X10870)	7.8	90	47.6	52.88	--	Ramparts	limestone	Powell Creek; 510494E, 7239401N
07LG-15-E (X10871)	0.67	215.2	89.2	41.44	--	Ramparts	limestone	Powell Creek; 510511E, 7239399N
08WZ-4-A (X10953)	0.61	970.73	683.03	70.36	1.0	Imperial	sandstone	Katherine Creek; 571404E, 7213955N
08WZ-4-B (X10954)	**0.20**	**426.53**	**78.45**	**18.39**	**1.68**	**Imperial**	**sandstone**	Katherine Creek; 571404E, 7213955N

Table 10.3.1. *Sample location data and gross composition results from solvent extraction analyses collected during the current study. TOC = total organic carbon, HC = hydrocarbons. Samples in bold are those thought to be related to a Cambrian-Ordovician,* G.prisca *source rock (K.G. Osadetz, pers. comm., 2008).*

Figure 10.3.1. *View northeast over north limb of Imperial Anticline, between Mountain and Carcajou rivers, Section LG-Z1. Sample locations of oil stained rocks located approximately. Note that Ramparts Formation ridge in middle distance was also oil stained. Franklin Mountains on the horizon, across Mackenzie River.*

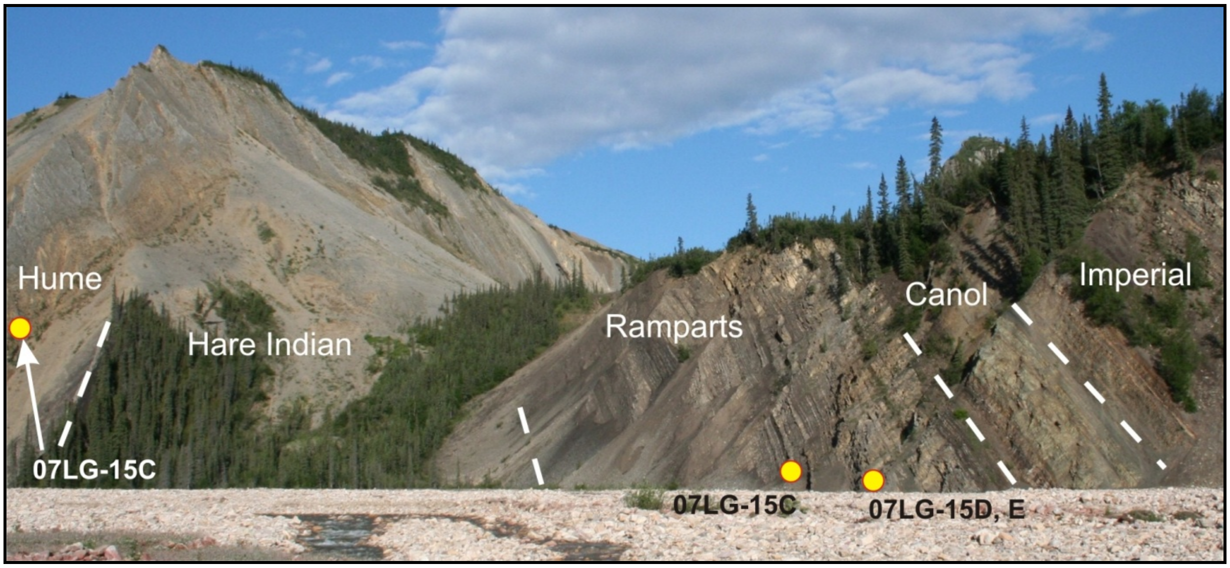

Figure 10.3.2. *View northwest across Powell Creek, Section LP-03. Sample locations of oil stained rocks in Ramparts Formation located approximately. Sample from Hume Formation was located near the strata level indicated, but closer to the creek level, off the left side of the figure.*

Figure 10.3.3. *View northeast of Imperial Formation outcrop on Katherine Creek. Sample locations of oil stained rocks located approximately. Note the probable fault, marked by a red dashed line.*

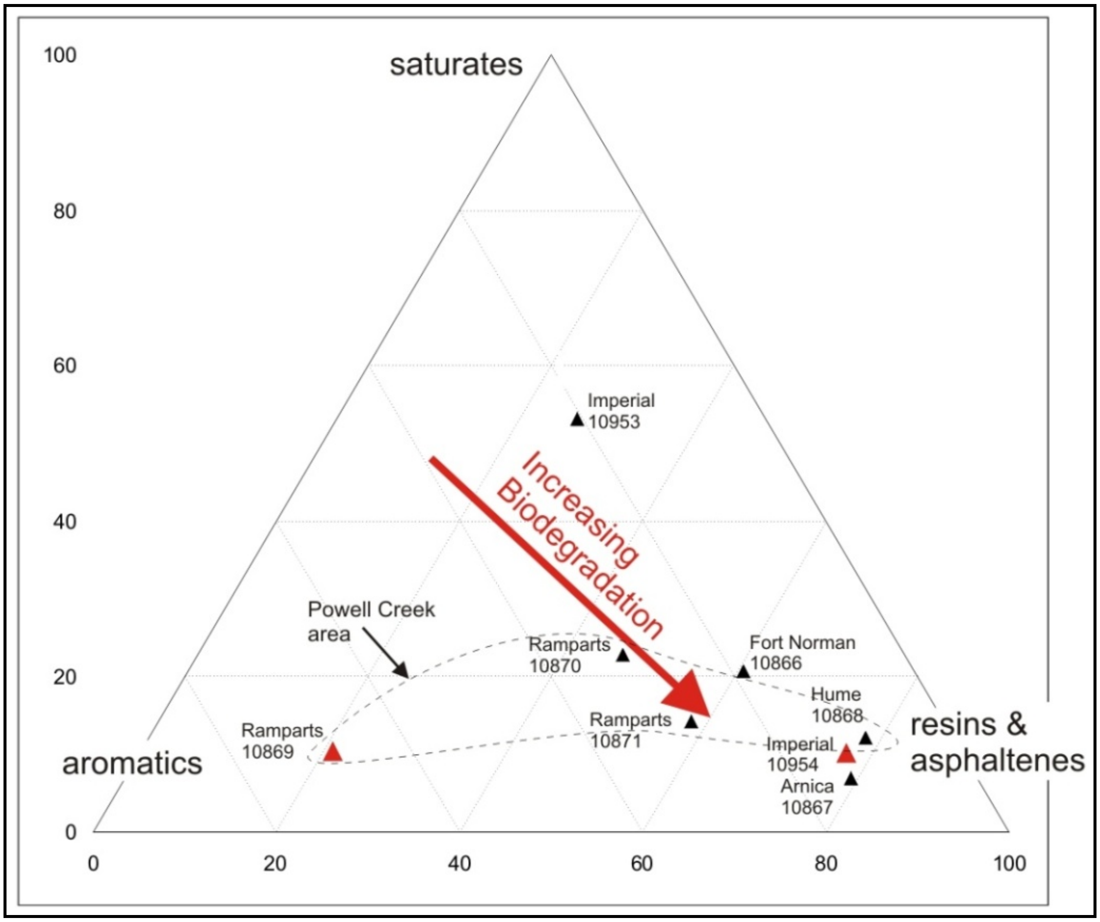

Figure 10.3.4. *Ternary diagram of petroleum composition from oil stained samples collected and analyzed during the current study. Sample points are triangles: black triangles represent Devonian "Norman Wells-type" oil, red triangles represent "Colville Hills-type" oil. See text for discussion. GSC sample numbers and formations are indicated (listed in Table 10.3.1). Samples collected from the Powell Creek area are within the dashed outline area. Note the range of biodegradation apparent; the trend is indicated by the red arrow. Figure modified from K.G. Osadetz (pers. comm., 2008).*

10.3.3 Gross Compositional Characteristics

K.G. Osadetz (GSC - Calgary) reports (pers. comm., 2008; 2009):

> "Samples range between 0.12 and 3.58% total organic carbon (TOC). Soxhlet solvent extract total yield was between 90 and 1252.1 mg. Hydrocarbons comprise between 52.88% and 10.90% of the extract by weight. The ratio of saturate to aromatic hydrocarbons in the extract is variable, probably due to combinations of differences in biodegradation, thermal maturity, and source rock chemistry. All of the samples can be considered oil stains for practical purposes, although both the hydrocarbon yields and the % hydrocarbon are much lower than that typically associated with stains in well cuttings or cores, probably due to a combination of biodegradation, weathering, and evaporation of lighter compounds."

10.3.4 Compositional Traits of Oil Family A: Norman Wells-type Crude Oils

K.G. Osadetz (GSC - Calgary) reports (pers. comm., 2008):

> "Samples X10866 (07LG-12-A), X10867 (07LG-12-B), X10868 (07LG-15-B), X10870 (07LG-15-D), X10871 (07LG-15-E), and X10953 (08WZ-04-A) appear to have been derived from a similar petroleum system, although samples exhibit variable effects of biodegradation and thermal cracking that makes the appearance of their data traces look quite different between samples (Figures 10.3.5a, 10.3.5b). Comparison of all of these samples to two samples of Norman Wells oil (Geological Survey of Canada library) suggests the samples could all be broadly assigned to Devonian petroleum systems; specific stratigraphic location of the source of these oils cannot be determined based on effects of both biodegradation and thermal cracking on compositions.
>
> Differential biodegradation is indicated; samples X10866 (07LG-12-A), X10871 (07LG-15-E), and X10870 (07LG-15-D; Figure 10.3.5b) are the most strongly biodegraded. Sample X10867 (07LG-12-B) is less biodegraded than the former three samples, and sample X10868 (07LG-15-B; Figure 10.3.5a) is the least biodegraded.
>
> Pristane-phytane ratios are variable, ranging between 0.5 and 1.0, suggesting an anoxic water column in the environment of source rock deposition. Terpane and sterane biomarker compositions vary. Samples X10866 (07LG-12-A), X10867 (07LG-12-B), X10870 (07LG-15-D), and X10953 (08WZ-04-A) all have abundant tricyclic terpanes compared to pentacyclic terpanes (Figure 10.3.6). Pentacyclic terpanes are typical of oils from a Devonian source rock either at Norman Wells or in Alberta. Steranes and diasteranes in these samples are consistent with this, and like Norman Wells oils, the C29 steranes are predominant (Figure 10.3.7). Sample X10871 (07LG-15-E) has abundant tricyclic terpanes, but the pentacyclic terpanes and steranes are very much reduced, particularly at higher elution times, which indicates that the higher molecular weight compounds are preferentially removed relative to the light compounds (Figure 10.3.8).
>
> Sample X10868 (07LG-15-B) essentially has no terpane or sterane biomarkers (Figure 10.3.9). This pattern of terpane and sterane degradation does not follow the typical pattern of solvent fraction gas chromatograph (SFGC) degradation. This suggests that the heavier and more complex biomarkers in sample X10871 (07LG-15-E) and all the terpane and sterane biomarkers in sample X10868 (07LG-15-B) are thermally cracked, probably prior to the biodegradation. Similar effects on biomarkers are seen in Alberta between the plains, where the biomarkers are retained, and the foothills where the biomarkers are inferred to be either totally or partially cracked thermally."

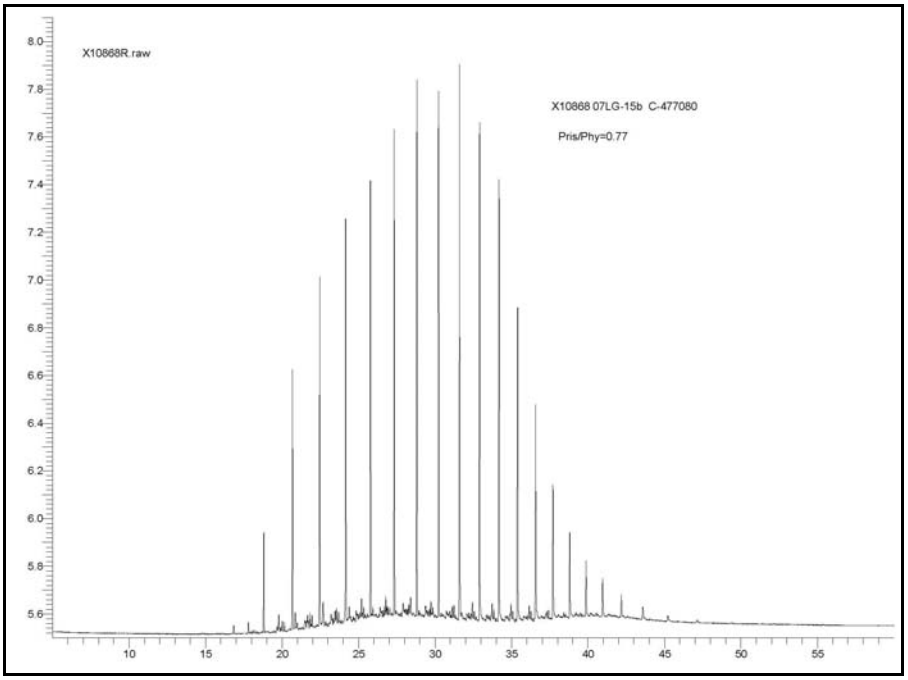

Figure 10.3.5a. *Saturate fraction gas chromatogram for sample 07LG-15-B, Hume Formation, Powell Creek. Y-axis is intensity, X-axis is time in minutes. Figure from K.G. Osadetz (pers. comm., 2008).*

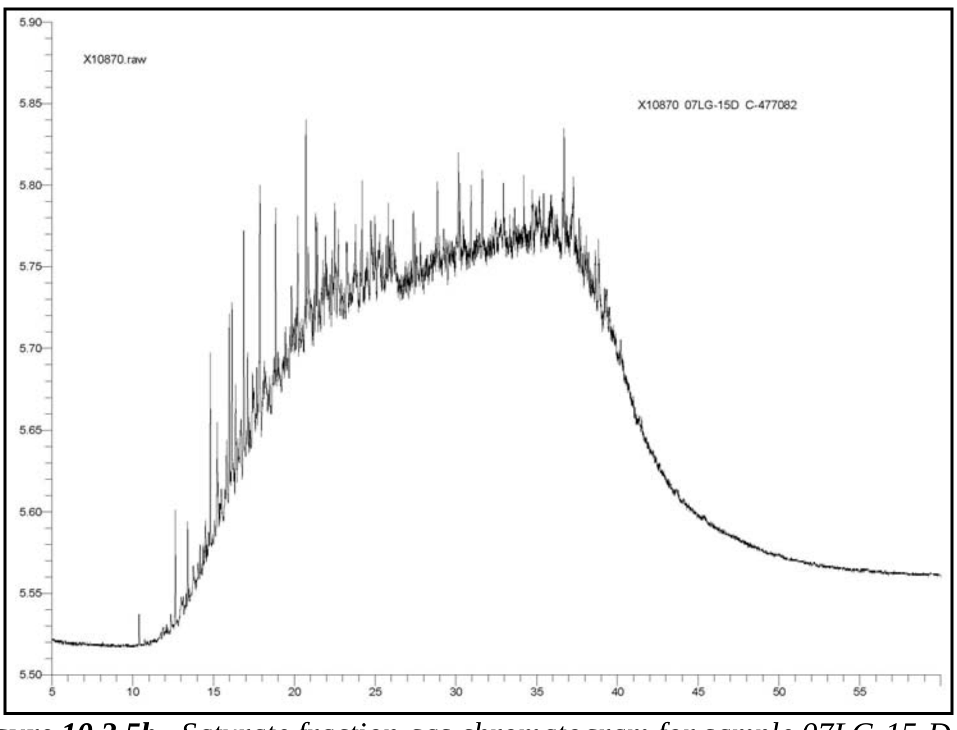

Figure 10.3.5b. *Saturate fraction gas chromatogram for sample 07LG-15-D, Ramparts Formation, Powell Creek. Y-axis is intensity, X-axis is time in minutes. The higher "hump" compared to Figure 10.3.5a is due to biodegradation, and resultant poorer resolution of individual compounds. This sample was collected about 300 m from 07LG-15-B. Figure from K.G. Osadetz (pers. comm., 2008).*

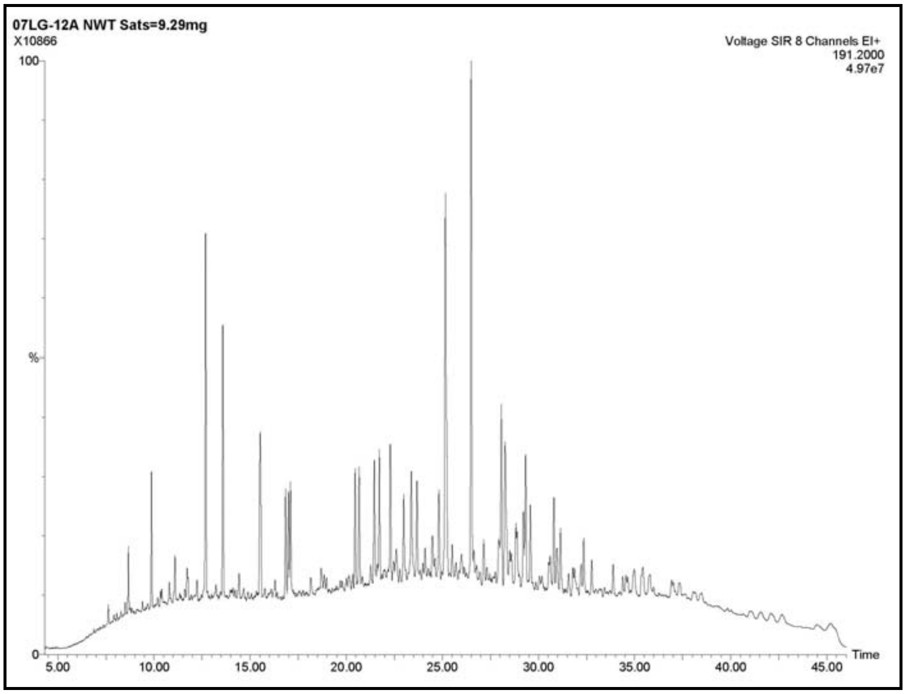

__Figure 10.3.6.__ Mass fragmentogram for sample 07LG-12-A, Fort Norman Formation, Imperial anticline. Y-axis is percent relative intensity, X-axis is time in minutes. Tricyclic terpanes, eluting before about 25 minutes are more abundant than pentacyclic terpanes, which have elution times greater than 25 minutes. Figure from K.G. Osadetz (pers. comm., 2008).

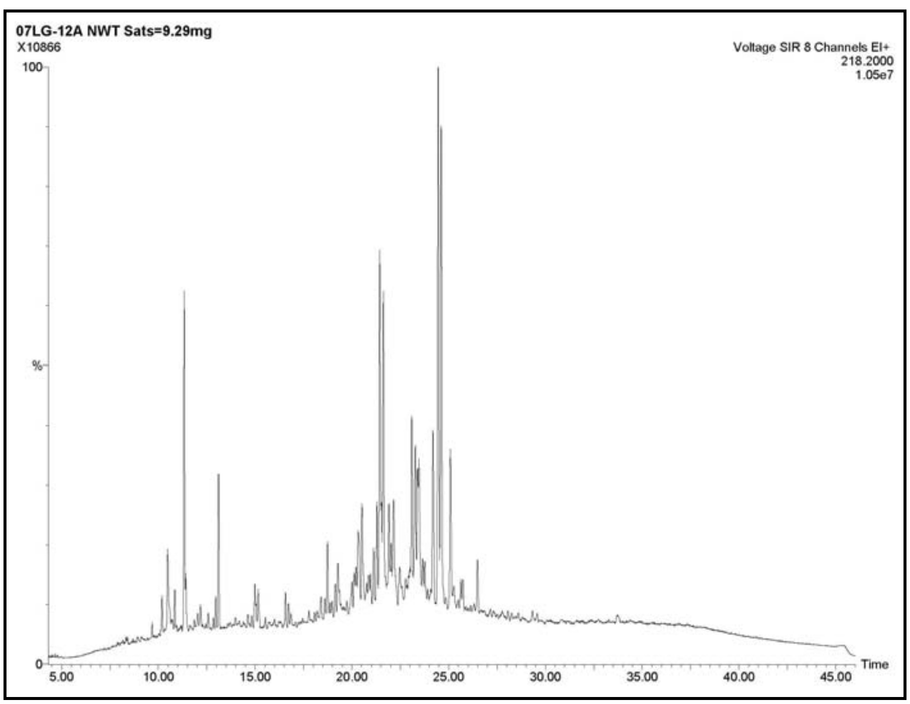

__Figure 10.3.7.__ Mass fragmentogram for sample 07LG-12-A, Fort Norman Formation, Imperial anticline. Y-axis is percent relative intensity, X-axis is time in minutes. The C-29 steranes, eluting from about 24 to 26 minutes, are dominant, which is a characteristic of Norman Wells oils. Figure from K.G. Osadetz (pers. comm., 2008).

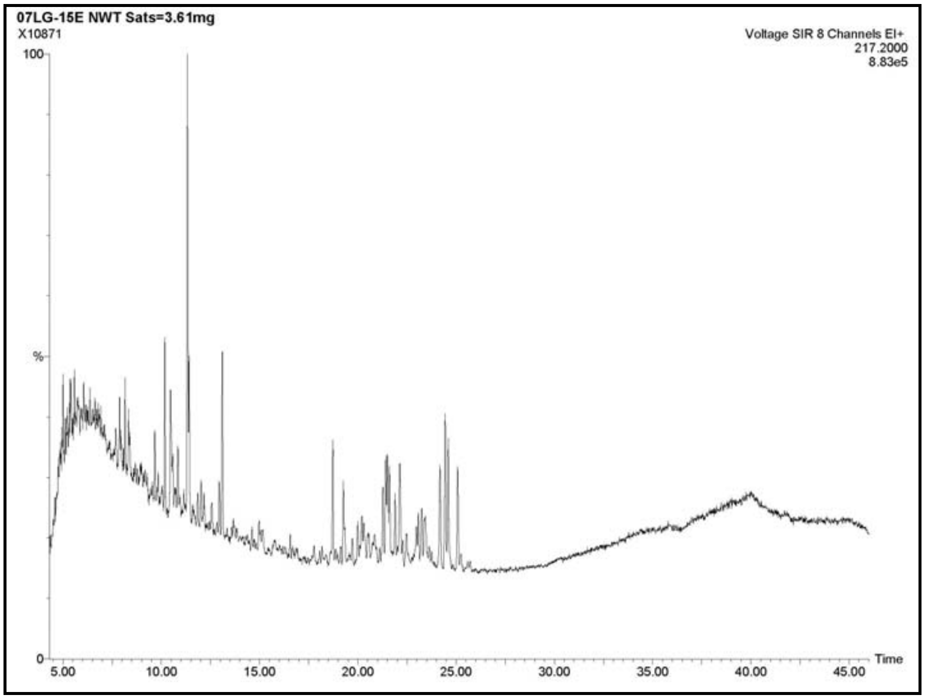

Figure 10.3.8. *Mass fragmentogram for sample 07LG-15-E, Ramparts Formation, Powell Creek. Y-axis is percent relative intensity, X-axis is time in minutes. The higher molecular weight compounds, including pentacyclic terpanes and steranes, eluting after about 26 minutes, are markedly reduced. Figure from K.G. Osadetz (pers. comm. 2008).*

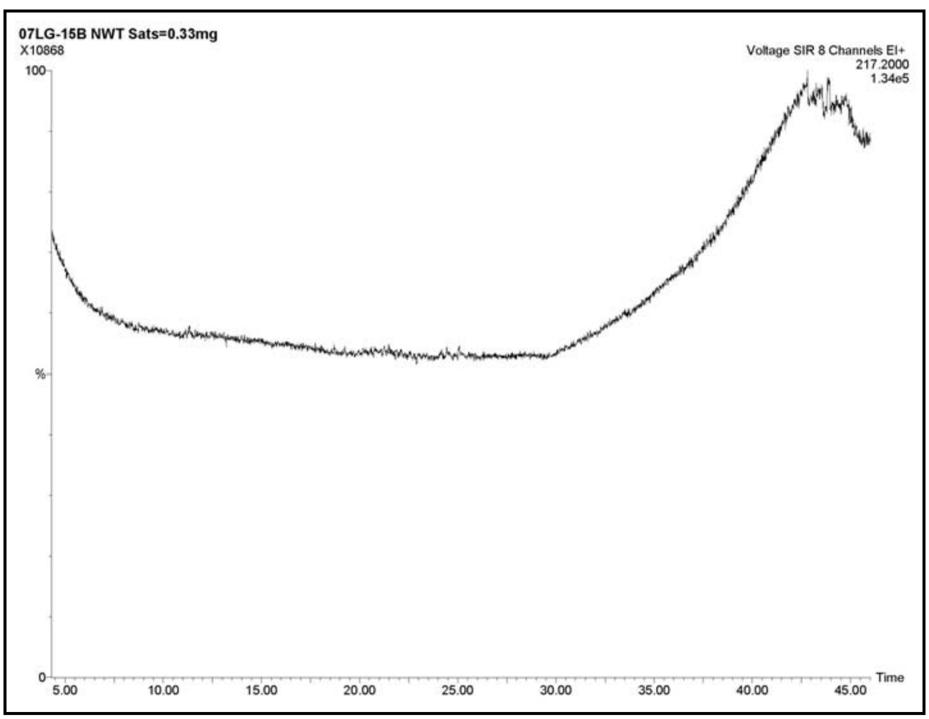

Figure 10.3.9. *Mass fragmentogram for sample 07LG-15-B, Hume Formation, Powell Creek. Y-axis is percent relative intensity, X-axis is time in minutes. There are essentially no biomarkers, having been thermally cracked. Figure from K.G. Osadetz (pers. comm. 2008).*

Samples 07LG-15-B to 15-E were collected within a 300 m thick section at Powell Creek (Figure 3, Section LP-03 in Pyle and Gal, 2007; Pierce and Jones, 2009). It is difficult to envision a differential tectonic or thermal history to explain the difference in cracking between sample sites 07LG15-B and 15-E and the other samples from the same area (07LG-15-C, 15-D). K.G. Osadetz (pers. comm., 2009) suggests that the contrast between the samples might be due to (in addition to the different source rock for 07LG-15C): different times of maturation and expulsion, or migration on different pathways, possibly from different geographic parts of the mature source rock pod. Regarding the latter two possibilities, burial history diagrams (section 10.3) suggest that there might have been episodes of both late Paleozoic and late Cretaceous maturation of Canol Formation. Also Canol Formation/Horn River Group strata are widely distributed, and migration pathways might well have been varied; especially if one considers that Late Cretaceous petroleum migration was probably syntectonic with Laramide deformation, resulting in reversal of regional dips, etc.

K.G. Osadetz (GSC - Calgary) further reports (pers. comm., 2008):

> "The high tricyclic to pentacyclic terpane ratio seen in the uncracked extracts are typically seen in post-Elk Point (Frasnian and Famennian) source rocks in Alberta and Saskatchewan. Source of these oils may therefore lie in the upper half of the Devonian succession, rather than in the lower parts.
>
> In summary, the oils have compositions substantially like Norman Wells oils sourced by Devonian Canol Formation shale deposited in open marine, but anoxic settings. Differential effects of thermal cracking of at least two samples (07LG-15-E and 07LG-15-B) may represent a distinction in the thermal or tectonic history of these two samples compared to samples 07LG-12-A, 07LG-12-B, and 07LG-15-D, which have retained their biomarkers" (although a distinct history is difficult to reconcile with the proximity of the sample locations within a coherent stratigraphic section).
>
> Differential biodegradation of samples was imposed subsequently, although it is uncertain if this is related to subsurface or outcrop-forming processes. Combined effects of thermal cracking and biodegradation preclude additional conclusions, or creation of subdivisions among these samples."

10.3.5 Compositional Traits of Oil Family B: Colville Hills-type Crude Oils

K.G. Osadetz (GSC - Calgary) reports (pers. comm., 2008):

> "Samples X10869 (07LG-15-C) and X10954 (08WZ-04-B) have several distinctive compositional traits including SFGC and biomarkers. Pentacyclic terpanes are much more abundant than tricyclic terpanes, which is in strong contrast with the other samples (Figures 10.3.10, 10.3.11). To the south (southern NWT and Alberta) this trait is seen typically in source rocks that occur in the Elk Point Group to Cambrian succession. The even-odd-predominance in the SFGC of sample X10869 (07LG-15-C), is reminiscent of features of oils from Cambrian and Ordovician *G. prisca* source rocks. Biomarkers appear to be completely consistent with this, with the single exception that C29 is much more predominant here than in the Cambrian and Ordovician-sourced oils in the south; there is also no indication for restricted or hypersaline environments in X10869 (07LG-15C), in

contrast to the Lower Paleozoic sourced oils seen to the south in the Western Canada Sedimentary Basin.

Effects of biodegradation and thermal cracking appear to be slight or minimal in sample X10869 (07LG-15-C). It can be distinguished as having a different, probably Cambrian or Ordovician source rock (or possibly Silurian because *G. prisca* alginite is found from Cambrian to Silurian rocks in various parts of North America). Sample X10954 (08WZ-04-B) exhibits a similar composition. The source for this oil is probably below the Middle Devonian succession, and most likely the Cambrian or Ordovician."

Mount Cap or Saline River formations are the most likely candidate source rocks based on their lithologies in Peel area.

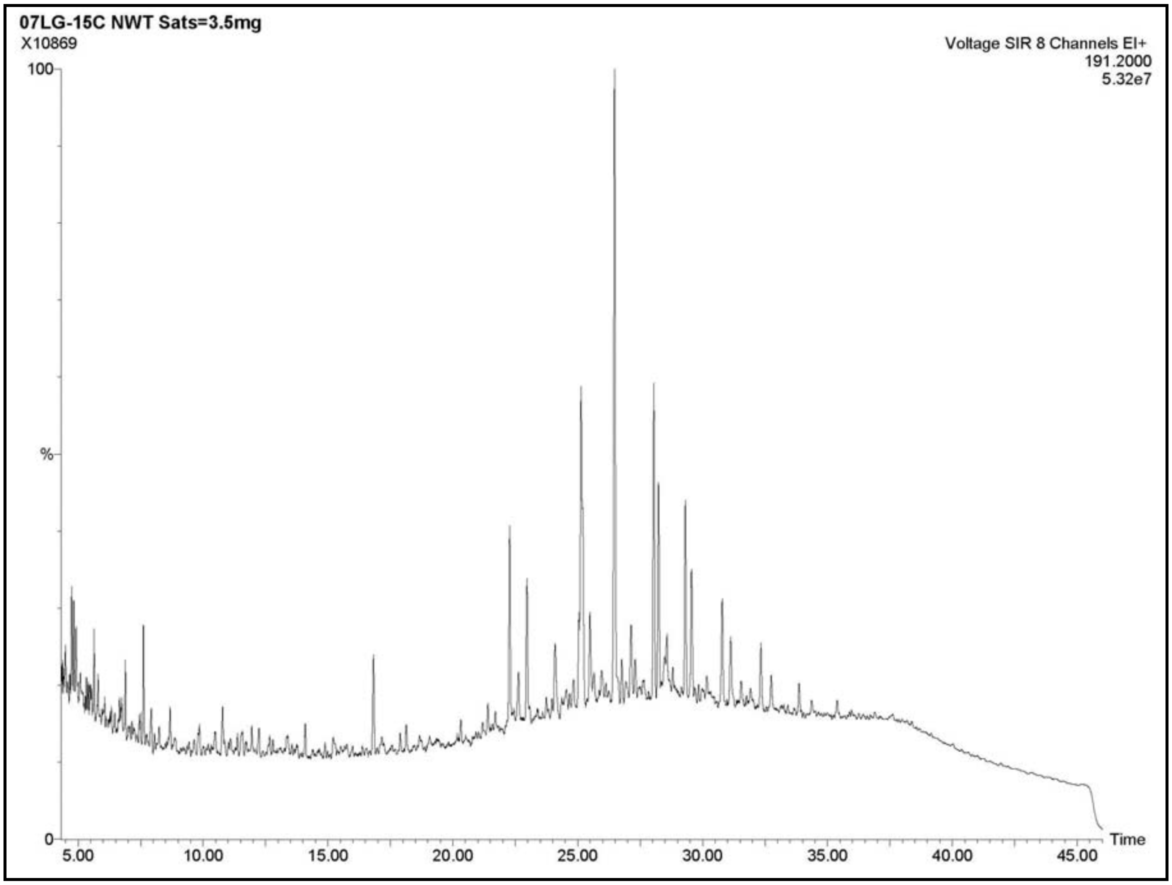

Figure 10.3.10. *Mass fragmentogram for sample 07LG-15-C, Ramparts Formation, Powell Creek. Y-axis is percent relative intensity, X-axis is time in minutes. Tricyclic terpanes, eluting before about 25 minutes are less abundant than pentacyclic terpanes, which have elution times greater than 25 minutes. Compare to Figure 10.3.6. Figure from K.G. Osadetz (pers. comm. 2008).*

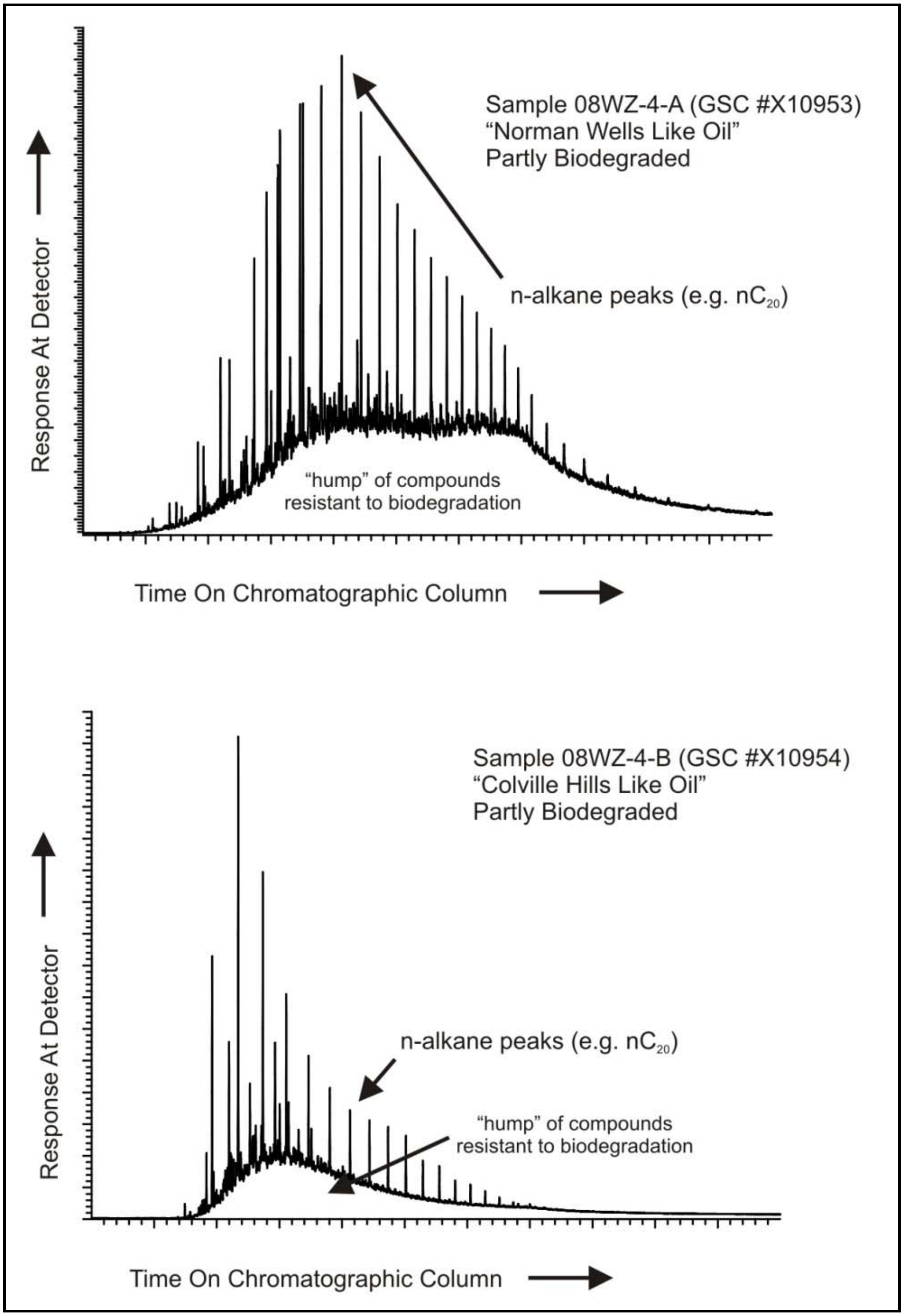

Figure 10.3.11. *Saturate fraction mass chromatograms for sample 08WZ-4-A (top) and 08WZ-4-B (bottom), both from Imperial Formation at Katherine Creek, southeast of Peel area. Y-axis is relative intensity of response, X-axis is time in increasing time to the right. The higher C number n-alkanes (higher than C20) are more readily apparent in the lower graph, from the "Colville Hills-type" oil of 08WZ-4-B. These samples were collected about 15 m apart stratigraphically, and 40 m apart laterally, from fine-grained sandstone beds less than 1 m thick (Figure 10.3.3). Figure from K.G. Osadetz (pers. comm. 2008).*

10.3.6 Summary

In summary, K.G. Osadetz (GSC - Calgary) reports (pers. comm., 2008):

> "Samples X10866 (07LG-12-A), X10867 (LG-12-B), X10868 (LG-15-B), X10870 (LG-15-D), X10871 (LG-15-E), and X10953 (08WZ-4-A) are derived from a Frasnian or Famennian marine source rock. These oils resemble the oil at Norman Wells, but they are differentially thermally cracked and biodegraded. Samples X10869 (07LG-15-C) and X10954 (08WZ-4-B) appear to have been derived from sources in the Cambrian or Ordovician succession, possibly from a *G. prisca* alginite; but certainly from strata as old or older than Middle Devonian Elk Point Group age-equivalents."

There is compelling new evidence for a pre-Middle Devonian, likely Cambrian-Ordovician aged, oil generated in or near the southeastern Peel area. The chemistry of this oil is similar to that in the Colville Hills, where Mount Cap Formation is a source rock (Wielens et al., 1990; Dixon and Stasiuk, 1998). These oils were found in Ramparts and Imperial formations, indicating that the oil migrated into the younger formations.

10.4 BURIAL HISTORY MODELS

L.P. Gal

One-dimensional burial history diagrams for several wells are illustrated in this section. These were constructed at GSC - Calgary using the BasinMod^{TM} program of Platte River Associates Inc. The aim of building these models was to provide a general idea of when various potential source rocks reached maturity within the oil window.

10.4.1 Parameters and Assumptions

Basic input data were formation thicknesses (from formation tops of Hogue and Gal, 2008 and Fraser and Hogue, 2007) and formation ages (compiled in Pyle et al., 2006). Crustal heat flow through geological time, the amount of eroded section (over and above that presently preserved in the well), average surface temperature, and average %TOC and kerogen type of source rocks were input parameters estimated for the model. An example of the data input table for the Grandview Hills No.1 (A-47) well is shown in Table 10.4.1.

Upon running the model, an expected thermal maturity versus depth curve was produced. The thermal maturity versus depth plot produced by the model was then compared to the measured thermal maturity values. Levels of thermal maturity were obtained from vitrinite reflectance values reported in the literature (compiled in Pyle et al., 2006). Selected Tmax values from Rock-Eval analyses (compiled in Stasiuk and Fowler, 2002; Stasiuk et al., 2002; and Pyle et al., 2006) were also used. Several Yukon wells benefited from new systematic Rock-Eval analyses from well cuttings (Allen et al., 2008b). Tmax values from Rock-Eval analyses were converted to equivalent vitrinite reflectance by the BasinMod^{TM} program.

Parameters of crustal heat flow over time, and amount of sediment deposition, and subsequent erosion, were varied until a reasonable fit was obtained between the modeled depth versus maturity curve and the measured values. The assumption was made that the most important episodes of erosion were at the base of the Cretaceous unconformity (erosion of Tuttle and Imperial formations), and post-Cretaceous erosion. No other unconformities were assumed to represent significant amounts of sediment deposited and then removed due to erosion. In many wells a good fit could not be obtained using reasonable parameter values (see discussion below).

Formation or Event name	Event Type	Age (Ma) Base of Formation or Event	Top (m) Formation or Event in well	Thick-ness (m)	Estimated Thickness (m)	Lithology	Source Rock Kerogen type	Total Organic Carbon (%)
Hiatus 0	hiatus	34	--	--	--	--	--	--
Cretaceous erosion	erosion	71	--	--	-3500	--	--	--
Hiatus 1	hiatus	99	--	--	--	--	--	--
Cretaceous deposition	deposition	112	--	--	2900	25-0-75	--	--
Jurassic uplift	erosion	200	--	--	-400	--	--	--
Hiatus 2	hiatus	355	--	--	--	--	--	--
Imperial deposition	deposition	368	--	--	600	60-40-0	--	--
Imperial	formation	382	33.5	200	--	60-40-0	III	1.0
Canol	formation	384	233.5	34.1	--	shale	II	6.5
Ramparts	formation	385	267.6	18.9	--	Sandstone	--	
Hare Indian	formation	386	286.5	185.9	--	Shale	III	1.0
Bluefish	formation	388	472.4	7.4	--	Shale	II	8.0
Hume	formation	391	479.8	91.7	--	Limestone	--	
Landry	formation	394	571.5	272.8	--	Limestone	--	
Arnica	formation	409	844.3	131.1	--	Dolomite	--	
Tatsieta	formation	416	975.4	80.4	--	Limestone	--	
Peel	formation	419	1055.8	149.2	--	Dolomite	--	
Hiatus 3	hiatus	424	1205	0.2	--	Dolomite	--	
Mount Kindle	formation	458	1205.2	229.5	--	Dolomite	--	
Franklin Mountain	formation	503	1434.7	563.3	--	Dolomite	--	
TD	formation	515	1998	200	--	Dolomite	--	
Measured Source Rock maturity								
Depth (m)	**Ro (%)**	**Tmax (°C)**						
236	--	436						
238	0.74	--						
853	0.79	--						
Heat Flow								
Heat Flow (W/m2)	**Surface T (°C)**	**Time (Ma)**						
40	0	2						
40	8	5						
40	6	20						
40	4	23						
40	4	36						
40	10	40						
45	15	110						
40	20	300						
40	20	340						

Table 10.4.1. *Input data for BasinMod^{TM} program for the Grandview Hills No.1 (A-47) well. The numbers in the lithology column represent percentage of: shale-siltstone-sandstone.*

10.4.2 The Dataset

Correlation between Vitrinite Reflectance and Tmax

Most of the well models were hampered by meager or suspect thermal maturity data points. Questionable vitrinite reflectance values in the literature from well samples could have been caused by the analysis of older, reworked material in Cretaceous samples particularly (yielding higher than expected maturity) or by caving of younger material down hole and included in older samples (yielding lower than expected maturity). Many Rock-Eval analyses were not included in the modeling because the Tmax values were not considered reasonable (indicated by low %TOC, low S_2 values, etc.; Peters, 1986). However, for the two modeled Yukon wells, the primary dataset was the Rock-Eval analyses of Allen et al. (2008b).

In some wells, there is a marked lack of correlation between Rock-Eval Tmax determinations (converted to equivalent vitrinite reflectance) and vitrinite reflectance measurements; that is, they seem to lie on different depth maturity trends in the same well. This may indicate some systematic sampling, conversion, or analysis problem that cannot be fully addressed here. However, a comparison of Tmax determinations (deemed reliable based on S2 and TOC values; Peters, 1986) with vitrinite reflectance measurements reported in the literature (and compiled in Pyle et al., 2006) from samples at or very near (within 4 m) the same depth in three different wells, was made (Figure 10.4.1). There is a general correlation between reflectance and Tmax values in this small sample set. A similar but larger sample set, with Tmax and reflectance measurements from samples within 100 m depth of each other, yielded a reasonable correlation between the maximum Tmax values at a given %Ro; and the reflectance values, over the oil window range (0.4-1.5% Ro). At higher maturity there was less correlation.

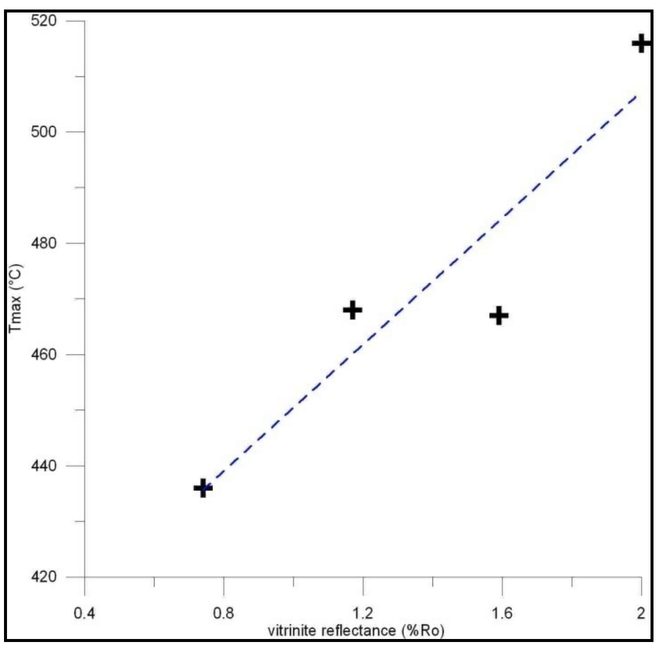

Figure 10.4.1. *Cross plot of Tmax versus vitrinite reflectance for samples taken very close together in the same well, within 4 m depth. There is a general correlation (linear fit blue dashed line). Data points from three wells in Peel area (Feinstein et al., 1988a; Pyle et al., 2006).*

Discontinuities in Depth versus Maturity Curves

From the depth versus maturity plots of several wells in western Peel area, there is an apparent discontinuity in the trend, evidently across the Cretaceous-Devonian contact. This is especially apparent in wells such as: South Peel D-64 (albeit with few data points), Stony I-50, Cranswick

Y.T. A-42, and North Ramparts A-59 (Figures 10.4.2, 10.4.3). Such discontinuities have been shown to exist in some wells in Mackenzie Plain (Feinstein et al., 1996). The data suggests that maximum temperatures in the sub-Cretaceous section of these wells were reached during burial by the Upper Paleozoic section, or that the Late Paleozoic heat flow was higher than estimated in the model, or a combination of both factors (K.G. Osadetz, pers. comm., 2009).

These discontinuities may be modeled with an increased thickness of Imperial and/or Tuttle strata deposited, and then eroded before Cretaceous deposition, to account for the apparent increase in maturity of Devonian and older rocks. An acceptable fit with the maturity data was obtained by adding and subsequently removing 6500 m of Devonian-Mississippian strata in North Ramparts A-59 (Figure 10.4.3), 6500 m in South Peel D-64, and 6700 m in Cranswick Y.T. A-42.

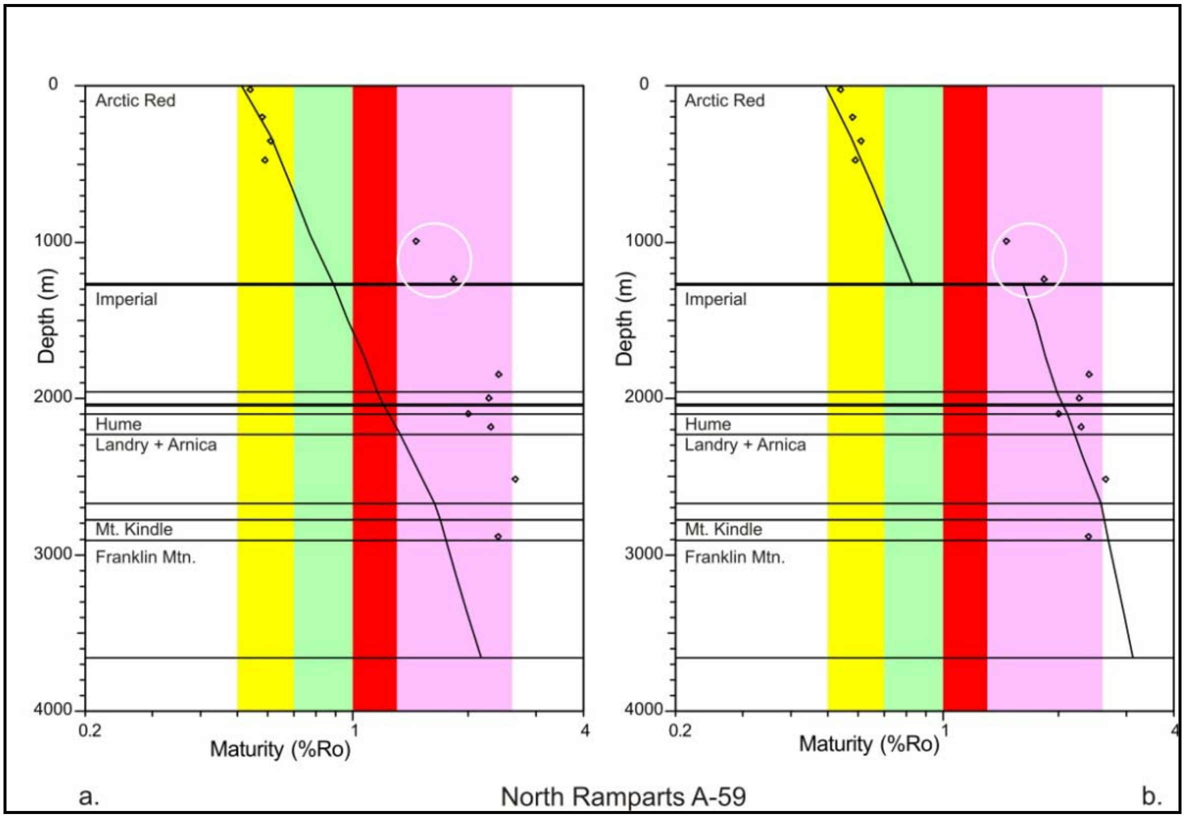

Figure 10.4.2. *Depth versus maturity plots for North Ramparts A-59 well. Plot (a.) on the left uses a heat flow of 45 to 65 mW/m^2, 800 m of Devonian-Mississippian strata deposited and removed, and 1800 m Cretaceous strata deposited and removed. Note the fit to the reflectance data is good only in the top 500 m of the well. Plot (b.) on the right assumes a discontinuity between Cretaceous and Devonian strata (top Imperial Formation indicated). A heat flow of 45 to 60 mW/m^2, 6500 m of Devonian-Mississippian strata deposited and removed, and 1800 m Cretaceous strata deposited and removed, is used to fit the data in two curve segments. The resultant fitted curve is better although the additional 6500 m of strata is unrealistic. Increased Late Paleozoic heat flow might also be a contributing factor. Note in both cases the reflectance values at the base of Arctic Red Formation; these are anomalously high and may reflect reworked Devonian material. Colours used to indicate levels of maturity are shown in Figure 10.4.3.*

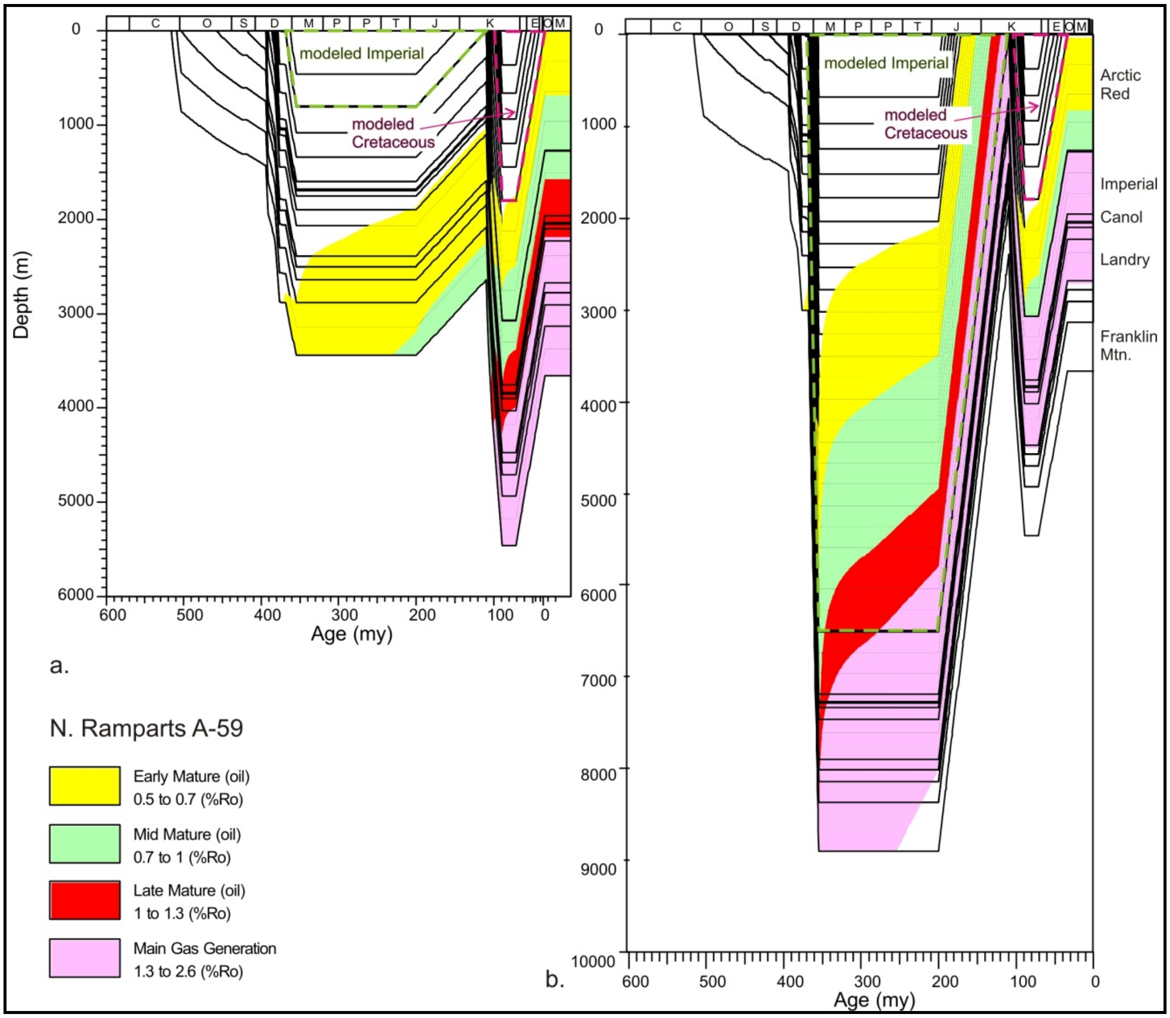

Figure 10.4.3. *Burial history diagrams for North Ramparts A-59 well. Diagram (a.) and (b.) correspond to the model parameters outlined for case a. and b. in Figure 10.4.2. Note that the extreme increased burial (green dashed outline) by "modeled Imperial" in (b.) causes overmaturity in lower Imperial and older formations. The extra thickness of "modeled Cretaceous" serves only to increase maturity of Arctic Red Formation to within the oil window at the base, resulting in a discontinuity at top Imperial Formation. In this case, Canol Formation would have passed through the oil window at the end of the Devonian, rather than in the middle Cretaceous as in case (a.). This of course has important implications for source rock maturity and expulsion relative to timing of structural trap formation.*

Considering the addition of excess Upper Paleozoic strata alone to account for the increased maturities, the magnitude required in these examples (more than three times the thickest known Imperial plus Tuttle in Peel area; Fraser and Hogue, 2007) lends doubt as to whether the discontinuity can be considered due to increased burial alone. This is especially true since adjacent wells do not require these huge added thicknesses to model depth versus maturity. Thus the requirement for apparently localized and spatially restricted major depocentres makes this interpretation doubtful.

Just increasing Late Paleozoic heat flow alone in the models does not generally result in a better fit to the data, because it results in a flattening of the maturity versus depth slope (i.e., higher maturities reached at shallower depths), rather than shifting the curve but retaining the slope. Regarding heat flows, it is recognized that the rates chosen in the model are conservative, but not unrealistic. It must be noted that Majorowicz and Morrow (1998) estimated a *modern* heat flow of 60 to 90 mW/m^2 in Peel area. Determinations and/or more detailed estimates of historic heat flows are beyond the scope of this chapter. This is an area where further research may be beneficial to understanding the tectonic history of Peel Basin.

K.G. Osadetz (pers. comm., 2009) suggests that the data might indicate a heretofore undocumented late Paleozoic heat flow event in Peel area (reflecting, perhaps, the effects of the Antler and/or Ellesmerian orogenies). In Liard Plateau region of southwest Northwest Territories, Potter et al. (1993) present evidence of a late Devonian heating event, and generation of oils during the late Paleozoic to Early Mesozoic. The main source rock in this region, the Horn River Group equivalent Besa River Formation, entered the gas window in the Permian, and charged the underlying Manetoe dolomite gas reservoirs of the Pointed Mountain field and others in Liard Plateau (Morrow, 1991; Potter et al., 1993). Osadetz et al. (2005) note that this is contrary to the general trend of petroleum generation in the Cordilleran foreland of the Western Canada Sedimentary Basin, where structured accumulations are considered to have been syntectonic with the folded and stacked thrust sheets. However, Osadetz et al. (2002) did propose a late Paleozoic heat flow anomaly in Williston Basin, correlating with Middle Devonian to Carboniferous Kaskaskia subsidence patterns.

At this point the author concludes that the models may be unsatisfactory, particularly where there are apparent discontinuities in the depth versus maturity curves. Higher heat flows may have been present in the Late Paleozoic, although probably are not exclusively the causative factor. As noted above with the argument for anomalous thicknesses of Late Paleozoic sediments, these higher heat flows would only be required in some wells, while neighbouring wells would not require this “anomalous” heat flow to have the models fit the observed data.

10.4.3 Burial History Models

Bearing in mind the preceding arguments, five burial history plots representative of Peel area are presented and discussed below.

Eastern Peel Area

Grandview Hills No.1 (A-47)

Total depth (TD) for this well in northeast Peel area was within Franklin Mountain Formation, and an additional 200 m of strata was added beyond TD to account for the estimated full thickness of this formation (Table 10.4.1). Six hundred metres of additional Imperial Formation were added to the 200 m intersected in this well; 400 m of the added amount were assumed to have been eroded before deposition of Cretaceous beds. Almost 3 km of Cretaceous strata were assumed to have been deposited, and then eroded (along with additional underlying Imperial Formation).

There were only two reflectance data points used for this model; however, a plot of maturity versus depth gives a good fit through these two points using the thicknesses stated above, and conservative heat flows of 40 to 45 mW/m^2. The relatively low heat flow was chosen because the well location is outboard from the deformation front of the Cordillera. It should be noted, however, that Majorowicz and Morrow (1998) estimated a *modern* heat flow of 71 mW/m^2 in this well, and 60 to 90 mW/m^2 in Peel area in general.

From the burial history plot (Figure 10.4.4) it is apparent that the two best source rocks in Peel area, Canol Formation and Bluefish Member (below Imperial and Hare Indian formations, respectively; see Chapter 6, this volume) are mature (within the oil window). These strata reached maturity buried under a modeled thickness of Cretaceous siliciclastics. Cambrian Mount Cap Formation is likely to be at high maturity beneath this well, while the base of the Cretaceous would be into early maturity.

Ontaratue K-04

TD for this well in eastern central Peel area was within Saline River Formation, near the depositional edge of the unit (Pugh, 1983), and it was assumed that essentially the entire formation was penetrated. Seven hundred metres of additional Imperial Formation was added to the 135 m intersected in this well; this amount was assumed to have been eroded before deposition of the Cretaceous beds. The 700 m may be a conservative estimate, although increasing the amount of upper Devonian to Mississippian strata deposited and eroded did not have much effect on the model. In this well 3.5 km of Cretaceous strata were added, and then removed by post-Cretaceous erosion.

The measured reflectance and Tmax (converted to equivalent reflectance) data points have a fair degree of scatter, but the maturity versus depth plot generated by the model gives a satisfactory fit with the model-generated maturity versus depth curve in the upper 1000 m of the hole. A single Tmax value down hole at 2467 m appears to be anomalously high. Heat flow used in the model was 45 mW/m^2. Majorowicz and Morrow (1998) estimated a *modern* heat flow of 73 mW/m^2 in this well.

From the burial history diagram (Figure 10.4.5) the Canol Formation and Bluefish Member (below Imperial and Hare Indian formations, respectively) are at early maturity to within the oil window; and that they reached maturity under deposition of a modeled thickness of Cretaceous siliciclastics, and its subsequent exhumation. Cambrian Mount Cap Formation is likely to be at high maturity beneath this well to within the dry gas generating field, while the base of the Cretaceous (Martin House Formation) is at early maturity.

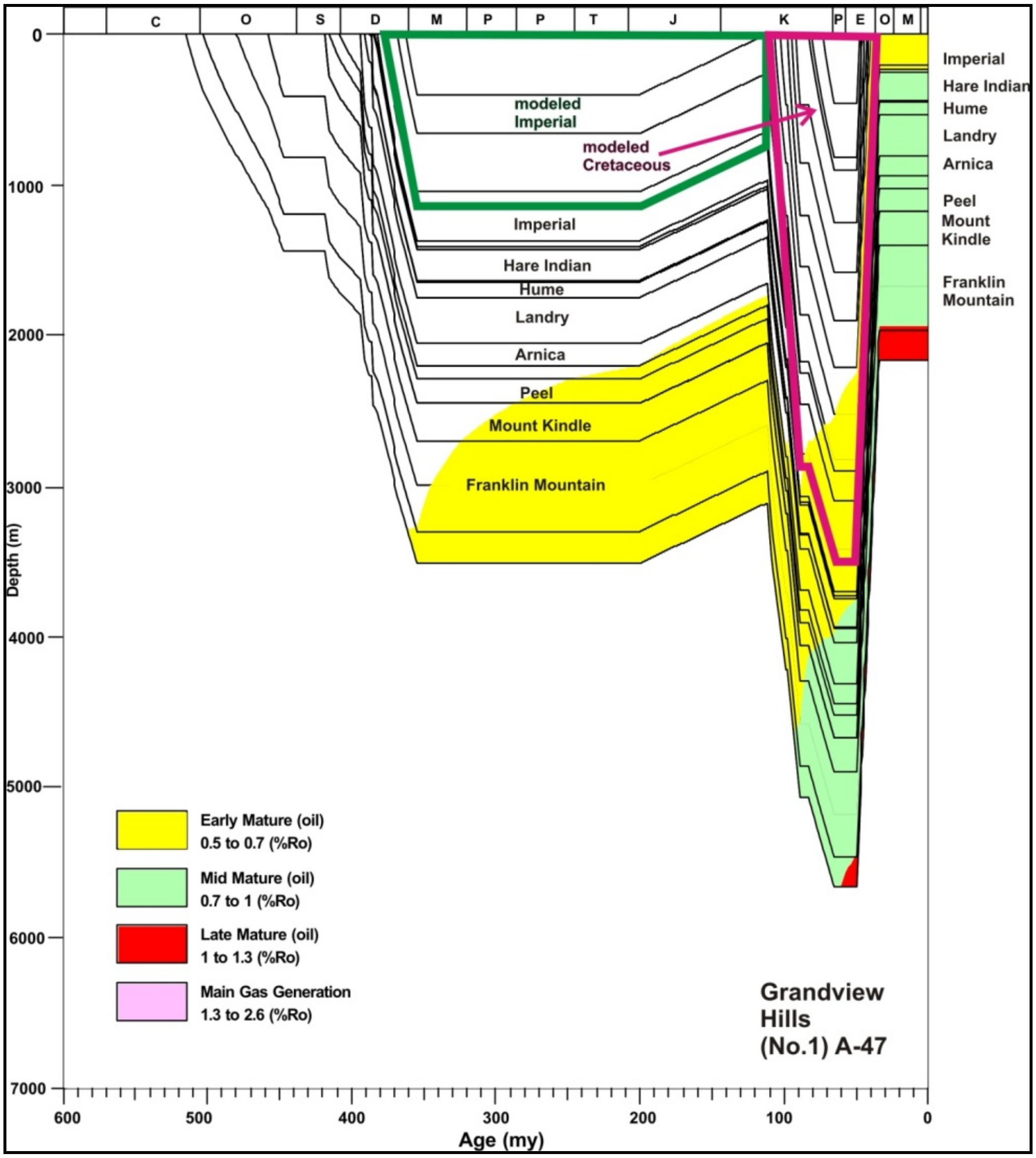

Figure 10.4.4. *Burial history diagram of the Grandview Hills No.1 (A-47) well. Selected formations are labeled, along with extra thicknesses of Imperial Formation (modeled Imperial) and Cretaceous sediments (modeled Cretaceous) used in the model. Note that this burial history model uses the more refined age dates and assumed thicknesses of post-Albian strata (see Chapter 9, this volume), while the following Figures 10.4.5 through 10.4.8 do not. The overall differences are not significant at the scale of this figure.*

Hume River L-09

TD for this well in southeastern Peel area was within Arnica Formation, and essentially the entire formation was penetrated. Nine hundred metres of additional Imperial Formation were added to the 644 m cored in this well; this amount was assumed to have been eroded before deposition of the Cretaceous beds. As with most of the models run, the extra Devonian to Mississippian strata, when added, did not have much of an effect on maturation of the underlying strata; whether it was eroded pre-Cretaceous or post-Cretaceous. The Cretaceous sediment pile that commenced deposition in the Albian has a much greater effect on maturation of the underlying sediments.

The relative maturity of Cretaceous versus Devonian-Mississippian strata (from reflectance and Tmax values) constrains this relationship. In the L-09 well, 2.6 km of strata were added, and then removed by post-Cretaceous erosion.

The reflectance and Tmax (converted to equivalent reflectance) data points used for this model have a fair degree of scatter, but the maturity versus depth plot generated by the model gives a satisfactory fit through the data. The scatter may be due to thrust faulting in this well associated with folding, which results in some anomalous thicknesses. Heat flows used in the model were 45 to 65 mW/m^2; the increased heat flow was modeled to coincide with Laramide deformation. Majorowicz and Morrow (1998) estimated a *modern* heat flow of 81 mW/m^2 in this well.

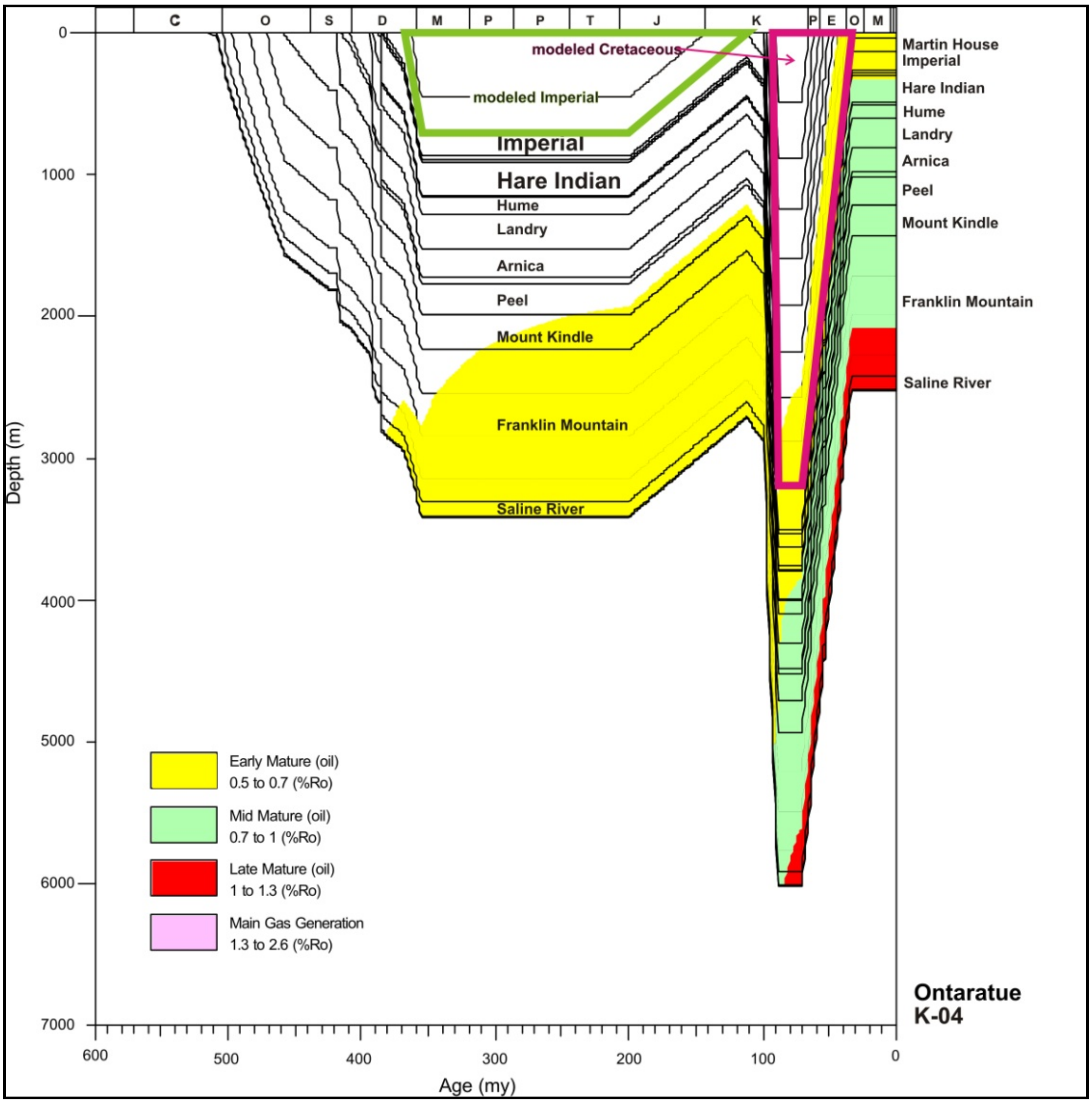

Figure 10.4.5. *Burial history diagram of the Ontaratue K-04 well. Selected formations are labeled, along with extra thicknesses of Imperial Formation (modeled Imperial) and Cretaceous sediments (modeled Cretaceous) used in the model.*

From the burial history diagram (Figure 10.4.6) the Canol Formation and Bluefish Member (below Imperial and Hare Indian formations, respectively) are highly mature (within the upper oil window); and that they reached maturity under a modeled thickness of Cretaceous siliciclastics. Cambrian Mount Cap Formation is likely to be at dry gas generating stage, while the base of the Cretaceous (Martin House Formation and overlying Arctic Red Formation) is within the oil window. The modeled effect of higher heat flow compared to Grandview Hills No.1 (A-47) and Ontaratue K-04 (Figures 10.4.4, 10.4.5) is seen here, as lower to middle Devonian formations (Arnica, Landry, and Hume formations) begin to enter the oil window by the Late Paleozoic, under the thickness of Upper Devonian +/- Mississippian siliciclastics.

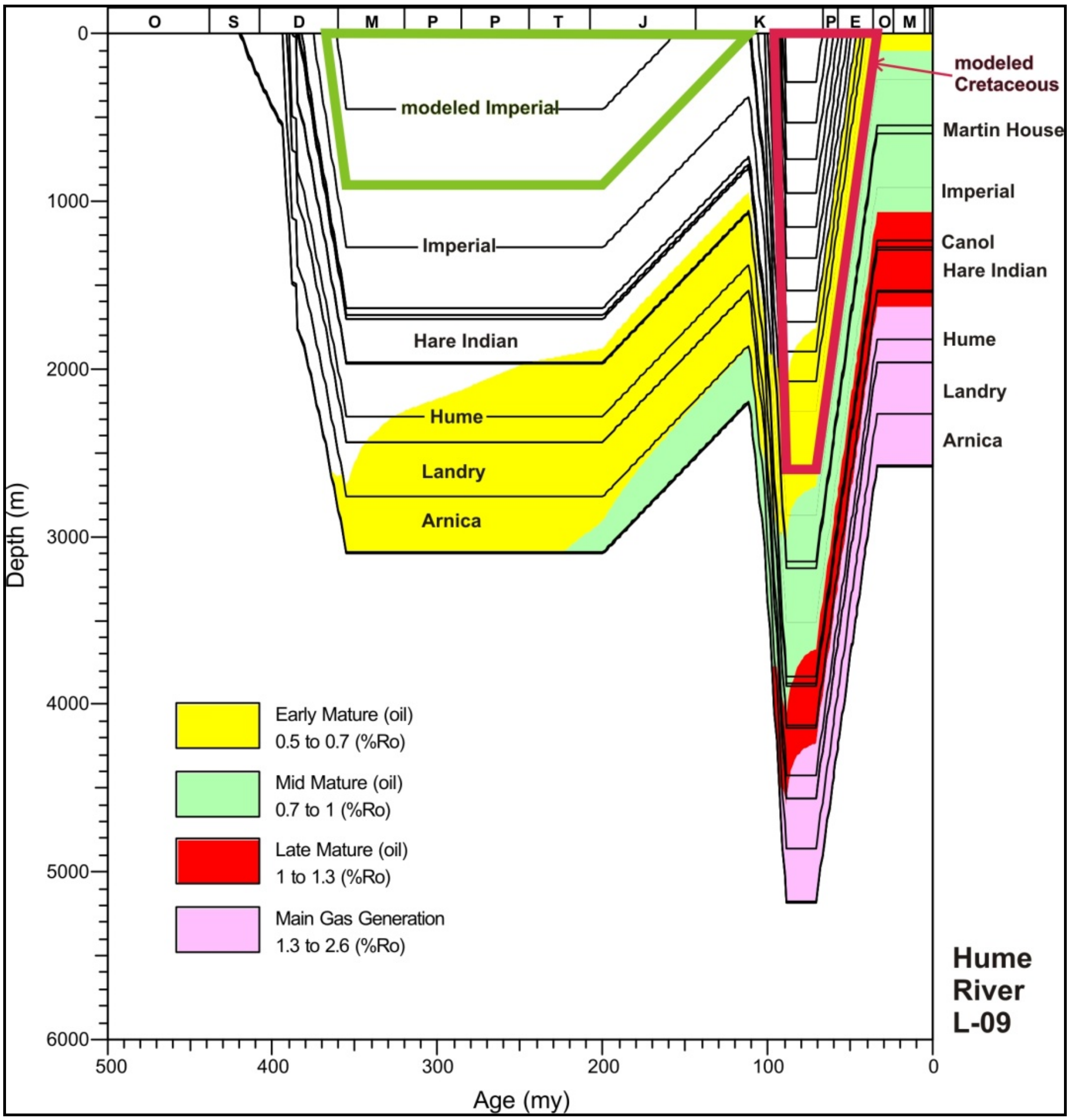

Figure 10.4.6. *Burial history diagram of the Hume River L-09 well. Selected formations are labeled, along with extra thicknesses of Imperial Formation (modeled Imperial) and Cretaceous sediments (modeled Cretaceous) used in the model.*

Western Peel Area

Satah River Y.T. G-72

TD for this well in central western Peel area was within Landry Formation, and it was assumed (from constructed isopach maps) that about half of the total formation thickness was penetrated. Five hundred metres of additional Tuttle formation strata was added to the 1643 m intersected in this well; this 500 m was assumed to have been eroded before deposition of the Cretaceous beds. Only 2 km of extra Cretaceous strata were added (and subsequently removed) in this well, in addition to the intersected 159 m, to fit the measured maturity data. This is less than for previous wells modeled. This may be a reasonable estimate, as this well is closer to the Richardson Mountain front, and thus may have been at a position inboard of the axis of maximum deposition in the Laramide foreland trough.

The maturity versus depth trend generated by the model fits reasonably with the new Rock-Eval data of Allen et al. (2008b), to a depth of 2 km. Heat flows used in the model were 45-60 mW/m^2; with the increased heat flow modeled to coincide with Laramide deformation. Majorowicz and Morrow (1998) estimated a *modern* heat flow of 58 mW/m^2 in this well.

From the burial history diagram (Figure 10.4.7), it is apparent that Canol Formation is mature and that it reached early maturity under the Imperial-Tuttle siliciclastic pile, and continued into the oil window under Cretaceous deposition. Landry Formation (and presumably the equivalent upper part of Road River Group source rocks) also reached the oil window under Cretaceous burial. It is noteworthy that here only the lower half of Imperial Formation is at middle maturity (since the Late Cretaceous); Tuttle Formation and younger strata are at early maturity.

Taylor Lake Y.T. K-15

TD for this well in southwest Peel area was within Mount Kindle Formation, and an extra 260 m of Mount Kindle strata were added to the base of the well in this model to account for the estimated total thickness of the formation. Fourteen hundred metres of additional Imperial plus Tuttle formation strata were added to the 610 m intersected in this well. Three km of extra Cretaceous strata were added (and subsequently removed) in this well, in addition to the intersected 658 m, to fit the measured maturity data.

The maturity versus depth trend generated by the model fits reasonably with the new Rock-Eval data of Allen et al. (2008b) in the upper 500 m; below this, maturities seem to increase, perhaps suggesting higher heat flow at those times (see discussion above). However, the inclusion of two reflectance data points (Pyle et al., 2006) at around 1300 m depth lie on the modeled trend. This was the case for several wells examined in Peel area, where reported Rock-Eval Tmax and vitrinite reflectance values seem to lie on different trends with respect to depth (as discussed above). Heat flows used in this model were 45-65 mW/m^2; with the increased heat flow modeled to coincide with Laramide deformation.

From the burial history diagram (Figure 10.4.8), it is apparent that Canol Formation is essentially overmature and that it reached middle maturity under Cretaceous burial, continuing to mature during exhumation due to relatively higher heat flow modeled through the Laramide Orogeny. Road River Group equivalent rocks began to reach the middle of the oil window in latest

Paleozoic and early Mesozoic, and are now at dry gas generating stage to overmature. Imperial, Tuttle, and basal Cretaceous formations are now at high maturity.

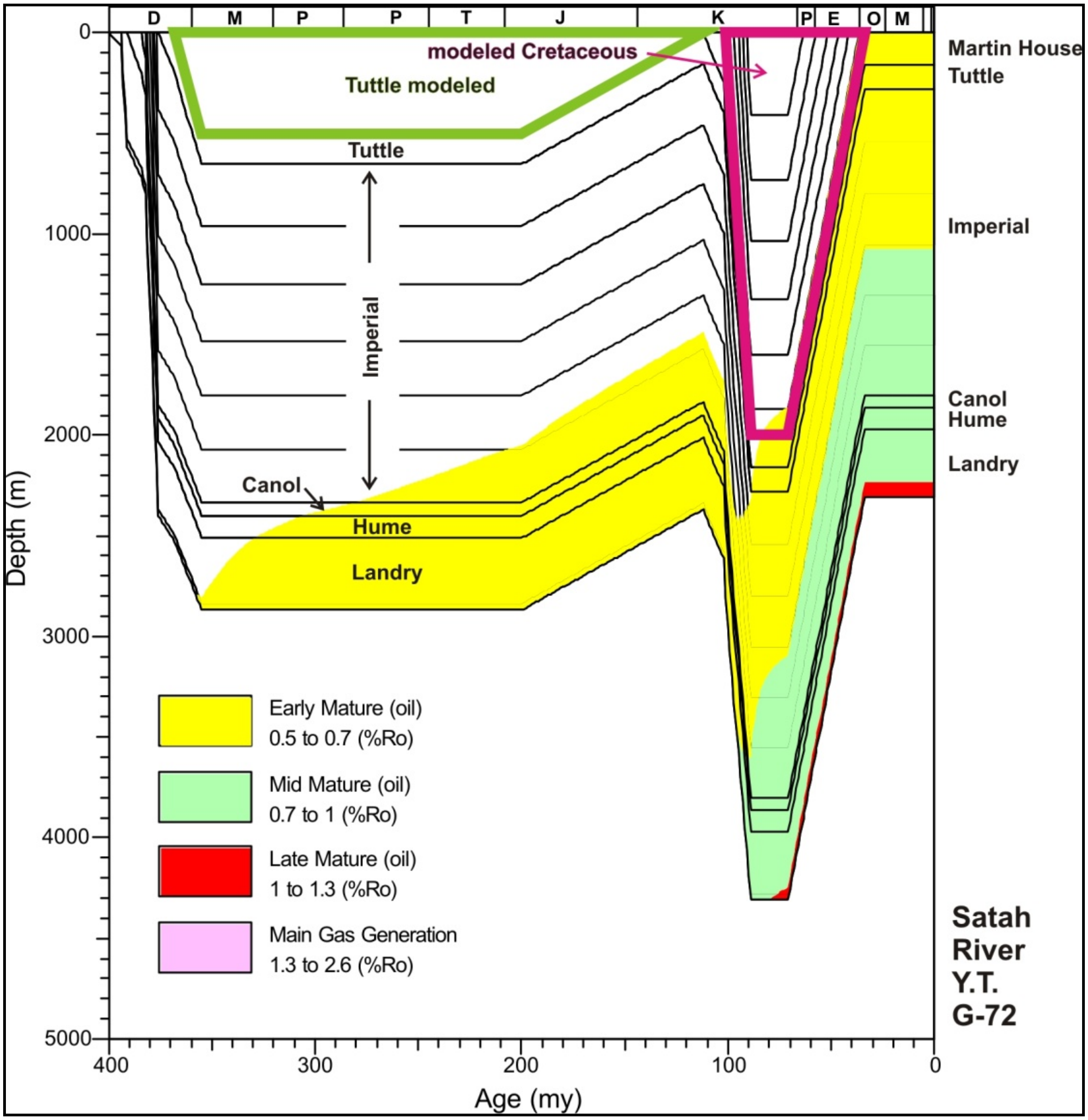

Figure 10.4.7. *Burial history diagram of the Satah River Y.T. G-72 well. Selected formations are labeled, along with extra thicknesses of Tuttle Formation (modeled Tuttle) and Cretaceous sediments (modeled Cretaceous) used in the model.*

Northwest Peel Area

A few wells (Ft. McPherson C-78, McPherson B-25, and Stony I-50) in northwest Peel area were modeled. These wells required modeled burial by 3.2 km to 4.0 km of Cretaceous strata, and 2.5 km to 2.9 km of Imperial plus Tuttle formations to fit the data, in addition to generally higher heat flows. Majorowicz and Morrow (1998) estimated relatively low *modern* heat flow in this part of Peel area.

The model fit to depth versus maturity data was generally poor, with apparent slope changes or discontinuities. Maturity data for these wells indicate high maturity at shallow depths, except the Stony I-50 well which had immature to low maturity strata at very shallow depths, and then sharply increasing maturities. Ultimately the simple model presented for Peel wells was rejected for this area. It is assumed that the burial history of these wells, adjacent to the northern Richardson Mountains, is more complex than elsewhere in Peel, and probably involved repeated Mesozoic burial and exhumation, particularly (assumed) Jurassic and Cretaceous strata (Norris, 1997).

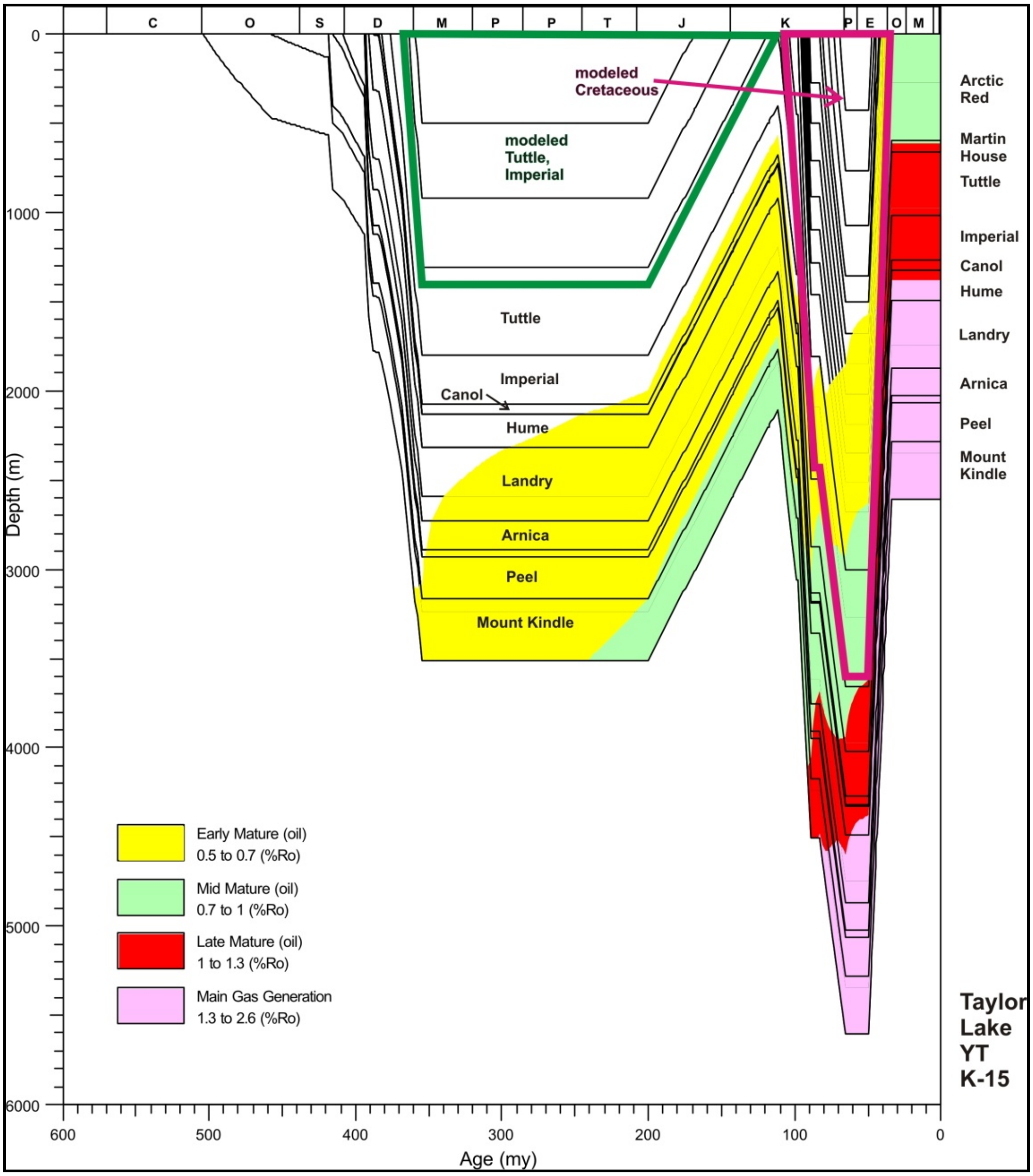

Figure 10.4.8. *Burial history diagram of the Taylor Lake Y.T. K-15 well. Selected formations are labeled, along with extra thicknesses of Imperial plus Tuttle Formation (Imperial, Tuttle modeled) and Cretaceous sediments (Cretaceous modeled) used in the model.*

10.4.4 Conclusions

One-dimensional models using the BasinMod^{TM} program of Platte River Associates Inc., limited reflectance and Tmax data, and simplified treatment of burial and exhumation history, has led to a fairly consistent pattern across the Peel area. In eastern Peel area, the major source rock units (Canol Formation and Bluefish Member) did not reach maturity (within the oil window) until burial by an envisioned thick (about 3 km) Cretaceous sequence, mostly since eroded. This Cretaceous maturity suggests that expulsion from the source rocks could have been favourable with respect to early Laramide structures. This is important since the possibility of structural traps opens up a wider range of possible reservoirs to accept charge from Canol Formation and/or Bluefish Member.

In western Peel area, this relationship holds true in some cases, although the combined thickness of Devonian-Mississippian and Cretaceous clastic rocks in some wells was enough to push Canol Formation into overmaturity by mid to late-Cretaceous time, probably pre-dating some Laramide structuring.

Cambrian to Devonian Road River Group likely began to enter the oil window in the late Paleozoic; this is in agreement with Link and Bustin (1989). This predates structural trap formation, and suggests that migrating petroleum from these possible source rocks would have had to find a potential reservoir in a stratigraphic trap setting.

Some notable discontinuities in the burial depth versus maturity profiles, particularly apparent between Cretaceous and Late Paleozoic rocks of certain wells may indicate that there was considerably more Late Paleozoic sediment deposited (and later eroded) at these well locations, or that Late Paleozoic heat flow was much higher than estimated, or some combination of both factors. Increased thickness of deposited and eroded Upper Paleozoic sediments alone as a controlling factor was rejected, because of the need for spatially restricted depocentres holding huge thicknesses of Imperial and Tuttle formations. Thus, higher heat flows in the Upper Paleozoic may have been the controlling factor, although a study of historic heat flows is beyond the scope of this chapter.

10.5 PLAYS AND PETROLEUM SYSTEMS

L.P. Gal, T.L. Allen, T. Hadlari, and W.G. Zantvoort

10.5.1 Conceptual Plays and Petroleum Systems in Peel Area

Seven conceptual petroleum plays have been introduced in the preceding chapters of this volume. These are: Basal Cambrian clastics play (Chapter 3), Lower Paleozoic platform play (Chapter 4), Arnica-Landry platform and Kee Scarp plays (Chapter 6), the Imperial Formation and Tuttle Formation plays (Chapters 7 and 8, respectively), and the Basal Cretaceous Sandstone play (Chapter 9).

These conceptual plays can be considered pairings of two basic elements of a petroleum system, namely, a reservoir and a trap. A petroleum system "encompasses a pod of active source rock and all related oil and gas and includes all the essential elements and processes needed for oil and gas accumulations to exist" (Magoon and Dow, 1994). Thus, a petroleum system is based primarily on the existence of a pod of mature source rock. Other elements of petroleum systems, such as source rock type, richness, and maturity, have been discussed in several of the preceding chapters.

The petroleum systems here are named according to the convention of Magoon (1987), i.e., the name of the source rock, the major reservoir rock, and degree of certainty. The degrees of certainty are: *known*, where a geochemical match exists between the active source rock and the petroleum accumulation; *hypothetical*, where geochemical information identifies a source rock, but no geochemical match between source rock and accumulation exists; and *speculative*, where the existence of a source rock or petroleum is postulated on the basis of geological or geophysical evidence.

In relating a conceptual play to a particular petroleum system, one needs to make an association between a potential reservoir and a source rock, for example: a compositional correlation between a reservoired crude oil and source rock solvent extract composition; or stratigraphic/spatial (facies or adjacent) relationships between petroleum source rock strata and reservoir strata (K.G. Osadetz, pers. comm., 2009). Table 10.5.1 lists conceptual plays in Peel area, related petroleum systems, and the basis for proposing the relationship.

Note that in the preceding chapters, many instances were mentioned where a given source rock interval could potentially provide a charge to a number of potential reservoirs. For example, Canol Formation and/or Bluefish Member could potentially charge Franklin Mountain or Arnica formation dolostones, or Imperial Formation sandstone. For simplicity, these scenarios are discussed under the Horn River-Ramparts petroleum system; although from new oil stain data presented in section 10.3, there are hypothetical Mount Cap-Ramparts, Mount Cap-Imperial, Horn River-Arnica, and Horn River-Imperial petroleum systems technically present in southeast Peel area. It is recognized that structural traps that juxtapose Canol and/or Bluefish shale with older (or even younger) reservoir beds may form an important exploration target in Peel area.

In the following section, the conceptual plays introduced previously will be reviewed, illustrated with play maps, and discussed in the context of related petroleum systems.

10.5.2 Basal Cambrian Clastics Play and Mount Clark-Mount Cap Petroleum System

The Mount Cap-Mount Clark petroleum system is described as known because there is good geochemical evidence for a Cambrian-Ordovician oil that can be reasonably inferred to have originated in Mount Cap (or possibly Saline River) Formation. The basal Cambrian clastic play is considered conceptual because there is no evidence for accumulations in Peel area in potential Mount Clark or Mount Cap sandstone reservoirs. That does not mean that oil and/or gas generated could not have migrated into younger formations, and in fact our new data shows it certainly migrated into Ramparts and Imperial formations at the least.

Conceptual Play	Petroleum System	Basis of Association	Comments
Basal Cambrian Clastics	Mount Cap-Mount Clark (known)	Geochemical evidence for a probable Cambrian-Ordovician oil (Mount Cap Formation). Mount Clark (possible reservoir) and Mount Cap (probable source rock) formations are stratigraphically adjacent and/or facies equivalents.	Analogue is Colville Hills
Lower Paleozoic Platform (Ronning)	Road River-Ronning (hypothetical)	Geochemical evidence for Road River source rock potential. Potential reservoir rocks (Ronning Group) are facies equivalents of Road River Group in a shelf-basin transition setting.	--
Arnica-Landry Platform	Horn River-Arnica (known)	Geochemical evidence for a Devonian "Norman Wells-type" oil (Horn River Group source rock) in Arnica Formation and equivalents. There is evidence for reservoir potential in Arnica Formation and equivalents, but no adjacent source rock. This petroleum system is discussed under the Horn River – Ramparts system (below).	Possible analogue is Summit Creek B-45 well
Kee Scarp (Ramparts)	Horn River-Ramparts (known)	Geochemical evidence for a Devonian "Norman Wells-type" oil (Horn River Group source rock) in Ramparts Formation. Ramparts Formation potential reservoir stratigraphically adjacent to overlying Canol Formation and lower Ramparts organic-rich shale (i.e., Carcajou marker beds).	Analogue is Norman Wells
Imperial	Imperial-Imperial (hypothetical)	Geochemical evidence for Imperial Formation source rock potential, potential (if relatively poor) Imperial Formation reservoir rocks are interstratified. Known oils from Imperial Formation (section 10.3) are probably sourced from Cambrian-Ordovician and Devonian Horn River source; thus not of an Imperial-Imperial system.	--
Tuttle	Tuttle-Tuttle (hypothetical)	Geochemical evidence for Tuttle Formation source rock potential, potential reservoir rocks in Tuttle Formation are interstratified. Potentially richer source rocks of Ford Lake Shale are stratigraphically adjacent, and/or facies equivalents. Known oils from Tuttle Formation have not been conclusively attributed to Tuttle Formation source.	--
Basal Cretaceous Sandstone	Arctic Red-Martin House (known)	Geochemical evidence for Cretaceous oil in Peel Plateau, found in oil stained basal Cretaceous clastic (potential reservoir) rock. Arctic Red (and Slater River) formations source rock potential, Martin House Formation potential reservoir is stratigraphically adjacent. Oil stained Cretaceous rocks in southeast Peel area have not been geochemically analysed to determine affiliations with source rocks.	Analogues are Stewart D-57 and East MacKay B-45 wells in Mackenzie Plain

Table 10.5.1. *Conceptual plays in Peel area, with proposed affiliation to petroleum systems.*

Play Review and Play Map

This play was introduced in Chapter 3. It is conceptual in Peel area, and established in Colville Hills area east of Peel area. The Colville Hills area provides an analogue; the source rock is considered to be Mount Cap Formation (Weilens et al., 1990; Dixon and Stasiuk, 1998; Dixon et al., 2007). No petroleum shows have been found in Cambrian rocks in Peel area; and from limited borehole data, and outcrop exposures southeast of Peel area, the outlook for a Cambrian petroleum system being present in eastern Peel area, was at the outset of this project, rather bleak. However, new evidence from oil stained samples discussed above, suggests the presence of lower Paleozoic, probably Cambrian-Ordovician oil. From examination of limited outcrop and subsurface data, Mount Cap (or Saline River) formations are the most likely candidate for a source rock of this age. Oils analyzed bear similarities to those found at Colville Hills to the east (K.G. Osadetz, pers. comm., 2008).

Distribution of potential Mount Cap Formation source rock in Peel area is not well delineated, but may occur as far west as the crest of Mackenzie-Peel Arch. Pugh (1983) mapped Mount Cap Formation subsurface lithofacies and noted black shale only in the east and northeast parts of Peel area.

Distribution of Mount Clark Formation quartz sandstone potential reservoir is also poorly constrained, but likely is restricted to the eastern margin of Peel area (e.g., Canadian Gas Potential Committee, 2005). However, Lemieux et al. (2008) indicate a conceptual Cambrian clastic play occurring as far west as about 131°W. A play map is shown in Figure 10.5.1. The western limit of the conceptual play is shown here as coinciding with the extent of Mount Cap Formation and the crest of Mackenzie-Peel Arch. The westward extent of Saline River Formation is shown, because the salt member provides an important regional seal. It is not possible to assess the best area of this play (if any) because of a lack of information. However, the Cambrian-Ordovician sourced oil was found at the extreme southeastern edge of Peel area, and further southeast.

In Peel area, perhaps the most likely traps would be lateral facies pinchouts, stratigraphic pinchouts against paleotopgraphic highs; and possibly extensional fault related traps, or re-activations of Proterozoic faults (Hannigan et al., 2006). Structural traps related to Laramide deformation are also possible but less likely because the generation of Mount Cap Formation petroleum very likely pre-dated Laramide deformation.

Play and prospect-level risks were discussed in Chapter 3 (this volume). While there is some encouragement with respect to source rocks, reservoir rock quality is a major risk in Peel area. Hannigan et al. (2006) list adequate reservoir, adequate source, and communication with source as play-level exploration risks. Furthermore, seal, trap, and especially preservation risks at the prospect level make this a conceptual play of relatively low potential in Peel area.

Burial History, Generation, and Migration of Cambrian Petroleum

A one-dimensional burial history diagram for the Grandview Hills No.1 (A-47) well is shown in Figure 10.4.4. The total depth (TD) of the well was in Franklin Mountain Formation, which can serve as a proxy for underlying Cambrian formations in Peel Plain. Based on modeled depth versus maturity data (see section 10.4) the basal Cambrian entered the oil window in the early Late Devonian, as a result of burial under Imperial Formation. This is in general agreement with Brock et al. (1983), who proposed that the earliest possible petroleum generation from Mount Cap Formation commenced in the middle Devonian in Peel Plain, based on their burial history model for the Ontaratue H-34 well. Early expulsion and migration of Mount Cap sourced oil would thus predate any Laramide structural traps. From existing evidence, it is very likely that Mount Cap oil migrated into younger rocks (as young as Imperial Formation) in the latest Paleozoic to Mesozoic time.

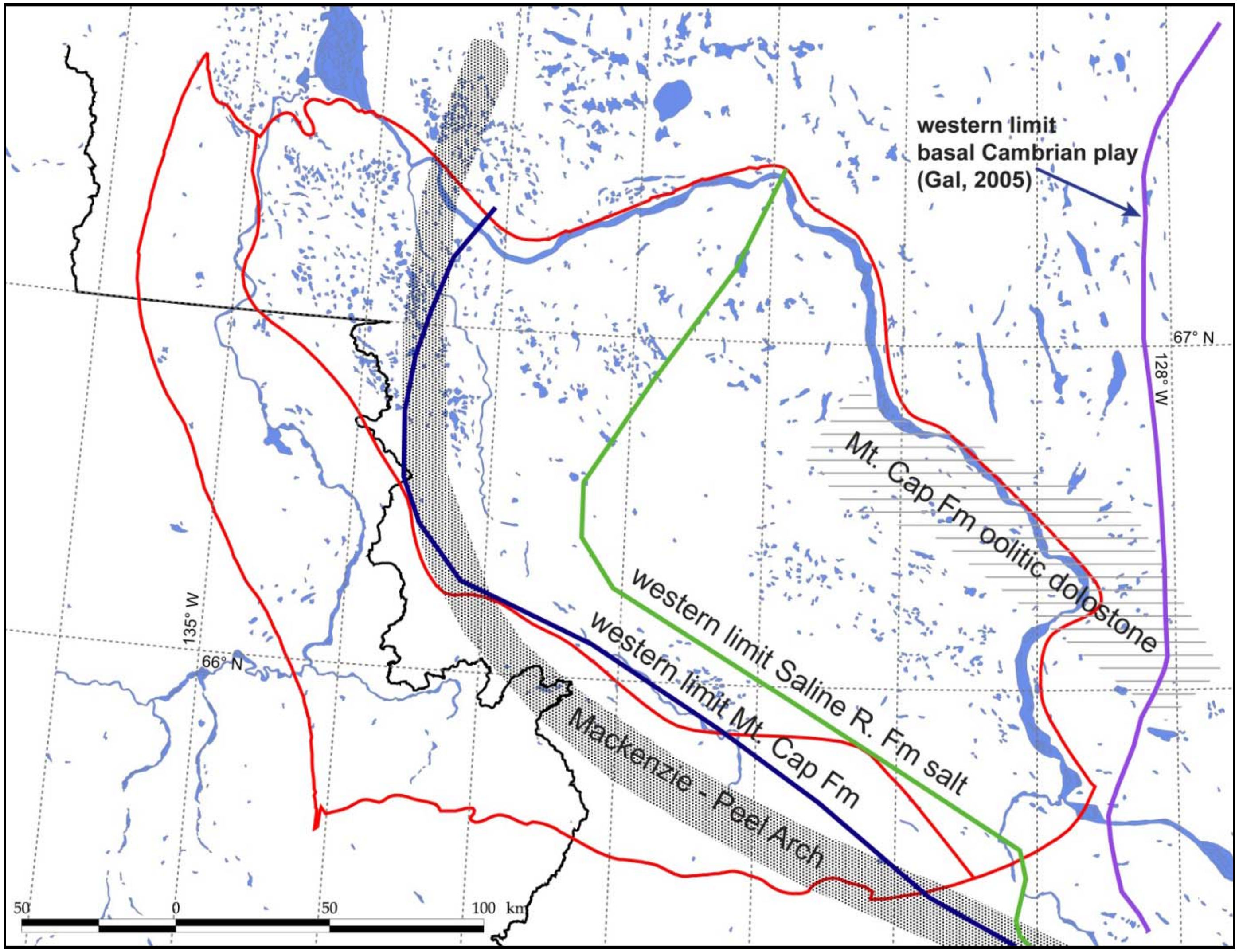

Figure 10.5.1. *Basal Cambrian clastics play map. Canadian Gas Potential Committee (2005) and Gal (2005) placed the western edge of this play area just east of Peel area, as shown. Lemieux et al. (2008) indicates the play extends as far west as about 131°W. In the current study, we consider the play to extend to the western limit of Mount Cap Formation, about at the crest of Mackenzie-Peel Arch. The mapped extent of oolitic Mount Cap Formation dolostone (a possible reservoir) is shown in the lined hachure (after Meding, 1998). The western limit of Saline River Formation middle salt member is shown.*

Later burial by Cretaceous sediments further matured Cambrian strata into the oil window, and probably into the dry gas field, with increased generation in Mount Cap Formation, and possible *in situ* cracking in Mount Clark reservoirs. Migration of gas may have flushed existing reservoirs (in which case bitumen plugging porosity would likely negatively affect reservoirs). Eastward migration and re-mobilization may have occurred, up the regional dip, east of Peel area and toward subcrop edges of basal Cambrian strata along the flank of Keele Arch. Breaching, water washing, and biodegradation very likely affected any accumulated petroleum at the subcrop edge, especially during Tertiary and later uplift and erosion (Morrell, 1995).

Petroleum Systems Events

A proposed petroleum system events chart for the Mount Cap-Mount Clark system is presented in Figure 10.5.2. In this figure and subsequent events charts, time is indicated at the top of each column by a letter symbolizing period names (C= Cambrian, O= Ordovician, S= Silurian, etc.) and the corresponding width for each column. System events are listed along the right side of the chart, and the corresponding bars in each row indicate the timing of each event. Time bars are colour coded: green implies some confidence, light green less so, while yellow indicates the highest uncertainty. Significant unconformities are indicated by red lines on the row labeled "overburden". The critical moment is marked by a dot at the beginning of the preservation period in each case.

Figure 10.5.2 shows reasonable confidence in a Mount Cap source rock that was active (and is now spent). The location and extent of this source rock is poorly known, it may have been restricted to a small area south and southeast of Peel area. Mount Clark reservoir is less than certain in southeastern Peel area, samples collected during the current study showed poor reservoir qualities. Seal rocks were probably effective, especially where Saline River Formation was deposited. If oil generation commenced in the Late Paleozoic, as shown (gen./mig./accum. row), and migrated early, it would have had to been preserved in stratigraphic traps during a very long hiatus (not shown) over the latest Paleozoic and much of the Mesozoic. It is not known how far generation, migration, or accumulation progressed by the time of renewed Cretaceous burial, which would have exhausted remaining Mount Cap potential, generating gas which could have flushed previously reservoired oil. It is possible that later gas generated under Cretaceous burial could have post-dated Laramide structures, and thus have migrated into structural traps.

Critical Moment

The critical moment (bottom row of Figure 10.5.2) is the point in time that represents the peak generation-migration-accumulation in the petroleum system (Magoon and Dow, 1994). Here the critical moment is placed in the early Tertiary, at the end of dry gas generation. This is conjectural, because, as mentioned, it is not known how far the generation of Mount Cap-sourced petroleum had progressed by the time of post-Late Paleozoic hiatus. However, since the system likely generated gas after burial in the Cretaceous, based on the burial history diagrams, this is probably the hydrocarbon of interest at the present. That is, the play is probably for gas.

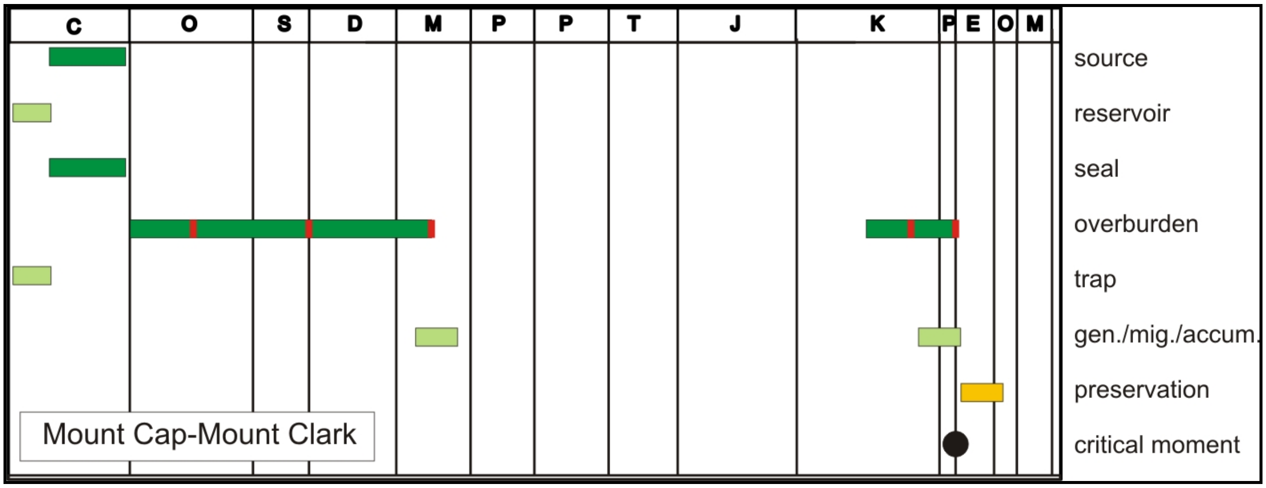

Figure 10.5.2. *Theoretical events chart for a Mount Cap/Mount Clark (?) petroleum system in Peel area. The bar for generation-migration-accumulation (**gen./mig./accum.**) shows that oil generation likely started in the late Paleozoic.*

Figure 10.5.3 is a schematic regional cross section across from southeastern Peel area in the west, eastward toward the Keele Arch. The section is drawn to represent conditions about the time of the critical moment in this system, therefore Mount Cap Formation is depicted as largely overmature and generating gas. The inset boxes show possible migration into Mount Clark Formation potential reservoirs; in stratigraphic pinch-outs, and growth fault-bounded traps (syn-depositional, formed during Cambrian rifting). Of course at the proposed critical moment, Laramide structural traps may have formed as well; these are not shown for simplicity.

Summary

The known Mount Cap-Mount Clark petroleum system operated in the late Paleozoic when oil was generated in Mount Cap Formation. At least some of this oil migrated into rocks as young as Imperial Formation. Increased burial by post-Albian sediments probably resulted in renewed generation of gas in Mount Cap Formation, to exhaustion of the source rock which is now overmature in southeastern Peel area.

The basal Cambrian play carries high exploration risks in Peel area. Any reservoired oil would have had to have been preserved over very long and tectonically active time periods. Reservoired gas is perhaps more likely, but risk of poor reservoir, inadequate source, and inadequate and/or failed trap (from a variety of causes) give this conceptual gas play relatively low potential in Peel area.

The Sammons H-55 well just southeast of Peel area was drilled to a Cambrian target, but failed to encounter porosity in Mount Clark Formation (or in Proterozoic quartz sandstone; Rose, 1984).

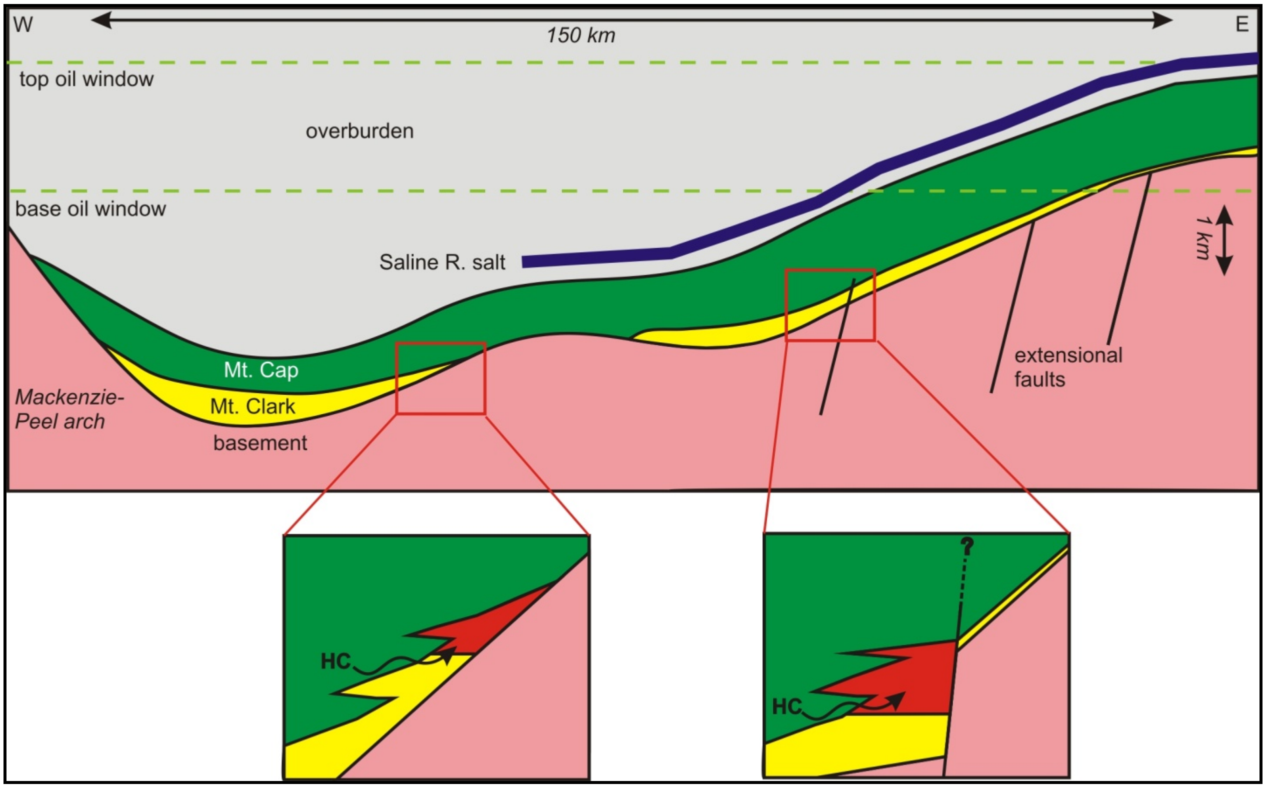

Figure 10.5.3. *Diagrammatic representation of Mount Cap/Mount Clark formations in Peel area and to the east around the time of dry gas generation, further maturation and/or remobilization in Mount Cap Formation. The scales indicated are highly schematic. The inset boxes show possible trapping geometries in updip pinch-outs of Mount Clark sandstone (left) and a growth fault-bounded trap (right). The "HC" and wavy arrows indicate possible petroleum migration. Not shown are possible Laramide aged structural traps, which may have been in place during the time of Mount Cap gas generation.*

10.5.3 Lower Paleozoic Platform Play and Road River-Ronning Petroleum System

This petroleum system is described as hypothetical because there is good geochemical evidence for Road River Group being an effective and rich, now post-mature and inactive, source rock. However, there is no published evidence for petroleum accumulations in Ronning Group (or elsewhere) that have been correlated to Road River Group potential source rocks. The lower Paleozoic platform play is considered conceptual because there have been no discoveries, only a few minor shows in Ronning Group rocks, despite several tests of this horizon in Peel area.

Road River Group petroleum could have charged lower Devonian reservoirs, in particular Arnica Formation. Osadetz et al. (2005) and Hannigan et al. (2006) noted that Road River Group hydrocarbons may not have been trapped at the Mackenzie-Peel carbonate shelf edge, and could have continued to migrate into the middle shelf. As with the timing of generation and migration, possible migration pathways are not well understood, but the dominance of tight carbonate rocks in the stratigraphic section from Franklin Mountain Formation to Hume Formation suggests that migration pathways were not widely developed, and this may have hindered long distance hydrocarbon migration.

Play Review and Play Map

The lower Paleozoic platform play is a conceptual play in Peel area, and elsewhere in NWT (Pyle, 2008), with a few minor gas shows known from Peel area (e.g., Peel Y.T. H-71, Peel Y.T. F-37, Taylor Lake Y.T. K-15).

Geochemical data from Road River Group suggest that it was, at least locally, a good oil-prone source rock. Values of up to 9% TOC suggest original values may have been higher, as the rocks are now overmature to post-mature.

Bitumen is found in Franklin Mountain and Mount Kindle formations, locally near the platform edge (e.g., Stony I-50 well). This bitumen may be the remnants of oil that travelled through, or was stored in and then flushed from, Ronning Group reservoirs. There are few reports of oil stained Ronning Group rocks as well. In Chapter 4 (this volume) it was noted that oil-cut fluids recovered on DST from Ronning Group just east of Peel area (e.g., Hanna River J-05), are thought to be sourced from younger oils.

From examination of outcrops, reservoir quality rocks are volumetrically minor, but are found locally in Ronning Group. Vuggy dolostone is known from Franklin Mountain Formation (Figure 10.5.4; Chapter 4, this volume); but the controls on, and timing of formation of this porosity are not known. From textural evidence there is a diagenetic, and possibly hydrothermal component to their formation, the timing of which may (or may not) pre-date generation and migration of Road River petroleum.

Potential reservoir rock at the Mackenzie-Peel platform edge, adjacent to basinal Road River Group rocks, are not known with the exception of vuggy and possibly hydrothermal dolomite in Stony I-50 well (Chapter 4, this volume). The platform edge facies transition was not studied in detail in the field in this study because it is very remote. A few shelf-edge buildups, imaged by seismic, have been explicitly mentioned in well history reports and have been tested without success (e.g., McPherson B-25; Morris, 1972). Lemieux et al. (2008) compiled indicated closures on the Lower Paleozoic platform carbonate surface in the Mackenzie Corridor from publicly available seismic survey data, but the area examined did not extend to the western platform margin.

Stratigraphic traps might be expected to be important at the interfingering shelf to basin, carbonate to shale transition. In the absence of biohermal buildups, however, the interfingering carbonate and shale beds at the shelf margin have westward depositional (and later enhanced by Laramide tectonic) dips that are not conducive to sealing geometries (Osadetz et al., 2005; Hannigan et al., 2006).

The play area (Figure 10.5.4) extends essentially throughout the Peel area. It is not possible to identify an area or "fairway" within this play that is relatively more favourable. Figure 10.5.4 shows the location of the Mackenzie-Peel shelf edge, and the near coincident eastward limit of Road River Group. Instances of coarse-crystalline and vuggy dolomite in Franklin Mountain Formation well samples, core, and outcrop are indicated, as is the approximate extent of "redbeds" which include quartzose sandstones that are potential reservoir strata.

Burial History, Generation and Migration of Road River Petroleum

A one-dimensional burial history diagram for Taylor Lake Y.T. K-15 well (Figure 10.4.8) shows facies equivalents (Landry and older formations) of Road River Group which lie just southeast of this well. Based on modeled depth versus maturity data, Road River Group entered the middle oil window in late Paleozoic time, which is in general agreement with the conclusion of Link and Bustin (1989). Oil and/or gas were probably generated, and migrated as early as late Paleozoic time, under burial by the Imperial/Tuttle Formation siliciclastic rocks. Expulsion and migration of Road River-sourced oil would thus predate any Laramide structural traps (Hannigan et al., 2006).

Road River Group underwent further maturity probably under burial by Albian and later siliciclastic rocks. At this time, dry gas was likely generated in Road River Group source rocks, and possibly *in situ* within any Ronning Group accumulations, possibly explaining the residual and pore-lining bitumen seen locally. Increased maturation, re-migration, and displacement of oil by gas may have occurred in the latest Cretaceous, possibly post-dating the earliest formed structures at the fronts of the Richardson and Mackenzie mountains.

It is unknown whether and how far Road River oil (and/or gas) migrated eastward from the Richardson Trough, and whether migration into younger strata than Ronning Group was possible.

Petroleum Systems Events

Figure 10.5.5 (events chart) shows reasonable confidence in a Road River source rock, although the source rock intervals are poorly constrained with respect to age. Road River Group can now be considered inactive or spent. The reservoir and stratigraphic traps are shown with less confidence, as reservoir quality Ronning Group rocks are volumetrically limited, and stratigraphic trapping environments are poorly understood. If oil generation commenced in the Late Paleozoic, as shown, and migrated early, it would have had to be preserved (not shown) in stratigraphic traps over a number of very long hiatuses over the latest Paleozoic and much of the Mesozoic. Oil generated in late Paleozoic time could have migrated into suitably situated adjacent carbonate rocks of Ronning Group, but whether any petroleum was trapped there is conjectural, given the unfavourable regional dip, and seeming dearth of shelf-edge buildups.

Limited examples of bitumen in subsurface of western Peel area Ronning Group (e.g., Stony I-50 well) show that at least some oil had migrated through these rocks; Road River Group was the probable source of this. It is not known how far generation, migration, or accumulation progressed by the time of renewed Cretaceous burial, which would have increased Road River Group maturation into the dry gas zone, perhaps flushing previously reservoired oil that had managed to persist. It is possible that any gas generated under Cretaceous burial could have post-dated Laramide structures, and thus have migrated into structural traps.

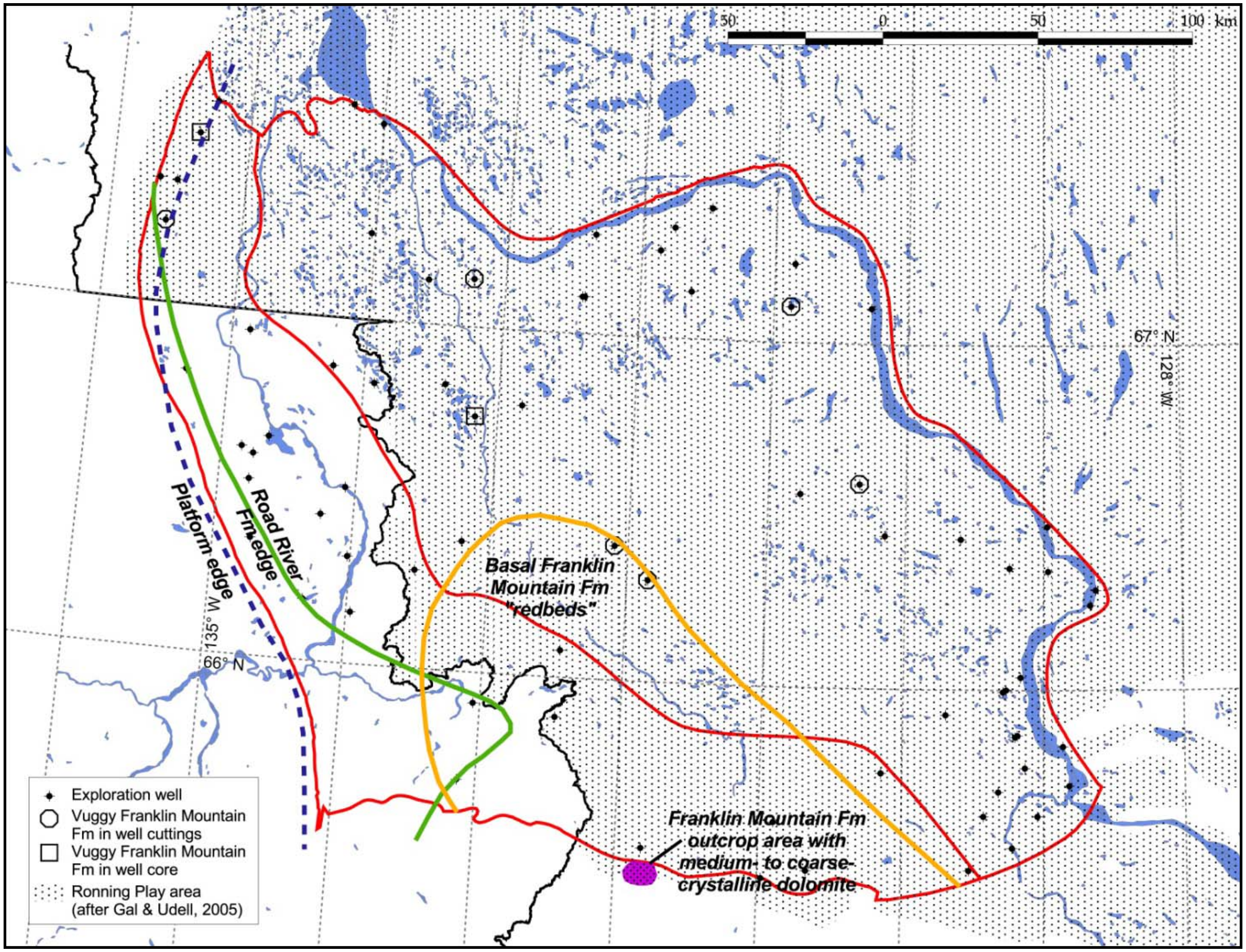

Figure 10.5.4. *Ronning play map. The play area (shaded region in NWT from Gal and Udell, 2005) extends across Peel area to the western platform edge (unshaded in Yukon). This essentially corresponds to the eastern edge of mapped Road River Group, which is everywhere overmature to post-mature. Also shown on this map are features relating to reservoir potential in Franklin Mountain Formation: locations of porous white dolomite in core, outcrop, and cuttings; and the extent of basal redbeds and quartz sandstones, which are localized over the crest of Mackenzie-Peel Arch.*

Critical Moment

The critical moment for this petroleum system is placed in the early Tertiary (Figure 10.5.5), at the end of proposed dry gas generation. This is conjectural, because, as it was mentioned, it is not known how far the generation of Road River-sourced petroleum had progressed by the time of post-Late Paleozoic hiatus. However, since the system likely generated gas after burial in the Cretaceous, this is probably the hydrocarbon of interest at the present. That is, the play today is probably for gas.

Figure 10.5.6 is a schematic regional cross section from the Richardson Trough, across western and central Peel area. The section is drawn to represent conditions about at the time of peak oil generation, supposedly in the late Paleozoic. The same section could be used to depict the critical moment, by moving the green lines bounding the oil window to a higher stratigraphic level. The inset box at left shows a possible, although problematic, trapping situation at the shelf edge carbonate-shale transition. Also shown in inset boxes are a shelf margin buildup (not as commonly seen as might be expected, although based on widely-spaced seismic surveys) and intra-formational vuggy dolomite (associated with a speculative basement fault; the timing of this diagenesis with respect to petroleum generation and migration is not known). Of course at the proposed critical moment in the early Tertiary, Laramide structural traps may well have formed; these are not shown for simplicity.

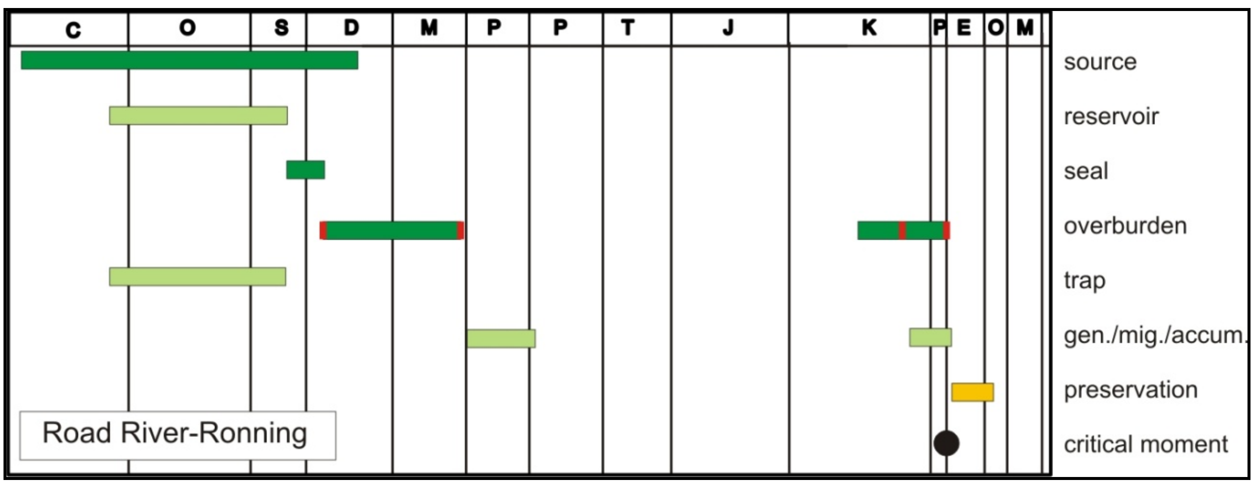

***Figure 10.5.5.** Theoretical events chart for Road River/Ronning (?) petroleum system. The **trap** row indicates stratigraphic traps, because maturity of Road River Group very likely preceded the main time of Laramide structural trap formation. The bar for generation-migration-accumulation (**gen./mig./accum.**) shows that oil generation likely started in the late Paleozoic, while gas generation may have occurred in the late Cretaceous.*

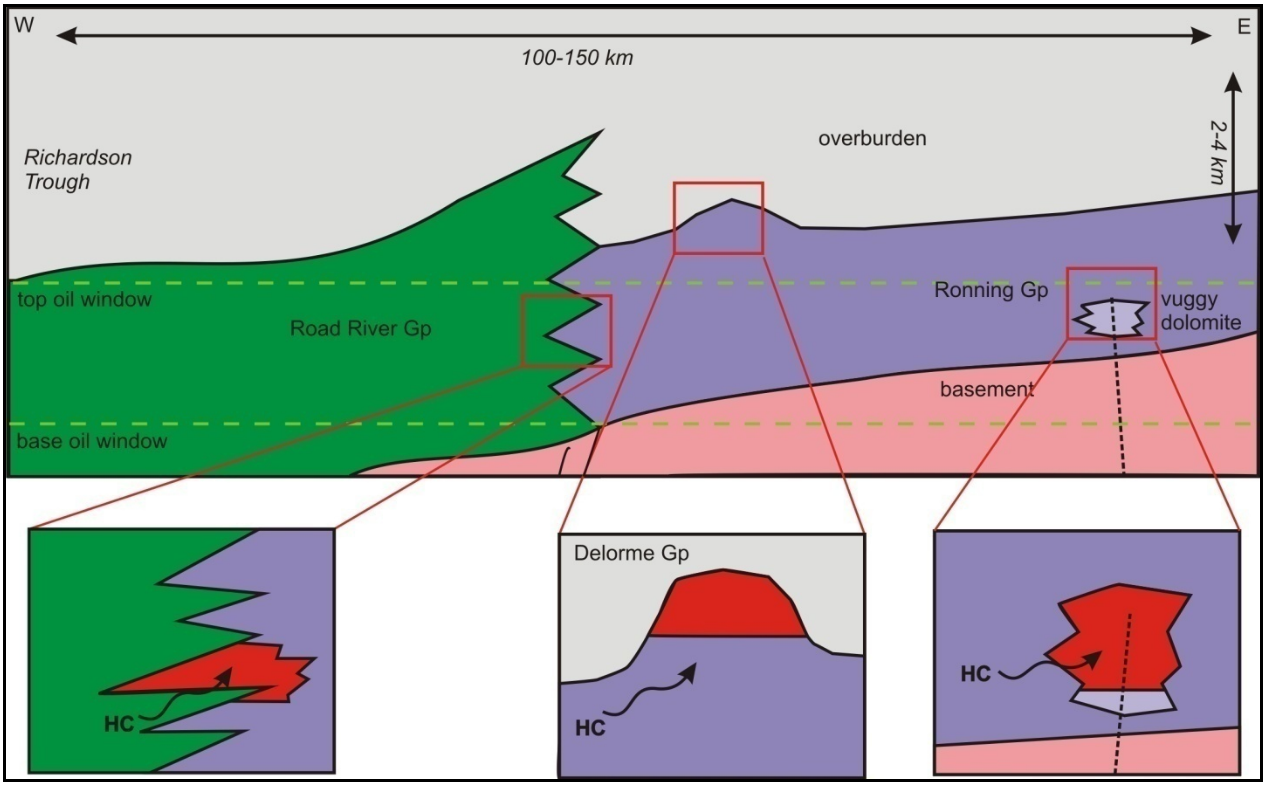

Figure 10.5.6. *Diagrammatic representation of Ronning/Road River groups in Peel area around the time of possible peak oil generation in Road River Group, in late Paleozoic time. The scales indicated are highly approximate. HC and wavy arrows indicate possible petroleum migration.*

Summary

The hypothetical Road River-Ronning petroleum system may have operated in the late Paleozoic when oil was generated in Road River Group. There is scant evidence that some oil, possibly from Road River Group, migrated into or through Franklin Mountain Formation. Stratigraphic traps at the shelf-basin transition seem to be rare, and tests have not been successful. Migration past the shelf edge and into Peel Plain is possible, particularly into porous sucrosic Arnica Formation dolostone. However, thick sequences of tight carbonates may have impeded migration.

Increased burial by post-Albian sediments probably resulted first in generation of dry gas in Road River Group, and later overmaturity. This gas may have flushed any oil that had been reservoired and remained preserved. The timing of late possible gas formation would have been more favourable with respect to Laramide structural traps at the front of the Richardson Mountains.

The lower Paleozoic platform play carries high exploration risk in Peel area. Any reservoired oil would have had to be preserved over very long and tectonically active time periods, in stratigraphic traps. Reservoired gas is perhaps more likely, but risk of poor reservoir, poor communication with source, inadequate trap, and failed preservation give this conceptual gas play relatively low potential in Peel area. Further compelling evidence is given in the number of negative tests of this stratigraphic interval through Peel Plain and Mackenzie Corridor (Osadetz et al., 2005). The McPherson B-25 well (Morris, 1972) was an example of a Ronning shelf-edge buildup test that was unsuccessful; there was some Ronning porosity but no indications of hydrocarbons.

As mentioned above, Road River source rocks could have also charged younger reservoir intervals. Brock et al. (1983) mention the Gossage (Arnica-Landry) platform edge to shale basin (Road River Group) transition as perhaps one of the most prospective zones of Peel area, given the biohermal buildups known in Arnica Formation, and further west in the Knorr Block. Such a system is not treated separately here, and the basic exploration risks would largely remain. In addition, Ronning Group reservoirs may hold petroleum sourced in the younger Horn River Group strata (Canol Formation, Bluefish Member). Thus, Ronning Group reservoirs may form an element of another petroleum system (section 10.5.4).

10.5.4 Kee Scarp and Arnica-Landry Platform Plays and Horn River-Ramparts Petroleum System

This petroleum system is described as known because there is good geochemical evidence in Peel area for a Devonian oil, found in Ramparts Formation limestone, that bears strong resemblance to Norman Wells oil (K.G. Osadetz, pers. comm., 2008) which is known to be sourced in Canol Formation (Snowdon et al., 1987). Canol Formation and Bluefish Member are considered the premiere source rock in Peel area. The two source rock units have been distinguished and geochemically linked with separate oils (Feinstein et al., 1988b), but they are treated together here. Both Canol Formation and Bluefish Member occur across a range of maturities through Peel area, including swaths that are presently in the oil window.

The name of this petroleum system is a simplification. In reality there are a range of possible reservoir rocks that could conceivably be charged by Horn River Group petroleum (we have direct evidence for this oil in Ramparts Formation and Imperial Formation), and it is not certain that Ramparts Formation contains (or contained) the major portion of any trapped petroleums. Ramparts Formation is used here to name the system because it is analogous to the system in place at Norman Wells.

Play Reviews and Play Maps

The Kee Scarp play can be considered conceptual in Peel area; however, it is established at Norman Wells, which provides an analogue. Gal (2005) extended the established Kee Scarp established play fairway northeast from Norman Wells almost to Peel area's southeast border; the suspended gas show at Carcajou D-05 underscores this. The conceptual Arnica-Landry play is considered here as well, as it is based on a Horn River Group source rock. The discovery in Mackenzie Plain at Summit Creek B-45 might prove to be an analogue for the Arnica-Landry platform play in Peel area.

Within Peel area, Bluefish Member of Hare Indian Formation, Canol Formation, and organic shale interbeds of the shale ramp facies of Ramparts Formation, are the premiere source rocks (Figure 10.5.7, Gal et al., 2007). They are grouped here with the designation Horn River Group

(Pugh, 1983, Morrow, 1999; Chapter 6, this volume), and are rich, viable petroleum sources widespread across Peel area (particularly Canol Formation).

Maturity of these strata range from immature in the northeast to overmature and post-mature in the west and southwest. There is a northwest-trending swath of Canol Formation across Peel area that is currently in the oil window, and a corresponding but narrower zone for Bluefish Member (Figure 10.5.8). For the most part, the source rocks are oil-prone.

Ramparts Formation occurs in outcrop along the eastern edge of Peel area and as far west in the subsurface as 132°W longitude (Pugh, 1983). Reefal Kee Scarp member is restricted to southeast Peel area (Williams, 1985). Porosity is variable, but at Norman Wells, much of the porosity is microscopic and diagenetic (Al-Aasm and Azmy, 1996). If similar conditions existed at Peel area, then these porous rocks may not have been recognized in the field, and thus were under-sampled in the current study. Several shows are known from Peel area (Chapter 6, this volume; Figure 10.5.9).

Arnica Formation has far more potential than Landry Formation as a reservoir rock (Gal, 2008), although oil and gas shows have been found in Peel Formation within both formations (Chapter 6, this volume).

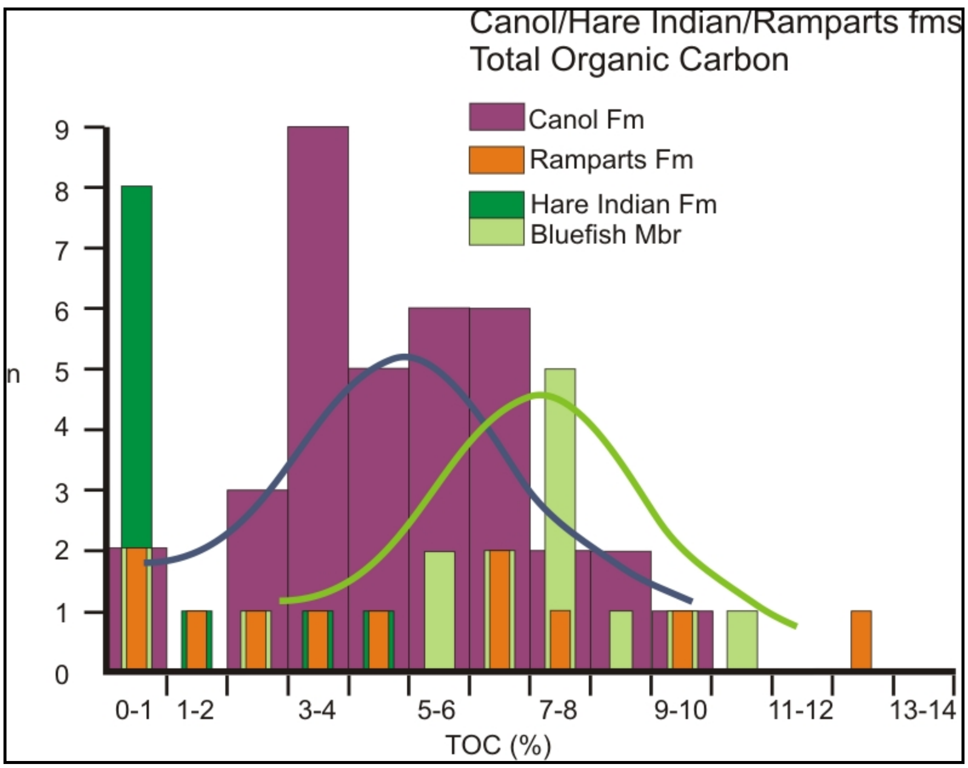

Figure 10.5.7. *Histogram of % TOC values from samples collected during this study from Canol, Ramparts, and Hare Indian formations (Horn River Group). Schematic distribution curves are indicated for Canol Formation data (in purple) and Bluefish Member (green) suggesting that average TOC values of Bluefish Member samples are higher than Canol Formation. Note also that some Ramparts Formation samples (e.g., Carcajou member, shale ramp facies) have very high TOC values.*

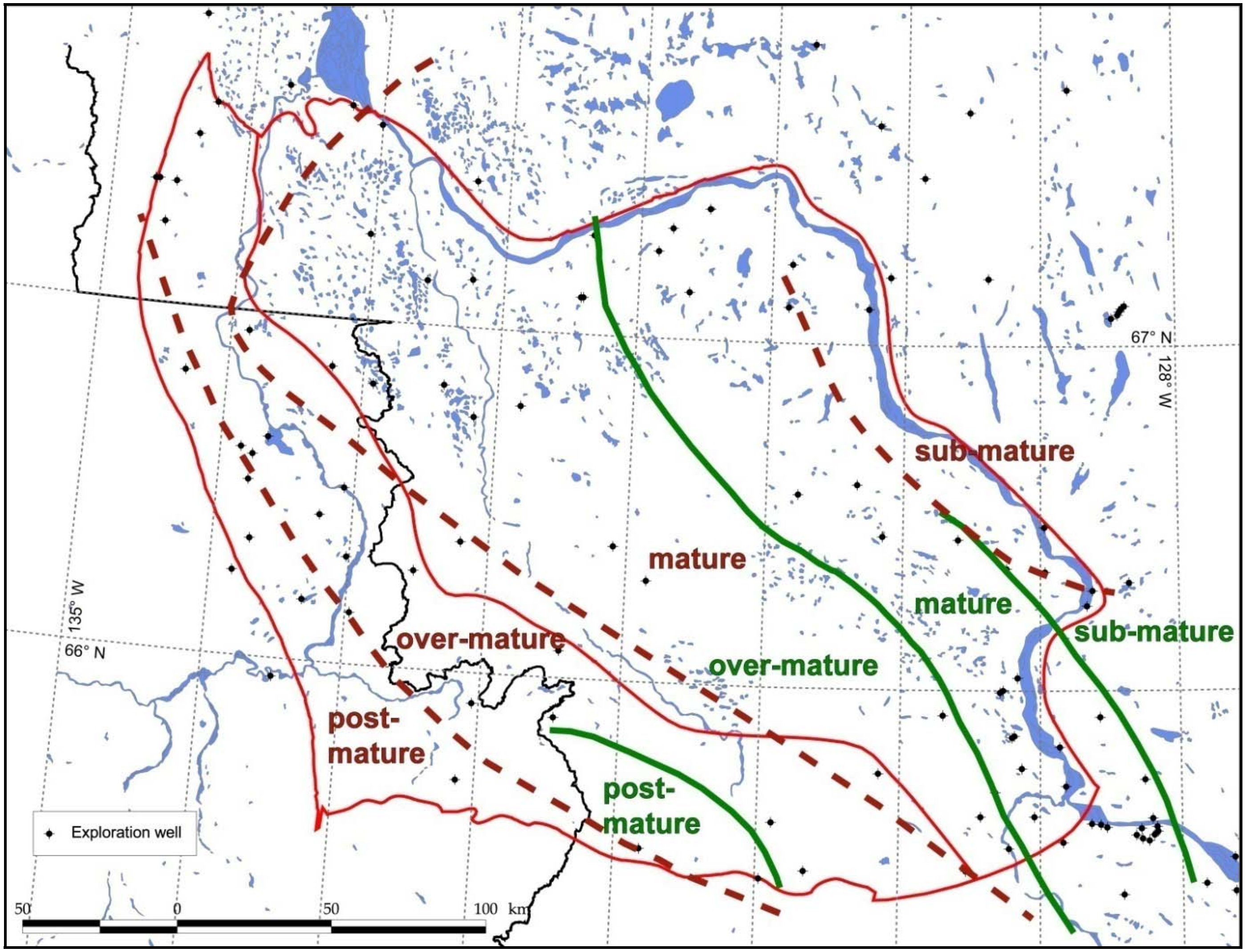

Figure 10.5.8. *Map of Peel area showing zones of source rock maturity for Canol Formation (brown dashed lines) and Hare Indian Formation (generally Bluefish Member, green solid lines). Mature rocks are within the oil window, over-mature are gas generating, and post-mature are beyond dry gas generation. Zones are drawn based on a range of published and unpublished Rock-Eval and vitrinite reflectance data from outcrop and subsurface. Data sources include: Stasiuk and Fowler (2002), Stasiuk et al. (2002), Pyle et al. (2006), Gal et al. (2007), Allen and Fraser (2007), Allen et al. (2008b).*

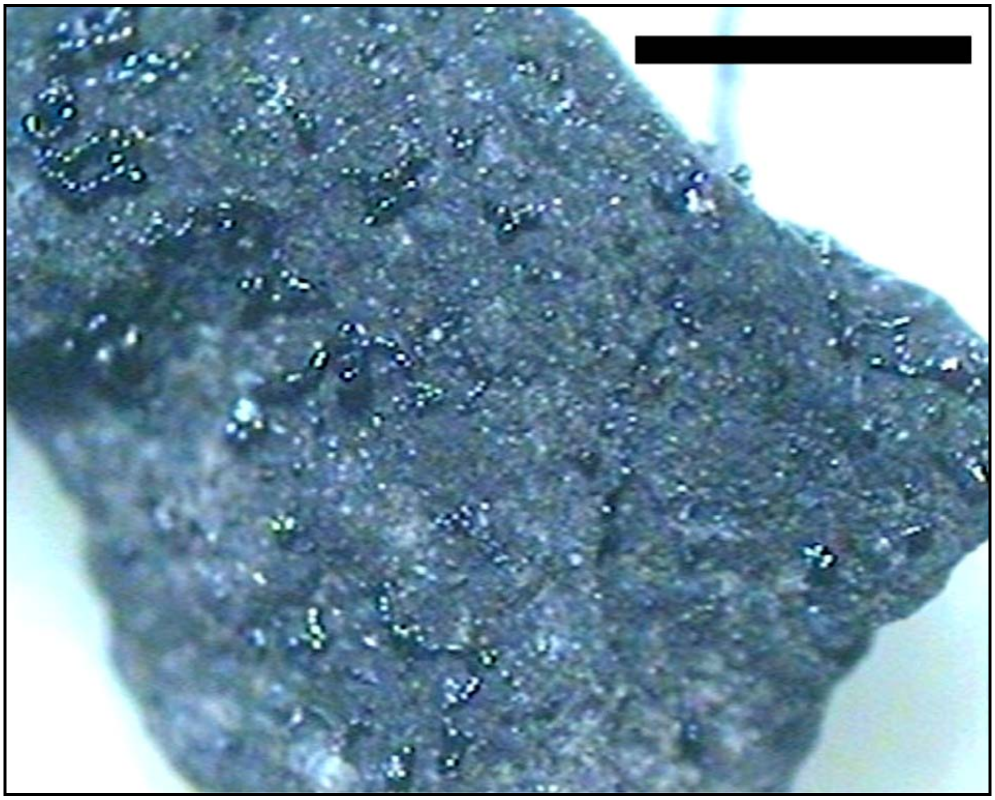

Figure 10.5.9. *Well cuttings chip from Hume River D-53 well at 335 m depth, Ramparts Formation (1110-1120 ft sample). Note oil staining and beads of live oil. Black scale bar is 1 mm.*

Kee Scarp member of Ramparts Formation is largely a stratigraphic play, and has been the focus of exploration in Ramparts Formation. Other possible stratigraphic trapping geometries in Ramparts Formation include Kee Scarp reefal margins, reefal foreslopes, Charrue sandstone member on the flanks of the reefal buildup, and siltstone lenses within Hare Indian Formation (e.g., Devlan Exploration Inc., in Lariviere and Gal, 2005).

Play maps are shown in Figures 10.5.10 and 10.5.11. The Ramparts play area covers eastern Peel area, with the reefal Kee Scarp member in the southeast (Williams, 1985). The areas of mature Canol Formation, and mature to overmature Ramparts Formation are indicated. In places Kee Scarp member is overlain by Cretaceous strata and/or Imperial Formation, which will negatively affect top seals (Figure 10.5.10). The lowest-risked part of the Kee Scarp stratigraphic play in Peel area, where reefal rocks are overlain by Canol Formation seal, is a rather restricted area. This area has had five exploration wells, only one of which (Mountain River O-18) tested the Ramparts Formation (DST recovered mud, no gas to surface).

The Arnica-Landry platform play area is shown in Figure 10.5.11. While the play area, based on the extent of possible reservoir rock, is essentially throughout Peel area, it is felt that the lowest-risked area of the play is within the zone of Canol Formation maturity, and in relative proximity to the fronts of the Franklin and Mackenzie mountains (Gal, 2008). This is because structural juxtaposition of Horn River Group shale with Arnica (or Landry) reservoirs probably represents the best potential for an accumulation, and is the basis for including this play as an element of a Horn River petroleum system.

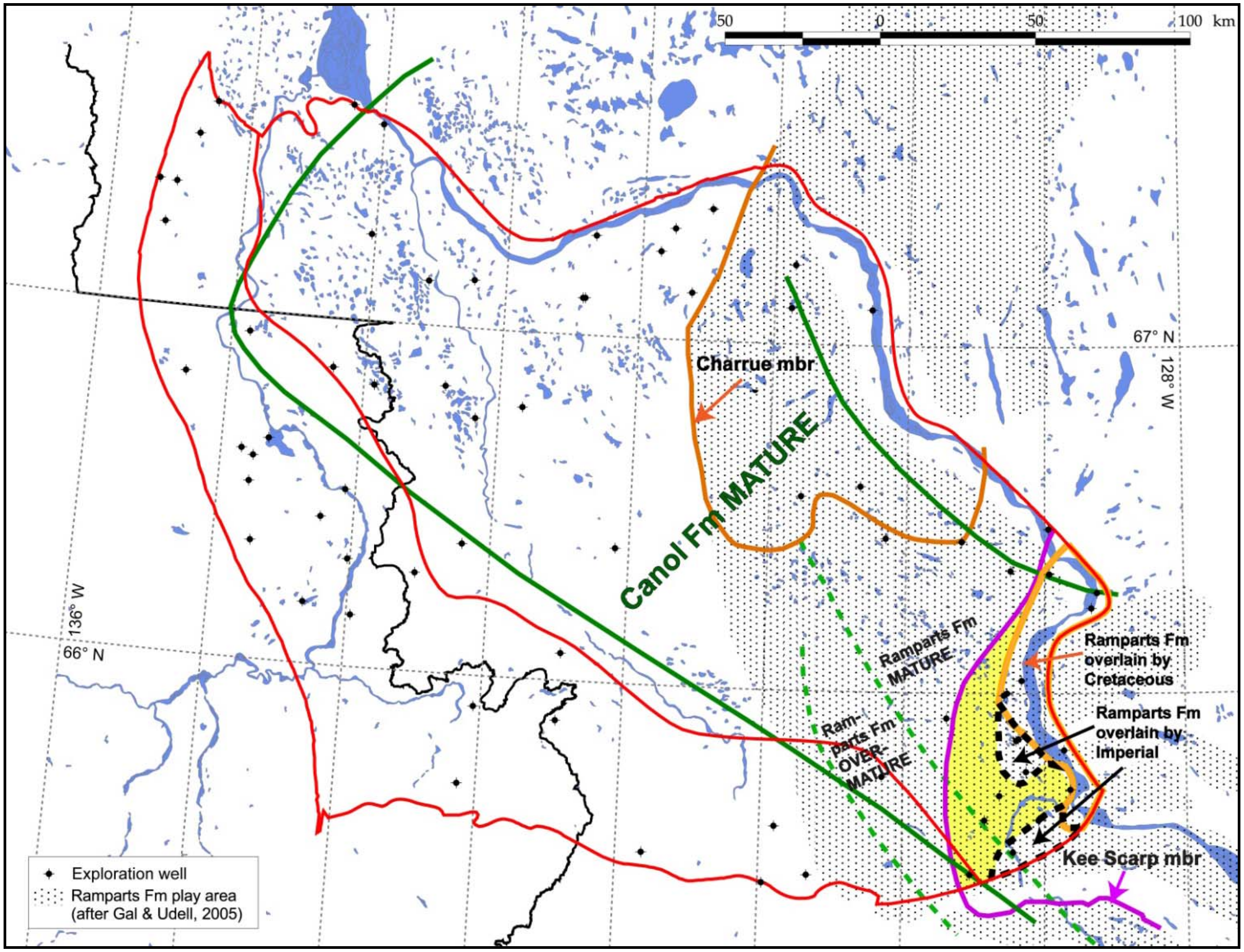

Figure 10.5.10. *Kee Scarp play map. The Ramparts play area (stippled region; Gal and Udell, 2005) covers eastern Peel area. The extent of Charrue member in northeast Peel area and Kee Scarp member (after Williams, 1985) in southwest are indicated by coloured lines. Areas where Ramparts Formation is overlain by Cretaceous strata and/or Imperial Formation will negatively affect top seals. The areas of mature Canol Formation, and mature to overmature Ramparts Formation are also indicated. The yellow shaded area represents likely the lowest-risked part of the Kee Scarp play in Peel area.*

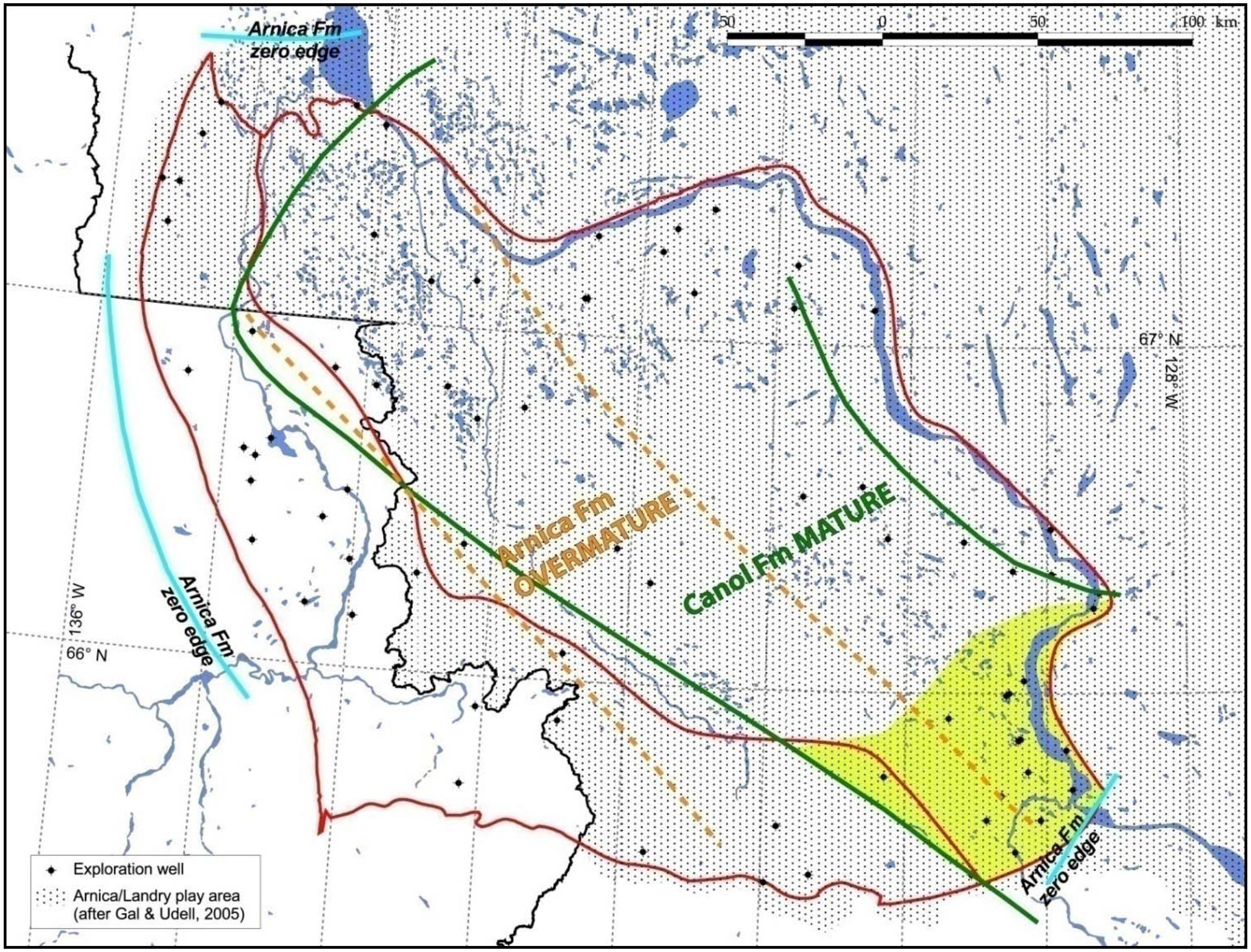

Figure 10.5.11. *Arnica-Landry play map. The play area (stippled region in NWT; Gal and Udell, 2005) extends across Peel area to the western platform edge (labeled Arnica Fm zero edge; play area is unstippled in Yukon). The Arnica Formation zero edge in southeast Peel area is a depositional limit at the gradational facies change with Fort Norman Formation. Zones of Canol Formation maturity and Arnica Formation overmaturity (dry gas zone) are shown by coloured lines. The yellow shaded area represents possibly the best part of the play; within the Canol Formation oil window, and adjacent to the structural zones of the Franklin and Mackenzie mountains.*

Burial History, Generation, and Migration of Horn River Group Petroleum

Based on modeled depth versus maturity data for Hume River L-09 well in eastern Peel area, Horn River Group entered the middle oil window soon after deposition of Albian and younger foreland trough sediments (Figure 10.4.6). Expulsion and migration of Horn River-sourced oil, possibly as late as Eocene, would post-date the earliest Laramide structural traps. This has important ramifications for the potential of structural traps in Peel area. Brock et al. (1983) proposed that the earliest petroleum generation from middle Devonian (but presumably including Late Devonian Canol Formation) in the Norman Wells area was at about 100 Ma, which is in general agreement with our findings.

In western Peel area; maturation, expulsion, and migration may have occurred somewhat earlier, with Canol Formation entering the oil window after burial by a thick package of Imperial and Tuttle formations (Figures 10.4.7, 10.4.8). Initial oil was followed by dry gas generation, perhaps with burial by Cretaceous sediments after an early to middle Mesozoic depositional hiatus. Thus the Kee Scarp play, because it is essentially restricted to eastern Peel area, is for oil and associated gas, while other reservoirs charged by Horn River Group in western and central Peel may be gas targets.

Oil staining in rocks from Mount Kindle Formation through Devonian strata is known in southeastern Peel area. As discussed above, these oil stains have geochemical affinities to an upper Devonian marine source (likely Horn River Group). Possible reservoirs to accept Horn River petroleum charges range through the stratigraphic column, from Franklin Mountain Formation to Martin House Formation, particularly where structural traps are favoured (Chapters 4 through 8, this volume).

Unconventional Petroleum Potential

An aspect of Peel area petroleum geology, and the Horn River-Ramparts petroleum system in particular, despite being beyond the scope of this study, is the unconventional petroleum potential of Horn River Group, particularly Canol Formation and to a lesser extent, Bluefish Member. As mentioned above, Canol Formation at outcrop and shallow subcrop along the eastern margin of Peel area is largely immature to low maturity, and while TOC values are not extremely high (averaging 4.85% TOC in samples collected for this study), there may be some potential for this unit as an oil shale.

Perhaps more importantly, Canol Formation may be a viable shale gas reservoir in subsurface locations. The lithology of the unit (siliceous and cherty) and its tendency to be highly fractured in outcrop (Figures 59, 60, 91 in Chapter 6, this volume), may be positive factors in considering shale gas potential. It is also widespread throughout the area, with typically consistent TOC values throughout its extent. The gas show (manifested as a blowout) at Tree River H-38 in north Peel area was likely from Canol Formation.

Petroleum System Events

Figure 10.5.12 (events chart) shows a source rock of Middle to Upper Devonian age (Horn River Group). There is high confidence attached to the source rock because there are Peel area oil stains that have affinities to Norman Wells oil (K.G. Osadetz, pers. comm., 2008), which has been linked geochemically to a Canol Formation source rock (Snowdon et al., 1987). The Ramparts Formation reservoir is spatially associated with the source rocks, although less confidence is assigned because the porosity distribution and processes are not well understood; most outcrop exposures of Ramparts Formation, while oil stained, appear tight. The trap indicated here is stratigraphic, although structural trapping possibilities have been mentioned. According to the burial history diagrams, Canol Formation reached maturity in the oil window, under burial by Albian and younger siliciclastics.

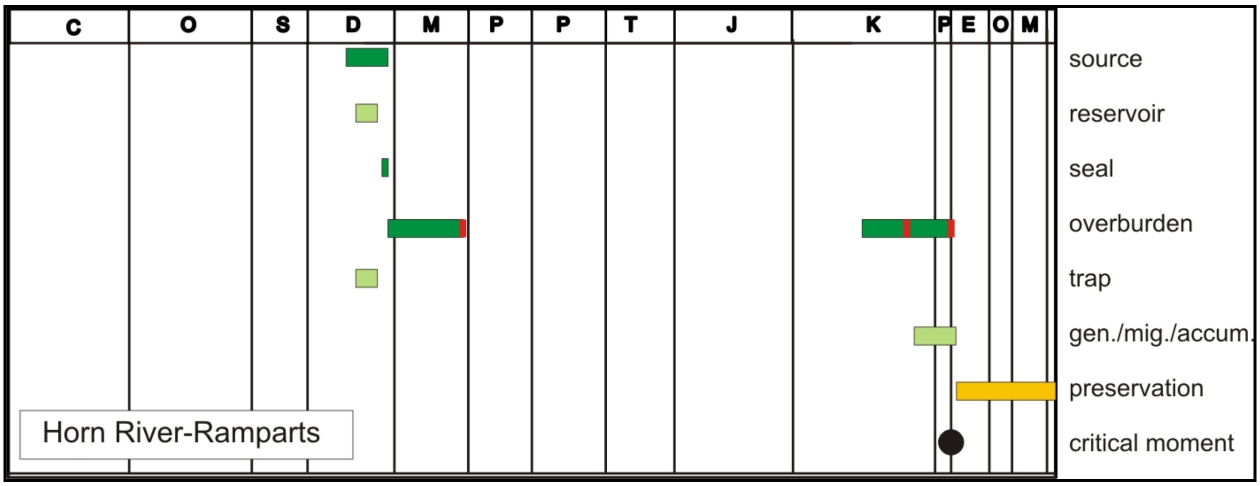

***Figure 10.5.12.** Simplified and theoretical events chart for Horn River/Ramparts petroleum system. The **trap** row indicates stratigraphic traps mainly associated with the Kee Scarp reefal member, although later structural traps are possible. The bar for generation-migration-accumulation (**gen./mig./accum.**) shows that oil generation likely started in the late Cretaceous to early Tertiary. Thus the **critical moment** for this system (black dot) is placed in the early Tertiary, at the beginning of the preservation period.*

Critical Moment

The critical moment in the events chart (Figure 10.5.12) is placed in the early Tertiary, once the peak oil (and possibly gas) had been generated. This possibly occurred after Laramide traps had formed, so Horn River petroleum may well have migrated into older (and younger potential reservoirs).

As mentioned previously, the critical moment in western Peel area may have occurred in the latest Paleozoic, when oil was generated in Canol Formation after burial by Imperial and Tuttle formations. It is not known to what extent Canol Formation produced petroleum at this time, relative to later burial by Albian and younger siliciclastics which moved Canol Formation into the dry gas window, and eventually overmaturity in Peel Plateau.

Figure 10.5.13 depicts a schematic section across Ramparts Formation in southeastern Peel area at the time of peak petroleum generation in Horn River Group. Stratigraphic traps are indicated in the Kee Scarp member reef margins and foreslopes, the Charrue sandstone, and a siltstone lens in Hare Indian Formation. Petroleum generation and migration from Canol Formation, Bluefish Member, and shale ramp of Ramparts Formation are indicated.

Figure 10.5.14 is a schematic cross section across the Mackenzie Mountain front at the critical moment for a Horn River-Arnica system. A Laramide thrust-faulted anticline is shown, juxtaposing Arnica and/or Landry formations in the hanging wall with footwall Horn River Group active source rocks. The inset box schematically shows possible occurrences of porosity within Arnica Formation in an anticlinal trap, including fracture porosity and sucrosic dolostone. Note that Bear Rock-type solution collapse breccias are also shown, although a large part of the breccia formation may have occurred recently, post-dating migration of petroleum (Morrow, 1991). However, oil stained Bear Rock breccias at Powell Creek, Loretta Canyon (Imperial River), and to the southeast at Little Bear River, possibly attest to the presence of at least some breccias pre-dating petroleum migration.

The critical moment in eastern Peel area was followed by a period of preservation, which would have had to persist through uplift and erosion of Cretaceous (and likely Tertiary) strata, to the present day. It is these periods of uplift and erosion, coupled with the relatively shallow depth of Ramparts Formation in southeast Peel area, that pose play level risks of trap breaching and failure.

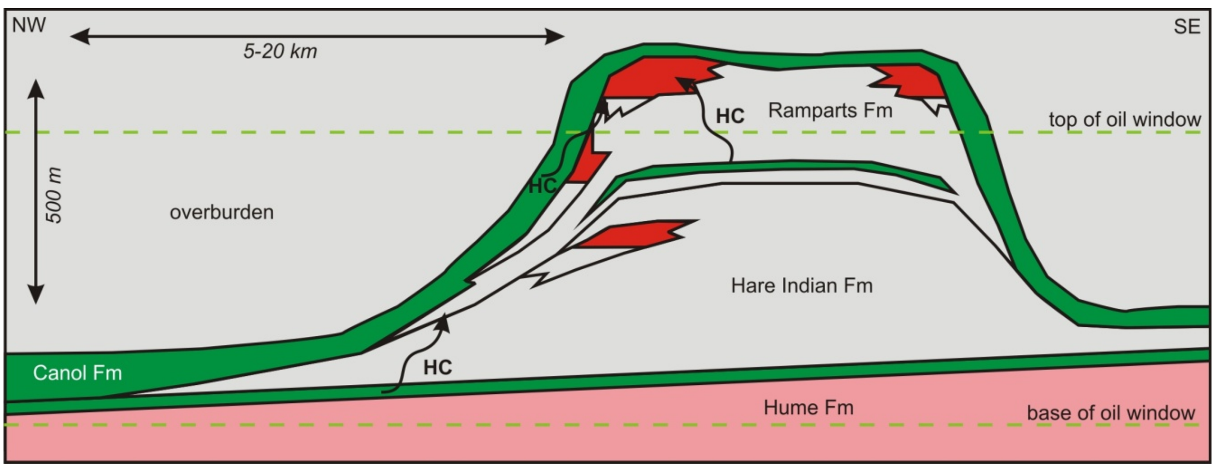

Figure 10.5.13. *Diagrammatic representation of Horn River Group around the time of peak hydrocarbon generation in Canol Formation. Scales indicated are highly approximate. Possible source rocks in green; possible stratigraphic traps in red include Kee Scarp reefal margins, reefal foreslopes, Charrue sandstone, and Hare Indian Formation siltstone lens. The "HC" and wavy arrows indicate possible hydrocarbon migration.*

Summary

There is strong evidence for considerable oil and/or gas generating potential by Horn River Group rocks. There are oil stains in Arnica, Fort Norman, Hume, Ramparts, and Imperial formations that can reasonably be associated with Horn River Group source rocks. Thus we can be confident of a Horn River-Ramparts petroleum system that operated in eastern/southeastern Peel area. The possibility of other reservoir rocks, involved in structural traps and receiving a charge of Horn River petroleum, is quite good; therefore, a Horn River-Arnica petroleum system can also be proposed.

Nevertheless, there are significant exploration risks, mainly at the prospect level, most of which were reviewed in preceding chapters. Chief among these is the risk of failed preservation, due to post-Albian (Chapter 9, this volume) and post-Tertiary erosion as well as recent erosion, any or all of which may have caused breaching of reservoirs, failure of top seals due to shallow overburden and proximity to outcrop (Hannigan et al., 2006) and Laramide-induced fracturing, biodegradation of accumulations, incursion of meteoric waters, etc. For the Kee Scarp play, there is additional significant risk of insufficient reservoir development (not fully evaluated in the current study) and thus poor stratigraphic trapping. Laramide tectonic tilting may have negatively affected stratigraphic traps that had only poorly developed lateral seals. The Kee Scarp play within Peel area is given moderate potential, albeit in a relatively restricted area (Figure 10.5.10). Note that almost all, if not all Ramparts tests in southeastern Peel have been negative (wet, poor permeability, etc), although there is the possibility that some of these tests have not been conclusive or could have been done on more prospective intervals, based on well logs (e.g., Gal, 2005).

Structural traps, including potential reservoirs such as Arnica/Landry platform, may hold more promise. There is significant risk at the prospect level of adequate reservoir. A number of the large structures have been tested already (e.g., Hume River L-09) with no apparent porosity in Arnica or Landry formations, or Bear Rock breccia. Again, there are prospect-level risks of failed preservation due to uplift, erosion, and breaching. However, the possibility of increased preservation potential for older reservoir strata at lower stratigraphic and structural levels, may be a positive factor.

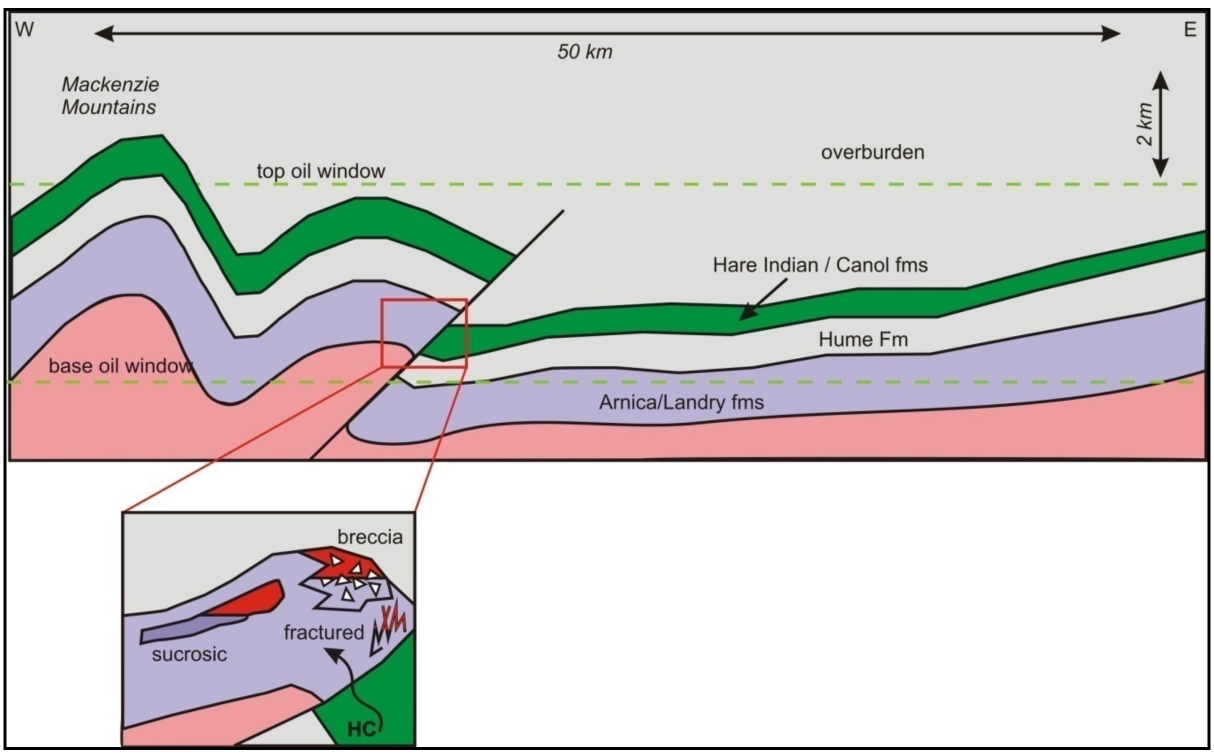

Figure 10.5.14. *Diagrammatic representation of Hare Indian/Canol formations (Horn River Group) and Arnica/Landry formations in Peel area around the time of Laramide trap formation and hydrocarbon generation in Horn River Group. Scales indicated are highly approximate. Inset box, outlined in red, shows possible reservoir or porosity types in an anticlinal trap, including sucrosic dolomite, porous breccia, and fracture porosity. The "HC" and wavy arrows indicate possible hydrocarbon migration.*

10.5.5 Imperial and Tuttle Plays, Tuttle-Tuttle and Imperial-Imperial Petroleum Systems

The Tuttle-Tuttle petroleum system is considered hypothetical because there is new geochemical evidence for source rock potential in the Tuttle Formation-Ford Lake Shale succession. There is also new evidence from analyses of oil stained Tuttle and Imperial formations and Ford Lake Shale that suggests an Upper Paleozoic marine source rock; which may be as old as Horn River Group, but could be from Tuttle/Ford Lake sources (Allen et al., 2008a; Chapter 8, this volume). In addition, there are gas shows from Tuttle Formation sandstones in exploration wells; these sandstones are interstratified with potential source rock shale.

The Imperial-Imperial petroleum system is considered hypothetical because minor gas shows are known to possibly occur in Imperial Formation in three Yukon wells (Satah River Y.T. G-72, Peel Y.T. L-19, Peel Y.T. F-37) and inferred to occur from well logs in Ramparts F-46 (Morrell, 1995), Hume River I-66, and Maida Creek O-65 (Gal, 2005). These Imperial shows (possible and inferred) occur within sand beds that are interstratified with shale that show some geochemical evidence of modest source rock potential. Oil stains in Imperial Formation in southeastern Peel area have been geochemically linked to Cambrian-Ordovician source and a Devonian source (likely Horn River Group) so this is not considered evidence for a Imperial-Imperial petroleum system. Likewise, a sample of oil stained Imperial Formation from western Peel was geochemically linked to an Upper Paleozoic marine source rock (Allen et al., 2008a), which does not preclude Imperial Formation as the source rock.

The two systems are grouped together for the purposes of this discussion because of the gross similarity of the potential source rocks respect to age, depositional environments, potential trapping styles, and to some extent, potential reservoir rocks. Each formation can be considered a self contained petroleum system, hence the name Tuttle-Tuttle, for example. However it is recognized that the contact between formations in the field is gradual (Chapter 8, this volume) and it might be expected that potential Imperial Formation-sourced petroleum may migrate into Tuttle reservoirs, and vice versa.

Play Reviews and Plays Map

Within each formation there are significant volumes of potential source rocks of modest quality. These are likely to be dominantly gas-prone source rocks except for Ford Lake Shale which has mainly Type II kerogen (Chapters 7 and 8, this volume). Tuttle Formation shale typically has values between 1% and 2% TOC, and Ford Lake Shale averages 4.63% TOC (Chapter 8, this volume). Imperial Formation averages just under 2% TOC (Chapter 7, this volume). Imperial Formation ranges from mature in eastern Peel to overmature in central and western Peel area. Tuttle Formation is within the oil window through much of Peel Plateau, with maturity increasing westward toward the Richardson Mountains. Increasing maturity with depth, based on Tmax values is seen in several well (Allen et al., 2008b). Ford Lake Shale is mature, to just within the oil window.

Imperial Formation sandstones are very fine-grained to rarely medium-grained, with porosities as high as 24.7%, generally 11% to 19%, and very low permeabilities. They can be characterized as tight, for the most part. Tuttle Formation sandstones are fine- to coarse-grained, grading up to granule and pebble conglomerates. Porosities and permeabilities occur through a range (generally 5% to 26% porosity and 0.1 mD to 100 mD permeability), and the better reservoir properties are a function more of increased chert than grain size (Chapter 8, this volume).

Potential traps in both units may be stratigraphic sandstone bodies, sealed in shale, with or without a structural component.

A play map (Figure 10.5.15) illustrates the extent of the plays, based on the distribution of each formation, with allowances for the reduction of play boundaries at subcrop edges, particularly Imperial Formation which thins to a feather edge in northeast Peel area under the pre-Cretaceous unconformity. Also shown are the zones of mature Imperial and Tuttle strata; maturation in each case increases to the south and west. It is not possible to ascertain any fairways within the play areas, although structural traps would be expected adjacent to the Richardson, Mackenzie, and to a lesser extent, the Franklin Mountains. However, Osadetz et al. (2005) regarded the Peel Plateau west of Trevor Fault to have less potential than the area to the east, including the Yukon portion of Peel Plain. This fault essentially forms the western boundary of the Tuttle play area illustrated in Figure 10.5.15.

Burial History, Generation, and Migration of Imperial and/or Tuttle Petroleum

From the burial history diagram for the Satah River Y.T. G-72 (Figure 10.4.7), Imperial Formation entered the upper oil window in Late Paleozoic time, and Tuttle Formation in early Late Cretaceous time. Between these times there was a period of uplift and erosion (in this instance modeled as Tuttle Formation alone, but in other areas, Tuttle plus Imperial). It is likely that most of the petroleum (gas and possibly some oil) was generated under burial by the Cretaceous foreland trough siliciclastics. This would almost certainly be the case in eastern Peel area, where perhaps the Tuttle Formation was not deposited as thickly.

Structures may have formed along the Richardson Mountain front in western Peel area or along the Mackenzie and Franklin mountain fronts that pre-dated late Cretaceous and Tertiary migration of hydrocarbons; this is an important implication for exploration in structural traps. A proposed events chart is presented in Figure 10.5.16.

An aspect of an Imperial-Imperial petroleum system that is not explicitly addressed here is the potential for unconventional “tight” gas. Imperial Formation is widely distributed through central and western Peel area, attains considerable thickness through much of Mackenzie-Peel shelf, and generally comprises tight sandstone beds within siltstone and shale with moderate source rock potential.

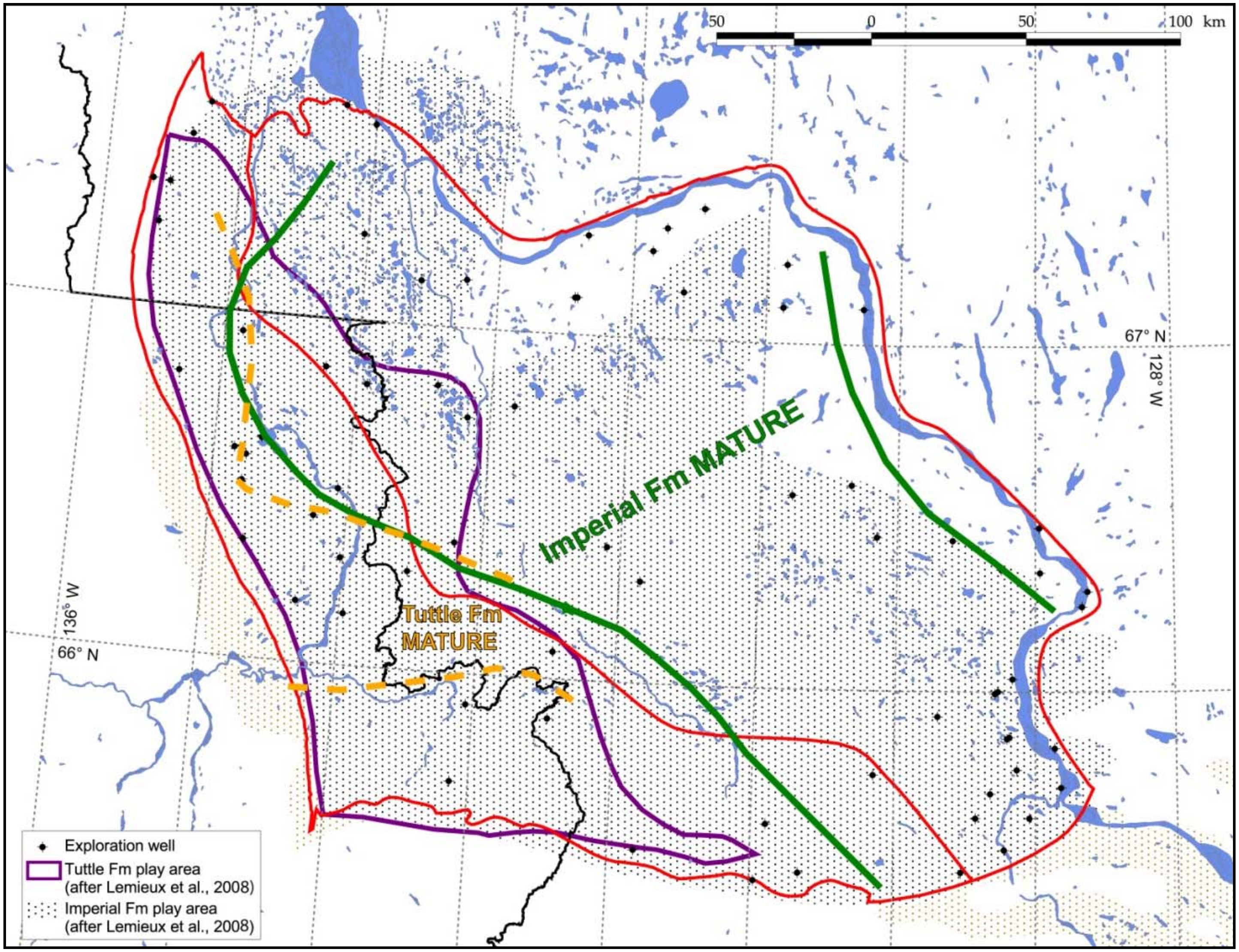

Figure 10.5.15. *Imperial and Tuttle plays map. The Imperial play area (stippled region; after Lemieux et al., 2008) covers much of Peel area. The Tuttle play (purple outline; after Lemieux et al., 2008) is largely restricted to Peel Plateau and Yukon. Zones of Imperial and Tuttle formation maturity (within oil window) are labeled and indicated with solid green, and dashed orange lines, respectively.*

Petroleum System Events

Figure 10.5.16 (events chart) represents Imperial and Tuttle formations together as a Devonian-Mississippian source rock, reservoir rock, seal, and (stratigraphic) trap. There is a long hiatus when some Imperial Formation source rock may have generated hydrocarbons. There is a pre-Cretaceous unconformity which eroded large amounts of Imperial and Tuttle formations, possibly breaching early formed petroleum accumulations. The major period of generation, migration and accumulation occurred in Albian and later times, up into the Tertiary. The post-Cretaceous unconformity, which in Peel area likely involved great amounts of uplift and erosion, has major implications for preservation of any petroleum reservoired in Imperial and/or Tuttle formation stratigraphic and/or structural traps. In places it is likely that most or all of the Cretaceous (and Tertiary) strata that was deposited was eroded away; erosion probably continued into the upper Paleozoic rocks, which are now at subcrop through much of western and central Peel area, or underlying only a thin Cretaceous veneer.

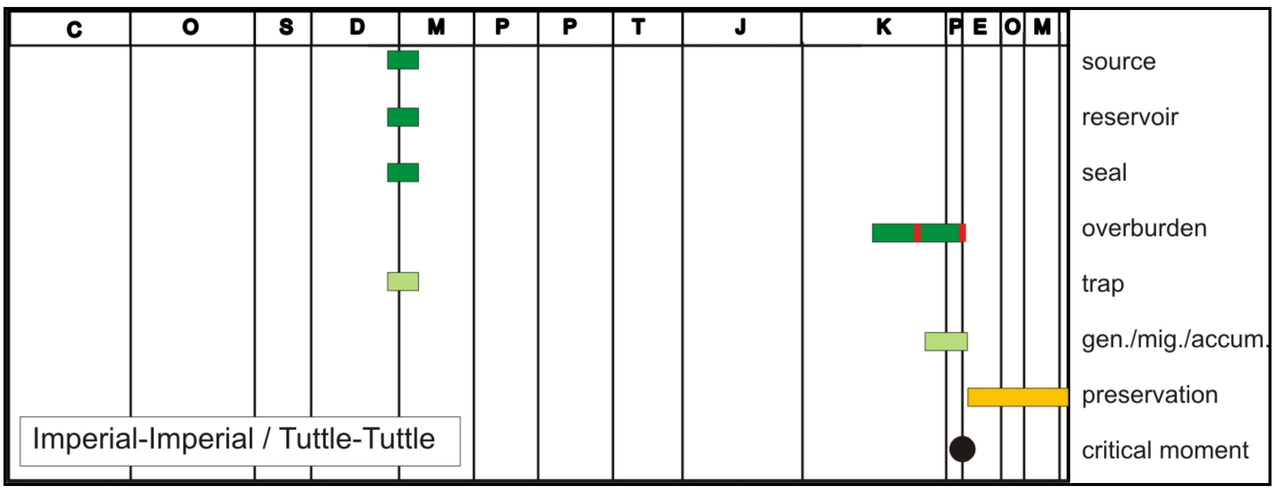

Figure 10.5.16. *Simplified and theoretical events chart for Imperial-Imperial and Tuttle-Tuttle petroleum systems. The **trap** row indicates stratigraphic traps in Imperial and Tuttle formations, although structural traps are also possible. The bars for generation-migration-accumulation (**gen./mig./accum.**) shows that Imperial Formation gas generation in western Peel area started in the Late Paleozoic, while in eastern Peel area it likely started in the Late Cretaceous to Early Tertiary. Thus the **critical moment** for these systems (black dot) is placed in the early Tertiary, at the end of the petroleum generation.*

Critical Moment

Figure 10.5.17 is a schematic cartoon across the front of the Richardson (or Mackenzie) mountains into Peel Plateau and Plain, drawn to depict the time of petroleum generation and migration in Tuttle Formation (i.e., post-Albian to Tertiary). For simplicity, Imperial and Tuttle formations are shown as facies equivalents that grade into one another. Laramide structures have formed, and intraformational porous sandstone bodies can receive a petroleum charge in structured traps, or in stratigraphic traps outboard of the mountain front. Note that the unconformity related traps (both structured and stratigraphic) are problematic because of the poor sealing characteristics of the basal Cretaceous Martin House Formation, which is widely distributed (Chapter 9, this volume).

Summary

The Tuttle-Tuttle petroleum system possibly was in operation in western Peel area, generating petroleum after largely gas-prone source rocks were buried under a thick pile of Albian and younger siliciclastic rocks in a foreland trough. However, oil stained samples (Chapter 8, this volume) of Tuttle Formation and Ford Lake Shale are likely sourced in the Late Paleozoic (Canol, Imperial, Tuttle, Ford Lake formations, or M0 unit). This indicates the possibility of oil in the Tuttle-Tuttle petroleum system, where previously only gas had been considered (e.g., Osadetz et al., 2005).

An Imperial-Imperial petroleum system possibly also operated, perhaps generating petroleum (probably gas) as early as late Paleozoic, under burial by the formation itself and overlying Tuttle Formation. In both cases, however, it is probable that the peak petroleum generation and migration occurred in the late Cretaceous to Tertiary.

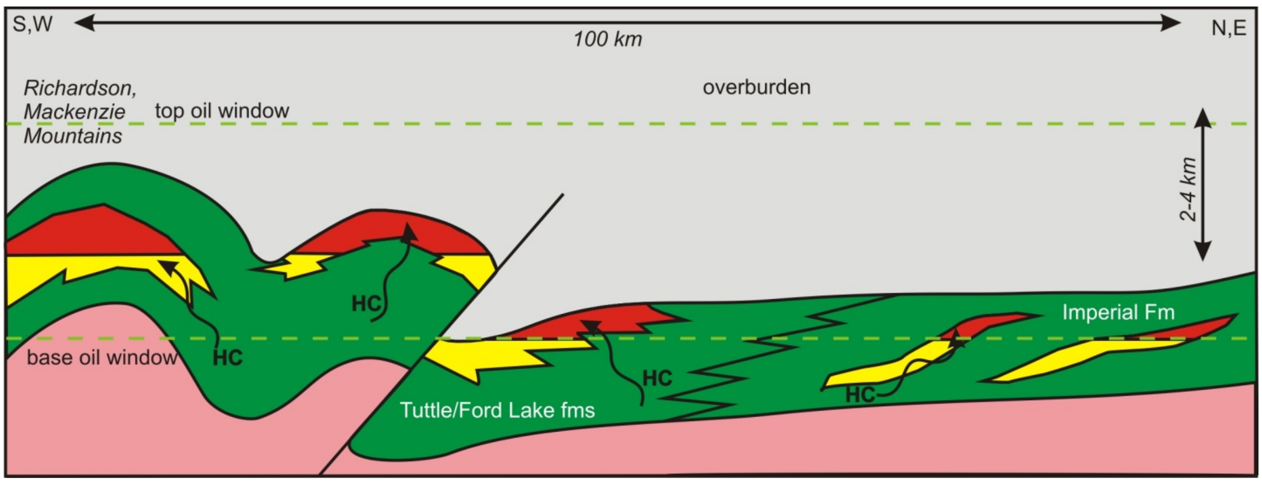

Figure 10.5.17. *Diagrammatic representation of Imperial and Tuttle formations around the time of peak hydrocarbon generation in Tuttle Formation and Ford Lake Shale. Imperial and Tuttle/Ford Lake formations are shown simplistically as facies equivalents. Scales indicated are highly approximate. Structural traps in Tuttle sandstone bodies, associated with Richardson and Mackenzie mountains structures, are shown at the left. Stratigraphic traps in intra-formational sand bodies are shown at centre and right side of cartoon. The "HC" and wavy arrows indicate possible hydrocarbon migration.*

Laramide structures thus had opportunity to form prior to petroleum migration, and there are possibilities for structural traps; some of these have been tested. Peel Y.T. B-06 and B-06A tested small volumes of gas from structured Tuttle Formation, essentially confirming the presence of this structural play (Osadetz et al., 2005), likely in the Tuttle-Tuttle system. This play has not been fully explored west of Trevor Fault (Osadetz et al., 2005). East of Trevor Fault there are likely to be opportunities. For example, Lemieux et al. (2008) identify Tuttle Formation involved in a large structure in South Peel D-64 well, where no DSTs were performed.

There have been six gas shows from DSTs in Tuttle Formation in Peel Plateau. These shows occur in a relatively restricted and stratigraphically (although not structurally) coherent area.

Play-level risks associated with the Tuttle play generally have to do with preservation of accumulations, given the shallowness of potential reservoir rocks through Peel area, and the effects of pre- and post-Cretaceous erosion (including the relatively thin strata along the subcrop edge; Hannigan et al., 2006; Pyle et al., 2008). Osadetz et al. (2005) regarded Upper Paleozoic Clastics plays (Tuttle and Imperial plays of this study) in Peel Plateau and Plain as second only to the Mesozoic clastics as the most promising play in Yukon portion of Peel area. This favourable assessment can be considered to extend through the remainder of Peel Plateau, at least where reasonably thick Tuttle Formation and/or overlying Cretaceous strata remain.

The Imperial-Imperial petroleum system, if present, was perhaps somewhat less effective than the Tuttle system; information that we have about the constituent elements is generally less favourable. There are less definite Imperial Formation DST shows than from Tuttle, although based on well logs, a few untested intervals in wells from eastern Peel area were inferred to hold gas (e.g., Morrell, 1995). Generally, the best possible Imperial Formation reservoirs are located in the east, at or near subcrop, while the best source rocks lie to the west, where possible reservoirs have negligible porosity (Zantvoort, 2007; Chapter 7, this volume). Play level risks, as with Tuttle Formation, especially in central and eastern Peel area, concern preservation of accumulations due to shallowness of outcrop and feather-edge subcropping under thin or absent Cretaceous strata (generally with a porous basal sandstone where it does occur). In addition, adequate reservoir is a play level risk as the sandstones are generally tight. At the prospect level, risks for an Imperial play involve adequate reservoir, trap closure, seal, and preservation (as with Tuttle Formation).

The Tuttle play is here considered to have moderate potential in western Peel Plateau, and Imperial play low to moderate potential throughout much of Peel area.

10.5.6 Basal Cretaceous Clastics Play and Arctic Red-Martin House Petroleum System

The Arctic Red-Martin House petroleum system is considered known because geochemical analysis of oil stains in a Cretaceous sample from Yukon linked the oil to a Cretaceous source (Allen et al., 2008b). The system name is an oversimplification; Cenomanian-Turonian Slater River Formation is a likely source rock along with Albian Arctic Red Formation (Chapter 9, this volume). In southeast Peel area, oil stained Martin House Formation is common, and there are minor shows of gas and oil from DSTs; however, none of these shows or stains have been linked to Cretaceous source rocks. Nevertheless, both Arctic Red and Slater River formations are indicated to be potential source rocks, as they are thermally mature through part of Peel area.

Play Review and Play Map

Arctic Red and Slater River formations have fair potential as source rocks (average 1.64% and 1.8% TOC, respectively). Cretaceous strata are: immature to just within oil window at the Imperial River section just southeast of Peel area, mature along Hume River section, over-mature in Arctic Red River area, and post-mature in Snake River area; thus generally increasing in maturity from east to west across the southern Peel area. In several wells in southwest Peel area, where a reasonably thick Cretaceous section is preserved, maturity can be seen to increase with depth (Figure 10.5.18; Allen et al., 2008b).

The formations are likely gas prone, although Slater River Formation may be oil prone, as it is further southeast of Peel area in Mackenzie Plain and Great Bear Plain (Dixon et al., 2007).

Martin House Formation is the main reservoir rock, while younger Trevor Formation sandstones have limited potential because they are less porous, mostly thin, and outcrop in Peel Plateau (Hadlari and Zantvoort, 2007; Chapter 9, this volume). Martin House Formation occurs across southern Peel area, and has porosities up to 21.5% with high permeabilities. The basal sandstone of Martin House Formation and non-marine Tukweye member (called the Gilmore Lake member in many industry reports) are the most promising potential reservoir facies (Chapter 9, this volume; Hadlari and Zantvoort, 2007).

Stratigraphic traps might be expected in fluvial channels, etc., of Tukweye member and inferred marine barrier bar sandstones of basal sandstone Martin House Formation (Chapter 9, this volume). Structural and structural/stratigraphic traps are also possible.

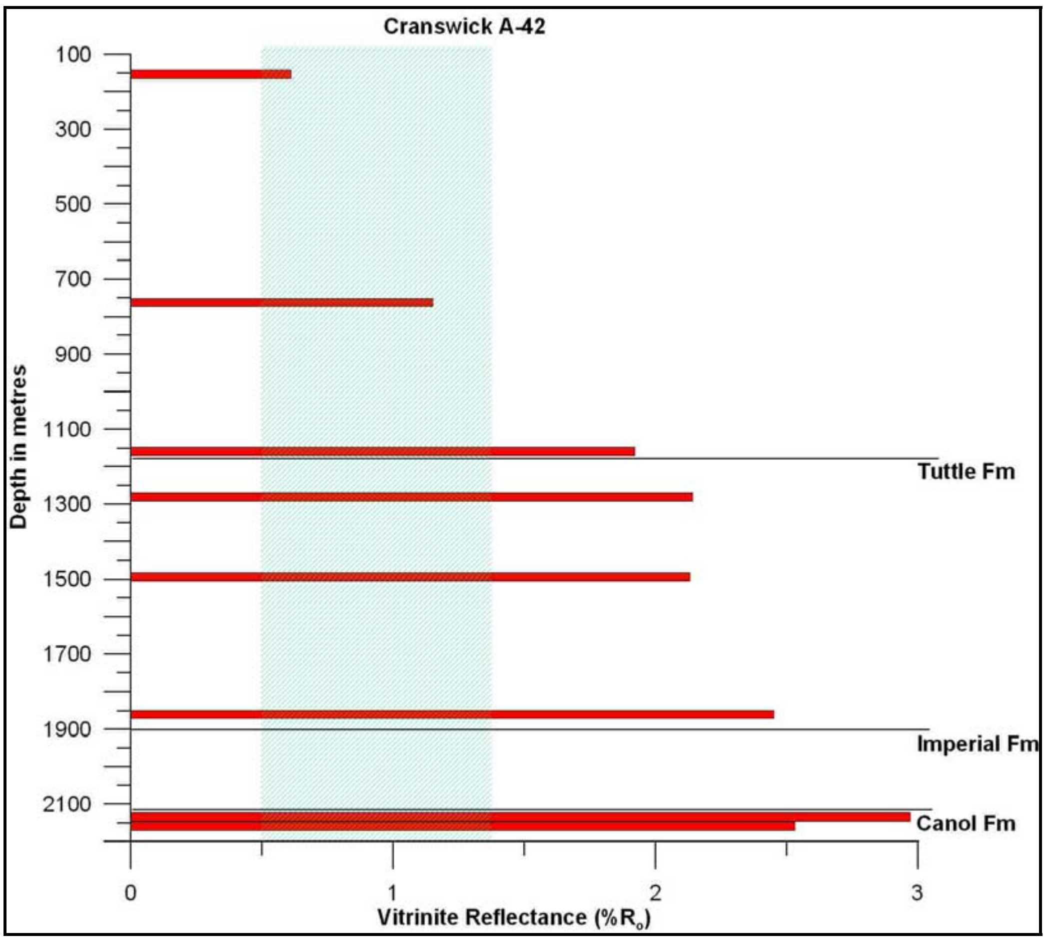

Figure 10.5.18. *Vitrinite reflectance (and equivalent vitrinite reflectance) in %Ro versus sample depth in Cranswick Y.T. A-42 well. The oil window is indicated by the green shaded bar. Note increasing maturity with depth in Cretaceous strata (above top Tuttle Formation). Reflectance data from GeoChem Laboratories (Canada) Ltd. and Applied Geoscience and Technology (AGAT) Consultants Ltd. (1977).*

A play map (Figure 10.5.19) shows the extent of the play through southern Peel area. The play area essentially follows the distribution of the Cretaceous strata, with some allowance for the reduction of play boundaries at subcrop edges where the Cretaceous thins to a feather edge. Also shown is the zone of mature Arctic Red Formation, which is somewhat approximated, as thick sequences of the formation show a range from mature to over-mature in southwestern Peel area. The area of Slater River Formation maturity is not shown, but would be somewhat more restricted. More favourable areas within the play area have not been indicated; however, one might restrict them to the thickest parts of the Cretaceous sequence, and the most favourable facies of Martin House Formation (Chapter 9, this volume). Osadetz et al. (2005) regarded the Mesozoic clastics play of Peel Plain and Plateau as hosting the greatest in-place gas resource in their assessment of the Yukon portion of Peel area.

Burial History, Generation, and Migration of Cretaceous Petroleum

New and previously existing thermal maturity data for Cretaceous rocks have indicated that a considerable thickness of Albian and younger (probably including Tertiary) strata would have had to have been deposited, and then removed by erosion, to result in the mature to overmature rocks seen in outcrop in the present. Burial history diagrams (e.g., Figures 10.4.4 through 10.4.8) suggest 2 km to 3 km of Albian and younger strata were deposited, in addition to what is currently preserved. Higher heat flows than those used in the burial history models (section 10.4) were possible, even probable; however the observed thermal maturity versus depth data could not be modeled by increased heat flow alone.

Refined age determinations (Chapter 9, this volume) for Cretaceous rocks in Peel area show that considerable strata was deposited in the Albian, then following a hiatus, more deposited in the Cenomanian-Turonian, and finally most likely more again in the latest Cretaceous and Tertiary. This step-wise sequence of burial, then uplift and erosion and/or non-deposition, resulted in thermal maturity in Arctic Red Formation that was likely not reached until the very latest Cretaceous and Tertiary. Migration may not have occurred until the Tertiary, post-dating or syntectonic with Laramide structures. This syntectonic charging of Laramide reservoirs is typical in the Western Canada Sedimentary Basin (Osadetz et al., 2005). It is not known if Tertiary uplift and erosion may have negatively affected migration from Cretaceous source rocks.

Generally it is assumed that the timing, generation, and migration of Cretaceous petroleum (gas and/or oil) was favourable with respect to the formation of Laramide structural traps along the fronts of the Mackenzie, Richardson, and Franklin mountains.

Petroleum System Events

In the proposed events chart (Figure 10.5.20) source rock, reservoir rock, and seal (at least locally) are all considered to be present with some degree of confidence. The late Cretaceous-Tertiary generation, migration, and accumulation indicated confer upon the Arctic Red-Martin House petroleum system the most favourable situation of timing amongst all potential and known petroleum systems that operated in Peel area.

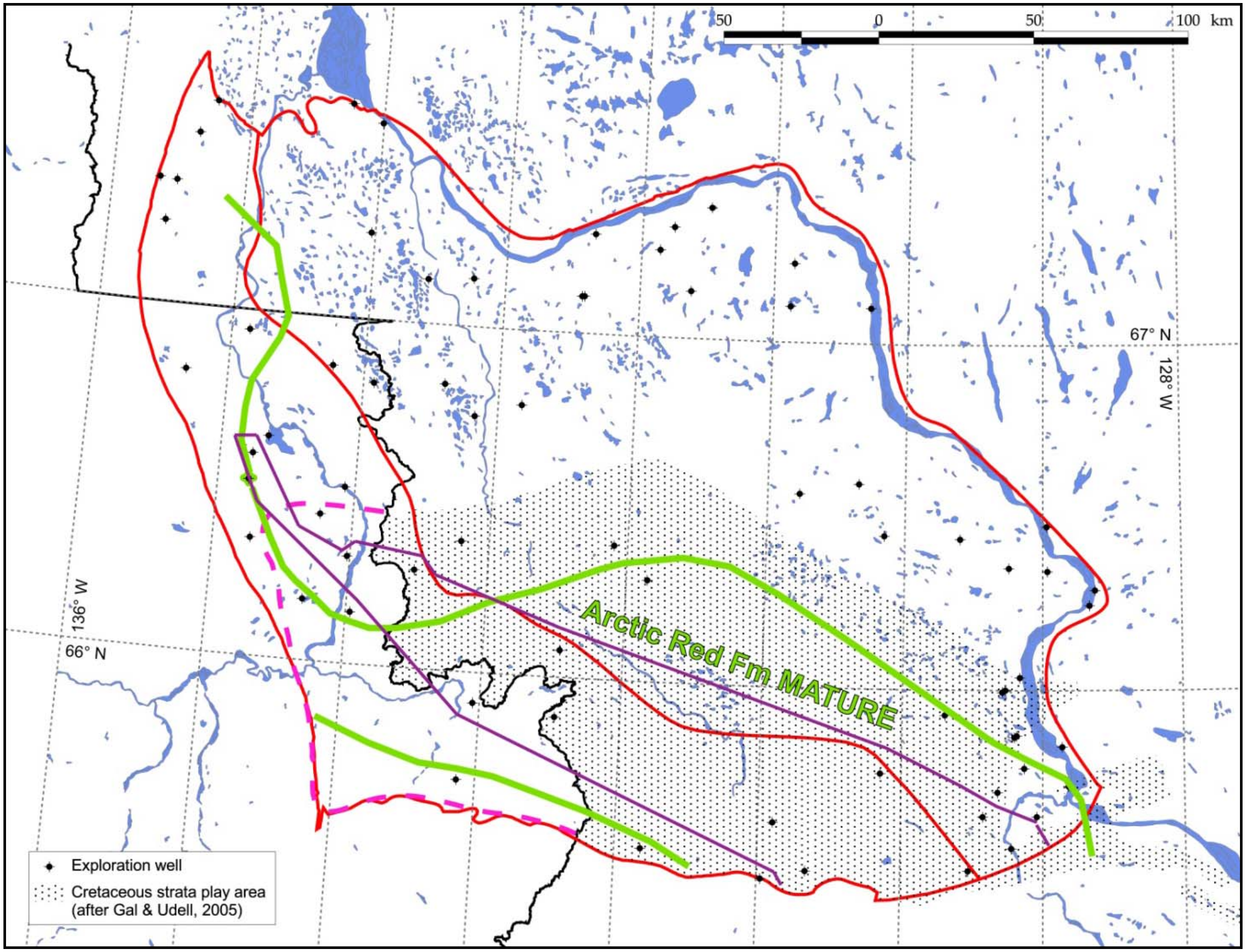

Figure 10.5.19. *Cretaceous clastic play map. The Cretaceous play area (stippled region after Gal and Udell, 2005; pink dashed line in Yukon after Lemieux et al., 2008) covers southern Peel area. The zone of mature Arctic Red Formation is somewhat approximate; the formation shows a range of maturity through its thickness in southern and western Peel area. The purple solid line is the 500 m Cretaceous isopach (Chapter 9, this volume).*

The overburden row in Figure 10.5.20 indicates two hiatuses where considerable erosion was likely to occur; not shown are post-Tertiary and recent erosional episodes that are likely to be important as well. It is these episodes of erosion that may have severely affected preservation of any accumulations, particularly in eastern Peel area where Cretaceous strata are thinned.

The trap row illustrates stratigraphic traps; another bar to represent structural traps could be placed at a time coincident with generation-migration-accumulation, as discussed above.

Critical Moment

The critical moment in this system is placed in the early Tertiary, at the completion of generation, and coeval onset of migration, accumulation, and structural trap formation. Figure 10.5.21 is a schematic section across Peel area eastward to the flank of Keele Arch, drawn to represent conditions at about the time of peak petroleum generation in Arctic Red and Slater River formations. Martin House Formation potential reservoirs are shown to onlap the Keele Arch and to depositionally pinch out in the west (in actual fact to the northwest; Chapter 9, this volume). Inset boxes schematically show stratigraphic traps associated with: a facies pinch-out of basal clastic sandstones (with problematic up-dip seal); a fluvial channel (e.g., Tukweye member); and an onlap of basal Cretaceous sandstone onto the flank of the Keele Arch (which would occur east and south of Peel area). Also shown is a faulted anticlinal structural trap, as might be associated with Laramide deformation.

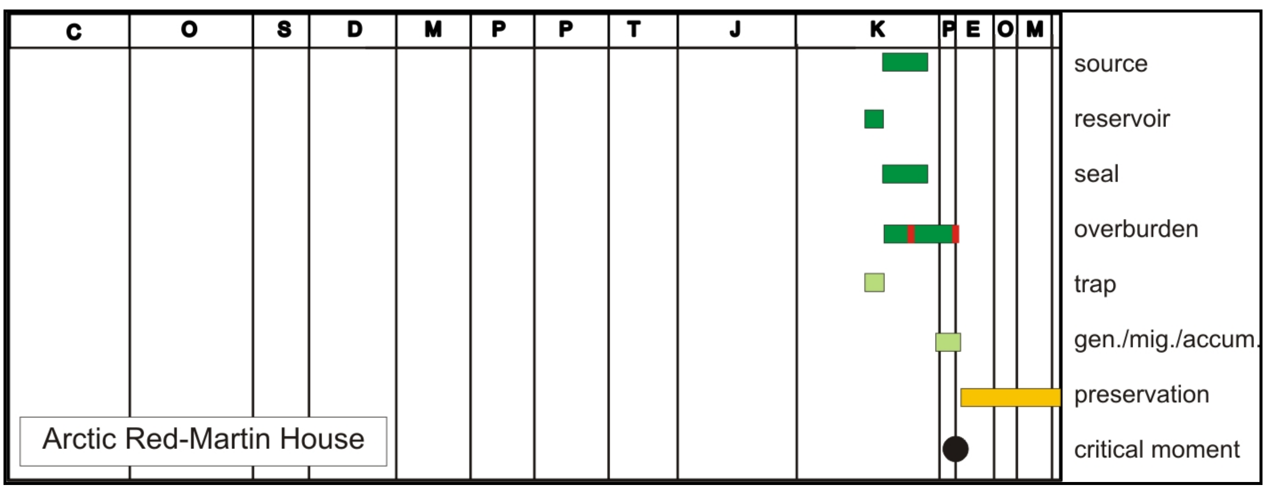

Figure 10.5.20. *Simplified and theoretical events chart for Arctic Red/Martin House petroleum system. The* ***trap*** *row indicates stratigraphic traps in Martin House Formation, although structural traps are likely to predate hydrocarbon generation and migration as well. The bar for generation-migration-accumulation (****gen./mig./accum.****) shows that gas generation likely started in the latest Cretaceous to early Tertiary. Thus the* ***critical moment*** *for this system (black dot) is placed in the early Tertiary, at the beginning of the preservation period.*

Summary

The Arctic Red-Martin House petroleum system has been shown to exist, based on geochemical analysis of an oil stain from Cretaceous sandstone linked to a Cretaceous source rock. Based on our data, Arctic Red and Slater River formations are likely source rocks, the latter being perhaps more oil prone. There are gas shows in Peel Plateau (Peel River Y.T. B-06; Osadetz et al., 2005) where a Cretaceous source can be inferred. There have been some gas shows in the Cretaceous clastics in southeast Peel area (e.g., Hume River I-66, East Hume River I-20), and oil staining in these rocks is fairly common. These petroleums have not been associated geochemically with Arctic Red or Slater River formations. It is possible that Horn River Group shale could have been the source for some or all shows in eastern Peel area. For example, in southeastern Peel area where the sub-Cretaceous unconformity cuts downward into Ramparts Formation, hydrocarbons may have migrated directly from Canol Formation into basal Cretaceous sandstone. This is an area for further study, but by analogy with Cretaceous petroleum systems in Mackenzie Plain (e.g., Feinstein et al, 1988b), it seems reasonable to infer the system operated in eastern Peel Plain as well as Peel Plateau.

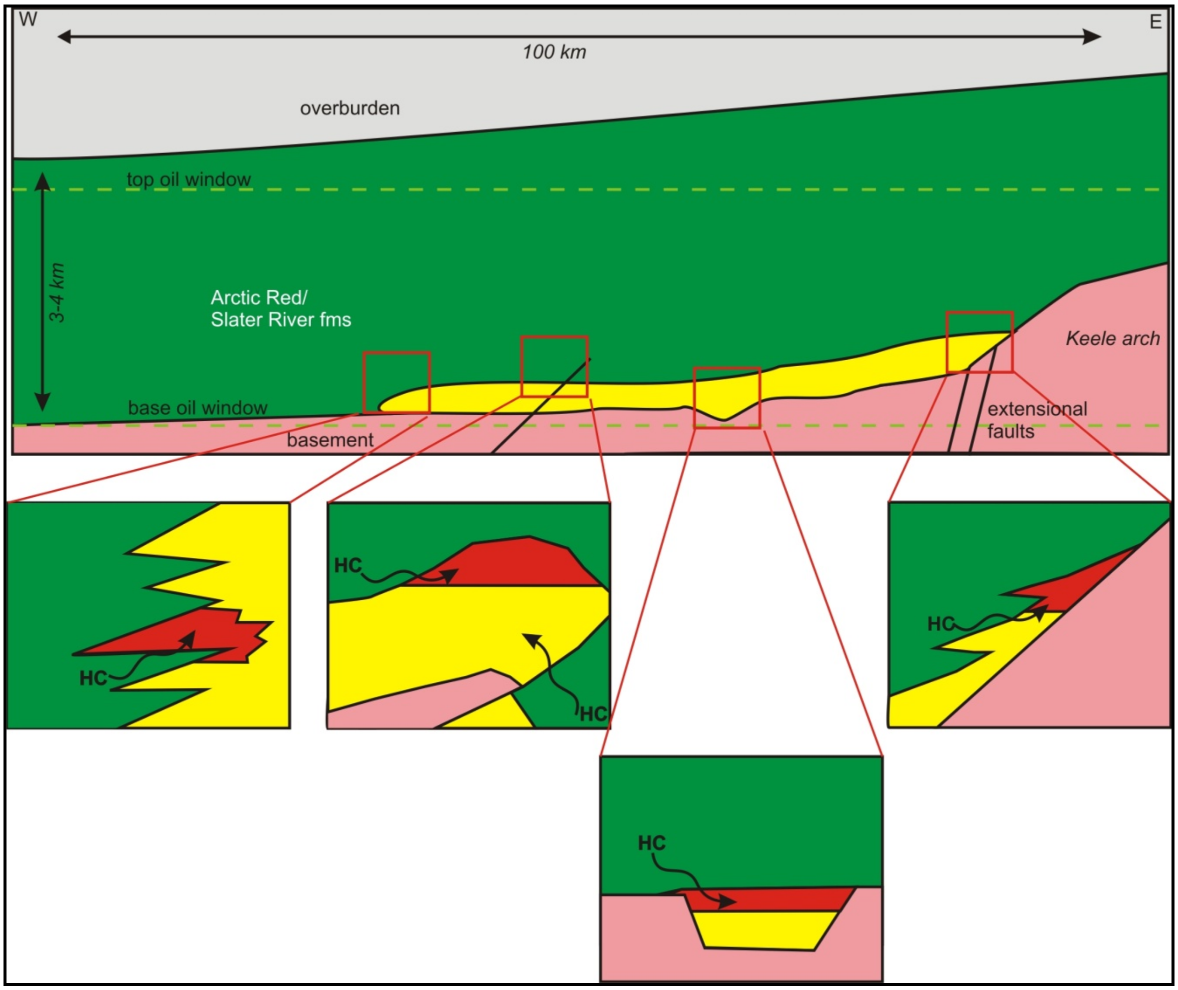

Figure 10.5.21. *Diagrammatic representation of basal Cretaceous clastics (Martin House Formation) around the time of peak hydrocarbon generation in Arctic Red and Slater River formations. Scales indicated are highly approximate. Inset boxes schematically show traps associated with: at far left, a facies pinch-out of basal clastic sandstones; middle left, a faulted anticlinal trap; middle right, an incised channel; and far right, onlap of basal sandstones onto high of Keele Arch (which lies east and south of Peel area). "HC" and wavy arrows indicate possible hydrocarbon migration.*

The main prospect-level risks associated with the Cretaceous play are likely to be trap (closure and seal) and preservation (breaching, leaking, biodegradation, and water washing). Hannigan et al. (2006) also note adequate reservoir as a play-level exploration risk. The episodes of post-Albian uplift and erosion (including post Tertiary and recent) have thinned Cretaceous strata and left many potential reservoirs at or near surface. This is especially true in northern and eastern Peel area. Brock et al. (1983) list shallow Cretaceous strata as a negative factor in the Peel area. The thickest remaining areas of Cretaceous strata, along a synformal trough or keel adjacent, but not abutting, the Mackenzie and Richardson mountain fronts (Figure 10.5.19; Chapter 9, this volume) might hold the best promise.

Osadetz et al. (2005) rated the Mesozoic clastics play of Peel Plain and Plateau in Yukon as likely to hold the greatest in-place gas resource of all plays examined in that study. It was agreed that the Cretaceous petroleum system has moderate to high exploration potential in the western and southern Peel area, west of Trevor Fault where Cretaceous strata are thicker, and where large structures are more likely to have remained un-breached. Stratigraphic traps are also possible, in eastern Peel area as well, perhaps as far east as Hume River. New stratigraphic and sedimentological insights (Chapter 9, this volume) may help target such prospects.

10.5.7 Summary of Peel Petroleum Plays Prospectivity

This section is a subjective summary of the overall prospectivity of conceptual petroleum plays in Peel area. The following conceptual plays are ranked in this section according to their qualitative potential. Unconventional accumulations are beyond the scope of this chapter; Horn River Group shale gas, however, and Imperial Formation (and younger strata) tight gas potential in central and western Peel area might be worthy of consideration. Table 10.5.2 summarizes some exploration risks at the play level of these conceptual plays.

1. **Basal Cretaceous Sandstone Play**
   There is good evidence that a Cretaceous petroleum system did operate, at least in Peel Plateau. The main problem is that Cretaceous rocks are thin throughout much of Peel area and at outcrop. Exploration should focus on regions where preservation potential might be enhanced, in regions of thicker Cretaceous strata, in Peel Plateau and southern Peel Plain. These areas generally coincide with regions where structures adjacent mountain ranges might be expected and so un-breached structural accumulations are possible. Seismic coverage is not comprehensive enough to condemn the area for lack of structures, and in southwestern Peel area at least, the structural geology is very likely to be more complex than existing surface maps indicate (e.g., Osadetz et al., 2005; Lemieux et al., 2007).

2. **Tuttle Play**
   The Tuttle play has some of the same positives, but suffers the same problems as the Cretaceous, namely being close to surface or at outcrop, and in addition having undergone significant pre-Albian erosion. Thus, exploration should focus in Peel Plateau where Tuttle Formation is thickest. While Tuttle Formation itself has only moderate source rock potential, the associated Ford Lake Shale is mature and probably a better potential source rock.

3. **Arnica-Landry Platform Play**
   It is tempting to tout this play, based on analogy with the Summit Creek B-45 discovery in Peel Plain. What is required is the structural juxtaposition of potential reservoir rocks (which are variable with respect to genesis and volumetric percentage of the formations) with the source rocks that form the basis of the Horn River petroleum system. Thus, exploration should focus adjacent the mountain fronts, and in the area of oil to gas zone Horn River Group rocks, and attempt to find unbreached faulted and or folded structures.

4. **Kee Scarp Play**
   There is good evidence for a Horn River Group based petroleum system. This play has understandably been the focus of exploration in southeast Peel area, given the direct analogy that can be drawn with Norman Wells. The main problem, aside from poorly understood reservoir characteristic in the region, is that the Kee Scarp member outcrops widely, is shallow in the subsurface, and in places has been breached by pre-Albian erosion. Thus, there are opportunities for failed preservation of accumulations for both Late Paleozoic and Late Cretaceous generation and migration from Horn River sources. There is a relatively small area in southeast Peel area, where Ramparts Formation might be sufficiently buried for preservation. Evidence of leakage at surface outcrops is almost ubiquitous.

5. **Imperial Play**
   There is some evidence of an Imperial petroleum system, although petroleum definitively sourced in the formation has not been identified. As with Tuttle and Cretaceous formations, Imperial Formation subcrops widely, and the best reservoir rocks are at or near surface in southeast Peel area. In addition, Imperial Formation fine-grained sandstones can be generally described as tight, with very little permeability.

6. **Lower Paleozoic Platform Play**
   There is good geochemical evidence that Road River Group was a good source rock, but there is no direct evidence for petroleum of this age. Assuming some did form, one has to wonder if it migrated, and if so, how, where to, and when? The worst case is that petroleum never left the source rock, except in areas of fracturing (hence the bitumen “dykes” reported); the best case is that some petroleum did migrate and find its way into volumetrically insignificant reservoir facies (relative to overall Ronning Group thickness), was somehow trapped. It then would have had to reside there and be preserved over a long period of time.

7. **Cambrian Clastics Play**
   There is strong evidence for Cambrian-Ordovician (Mount Cap and/or Saline River formations) oil being formed. However, reservoir quality (and in fact, the presence of a reservoir in Peel area) is a big question. We can assume Cambrian petroleum did form, but whether it was ever reservoired in Cambrian strata or simply migrated up section (which it did locally, at least into Imperial Formation) away from Peel area, to escape to surface at the flanks of the Keele Arch, is a situation explorationists must consider.

Play	Source	Reservoir	Migration-Accumulation	Preservation	Shows
Cretaceous Basal Clastics	L to M	L	M	M	3
Tuttle	M	L	M	L to M	1
Arnica-Landry platform	L	M	M to H	M	4
Kee Scarp	L	M	M	M to H	2
Imperial	M to H	M to H	M	M	5
Lower Paleozoic platform	L to M	H	H	M to H	6
Cambrian Clastics	M	H	H	M to H	7

Table 10.5.2. *Qualitative play level risks of certain components of conceptual plays in Peel area. The plays names labeled in bold are associated with known petroleum systems, the others are associated with hypothetical petroleum systems. Play-level risk components are qualified as: H=high, M=medium, and L=low. The final column very qualitatively rates the number and quality of shows in historical explorations of Peel area to date (1-7, best or most to worst or least).*

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