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INTRODUCTION

The purpose of this report is to update and expand the inventory and interpretation of thermal maturation measurements for organic-rich shale units in the Devonian Horn River Group. The Horn River Group, and its equivalent strata in the southern part of the Northwest Territories (Horn River Formation), is extensive in the Mackenzie corridor. This stratigraphic interval contains the Canol Formation which is the source rock for the Norman Wells oilfield in the central part of the corridor (Feinstein et al., 1988a), and is therefore of interest as a target for shale oil and shale gas exploration. In the frontier basins of northern Canada, exploration wells are widely spaced. An initial dataset of thermal maturation parameters for the Mackenzie corridor was reported by Feinstein et al. (1988b) and included Rock-Eval pyrolysis (Tmax) and vitrinite reflectance measurements for well samples which were assigned to "Horn River and equivalent formations" at the time. Two reports covering the Middle Devonian of the Western Canada Sedimentary Basin expanded the dataset, adding measurements from some well samples north of 60°N: 1) reflectance measurements reported by Stasiuk and Fowler (2002), and 2) Rock-Eval/TOC data reported by Fowler et al. (2002). In these studies, undifferentiated Horn River and Hare Indian, Bluefish, Evie were grouped together as the "Elk Point and Beaverhill Lake" for the purpose of mapping Tmax values and isoreflectance of vitrinite and vitrinite equivalent data.

Recently, a study of source rock characterization refined Horn River Group stratigraphy within the central Mackenzie corridor by differentiating its units based on dense sampling intervals in both the subsurface and outcrops (Pyle et al., 2014). This study produced a large dataset of Rock-Eval pyrolysis results and reflectance measurements as part of a project managed and funded by the Northwest Territories Geoscience Office (NTGO), with laboratory support for analyses provided through the Geological Survey of Canada (GSC) GEM-Energy Program. The purpose of the present report is to assemble an updated Rock-Eval and thermal maturation dataset for each unit of the Horn River Group and its equivalent strata, incorporating new measurements published by Pyle et al. (2014). Data is concentrated within the Mackenzie Plain exploration area, but includes data from all regions of the northern mainland sedimentary basin (of Morrow et al., 2006). The eastern limit of the study area is around 116.8°W, the western limit at 135°W, the southern limit is 60°N, and the northern limit is 68.5°N (Figure 1).

SAMPLES AND METHODOLOGY

In the present study, data was compiled from four main sources (Feinstein et al., 1988b; Fowler et al., 2002; Stasiuk and Fowler, 2002; and Pyle et al., 2014) and their references within (Appendices C, E, and G; average Rock-Eval data in Appendix A). Rock-Eval6 data from the Pyle et al. (2014) study were generated at the Geological Survey of Canada in Calgary, Alberta (GSC-Calgary). The procedures and application of the method are provided by Lafargue et al. (1998) and Behar et al. (2001). Experimental procedures for the earlier studies are detailed within those sources and follow the guidelines developed by Peters (1986) for Rock-Eval2.

Based on the guidelines of Peters and Cassa (1994) and Peters (1986), Tmax corresponds to the oven temperature (°C) at which the peak release of hydrocarbons occurs by cracking of kerogen (S2 generation). Initiation of oil generation occurs at Tmax=435-445°C and the end of oil generation is at 470°C (Table 1). In compiling the Rock-Eval datasets, Tmax values are considered reliable only if the S2 value is greater than 0.2 mg HC/g. If S2 is too low, the peak is broad and Tmax cannot be picked reliably (Peters, 1986). Dewing and Sanei (2009) suggested that Tmax values were unreliable if S2 was less than 0.35 mg HC/g, based on analysis of a dataset from the Arctic Islands. Any Tmax values greater than 590°C represent artifacts. In compiling the Rock-Eval datasets, low S2 values are highlighted in grey (Appendix A).

Vitrinite reflectance (R_o) measurements were carried out at the Geological Survey of Canada in Calgary, Alberta, following the methodology outlined in Stasiuk and Fowler (2002) for Devonian samples. Measurements are made on the percentage of incident light reflected from maceral particles under oil immersion (subscript o in R_o for oil immersion). To evaluate the thermal maturation level of Devonian samples, a calculated vitrinite equivalent (%R_o Ve = 0.618 x %R_o bitumen + 0.40; from Jacob, 1985) is used. In Appendix B, the mean VR_o is reported in order to have a single value to map maturity trends. This mean value represents an average of several measurements reported in the original data sources. The value may represent several measurements from one sample at one stratigraphic interval, or the average of measurements throughout a stratigraphic unit as reported within the original sources.

Outcrop Samples

Outcrop sections and sites were sampled during three field seasons of the Mackenzie Plain Petroleum Project managed by NTGO (2010-2014) (Figure 2). Chip samples were taken throughout each measured section across one-, two-, or three-metre intervals, depending on the thickness of the units in outcrop. For example, the Bluefish Member is typically thin (< 20 m thick), and was sampled every one metre. Representative samples were taken from sites where not enough outcrop was exposed to measure. Chip samples were analysed to evaluate organic richness and source-rock potential using Rock-Eval pyrolysis and TOC measurement (451 samples; Appendix C), and vitrinite (or vitrinite equivalent) reflectance (33 samples; Appendix D). Additional measurements from outcrop reported by Grass (1988) are also included in Appendices C and D.

Exploration Wells

Twenty-six wells with Horn River Group cuttings or core within Mackenzie Plain were sampled from the Core and Sample Repository of the GSC-Calgary, also as part of the NTGO study. Selected wells are arranged in five roughly east-west transects (Figure 2). Intervals were selected for sampling after determining that enough suitable material was present. A twenty-gram sample was collected from the bagged unwashed cuttings of each selected interval. Sample material was weighed, sieved, washed and air-dried. Each split was picked under the microscope to remove (as far as possible) cavings, drilling mud, wood chips or other potential contaminants that had not been removed by sieving and washing. Cores were sampled from intervals as approved by the National Energy Board, and collected as small chips lying loose in the core boxes to avoid breaking intact core pieces. Rock-Eval pyrolysis was carried out on 479 samples at GSC Calgary (Appendix E). Selected samples (37 in total) were submitted to GSC-Calgary for thermal-maturation analysis through reflected-light microscopy (Appendix F) and additional reflectance data is compiled from Feinstein et al. (1988b) and Stasiuk and Fowler (2002) in Appendix B. Additional Rock-Eval measurements from cores and cuttings reported by Feinstein et al., (1988b) and Fowler et al. (2002) are compiled in Appendix G. Some of these intervals reported, such as those from wells in Peel Plateau and Plain, may be subject to future revision based on the changes to tops picks that became apparent through the detailed lithogeochemical characterization from the Mackenzie Plain wells.

Thermal Maturation Parameters

Thermal maturity of organic matter refers to the thermal alteration (temperature-time driven reactions) that transforms a source rock, leading to generation of oil, wet gas, or ultimately dry gas and pyrobitumen (Peters and Cassa, 1994). Thermal maturity levels of potential source rocks range from immature, to mature (early, peak and late mature), to postmature (Table 1). Immature source rocks are those in which there is nearly no bitumen or oil generation from kerogen, prior to burial temperatures greater than 60-80°C. Mature organic matter in the oil window is that which has been affected by thermal processes within the temperature range that generates oil (60-150°C). Early mature refers to generation of a minor amount of heavy oil and oily bitumens whereas peak maturity refers to generation of liquid oil. Postmature or overmature refers to the generation of condensate and gas when all possible oil has been generated (Stasiuk and Fowler, 2002).

Stage of Thermal Maturity	Maturation		Production
	Ro (%)	Tmax (°C)	PI [S1/(S1+S2)]
Immature	0.2-0.6	<435	<0.10
Early Mature	0.6-0.65	435-445	0.10-0.15
Peak Maturity	0.65-0.9	445-450	0.25-0.40
Late Mature	0.9-1.35	450-470	>0.40
Postmature	>1.35	>470	-

Table 1. Geochemical parameters describing level of thermal maturation (after Peters and Cassa, 1994).

STRATIGRAPHIC NOMENCLATURE

The present study refers the Hare Indian (and its basal Bluefish Member), Ramparts and Canol formations to the Horn River Group in the Mackenzie Plain area (Pugh, 1983; Table 2). In the subsurface, misidentification of units involved inclusion of Canol Formation with Imperial Formation, or exclusion of the upper part of the Hare Indian Formation. Pyle et al. (2014) characterized each organic-rich Horn River Group unit in outcrop and the subsurface using lithology, TOC content, chemostratigraphy based on trace elements and major oxides, and changes in semi-quantitative modal mineralogy obtained by X-ray diffraction.

Pyle et al. (2014) suggest using "Bell Creek member" instead of the informal "grey shale member" or "upper Hare Indian". They propose a reference section for the Horn River Group at Mountain River (Figure 1). The Bell Creek member is heterogeneous, and varies regionally. Where the Ramparts Formation is present, the grey Bell Creek member is organic-lean and consists of interbedded greenish-grey to dark grey, calcareous and non-calcareous, micaceous shale, calcareous siltstone, and argillaceous limestone. Where the Ramparts Formation is absent, dark Bell Creek member consists of dark grey shale and calcareous shale with rare lime mudstone. The dark Bell Creek is organic-rich and visually similar to the Canol Formation but is geochemically distinct. The Bell Creek member contains more terrigenous clastic material compared to both the Bluefish Member and Canol Formation (indicated by elevated major oxides such as Al_2O_3+Fe_2O_3+K_2O+TiO_2). Appendix A shows revision in outcrop nomenclature and in assignment of sample unit in ***bold italic.*** For some wells in which detailed study of the Hare Indian Formation has not yet been undertaken to differentiate units, the interval is reported as "Hare Indian".

In southern Northwest Territories the term Horn River Formation is currently used to refer to the Evie-Otter Park-Muskwa assemblage, after a type locality proposed by Whittaker (1922) along the Horn River and type well in northeast British Columbia (Gray and Kassube, 1963) (Figure 1). The unit's terminology, reviewed by Williams (1983), remains fraught with inconsistencies. For the purpose of this study, "Horn River" is used in those wells where no differentiation into members has been made and the terms "Evie" and "Muskwa" are used for those sample intervals of Stasiuk and Fowler (2002) and Fowler et al. (2002). The Evie Member correlates with the Bluefish Member and the Muskwa member correlates to the Canol Formation (Pugh, 1983; Table 2) so thermal maturity parameters for these units are grouped together for comparison in the present study.

Revision to tops picks by Pyle et al. (2014) illustrates the need for the undifferentiated "Horn River" and "Hare Indian" intervals to be reviewed to the north and south of Mackenzie Plain in order to ascertain correlations. Whole rock geochemistry, in conjunction with organic geochemistry, has proven to be a useful tool for characterizing individual stratigraphic units.

ROCK-EVAL RESULTS

Source Rock Quality and Organic Carbon Content

The total organic carbon content by weight (TOC, wt. %) was measured in samples from cores, well cuttings, and outcrop. TOC in the sample is quantified as sum of the total pyrolysable organic matter and residual carbon (Espitalié et al., 1985), and is a basic measure of potential richness as source rock. Based on TOC (wt. %), Peters and Cassa (1994) use the following the classification scheme to describe petroleum potential: poor (0-0.5%), fair (0.5-1.0), good (1-2), very good (2-4) and excellent (>4).

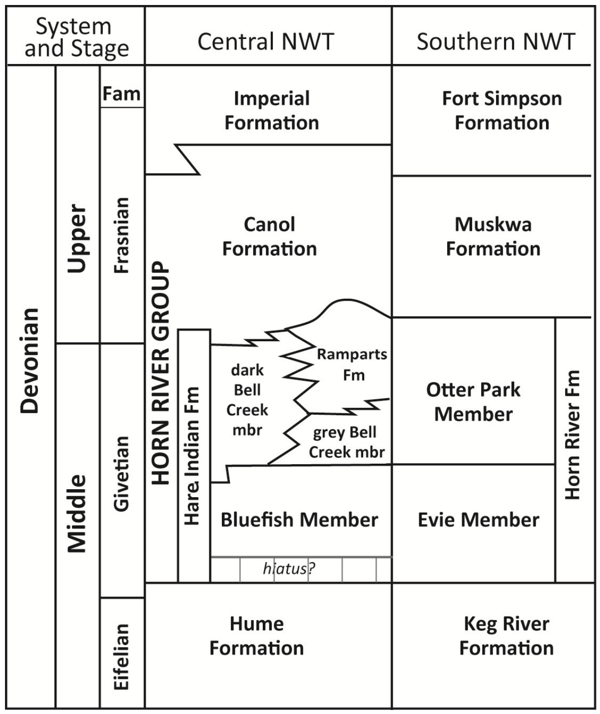

Table 2. Time-stratigraphic chart for Devonian strata in the Mackenzie corridor (Fam=Famennian).

The mean TOC values from those compiled from a total of 247 outcrop sections and wells (Appendix A) show that the Bluefish Member (42 wells and sections) and Canol Formation (101 wells and sections) have excellent source rock potential. Some values indicate excellent source rock quality within the Evie Member (21 wells and sections), Bell Creek member (33 wells and sections), undifferentiated Horn River Formation (13 wells), and Muskwa Formation (27 wells). The undifferentiated Hare Indian Formation samples (10 wells) suggest only some sites with mean very good potential. All units, except the Bluefish Member, had some mean values in the poor to fair range (<1% TOC; Table 3).

Unit	Range in Mean TOC content (wt. %)
Bluefish Member of Hare Indian Formation	1.50-7.97
Evie Member	0.65-7.57
Bell Creek member of Hare Indian Formation	0.10-8.13
Hare Indian Formation undifferentiated	0.16-2.58
“Horn River” Formation, undifferentiated	0.17-4.60
Canol Formation	0.24-16.66
Muskwa Formation	0.77-7.83

Table 3. Range in mean TOC content values (wt. %) from different outcrop and well sample intervals within the Mackenzie corridor (compiled in Appendix A).

Based on the earlier studies, excluding detailed study in Mackenzie Plain area discussed below, the compiled results from GSC studies (Appendix G) suggest the following average TOC content: Canol Formation 3.9% TOC (n=265), Muskwa Formation 2.26% TOC (n=179), Horn River Formation 2.53% TOC (n=36), Hare Indian Formation 1.16% TOC (n=62), Bluefish Member 3.49% TOC (n=78), Evie Member 3.5% TOC (n=59).

TOC from Outcrop Samples, Mackenzie Plain Area

A more detailed look at TOC distribution within Mackenzie Plain area is based on a total of 451 outcrop samples from 29 measured sections and field stations (Figure 2, Appendix B). Samples were collected as continuous chip samples over 1 to 3 m measured intervals, or as representative samples at spot locations. The majority of samples collected were from the Canol Formation (n=298), with 64 samples from Bell Creek member, 56 samples from Bluefish Member and 33 samples from Ramparts Formation. Data initially reported by Pyle and Gal (2012, 2013) and Pyle et al., (2011), were re-assigned according to the revised stratigraphy that further clarified units based on multi-proxy chemostratigraphic analysis (Pyle et al., 2014).

In outcrop, four Horn River Group units are potential source rocks: Bluefish and Bell Creek membesr, Ramparts and Canol formations. Median values for both the Canol Formation and Bluefish Member of the Hare Indian Formation are each greater than 5% TOC, and data distributions appear normal (Figure 3). Thin organic-rich shale intervals within the Ramparts Formation (median=3.98%) are limited in rock volume such as in the Carcajou member, but are potentially rich source rocks. More than 80% of Ramparts samples are from two sections only (Mountain River and Powell Creek). The Bell Creek member samples of the Hare Indian Formation display a bimodal distribution, with some high value outliers. A concentration of values <1% TOC represent the organic-lean, grey, calcareous Bell Creek member. This unit is restricted in its distribution to lenses underlying the Ramparts Formation. The dark, organic-rich Bell Creek member samples (47% of the samples) have an average of 4.85% TOC (n=30, from eastern and southern sections: Prohibition Creek, Vermillion Creek, Canyon Creek, Mackay Range, Little Bear 1 and 2, Dodo Canyon, and Carcajou 1).

Median TOC values by complete or nearly complete units show variations in TOC across the study area. Median TOC values for the Canol Formation are consistently excellent with ranges between 4.2% and 6% TOC (Table 4, Figure 3). The Bluefish Member sample medians range from 3.7 to 6.8%, and are also mostly excellent quality source rocks although with fewer samples per site. Median values for the dark Bell Creek member samples range from 3.4 to 6.8%, but are lower at the Mountain River section (median=1.6% TOC), where the unit is characterized as grey Bell Creek member (Table 3).

TOC from Subsurface Samples, Mackenzie Plain Area

A total of 479 well-cuttings samples were collected from 26 wells for pyrolysis analysis, as part of the NTGO's project. These data were previously reported by Gal and Pyle (2012) but required re-examination and revised interpretations based on new tops determinations (Pyle et al., 2014). The main issues from earlier reports of Rock-Eval data include: undifferentiated "Horn River" or "Hare Indian" units and inclusion of Imperial and/or Bluefish intervals with the Canol Formation. The data set reported herein (from Pyle et al., 2014) therefore includes 78 Imperial Formation samples that were originally included with Canol Formation and reports 99 samples from the newly recognized Bell Creek member.

Location	Median Canol TOC (wt. %)	Median Ramparts TOC (wt. %)	Median Bell Creek TOC (wt. %)	Median Bluefish TOC (wt. %)
Canyon Creek	5.09 (19)	unit absent	4.54 (3)	5.38 (3)
Powell Creek sections	4.50 (18)	3.67 (13)	no data	4.33 (3)
Mountain River	4.17 (32)	4.62 (14)	1.59 (6)	4.20 (22)
Dodo Canyon sections	5.03 (39)	unit absent	4.73 (2)	6.43 (6)
Carcajou 1	5.96 (13)	unit absent	4.14 (6)	3.70 (2)
MacKay Range West	4.60 (6)	unit absent	3.56 (5)	6.79 (5)
Little Bear 1	5.15 (26)	unit absent	6.83 (8)	5.69 (1)
Little Bear 2	5.34 (13)	unit absent	3.35 (3)	5.25 (8)
Turnabout Creek	4.24 (7)	unit absent	unit absent	5.42 (1)

Table 4. Median TOC values in weight percent, from Horn River Group units at select measured sections, with number of samples in brackets. Sample locations in Figure 2.

From select wells within Mackenzie Plain area, four Horn River Group units are potential source rocks. Median values for the Canol Formation (4.53% TOC) and Bluefish Member (5.02%) samples suggest both are rich potential source rocks (Figure 3). These values are slightly less than those reported for the outcrop samples, which may be due to some contamination from cavings. Data distributions appear normal in the histograms for these units. The Ramparts Formation was not a focus of subsurface sampling, thus the 11 samples analysed do not provide a meaningful picture of organic richness (median=1.45%). The Bell Creek member samples have a median value of 2.1% TOC, however the distribution is skewed with more than 35% of samples yielding <1% TOC. These sub-1% values correspond largely to grey Bell Creek member samples that underlie the Ramparts Formation. In wells where the Ramparts Formation does not occur, the dark Bell Creek member has a higher average TOC suggesting very good to excellent source rock potential, with the exception of the P-78 well (Table 5).

Kerogen Types

Three types of kerogens in source rocks are defined using Rock-Eval hydrogen index (HI) versus oxygen index (OI) diagrams based on data from both the outcrops and wells. Higher oil-generative potential is related to higher hydrogen content in kerogen (Types I and II). Type III have low HI and higher OI and may be gas-prone. Points plotting between the trends represent a mixture of kerogen types (Peters and Cassa, 1994; Peters, 1986).

A pseudo-von Krevelen cross plot of HI versus OI based on outcrop samples show a high HI and low OI for most of the Canol and Bluefish samples suggesting the presence of Types I and II kerogen (Figure 4A). One exception is a few samples of Canol Formation from the Little Bear 2 section that suggest Type III kerogen. Samples of the dark Bell Creek member mainly indicate Types I and II (e.g., from Mackay Range and Little Bear sections, Figure 4B), while those from the grey Bell Creek member suggest Type III kerogen (such as from Mountain River and Imperial Anticline sections; Figure 4B).

Well	Ramparts Fm present	Ave. TOC (wt. %)	Bell Creek member type
Carcajou L-24	Yes	0.33	Grey Bell Creek member
Discovery Ridge H-55	Yes	1.98	Grey Bell Creek member
Morrow Creek J-71	Yes	0.71	Grey Bell Creek member
Hoosier Ridge N-22	Yes	0.46	Grey Bell Creek member
Brackett Lake C-21	Yes	1.23	Grey Bell Creek member
Summit Creek K-44	No	5.57	Dark Bell Creek member
Mirror Lake N-33	No	4.65	Dark Bell Creek member
Redstone P-78	No	0.63	Dark Bell Creek member
Tate G-18	No	4.51	Dark Bell Creek member
Tate J-65	No	2.51	Dark Bell Creek member

Dahadinni B-20	No	2.18	Dark Bell Creek member
Bluefish K-71	No	3.88	Dark Bell Creek member
Bear Rock O-20	No	3.20	Dark Bell Creek member
Silvan Plateau G-51	No	3.32	Dark Bell Creek member
Blueberry Creek K-53	No	3.88	Dark Bell Creek member

Table 5. Average TOC in weight percent for Bell Creek member samples from well cuttings.

Pseudo-von Krevelen cross plots of HI versus OI based samples from the detailed sampling of Mackenzie Plain wells indicate Type I and II kerogen for most of the samples from the Canol Formation and Bluefish and dark Bell Creek members (Figures 5A-E). Some samples from the grey Bell Creek member shale in the northern transect and central transect 1 suggest Type II to Type III kerogen, although those from Carcajou L-24 well are unreliable due to low S2 values (Figures 5A, B). Samples from all units in the L-24 well lie between the trends of Type II and III. In southern transect 2, low S2 values suggest the data from Redstone J-42 and Redstone P-78 are unreliable (Figure 5E). Rock-Eval data for the Evie Member, Muskwa Formation and "Horn River" (Appendix G) show a range of kerogen types (Figure 6). A pseudo-von Krevelen cross plot shows relatively high HI values and low OI values for the Evie Member, but some data points lie between Types II and III. The Horn River data mainly lie between Types II and III, with some on the Type III trend. The bulk of the Muskwa samples have lower HI and OI and cluster around the origin; however, quite a few indicate a mix of Type II and III kerogen (Figure 6).

Thermal Maturity from Tmax

In Appendix A, Rock-Eval data averages are listed from Feinstein et al. (1988b; OF1944), Fowler et al. (2002; OF1579), Pyle et al. (2014; OF2014-06) and Grass (1988). In cases where data were reported from the same well by both Feinstein et al. (1988b) and Fowler et al. (2002), the average reported in Appendix A represents averages from all data points. In cases where some wells sampled in the earlier reports were re-sampled at a denser interval and reported by Pyle et al (2014), the denser datasets were taken to supersede those from the earlier reports. One exception is Hoosier Ridge No. 2 well in which the earlier reports provided a denser dataset, so these values were averaged after confirmation that they are in agreement with the thermal maturation range reported by Pyle et al. (2014).

Thermal maturity trends based on these average Tmax values from 247 outcrop sections and wells are mapped for each set of correlative units in Figures (7, 8, and 9). Those data considered unreliable are highlighted in grey in Appendix A and were filtered to remove them from the mapped trends. Stratigraphic revision to the unit reported, based on revised tops picks by Pyle et al. (2014), are listed in ***bold italic*** in Appendix A. Revisions to nomenclature for units listed by Feinstein et al. (1988b) were updated using the terminology used by Fowler et al. (2002). For example, where the former list a unit called "Horn River (A)", and the latter assigned the interval to "Muskwa". Values listed for "Hare Indian" and "Horn River" are mapped with Bell Creek member but it should be noted that this assignment is tentative (Figure 8). Some of the "Hare Indian" values may include Bluefish Member. The undifferentiated "Horn River" may include intervals that could be Evie or Muskwa equivalents. Some wells such as Clare F-79 are missing a top pick for the upper Hare Indian Formation, and data reported by Feinstein et al (1988b) as within the Canol Formation are herein assigned to Hare Indian Formation.

Canol and Muskwa Formations

Tmax values record an increase in maturity for the Canol Formation (Figure 7) from immature to marginally mature around Norman Wells and east of Mackenzie River, to post-mature to the northwest into Peel Plateau. The main zone of maturity lies in the central to western Mackenzie Plain (shades of green, Figure 7), with some sites east of Mackenzie River in the early mature stage (e.g., Bear Rock O-

20 well). The trend in Peel Plain to Peel Plateau is similar with increasing maturity from east to west. Anomalously immature Tmax values in southern Mackenzie Plain wells are possibly due to contamination of well cuttings from Cretaceous cavings. Tmax values with low organic matter content and high maturity are unreliable and should be regarded cautiously. There are also some outcrops in which Tmax values ranged from immature to mature (e.g., Canyon Creek and Little Bear 2) (Appendix A). The average Tmax value for K-53 well in the south-central Mackenzie Plain suggests immaturity, but Tmax values range from 294-484°C for this well. In Peel Plain, averages for H-37 (454-522°C) and O-65 (418-580°C) suggest post-maturity, but these stratigraphic intervals should have their tops picks confirmed using whole rock geochemistry. The N-02 well in Anderson Plain has Tmax values that range from 334-527°C, giving an average in the post-mature stage. Average Tmax values from two wells south of Mackenzie Plain also have a broad range in the Canol Formation within A-12 well (350-506°C) and G-60 (322-572°C) (Appendix A).

Thermal maturity trends for the Muskwa Formation show an increase from immature in southeastern Great Slave Plain, to post-mature westward. Thermally mature strata range from early to late mature within the central Great Slave Plain. Two wells in the Franklin Mountain exploration area (M-69 and I-60) indicate immaturity based on the average Tmax value; however, the Tmax range for M-69 well is 309-443°C and for the I-60 well is 368-505°C (Appendix A).

Bell Creek member and Hare Indian-Horn River Formations

Average Tmax values for the Bell Creek member record an increase in maturity from immature around Norman Wells to mature within Mackenzie Plain (Figure 8). Early maturity is indicated in the central part of Mackenzie Plain (O-20 well to Mackay Range section). Those wells that plot within the immature range do contain some mature values in their Tmax range, however, but their average Tmax indicates immaturity (Appendix A). For example, Canyon Creek (CC), Imperial Anticline (IA), and C-21 well all yielded some mature Tmax values. A zone of immaturity is indicated in the southern part of the plain, similar to the Tmax trend suggested by the Canol Formation data (Figure 7).

The data for the undifferentiated Hare Indian Formation is sparse, but suggests immaturity in southern Anderson Plain to mature within Peel Plain and central Anderson Plain to post-mature in northern Anderson Plain. For the undifferentiated Horn River Formation, the average Tmax values indicate maturity within the central Great Slave Plain, trending to post-mature westward (with the exception of M-70 well suggesting immaturity, at odds with its $\%R_o$ value discussed below), and immaturity suggested by the centrally located P-56 well (Figure 8).

Bluefish Member and Evie Member

Average Tmax values for the Bluefish Member record an increase in maturity from immature east of Mackenzie River around Norman Wells, to peak and late maturity along the western edge of Mackenzie Plain (Figure 9). As with the Canol Formation and Bell Creek member, a zone of immaturity is indicated in the southern part of Mackenzie Plain. Tmax values for the Bluefish Member are sparse in the northern corridor, but indicate post-maturity in Peel Plateau and in northern Anderson Plain, but early maturity in southern Anderson Plain. The average Tmax for the Tenlen A-73 well in the north suggests post-maturity, but the Tmax values range from 436-548°C for the Bluefish Member. The trend for the Evie Member in Great Slave Plain indicates early maturity in the south central part and post-maturity to the west, with the exception of three wells (Cli Lake G-15, M-69, I-60) that indicate immaturity (Figure 9).

Production Index (PI)

The production or productivity index [PI=S1/(S1+S2)] is a thermal maturity indicator derived from Rock-Eval pyrolysis (Peters and Cassa, 1994). It is a kerogen-specific maturity parameter also called the transformation ratio, referring to the ratio of already generated, volatile hydrocarbons (S1) in mg/g of rock to potential total recoverable hydrocarbon (S1+S2) (Macauley et al., 1985). A PI value of 0.1 is the minimum value to indicate the generation of oil. PI values ranging from 0.1 to 0.15 correspond to early mature stage; values from 0.25-0.4 are in the peak mature stage; values >0.4 are in the late mature stage. Values considered anomalous were removed from the dataset plotted on the maps for each Horn River Group unit (Figures 10, 11, and 12) by excluding samples with PI>0.2 and Tmax <435°C and for those in which PI>0.3 and Tmax ranges between 435-445°C (Peters and Cassa, 1994). In the Peel Plain, PI values show an increase from east to west (Figures 10, 11, 12). Scatter plots for each Horn River Group unit and equivalent strata show generally good agreement for an increasing average PI with increasing average Tmax, with some outliers for each dataset (Figure 13A, B, C).

PI Trends from Outcrop Samples in Mackenzie Plain

The PI values from three Canol Formation outcrop sections (Figure 14A), follow the trend of increasing maturity within Mackenzie Plain from east to west (Canyon Creek to Imperial River to Turnabout Creek). PI values increase from north to south from Mountain River to Dodo Canyon to Carcajou 1 and 2. Anomalous PI values for Canol samples are circled in Figure 14A.

For the Bell Creek member samples (Figure 14B), almost all are within the range of generation of oil, with some Tmax values likely unreliable for the Bell Creek West and Imperial Anticline samples due to low S2 peaks. The Bluefish Member outcrop samples (Figure 14C) show an increasing Tmax trend from east to west from Canyon Creek to Mountain River to Gayna Gorge and Turnabout Creek and corresponding elevation in PI values.

PI Trends from Well Samples in Mackenzie Plain

Based on Rock-Eval results, PI values for the Canol Formation show some trends. In the northern Mackenzie Plain (Figure 15A), there is a clear trend from immature to mature from east to west along the northern transect (Figure 2), from H-55 well to L-24 well. There is good agreement between the PI and Tmax values, with the exception of a few samples with PI<0.1 but Tmax >435ºC. In the central transects 1 and 2 (Figures 2, 15B), there is also good agreement and another clear trend in thermal maturation from eastern wells (O-20 and G-51) to the central and western plain (K-71, N-33, K-03). In wells of the southern transects (Figures 2, 15C), the data is contradictory in which there are anomalous data points with high PI >0.2 and low Tmax <435 ºC. Some data from the G-18 well have low PI <0.1 but Tmax <435 ºC which may represent contamination from cavings. A trend from immature in the east (P-78) to mature, but with high PI >0.4, in the west (K-53 and K-44) is evident.

For the Bell Creek member in wells within the northern and central transects (Figures 2, 16A), the PI values show an increase with increasing Tmax from the east (H-55) toward the central and western wells (J-71, L-24) in Mackenzie Plain. Data is contradictory for only a few points with low PI <0.1 but Tmax >435 ºC such as in (H-15) well. In the southern transects (Figures 2, 16B), again there are anomalous datapoints with high PI >0.2 and low Tmax <435 ºC and the K-44 well has most elevated PI >0.5.

For the Bluefish Member, as with the outcrop data, there are a few contradictory low PI <0.1 with Tmax >435 ºC in the north-central wells (Figure 17A). There is a clear trend of increasing maturity within the oil window and production index from east to west from C-21 and O-20 wells west to N-33 and K-03 wells. In the southern wells (Figure 17B), there are anomalous points with high PI and low Tmax such as the J-65 and G-51 wells and one point with low PI but Tmax >435ºC. The B-20 and K-44 wells have high PI >0.6.

VITRINITE REFLECTANCE RESULTS

Thermal maturity trend maps (Figures 18, 19, 20) based on average $\%R_o$ values for Horn River Group shale units and equivalent strata across the corridor generally follows the trends suggested by the Tmax values north of Keele River (~64°N). South of Keele River and in the Franklin Mountains region, the vitrinite reflectance values are high, but the Tmax values are low. South of 62°N, the trends match again.

There is largely good agreement between the datasets, based on average values, when they are compared (Figure 21). At locations where several reflectance values were measured within a stratigraphic interval, average $\%R_o$ values are used (Appendix B), based on GSC data and newer data compiled from both the outcrop and subsurface studies by Pyle et al. (2014) (Appendices D, F and summary in Appendix H). Evaluation of optical thermal maturity of Horn River and equivalent strata by Feinstein et al. (1988b) showed a general increase in thermal maturity from east of Norman Wells (<0.5 %Ro) west toward the Mackenzie Mountains (maximum >2.0 %Ro). Stasiuk and Fowler (2002) illustrated a similar trend in mapping %Ro for the "Upper Devonian Woodbend Group and equivalent strata" (containing Canol and Muskwa formations) and for the Middle Devonian "Elk Point Group and equivalent strata" from immature east of Norman Wells (<0.6 %Ro) to post-mature west and south. The present study compares the measured reflectance and Tmax values and trends for each unit in the Horn River Group and their equivalent strata of the Horn River Formation.

Comparison of $\%R_o$ and Tmax Data from Mackenzie Plain Dataset

Datasets resulting from dense sampling within the Mackenzie Plain outcrops and wells provide a comparison of reflectance and Tmax parameters in Horn River Group units.

Canol and Muskwa Formations

In general, both reflectance and Tmax values indicate increasing maturity from east to west, from the Norman Wells area (Quarry, Prohibition Creek and Canyon Creek samples just within the oil window based on $\%R_o$) to the Mackenzie Mountains, where most samples are well within the oil window (Figure 18). Samples from western Mackenzie Plain at Turnabout Creek indicate late maturity. From Canyon Creek south, samples trend from just within the oil window to peak maturity at MacKay Range, based on average $\%R_o$. Increasing maturity in the Canol Formation toward Dahadinni River East and Moose Prairie Anticline sections is indicated by reflectance measurements; however, suspect Tmax values due to very low S2 in these overmature rocks precluded resolution of this trend using Rock-Eval data. Decreasing maturity in an upsection direction is evident in the average $\%R_o$ values at locations such as Canyon Creek and the Mountain River section (Appendix H).

Maturity trends indicated by average $\%R_o$ (Figure 18) for the Canol Formation show a similar pattern to that indicated by Tmax values (Figure 7). Values range from immature along the eastern Peel Plain to postmature westward, within Peel Plateau. Both Tmax and $\%R_o$ data suggest the Canol Formation is post-mature north in Anderson Plain (N-02 well). In southern Mackenzie Plain and Franklin Mountains, however, the $\%R_o$ data suggest a zone of post-maturity where Tmax values suggested immaturity (e.g., A-28 and J-42 wells, Figure 21A). Within the zone of maturity throughout central and northern Mackenzie Plain, $\%R_o$ data suggest peak to late maturity for several wells and outcrop where Tmax indicated early to peak maturity (comparison of Figures 7 and 18).

For the Muskwa Formation, $\%R_o$ values (Figure 18) suggest immaturity in the southeastern Great Slave Plain (e.g., B-28, I-38, and K-45 wells, Figure 21A) whereas Tmax values suggest early maturity for these wells. The $\%R_o$ values also suggest overmaturity in the western Great Slave Plain and into Liard Basin, in agreement with the Tmax data (Figure 7), although a few data points are contradictory. For example, Tmax values for I-08 well suggest maturity whereas the average $\%R_o$ value suggests overmaturity. For the G-15 well, the average Tmax value suggests overmaturity but the average %R_o value suggests peak maturity. A study of the Muskwa Formation in northern British Columbia indicates reflectance values ranging from 1.59 to 2.45%R_o (Ferri and Griffiths, 2014).

Bell Creek member, Hare Indian Formation, and Horn River Formation

For those samples that yielded both reflectance and Rock-Eval data, the maturity data is mostly in agreement (Figure 21B), with some outliers. For the Bell Creek member, both datasets generally indicate an increase in maturity from east to west across Mackenzie Plain. The average %R_o value for the L-24 well in northern Mackenzie Plain suggests post-maturity (Figure 19) whereas the average Tmax value suggests maturity (Figures 8, 21B). The average %R_o value for the J-65 well in southern Mackenzie Plain suggests immaturity whereas the average Tmax suggests maturity. There are three data points for the Horn River Formation that differ (Figure 21B), where average %R_o values for the I-23 and J-05 wells suggest maturity but Tmax values suggest post-maturity. For the M-70 well, the average %R_o value suggests post-maturity but the Tmax data suggests immaturity. Otherwise both datasets are in agreement for maturity of the Horn River Formation in the central Great Slave Plain.

Bluefish Member and Evie Member

For those samples that yielded both reflectance and Rock-Eval data, the maturity data for both the Bluefish and Evie members are agreement, with some slight discrepancies (Figure 21C). Average %R_o values for the Bluefish Member indicate slightly greater maturity in the following wells compared to their average Tmax values (e.g., H-55, G-51, J-65, and K-44). The data for the I-46 well is at odds in which the average %R_o value suggests post-maturity (Figure 20) and Tmax values suggest immaturity (Figures 9, 21C). For the Evie Member, the average %R_o values suggests immaturity where the average Tmax values indicate early maturity (K-45, B-75, L-19) (comparison of Figures 9 and 20).

Comparison of %R_o and Tmax Data from Select Wells

For wells that yielded both reflectance and Rock-Eval data, a comparison of both parameters shows good agreement for some units but not for others. In the northern transect, L-24, mean vitrinite equivalent measurements on the Bluefish and Bell Creek members indicate post-maturity whereas most Tmax values suggests maturity (Figures 22A,B). The Bell Creek vitrinite equivalent measurements indicate a mix of different thermal maturities, possibly from Ramparts Formation cavings (see notes in Appendix F). In the H-55 dataset, mean %R_o values indicate samples from all units are in the oil window, whereas only a few Tmax values for the Bluefish and Bell Creek member suggest the early mature stage (Figures 22C, D).

Data from two wells in the central to southern Mackenzie Plain (N-33, K-44) are in good agreement (Figures 23A to D), whereas those from Tate J-65 are not. Most of the samples from the N-33 and K-44 wells for all units are within the oil window. For the Tate J-65 well, the Tmax values suggest immaturity and the vitrinite reflectance data suggest early maturity (Figure 23E, F). The notes in Appendix F describe cavings for the Bell Creek member and coaly matrix for the Bluefish Member which could be Cretaceous.

SUMMARY

Organic-rich intervals are present in each of the Horn River Group units (Canol Formation, Bluefish Member and dark Bell Creek member) and their correlative units in the southern Mackenzie corridor (Evie Member, undifferentiated Horn River Formation, Muskwa Formation), with very good to excellent source rock potential based on TOC content. The undifferentiated Hare Indian Formation and grey Bell Creek member are organic-lean. Rock Eval6 analyses from outcrop and the subsurface suggest that Horn River Group units in Mackenzie Plain contain dominantly Type II kerogen. The

grey Bell Creek member contains Type III kerogen. Data for the Muskwa, Evie, and Horn River units also suggest Types II and III kerogen with a range between Type II and III kerogen.
Maturity trends in Mackenzie Plain area based on Tmax and vitrinite reflectance (and equivalent) from samples of each Horn River Group unit suggest immature to marginal maturity around Norman Wells in the east, with a large part of the northern and central plain within the oil window. Data is contradictory in the southern Mackenzie Plain in which some Canol Formation samples produced reflectance values indicating post-maturity and Tmax values suggesting immaturity. This area requires more examination. Data is sparse for all units except the Canol Formation in Peel Plain and Peel Plateau, where a trend of increasing maturity from east to west is evident. In light of the stratigraphic revision to the Horn River Group units within Mackenzie Plain wells, some of the data from the Peel wells could be improved by lithogeochemical confirmation of the stratigraphic intervals sampled for Rock-Eval previously. In the southern corridor, data is more sparse, but a general trend toward higher maturity westward across Great Slave Plain is suggested. A trend of elevated average PI values from east to west corresponds with increasing average Tmax from east to west across both Mackenzie and Peel Plains. A similar trend is present for Horn River Group equivalent units in Great Slave Plain.

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ranges of maturity of Peters and Cassa (1994) in which yellow is immature, shade of green represent the oil window, and red is postmature.

Figure 10. Map of Mackenzie corridor showing Production Index values for the Canol and Muskwa formations based on outcrop and well samples. Data points represent averages, and are coloured according to the thermal maturity stages of Peters and Cassa (1994), where values ranging from 0.1 to 0.15 correspond to early mature stage; values from 0.25-0.4 are in the peak mature stage; values >0.4 are in the late mature stage. Inset map shows detail around Norman Wells.

Figure 11. Map of Mackenzie corridor showing Production Index values for Bell Creek member of the Hare Indian Formation, undifferentiated Hare Indian Formation, and Horn River Formation based on outcrop and well samples. Data points represent averages, and are coloured according to the thermal maturity stages of Peters and Cassa (1994), where values ranging from 0.1 to 0.15 correspond to early mature stage; values from 0.25-0.4 are in the peak mature stage; values >0.4 are in the late mature stage.

Figure 12. Map of Mackenzie corridor showing Production Index values for Bluefish and Evie members, based on outcrop and well samples. Data points represent averages, and are coloured according to the thermal maturity stages of Peters and Cassa (1994), where values ranging from 0.1 to 0.15 correspond to early mature stage; values from 0.25-0.4 are in the peak mature stage; values >0.4 are in the late mature stage.

Figure 13A-C. Scatter plots showing average Tmax vs. average PI values for (A) the Canol and Muskwa formations , (B) Bell Creek member, Hare Indian Formation, and Horn River Formation and (C) Bluefish and Evie members in the subsurface.

Figure 14A-C. Scatter plot of Rock-Eval data from outcrops showing Tmax vs. PI values for the (A) Canol Formation, (B) Bell Creek member and (C) Bluefish Member in outcrop. Anomalous datapoints for the Canol Formation are circled.

Figure 15A-C. Scatter plot of Rock-Eval data from wells showing Tmax vs. PI values for the Canol Formation from (A) northern wells, (B) central wells and (C) southern wells. Anomalous datapoints are circled. Note the change in scale in 15C to accommodate the range of values.

Figure 16A-B. Scatter plot of Rock-Eval data from wells showing Tmax vs. PI values for the Bell Creek member from (A) north-central wells and (B) southern wells. Anomalous datapoints are circled.

Figure 17A-B. Scatter plot of Rock-Eval data from wells showing Tmax vs. PI values for the Bluefish Member from (A) north-central wells and (B) southern wells. Anomalous datapoints are circled.

Figure 18. Map of Mackenzie corridor with vitrinite (or vitrinite equivalent) reflectance values for Canol Formation and Muskwa Formation samples in outcrop and wells. Data points represent averages, and are coloured according to the %R_o ranges of maturity of Peters and Cassa (1994) in which yellow is immature, shade of green represent the oil window, and red is postmature. Note the label "Imperial Well" for N-33 (circle with X) from which data is from the basal Imperial Formation rather than the Canol Formation following revision of tops picks. Inset map shows detail around Norman Wells.

Figure 19. Map of Mackenzie corridor with vitrinite (or vitrinite equivalent) reflectance values for Bell Creek member of the Hare Indian Formation, undifferentiated Hare Indian Formation, and Horn River Formation samples in outcrop and wells. Data points represent averages, and are coloured according to

the %R_o ranges of maturity of Peters and Cassa (1994) in which yellow is immature, shade of green represent the oil window, and red is postmature.

Figure 20. Map of Mackenzie corridor with vitrinite (or vitrinite equivalent) reflectance values for the Bluefish Member and Evie Member samples in outcrop and wells. Data points represent averages, and are coloured according to the %R_o ranges of maturity of Peters and Cassa (1994) in which yellow is immature, shade of green represent the oil window, and red is postmature.

Figure 21A-C. Comparative scatter plot of average Tmax vs. average %R_o values for wells and outcrops in which both results are available for (A) Canol and Muskwa formations, (B) Bell Creek member and undifferentiated Hare-Indian or Horn River Formation, and (C) Bluefish and Evie members.

Figure 22A-D. Comparison of Tmax vs. depth and %R_o vs. depth for select wells in northern Mackenzie Plain: (A) Tmax variation with depth for Carcajou L-24 well, (B) %R_o variation with depth for Carcajou L-24 well, (C) Tmax variation with depth for Discovery Ridge H-55 well, (D) %R_o variation with depth for Discovery Ridge H-55. Green shading represents the oil window.

Figure 23A-F. Comparison of Tmax vs. depth and %R_o vs. depth for select wells in central and southern Mackenzie Plain: (A) Tmax variation with depth for Mirror Lake N-33 well, (B) %R_o variation with depth for Mirror Lake N-33 well, (C) Tmax variation with depth for Summit Creek K-44 well, (D) %R_o variation with depth for Summit Creek K-44 well, (E) Tmax variation with depth for Tate J-65 well, (F) %R_o variation with depth for Tate J-65 well. Green shading represents the oil window.

APPENDICES

Appendix A. Compilation of average Rock-Eval results from the Horn River Group in the Mackenzie corridor. References for the data are as follows: OF2014-06=Pyle et al., 2014; OF1944=Feinstein et al., 1988b; OF1579=Fowler et al., 2002; Grass, 1988).

Appendix B. Compilation of average vitrinite reflectance (VR_o) for the Horn River Group in the Mackenzie corridor. References for the data are as follows: OF2014-06=Pyle et al., 2014; OF1944=Feinstein et al., 1988b; OF4341=Stasiuk and Fowler, 2002; Grass, 1988).

Appendix C. Rock-Eval results from Mackenzie Plain outcrop samples; analyses carried out at GSC-Calgary (data compiled from Pyle et al., 2011; Pyle and Gal, 2012, 2013), and additional TOC and Tmax data from a study by Amoco (Grass, 1988).

Appendix D. Vitrinite or vitrinite equivalent reflectance from outcrop samples from Mackenzie Plain (analyses by J. Reyes, GSC-Calgary; data reproduced from Pyle et al., 2011; Pyle and Gal, 2012, 2013).

Appendix E. Rock-Eval results from Mackenzie Plain subsurface samples; analyses carried out at GSC-Calgary (data reproduced from Gal and Pyle, 2012 with revised unit picks in *bold italic* by Pyle et al., 2014).

Appendix F. Vitrinite or vitrinite equivalent reflectance from well samples in Mackenzie Plain (analyses by J. Reyes, GSC-Calgary; data reproduced from Gal and Pyle, 2012).

Appendix G. Compilation of Rock-Eval results from Mackenzie corridor from Feinstein et al. (1988b) and Fowler et al. (2002).

Appendix H. Comparison of average vitrinite (or equivalent) reflectance (%R_o) and Tmax from Rock-Eval analyses of Horn River Group samples(† denotes suspect values of Tmax, due to very low S2 values).

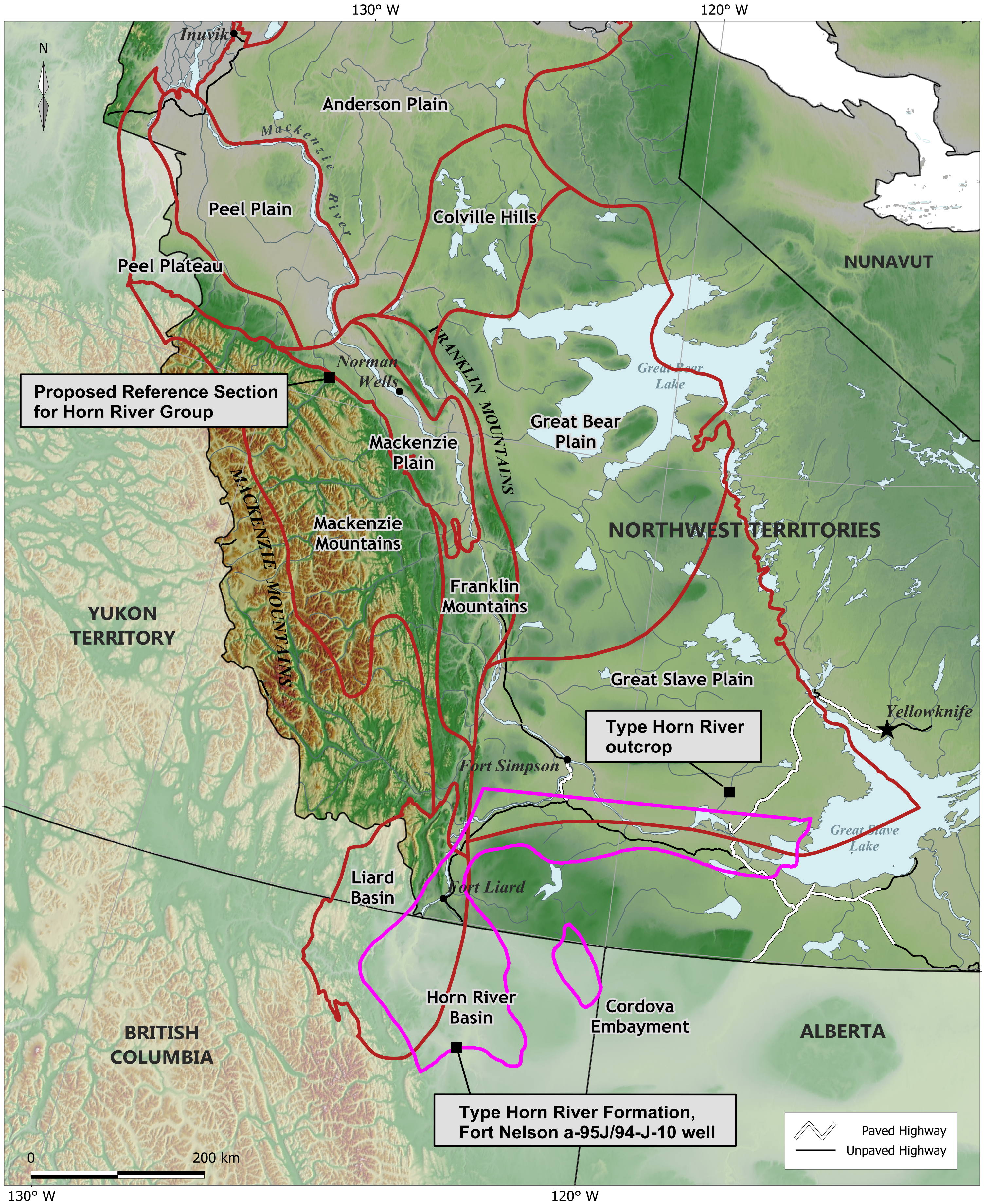
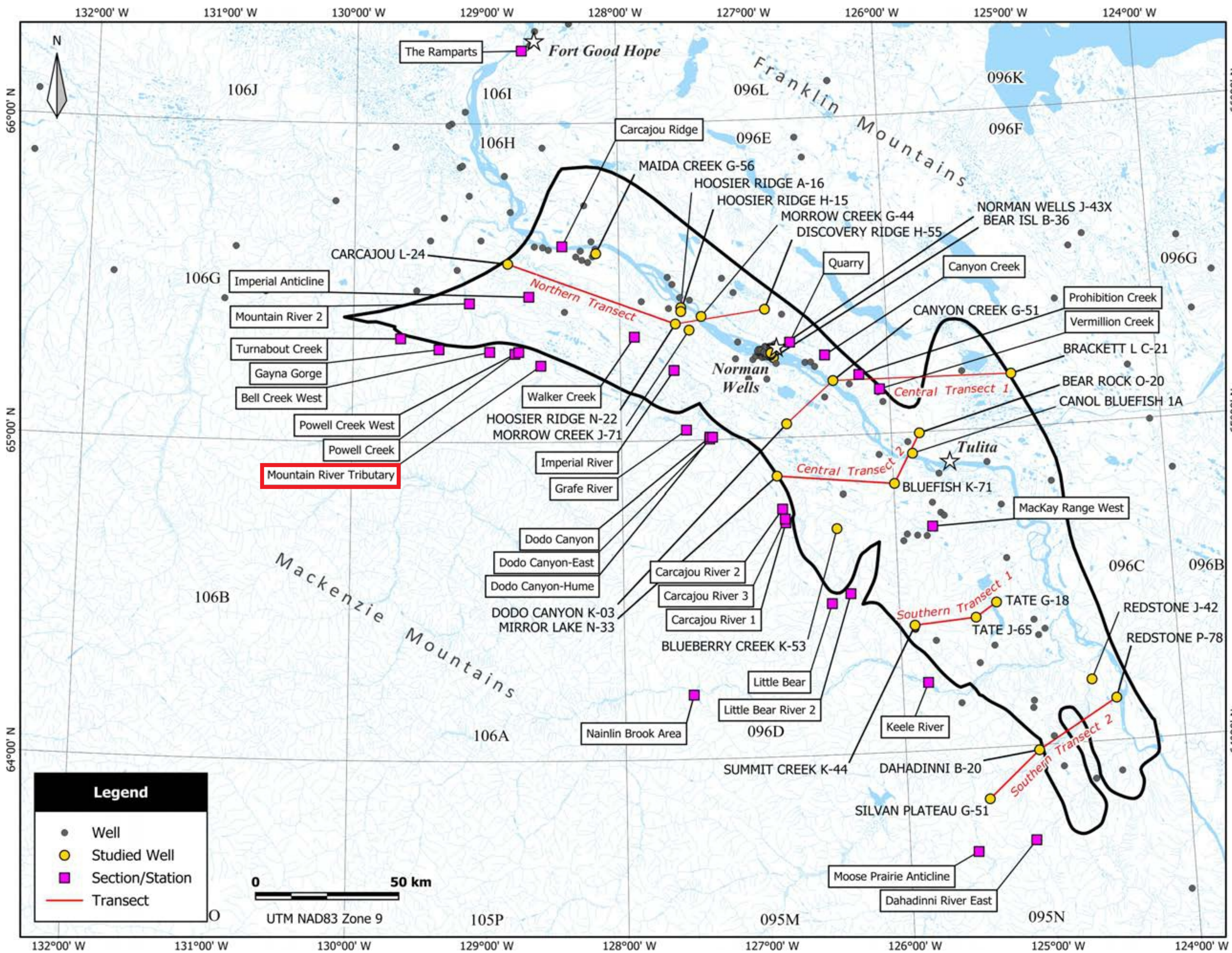

130° W
120° W
N
Inuvik
Anderson Plain
Mackenzie River
Peel Plain
Colville Hills
Peel Plateau
NUNAVUT
65° N
Norman Wells
FRANKLIN MOUNTAINS
Proposed Reference Section for Horn River Group
Great Bear Lake
Great Bear Plain
Mackenzie Plain
MACKENZIE MOUNTAINS
Mackenzie Mountains
NORTHWEST TERRITORIES
Franklin Mountains
YUKON TERRITORY
Great Slave Plain
Yellowknife
Type Horn River outcrop
Fort Simpson
60° N
Great Slave Lake
Liard Basin
Fort Liard
Horn River Basin
Cordova Embayment
BRITISH COLUMBIA
ALBERTA
Type Horn River Formation, Fort Nelson a-95J/94-J-10 well
Paved Highway
Unpaved Highway
0
200 km
130° W
120° W

Figure 1



132°00' W
131°00' W
130°00' W
129°00' W
128°00' W
127°00' W
126°00' W
125°00' W
124°00' W
66°00' N
65°00' N
64°00' N
N
The Ramparts
Fort Good Hope
Franklin Mountains
106J
106I
096L
096K
096F
106H
096E
Carcajou Ridge
MAIDA CREEK G-56
HOOSIER RIDGE A-16
HOOSIER RIDGE H-15
MORROW CREEK G-44
DISCOVERY RIDGE H-55
NORMAN WELLS J-43X
BEAR ISL B-36
CARCAJOU L-24
Quarry
Canyon Creek
096G
106G
Imperial Anticline
Northern Transect
Mountain River 2
CANYON CREEK G-51
Prohibition Creek
Vermillion Creek
Turnabout Creek
BRACKETT L C-21
Gayna Gorge
Norman Wells
Central Transect 1
Bell Creek West
Walker Creek
BEAR ROCK O-20
CANOL BLUEFISH 1A
HOOSIER RIDGE N-22
Powell Creek West
MORROW CREEK J-71
Powell Creek
Tulita
Imperial River
Mountain River Tributary
Central Transect 2
Grafe River
BLUEFISH K-71
MacKay Range West
Dodo Canyon
Dodo Canyon-East
096C
096B
Mackenzie Mountains
Dodo Canyon-Hume
Carcajou River 2
Carcajou River 3
Southern Transect 1
106B
TATE G-18
DODO CANYON K-03
Carcajou River 1
REDSTONE J-42
MIRROR LAKE N-33
TATE J-65
BLUEBERRY CREEK K-53
REDSTONE P-78
Little Bear
Little Bear River 2
Keele River
Nainlin Brook Area
106A
096D
Southern Transect 2
SUMMIT CREEK K-44
DAHADINNI B-20
Legend
Well
Studied Well
Section/Station
Transect
SILVAN PLATEAU G-51
0
50 km
Moose Prairie Anticline
Dahadinni River East
UTM NAD83 Zone 9
O
105P
095M
095N

Figure 2

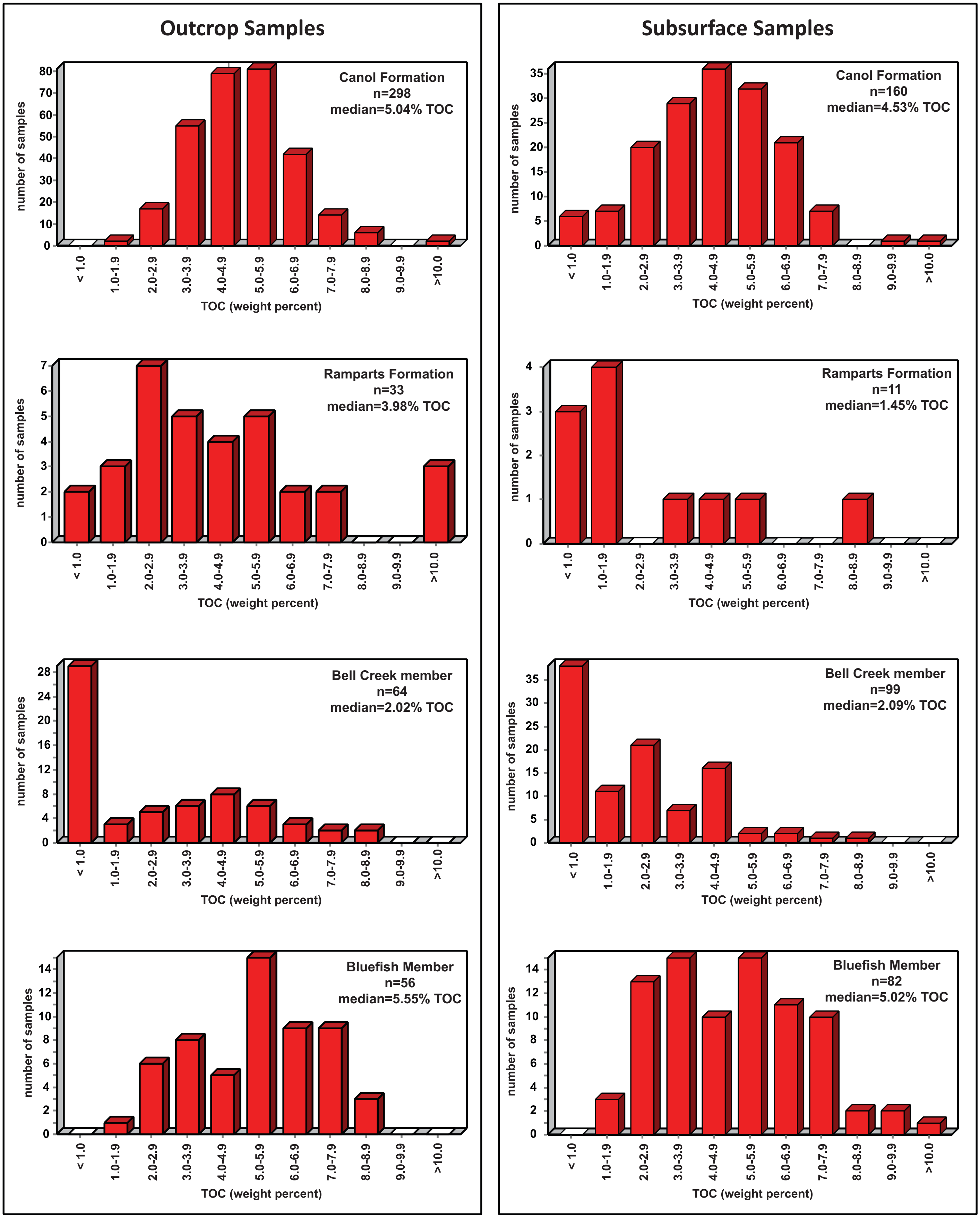
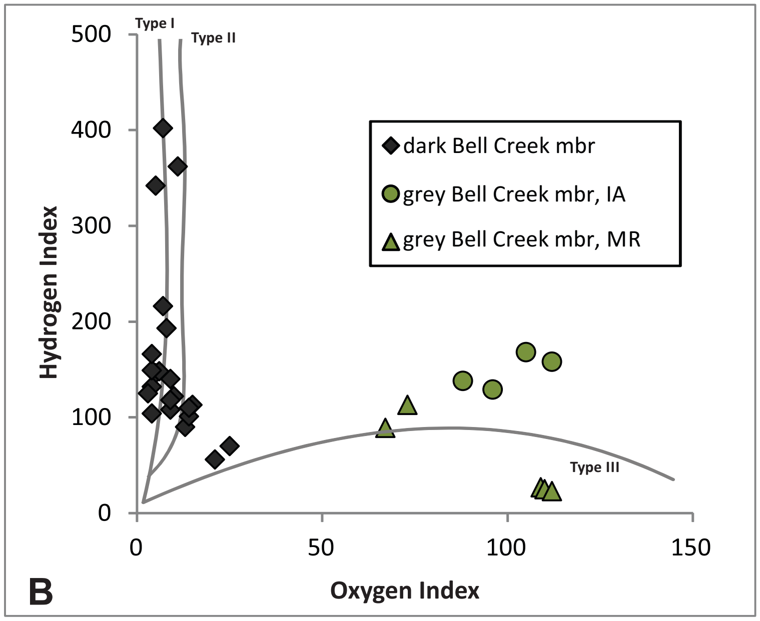

Outcrop Samples
Subsurface Samples
Canol Formation
n=298
median=5.04% TOC
Canol Formation
n=160
median=4.53% TOC
Ramparts Formation
n=33
median=3.98% TOC
Ramparts Formation
n=11
median=1.45% TOC
Bell Creek member
n=64
median=2.02% TOC
Bell Creek member
n=99
median=2.09% TOC
Bluefish Member
n=56
median=5.55% TOC
Bluefish Member
n=82
median=5.02% TOC
number of samples
TOC (weight percent)
< 1.0
1.0-1.9
2.0-2.9
3.0-3.9
4.0-4.9
5.0-5.9
6.0-6.9
7.0-7.9
8.0-8.9
9.0-9.9
>10.0

Figure 3


Type I
Type II
Type III
dark Bell Creek mbr
grey Bell Creek mbr, IA
grey Bell Creek mbr, MR
Hydrogen Index
Oxygen Index
0
100
200
300
400
500
0
50
100
150
B

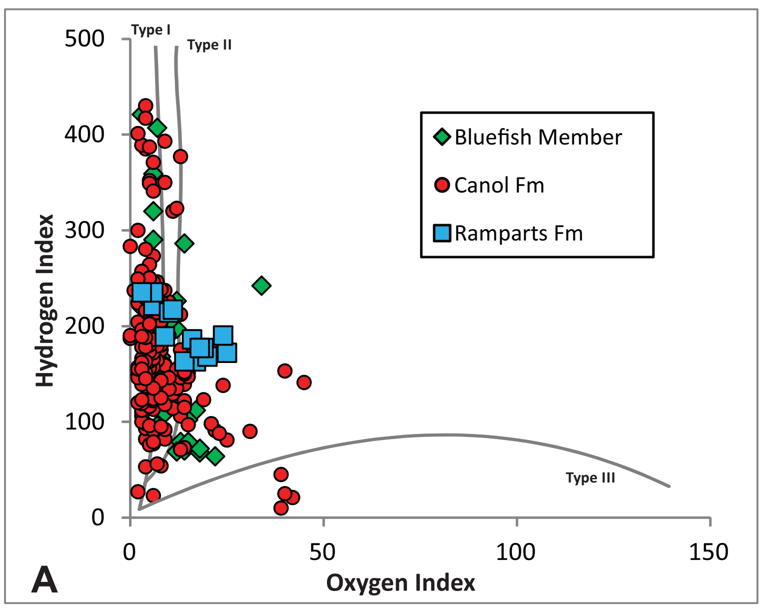
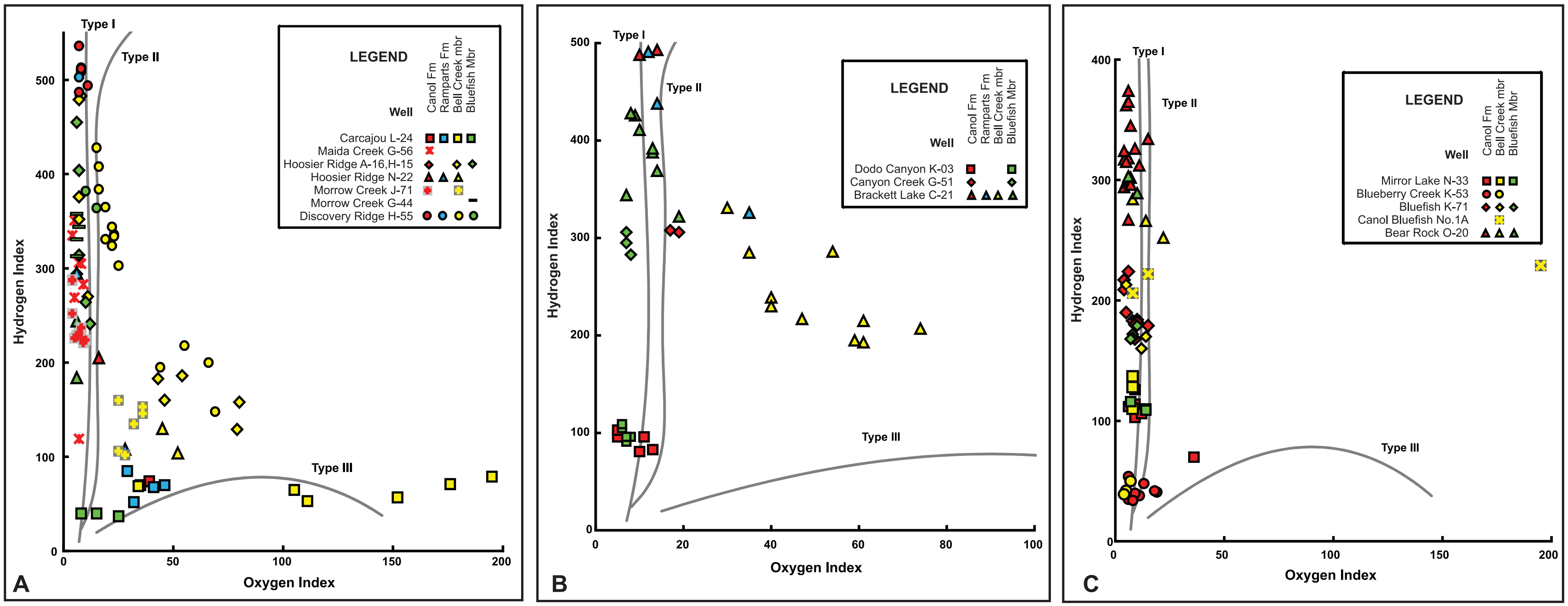

Type I
Type II
Type III
Bluefish Member
Canol Fm
Ramparts Fm
Hydrogen Index
Oxygen Index
0
100
200
300
400
500
0
50
100
150
A

Figure 4



A
Hydrogen Index
Oxygen Index
Type I
Type II
Type III
LEGEND
Well
Canol Fm
Ramparts Fm
Bell Creek mbr
Bluefish Mbr
Carcajou L-24
Maida Creek G-56
Hoosier Ridge A-16,H-15
Hoosier Ridge N-22
Morrow Creek J-71
Morrow Creek G-44
Discovery Ridge H-55
B
Hydrogen Index
Oxygen Index
Type I
Type II
Type III
LEGEND
Well
Canol Fm
Ramparts Fm
Bell Creek mbr
Bluefish Mbr
Dodo Canyon K-03
Canyon Creek G-51
Brackett Lake C-21
C
Hydrogen Index
Oxygen Index
Type I
Type II
Type III
LEGEND
Well
Canol Fm
Bell Creek mbr
Bluefish Mbr
Mirror Lake N-33
Blueberry Creek K-53
Bluefish K-71
Canol Bluefish No.1A
Bear Rock O-20

Figure 5

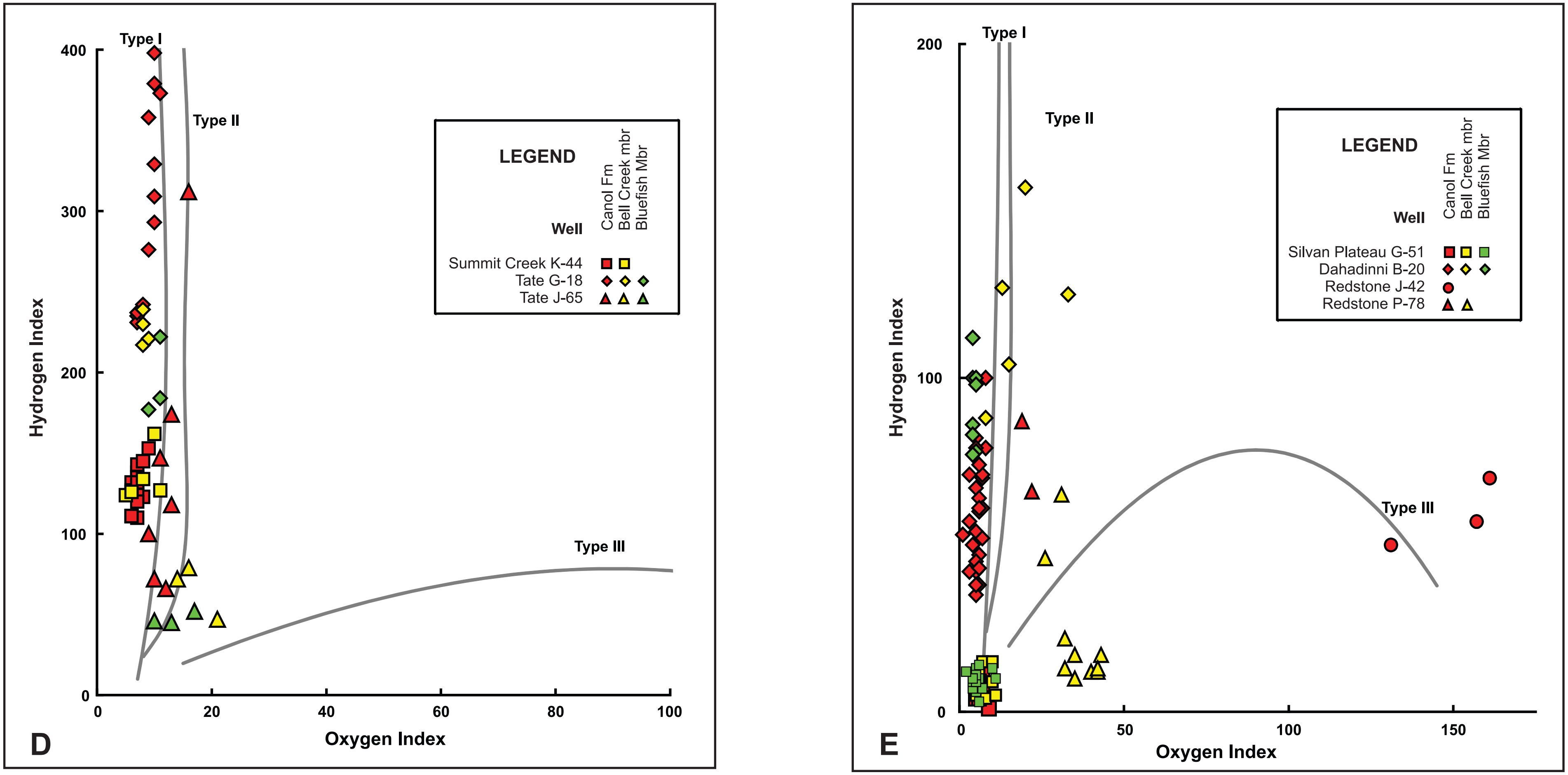
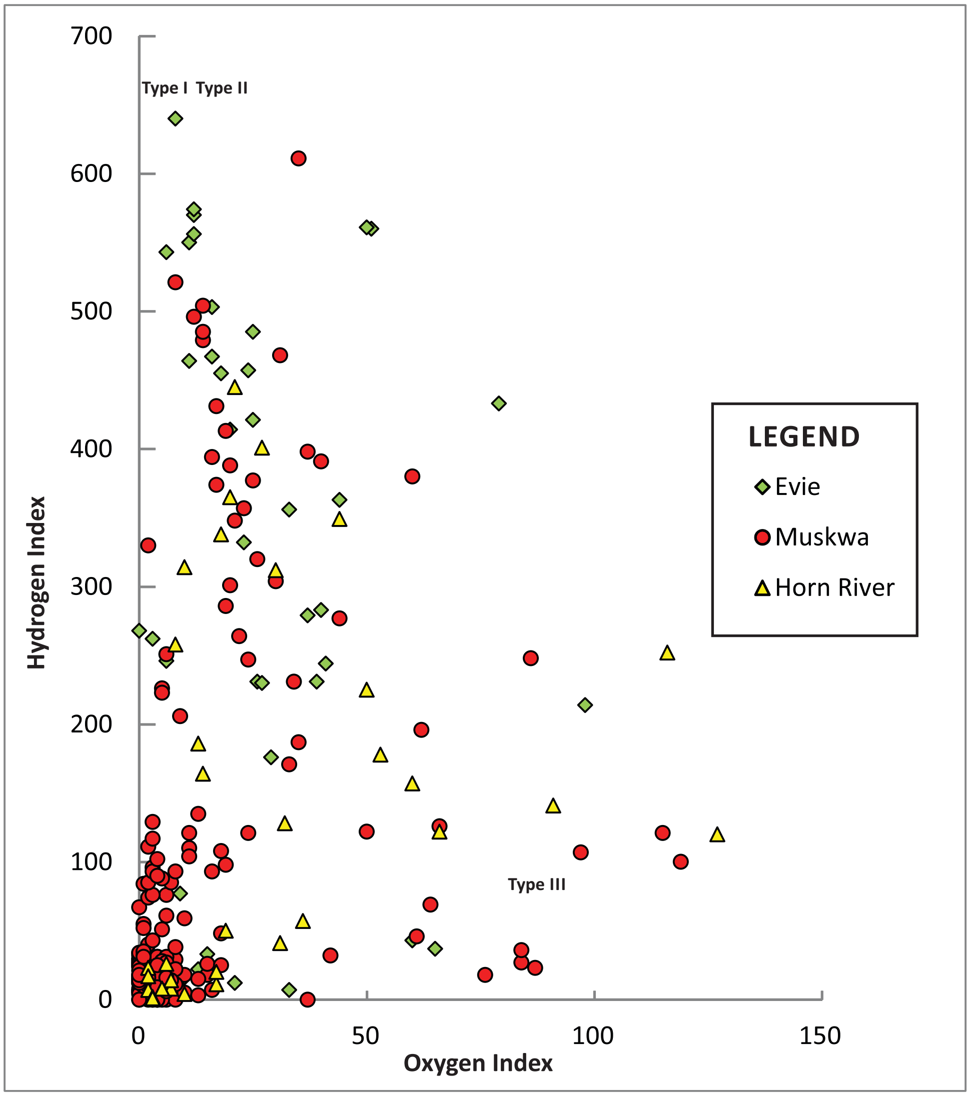
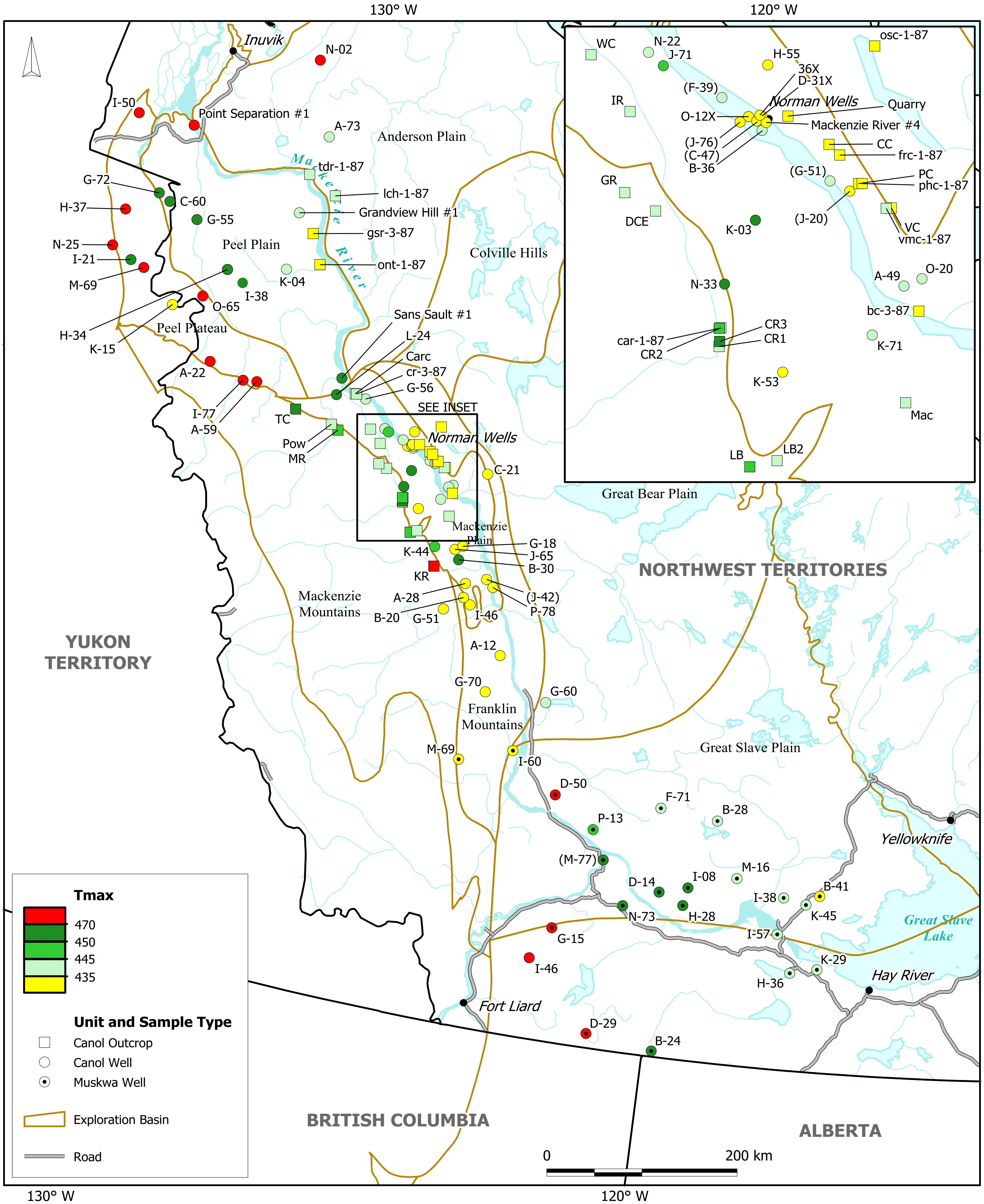

Type I
Type II
Type III
LEGEND
Well
Canol Fm
Bell Creek mbr
Bluefish Mbr
Summit Creek K-44
Tate G-18
Tate J-65
Hydrogen Index
Oxygen Index
D
LEGEND
Well
Canol Fm
Bell Creek mbr
Bluefish Mbr
Silvan Plateau G-51
Dahadinni B-20
Redstone J-42
Redstone P-78
Hydrogen Index
Oxygen Index
E

Figure 5



700
600
500
400
300
200
100
0
Hydrogen Index
Type I
Type II
Type III
0
50
100
150
Oxygen Index
LEGEND
Evie
Muskwa
Horn River

Figure 6



130° W
120° W
65° N
60° N
Inuvik
N-02
I-50
Point Separation #1
A-73
Anderson Plain
Mackenzie River
tdr-1-87
G-72
C-60
lch-1-87
H-37
Grandview Hill #1
G-55
gsr-3-87
N-25
Peel Plain
I-21
ont-1-87
Colville Hills
M-69
K-04
I-38
O-65
H-34
Peel Plateau
K-15
Sans Sault #1
L-24
Carc
A-22
cr-3-87
G-56
I-77
A-59
TC
SEE INSET
Pow
MR
Norman Wells
C-21
Great Bear Plain
Mackenzie Plain
G-18
J-65
B-30
K-44
KR
NORTHWEST TERRITORIES
Mackenzie Mountains
A-28
(J-42)
P-78
B-20
G-51
I-46
YUKON TERRITORY
A-12
G-70
G-60
Franklin Mountains
Great Slave Plain
M-69
I-60
D-50
F-71
B-28
P-13
Yellowknife
(M-77)
M-16
D-14
I-08
B-41
I-38
N-73
H-28
K-45
Great Slave Lake
G-15
I-57
K-29
I-46
H-36
Hay River
Fort Liard
D-29
B-24
WC
N-22
J-71
H-55
osc-1-87
36X
D-31X
(F-39)
IR
Quarry
O-12X
Mackenzie River #4
(J-76)
(C-47)
B-36
CC
frc-1-87
GR
(G-51)
PC
phc-1-87
DCE
K-03
(J-20)
VC
vmc-1-87
N-33
A-49
O-20
bc-3-87
CR3
car-1-87
CR1
CR2
K-71
K-53
Mac
LB
LB2
Tmax
470
450
445
435
Unit and Sample Type
Canol Outcrop
Canol Well
Muskwa Well
Exploration Basin
Road
BRITISH COLUMBIA
ALBERTA
0
200 km

Figure 7

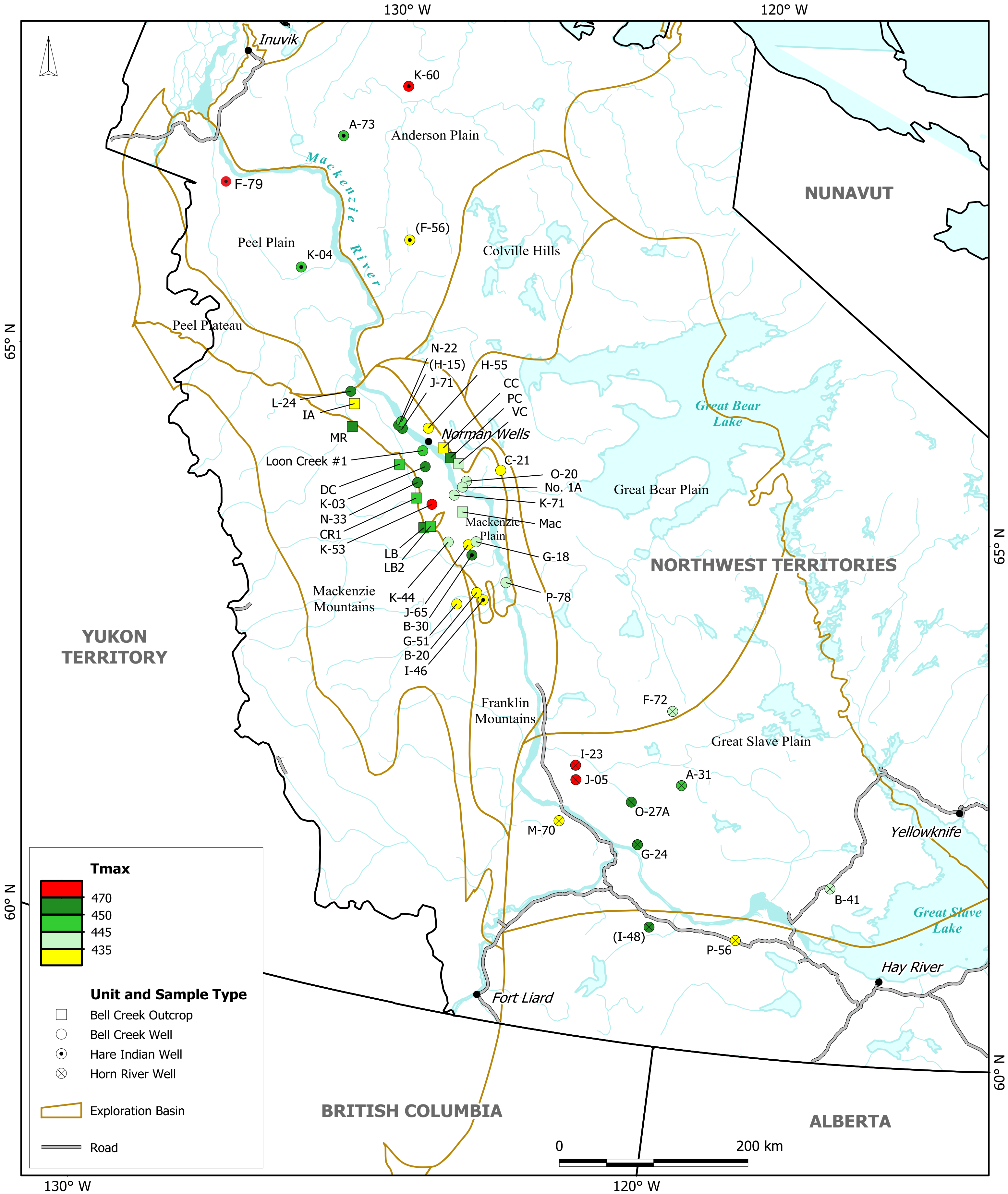

130° W
120° W
65° N
60° N
Inuvik
K-60
A-73
Anderson Plain
Mackenzie River
F-79
NUNAVUT
(F-56)
Peel Plain
K-04
Colville Hills
Peel Plateau
N-22
(H-15)
H-55
J-71
CC
PC
VC
L-24
IA
MR
Norman Wells
Great Bear Lake
Loon Creek #1
C-21
O-20
No. 1A
Great Bear Plain
DC
K-03
N-33
CR1
K-53
K-71
Mackenzie Plain
Mac
LB
LB2
G-18
NORTHWEST TERRITORIES
Mackenzie Mountains
K-44
J-65
B-30
G-51
B-20
I-46
P-78
YUKON TERRITORY
Franklin Mountains
F-72
Great Slave Plain
I-23
J-05
A-31
O-27A
M-70
Yellowknife
G-24
B-41
Great Slave Lake
(I-48)
P-56
Hay River
Fort Liard
Tmax
470
450
445
435
Unit and Sample Type
Bell Creek Outcrop
Bell Creek Well
Hare Indian Well
Horn River Well
Exploration Basin
Road
BRITISH COLUMBIA
ALBERTA
0
200 km

Figure 8

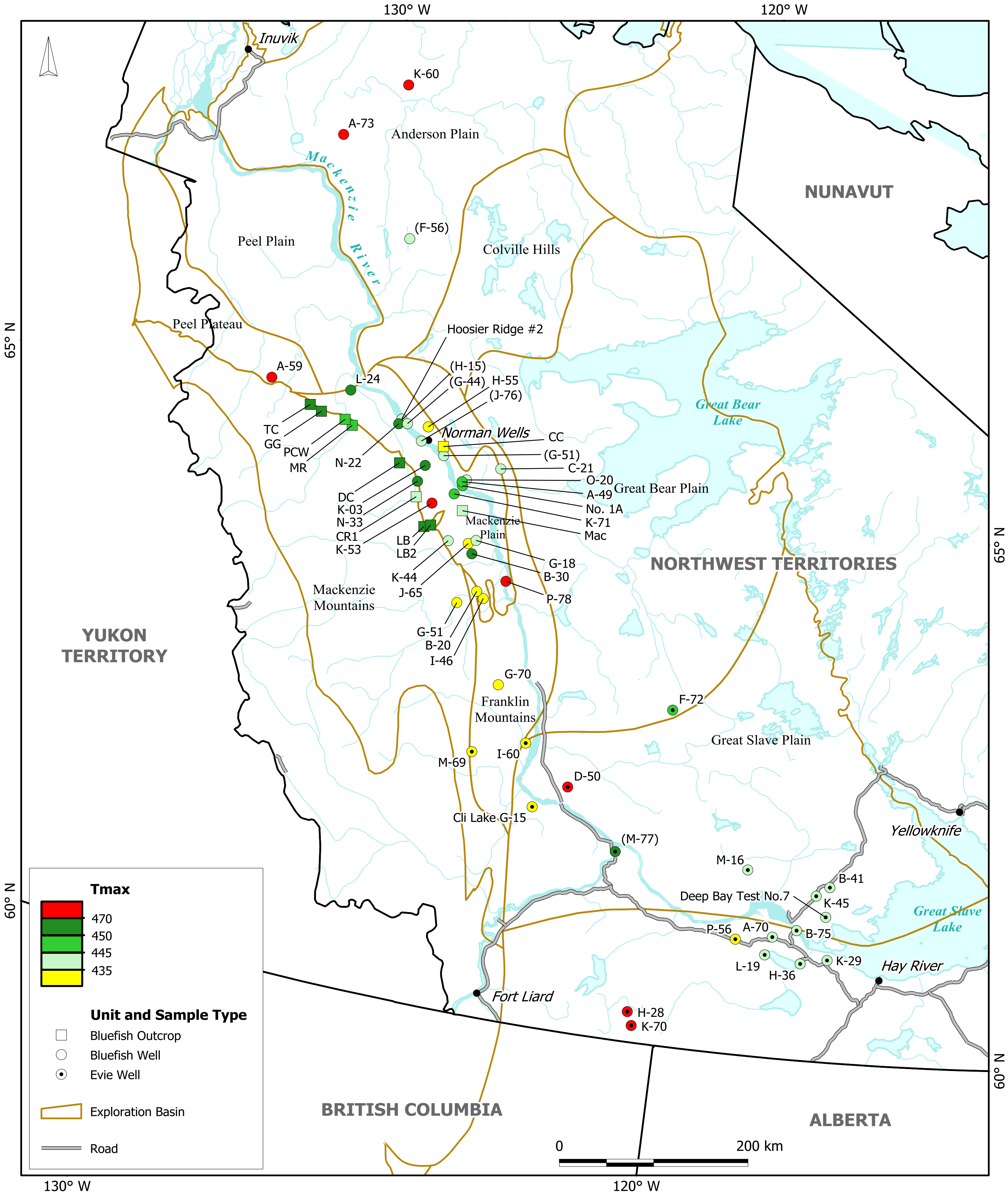

130° W
120° W
Inuvik
K-60
A-73
Anderson Plain
Mackenzie River
Peel Plain
(F-56)
Colville Hills
NUNAVUT
Peel Plateau
Hoosier Ridge #2
A-59
L-24
(H-15)
(G-44)
H-55
(J-76)
TC
GG
PCW
MR
N-22
Norman Wells
CC
(G-51)
C-21
O-20
A-49
No. 1A
K-71
Mac
Great Bear Lake
Great Bear Plain
DC
K-03
N-33
CR1
K-53
LB
LB2
Mackenzie Plain
G-18
B-30
P-78
K-44
J-65
NORTHWEST TERRITORIES
Mackenzie Mountains
G-51
B-20
I-46
YUKON TERRITORY
G-70
Franklin Mountains
F-72
Great Slave Plain
I-60
M-69
D-50
Cli Lake G-15
(M-77)
Yellowknife
M-16
B-41
Deep Bay Test No.7
K-45
P-56
A-70
B-75
Great Slave Lake
L-19
H-36
K-29
Hay River
Fort Liard
H-28
K-70
BRITISH COLUMBIA
ALBERTA
0
200 km
65° N
60° N
Tmax
470
450
445
435
Unit and Sample Type
Bluefish Outcrop
Bluefish Well
Evie Well
Exploration Basin
Road

Figure 9

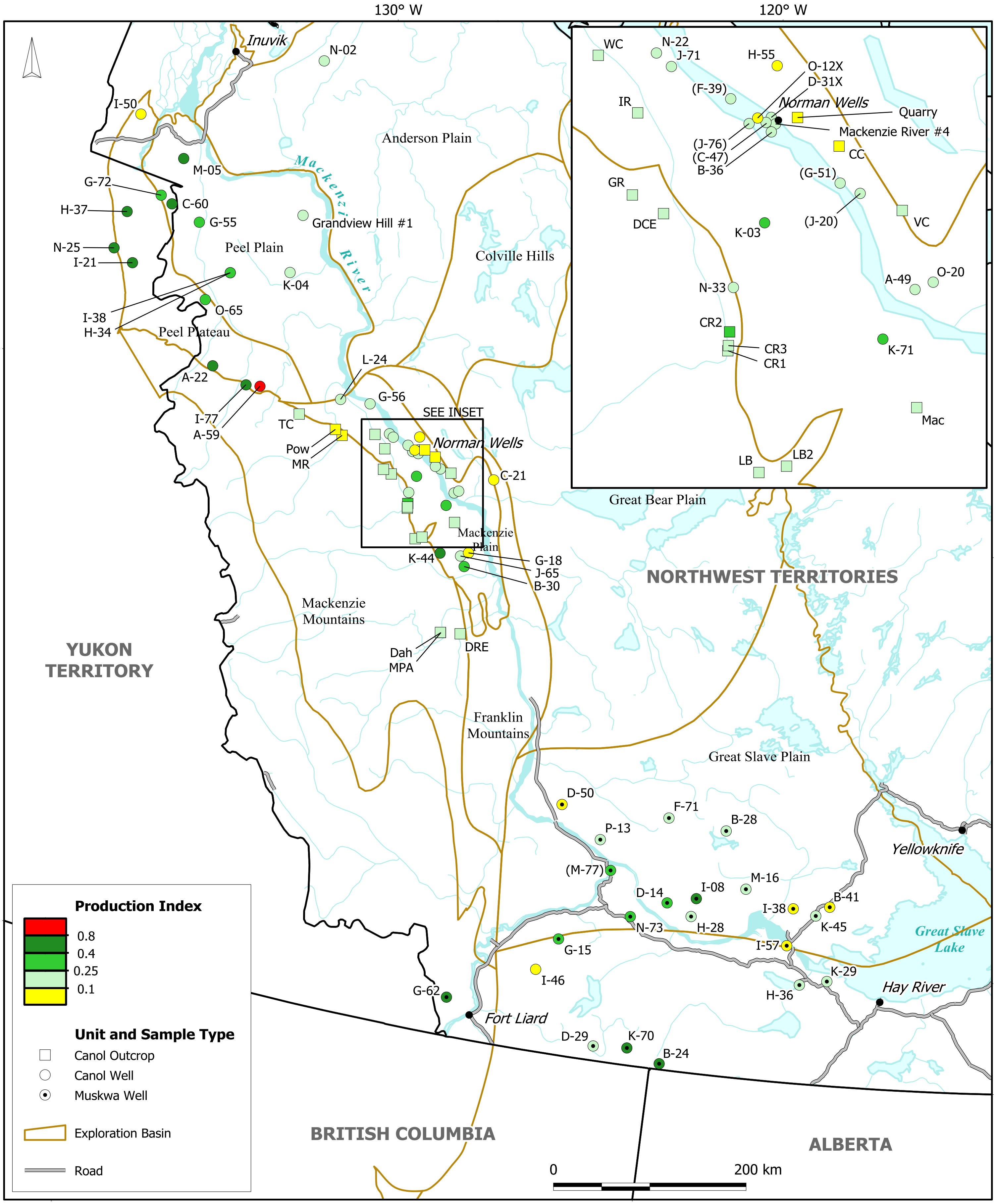

130° W
120° W
65° N
60° N
Inuvik
N-02
I-50
M-05
G-72
C-60
H-37
G-55
N-25
I-21
Grandview Hill #1
Anderson Plain
Mackenzie River
Peel Plain
Colville Hills
K-04
O-65
I-38
H-34
Peel Plateau
A-22
L-24
G-56
I-77
A-59
TC
Pow
MR
SEE INSET
Norman Wells
C-21
Mackenzie Plain
K-44
G-18
J-65
B-30
Mackenzie Mountains
Dah
MPA
DRE
YUKON TERRITORY
NORTHWEST TERRITORIES
Great Bear Plain
Franklin Mountains
Great Slave Plain
D-50
F-71
B-28
P-13
(M-77)
D-14
I-08
M-16
H-28
I-38
B-41
K-45
N-73
I-57
G-15
I-46
G-62
K-29
H-36
Yellowknife
Great Slave Lake
Hay River
Fort Liard
D-29
K-70
B-24
BRITISH COLUMBIA
ALBERTA
0
200 km
WC
N-22
J-71
H-55
O-12X
D-31X
(F-39)
IR
Quarry
Mackenzie River #4
(J-76)
(C-47)
B-36
CC
(G-51)
GR
DCE
K-03
(J-20)
VC
N-33
A-49
O-20
CR2
CR3
CR1
K-71
Mac
LB
LB2
Production Index
0.8
0.4
0.25
0.1
Unit and Sample Type
Canol Outcrop
Canol Well
Muskwa Well
Exploration Basin
Road

Figure 10

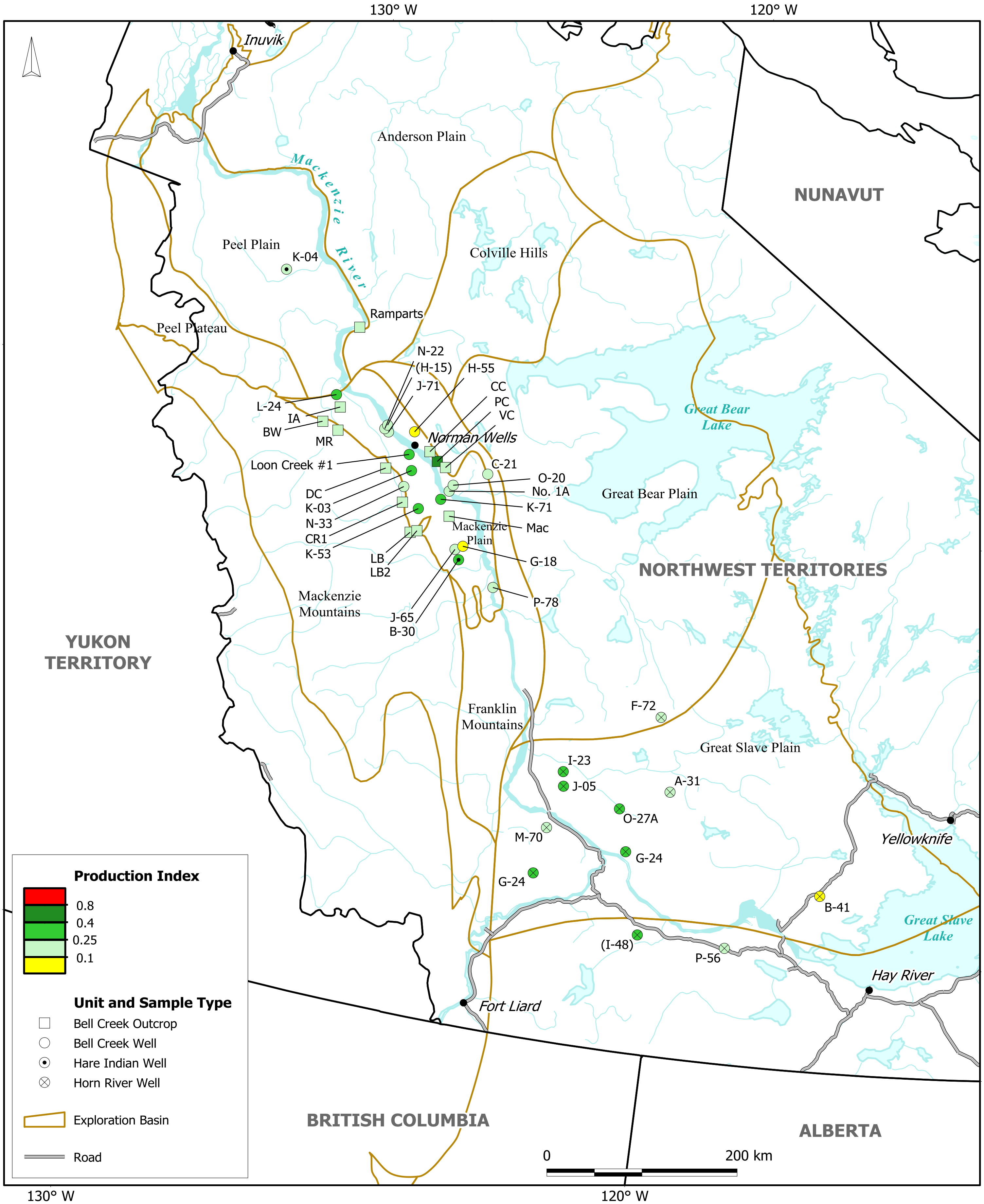
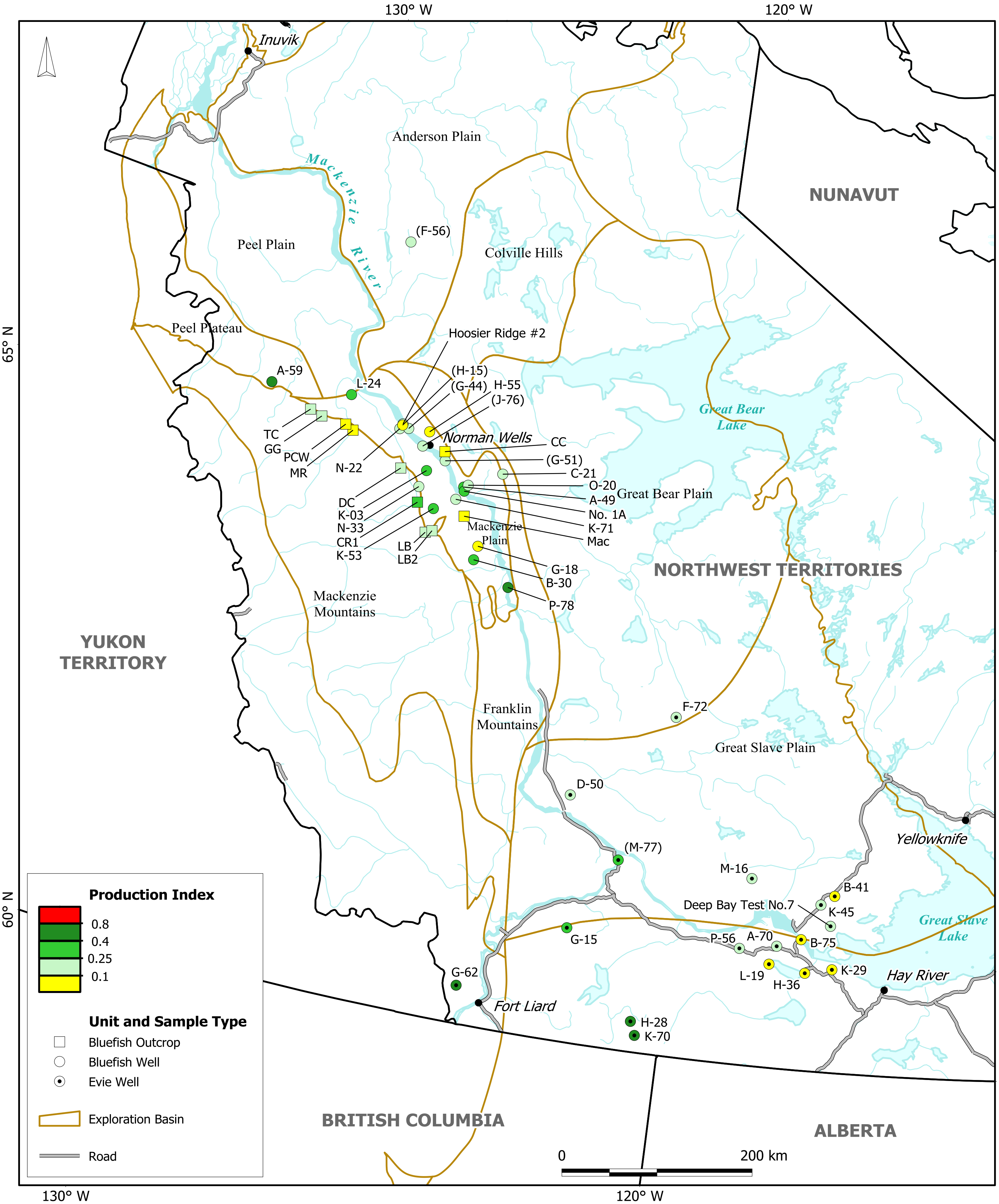

130° W
120° W
Inuvik
Anderson Plain
Mackenzie River
NUNAVUT
Peel Plain
K-04
Colville Hills
Ramparts
Peel Plateau
65° N
N-22
(H-15)
J-71
H-55
CC
PC
VC
L-24
IA
BW
MR
Norman Wells
Great Bear Lake
Loon Creek #1
C-21
O-20
No. 1A
Great Bear Plain
DC
K-03
N-33
CR1
K-53
K-71
Mackenzie Plain
Mac
LB
LB2
G-18
NORTHWEST TERRITORIES
Mackenzie Mountains
P-78
J-65
B-30
YUKON TERRITORY
Franklin Mountains
F-72
Great Slave Plain
I-23
J-05
A-31
O-27A
M-70
Yellowknife
G-24
G-24
B-41
Great Slave Lake
(I-48)
P-56
Hay River
Fort Liard
60° N
Production Index
0.8
0.4
0.25
0.1
Unit and Sample Type
Bell Creek Outcrop
Bell Creek Well
Hare Indian Well
Horn River Well
Exploration Basin
Road
BRITISH COLUMBIA
ALBERTA
0
200 km

Figure 11



130° W
120° W
Inuvik
NUNAVUT
Anderson Plain
Mackenzie River
Peel Plain
(F-56)
Colville Hills
Peel Plateau
Hoosier Ridge #2
A-59
L-24
(H-15)
(G-44)
H-55
(J-76)
Great Bear Lake
TC
GG
PCW
MR
N-22
Norman Wells
CC
(G-51)
C-21
O-20
A-49
Great Bear Plain
No. 1A
K-71
Mac
DC
K-03
N-33
CR1
K-53
LB
LB2
Mackenzie Plain
G-18
B-30
P-78
NORTHWEST TERRITORIES
65° N
Mackenzie Mountains
YUKON TERRITORY
Franklin Mountains
F-72
Great Slave Plain
D-50
(M-77)
Yellowknife
M-16
B-41
Deep Bay Test No.7
K-45
60° N
G-15
P-56
A-70
B-75
Great Slave Lake
G-62
L-19
H-36
K-29
Hay River
Fort Liard
H-28
K-70
Production Index
0.8
0.4
0.25
0.1
Unit and Sample Type
Bluefish Outcrop
Bluefish Well
Evie Well
Exploration Basin
Road
BRITISH COLUMBIA
ALBERTA
0
200 km

Figure 12

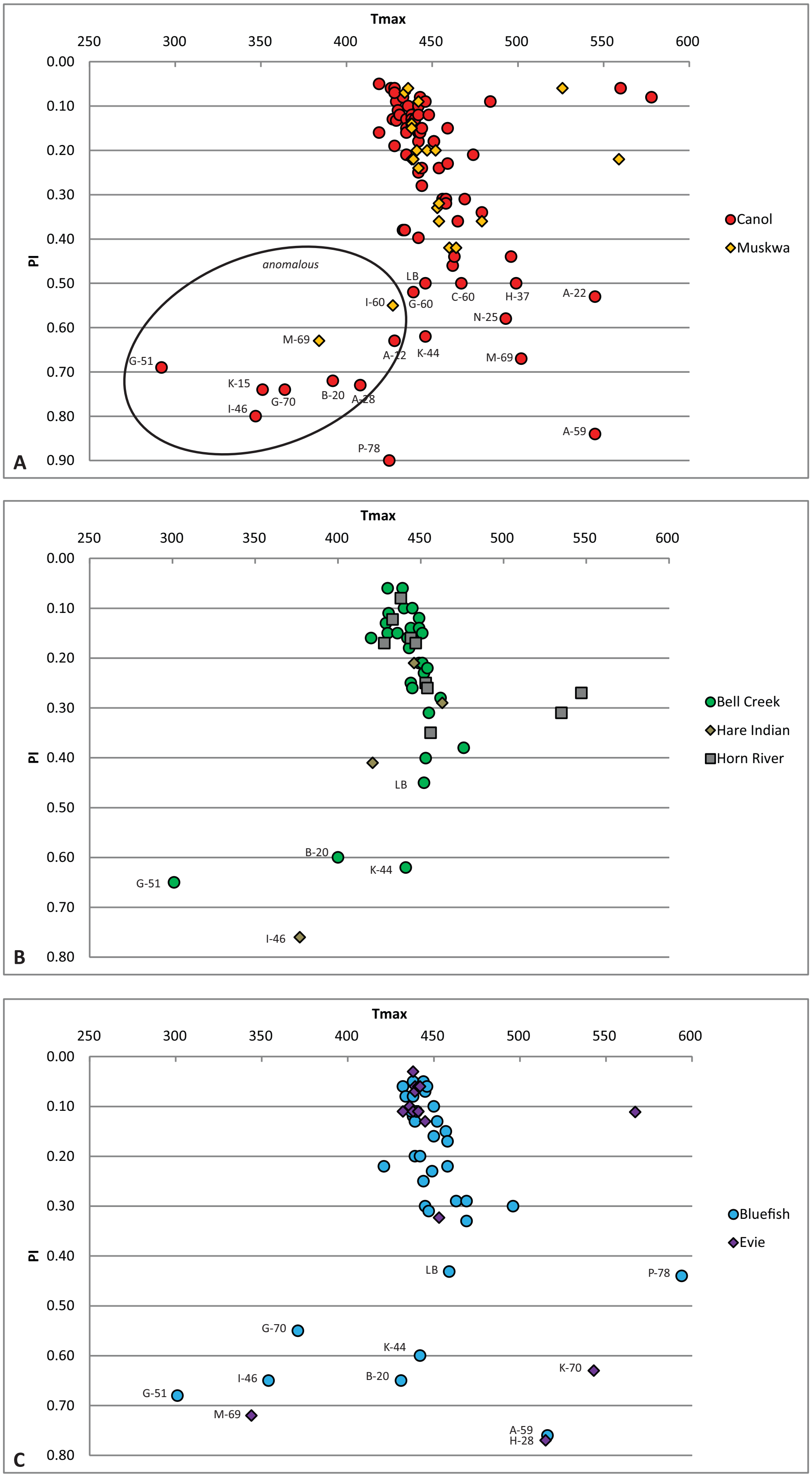
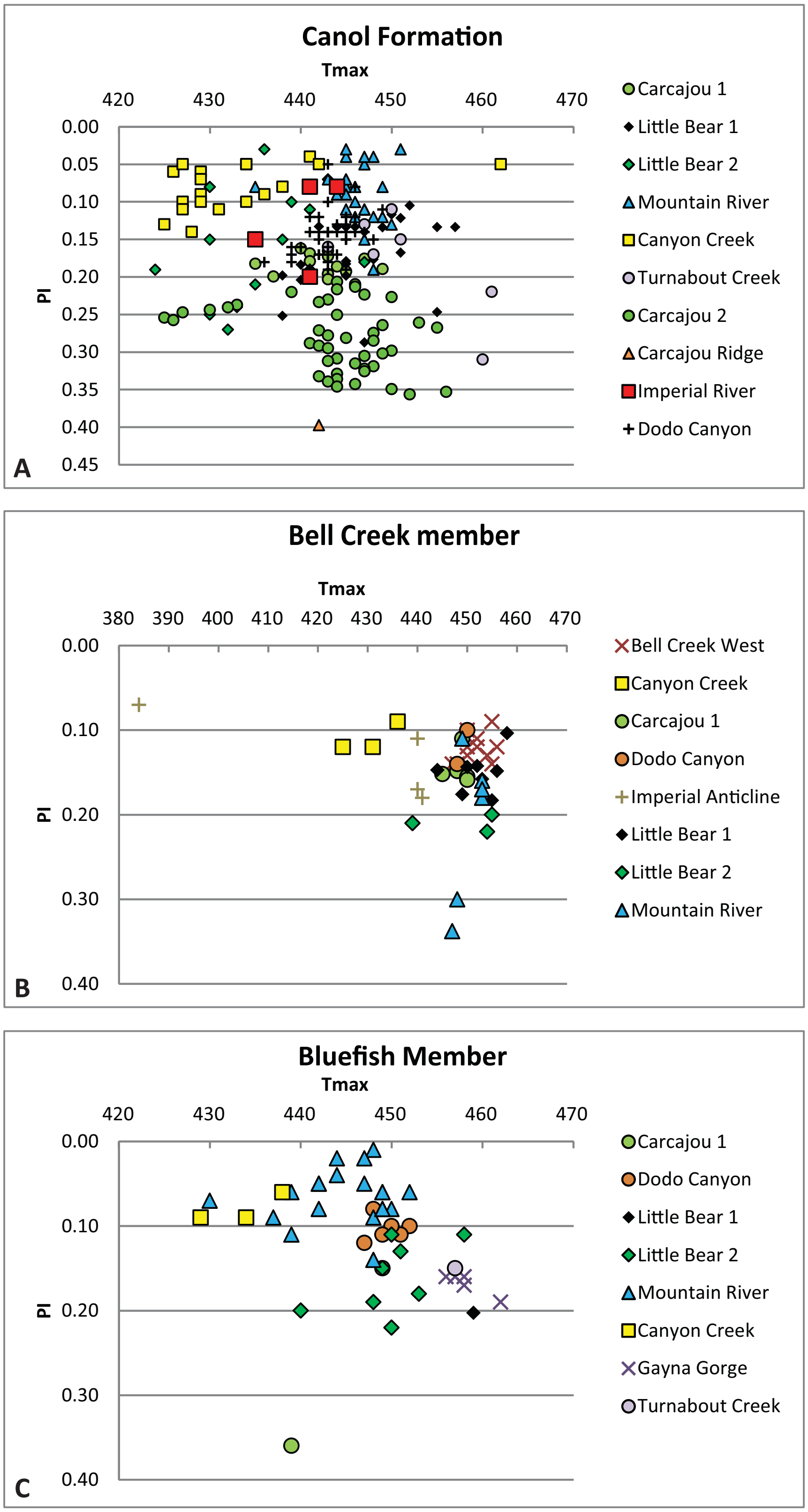

Tmax
PI
anomalous
Canol
Muskwa
LB
I-60
G-60
C-60
H-37
A-22
N-25
M-69
A-12
K-44
G-51
K-15
G-70
B-20
A-28
I-46
P-78
A-59
A
Bell Creek
Hare Indian
Horn River
B
Bluefish
Evie
K-70
H-28
C

Figure 13



Canol Formation
Tmax
420 430 440 450 460 470
0.00 0.05 0.10 0.15 0.20 0.25 0.30 0.35 0.40 0.45
PI
A
Carcajou 1
Little Bear 1
Little Bear 2
Mountain River
Canyon Creek
Turnabout Creek
Carcajou 2
Carcajou Ridge
Imperial River
Dodo Canyon
Bell Creek member
Tmax
380 390 400 410 420 430 440 450 460 470
0.00 0.10 0.20 0.30 0.40
PI
B
Bell Creek West
Canyon Creek
Carcajou 1
Dodo Canyon
Imperial Anticline
Little Bear 1
Little Bear 2
Mountain River
Bluefish Member
Tmax
420 430 440 450 460 470
0.00 0.10 0.20 0.30 0.40
PI
C
Carcajou 1
Dodo Canyon
Little Bear 1
Little Bear 2
Mountain River
Canyon Creek
Gayna Gorge
Turnabout Creek

Figure 14

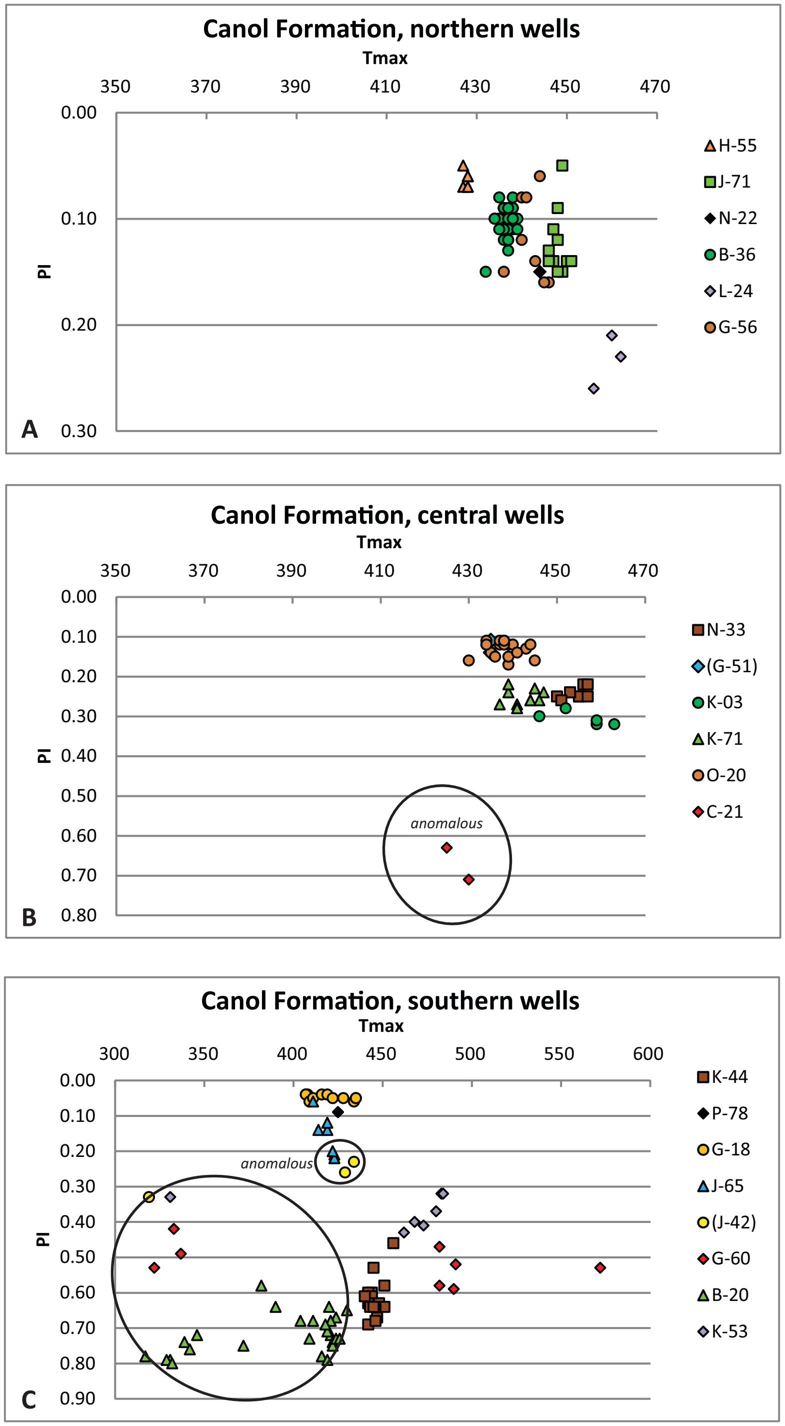
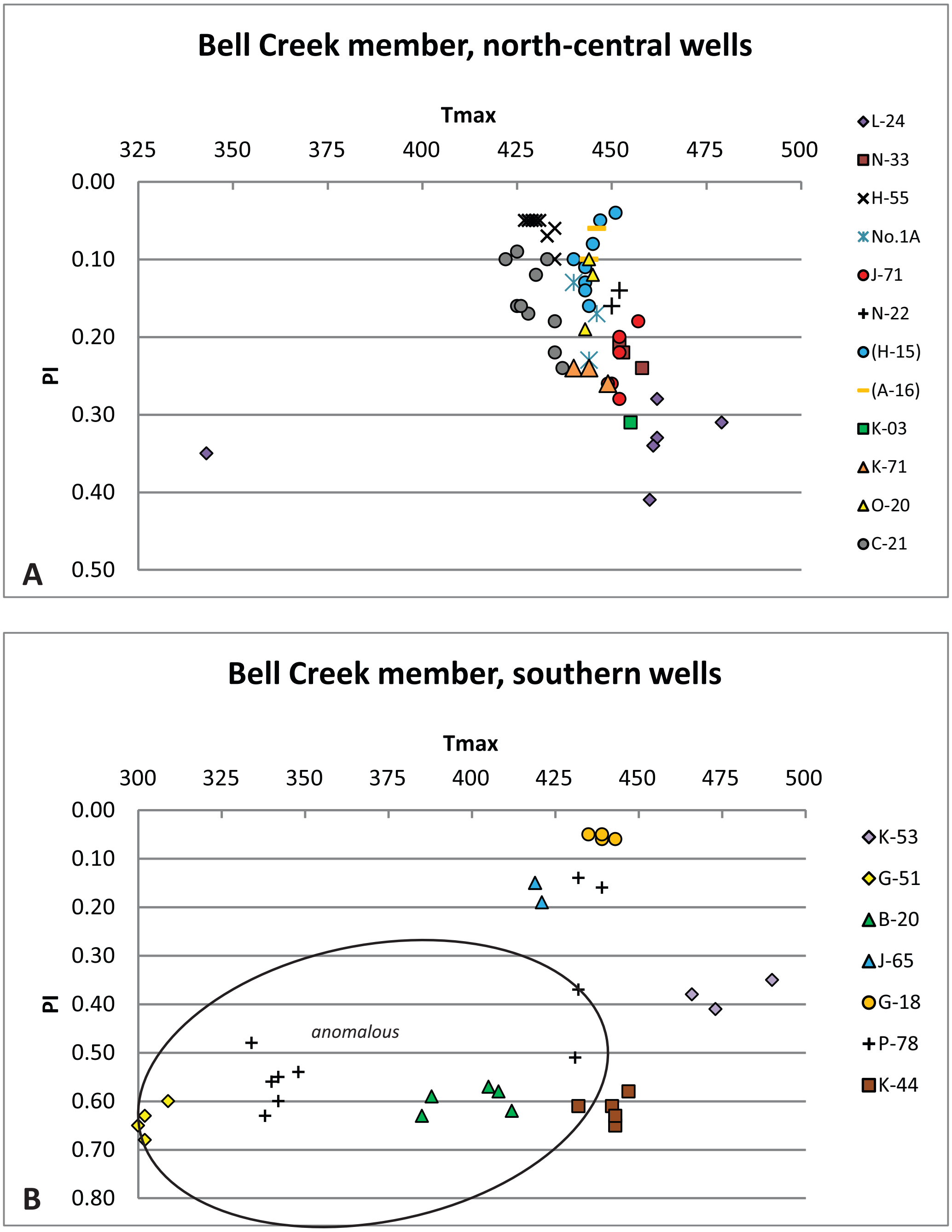

Canol Formation, northern wells
Tmax
350
370
390
410
430
450
470
0.00
0.10
0.20
0.30
PI
H-55
J-71
N-22
B-36
L-24
G-56
A
Canol Formation, central wells
Tmax
350
370
390
410
430
450
470
0.00
0.10
0.20
0.30
0.40
0.50
0.60
0.70
0.80
PI
N-33
(G-51)
K-03
K-71
O-20
C-21
anomalous
B
Canol Formation, southern wells
Tmax
300
350
400
450
500
550
600
0.00
0.10
0.20
0.30
0.40
0.50
0.60
0.70
0.80
0.90
PI
K-44
P-78
G-18
J-65
(J-42)
G-60
B-20
K-53
anomalous
C

Figure 15



Bell Creek member, north-central wells
Tmax
325
350
375
400
425
450
475
500
0.00
0.10
0.20
0.30
0.40
0.50
PI
A
L-24
N-33
H-55
No.1A
J-71
N-22
(H-15)
(A-16)
K-03
K-71
O-20
C-21
Bell Creek member, southern wells
Tmax
300
325
350
375
400
425
450
475
500
0.00
0.10
0.20
0.30
0.40
0.50
0.60
0.70
0.80
PI
anomalous
B
K-53
G-51
B-20
J-65
G-18
P-78
K-44

Figure 16

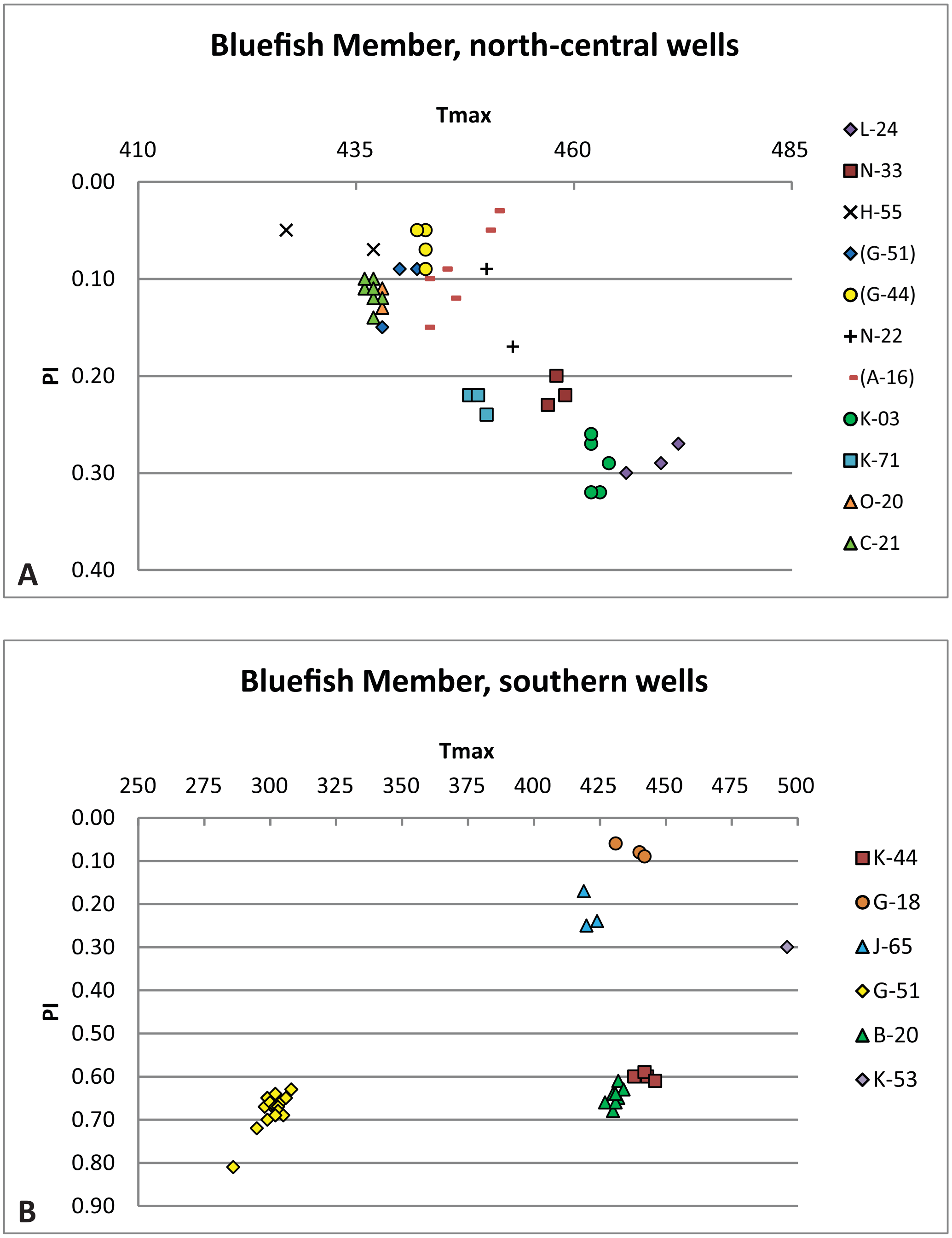
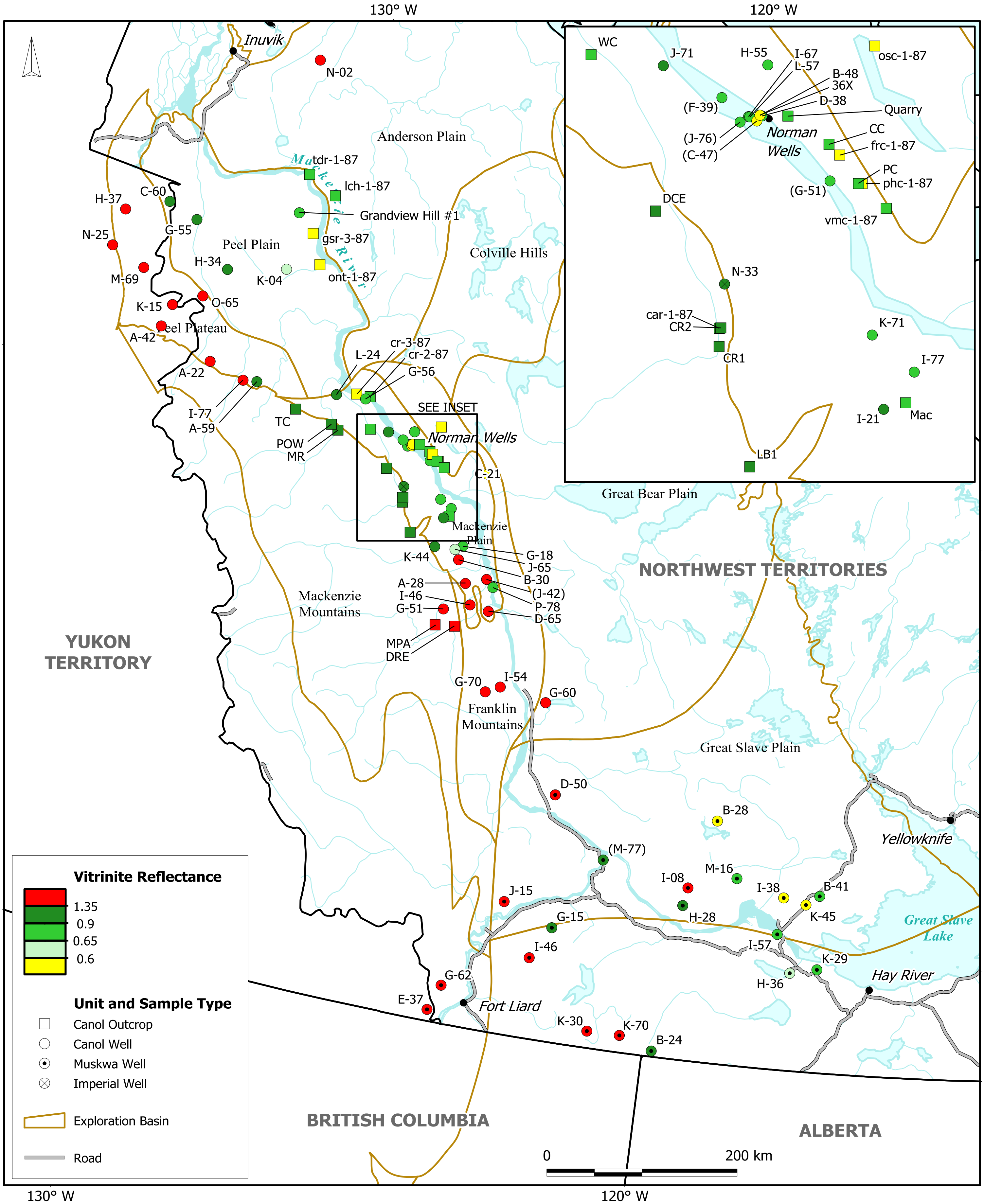

Bluefish Member, north-central wells
Tmax
410
435
460
485
PI
0.00
0.10
0.20
0.30
0.40
A
L-24
N-33
H-55
(G-51)
(G-44)
N-22
(A-16)
K-03
K-71
O-20
C-21
Bluefish Member, southern wells
Tmax
250
275
300
325
350
375
400
425
450
475
500
PI
0.00
0.10
0.20
0.30
0.40
0.50
0.60
0.70
0.80
0.90
B
K-44
G-18
J-65
G-51
B-20
K-53

Figure 17



130° W
120° W
65° N
60° N
Inuvik
N-02
Anderson Plain
Mackenzie River
tdr-1-87
lch-1-87
Grandview Hill #1
gsr-3-87
ont-1-87
Colville Hills
Peel Plain
H-37
C-60
G-55
N-25
H-34
K-04
M-69
K-15
O-65
A-42
Peel Plateau
A-22
I-77
A-59
L-24
cr-3-87
cr-2-87
G-56
TC
POW
MR
SEE INSET
Norman Wells
C-21
Mackenzie Plain
K-44
G-18
J-65
B-30
A-28
I-46
G-51
(J-42)
P-78
D-65
Mackenzie Mountains
MPA
DRE
YUKON TERRITORY
NORTHWEST TERRITORIES
G-70
I-54
G-60
Franklin Mountains
Great Bear Plain
Great Slave Plain
D-50
B-28
(M-77)
Yellowknife
I-08
M-16
J-15
I-38
B-41
H-28
K-45
G-15
I-57
Great Slave Lake
I-46
K-29
G-62
H-36
Hay River
E-37
Fort Liard
K-30
K-70
B-24
WC
J-71
H-55
I-67
L-57
osc-1-87
B-48
36X
D-38
(F-39)
Quarry
(J-76)
(C-47)
CC
frc-1-87
PC
phc-1-87
(G-51)
vmc-1-87
DCE
N-33
car-1-87
CR2
CR1
K-71
I-77
I-21
Mac
LB1
Vitrinite Reflectance
1.35
0.9
0.65
0.6
Unit and Sample Type
Canol Outcrop
Canol Well
Muskwa Well
Imperial Well
Exploration Basin
Road
BRITISH COLUMBIA
ALBERTA
0
200 km

Figure 18

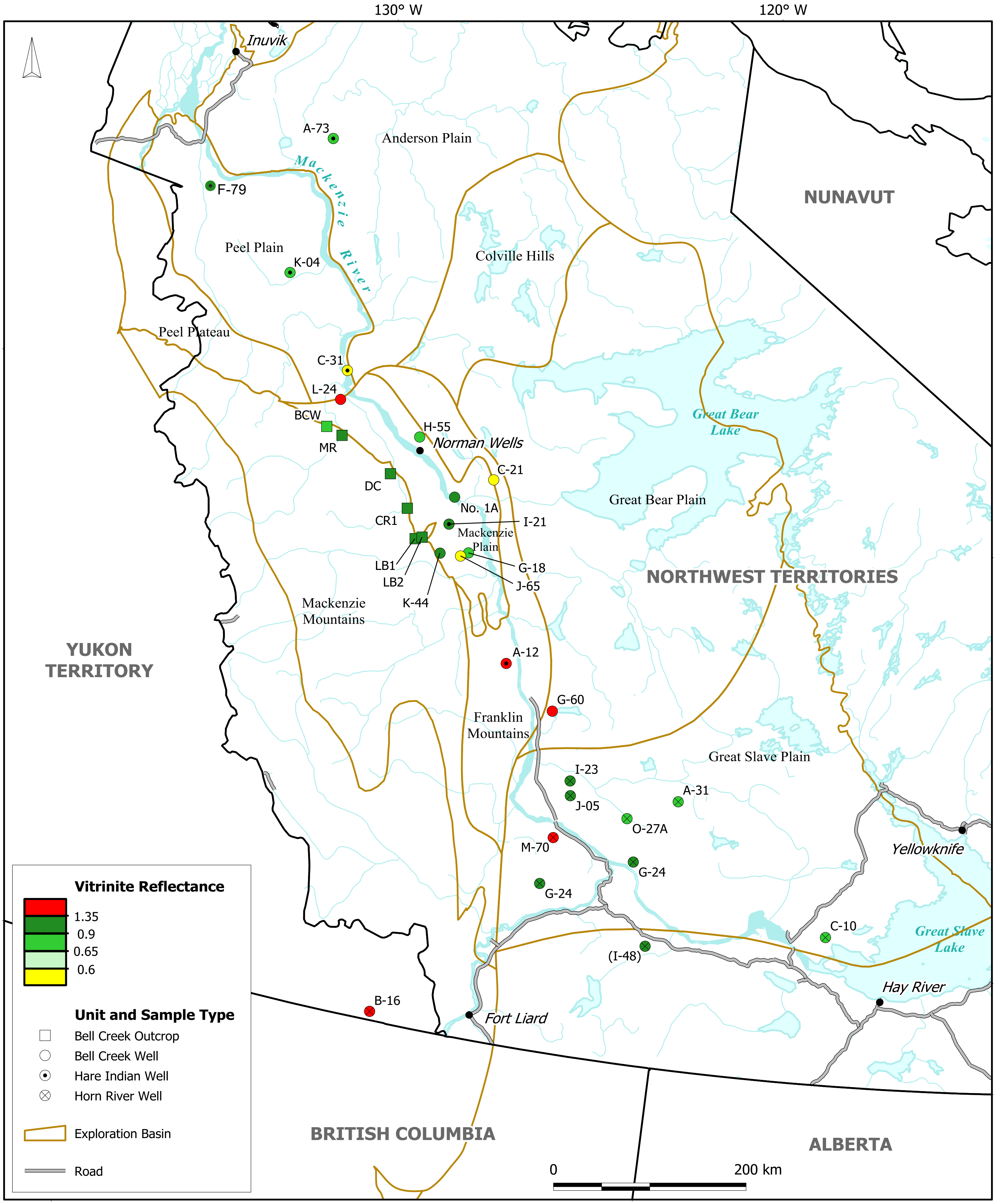
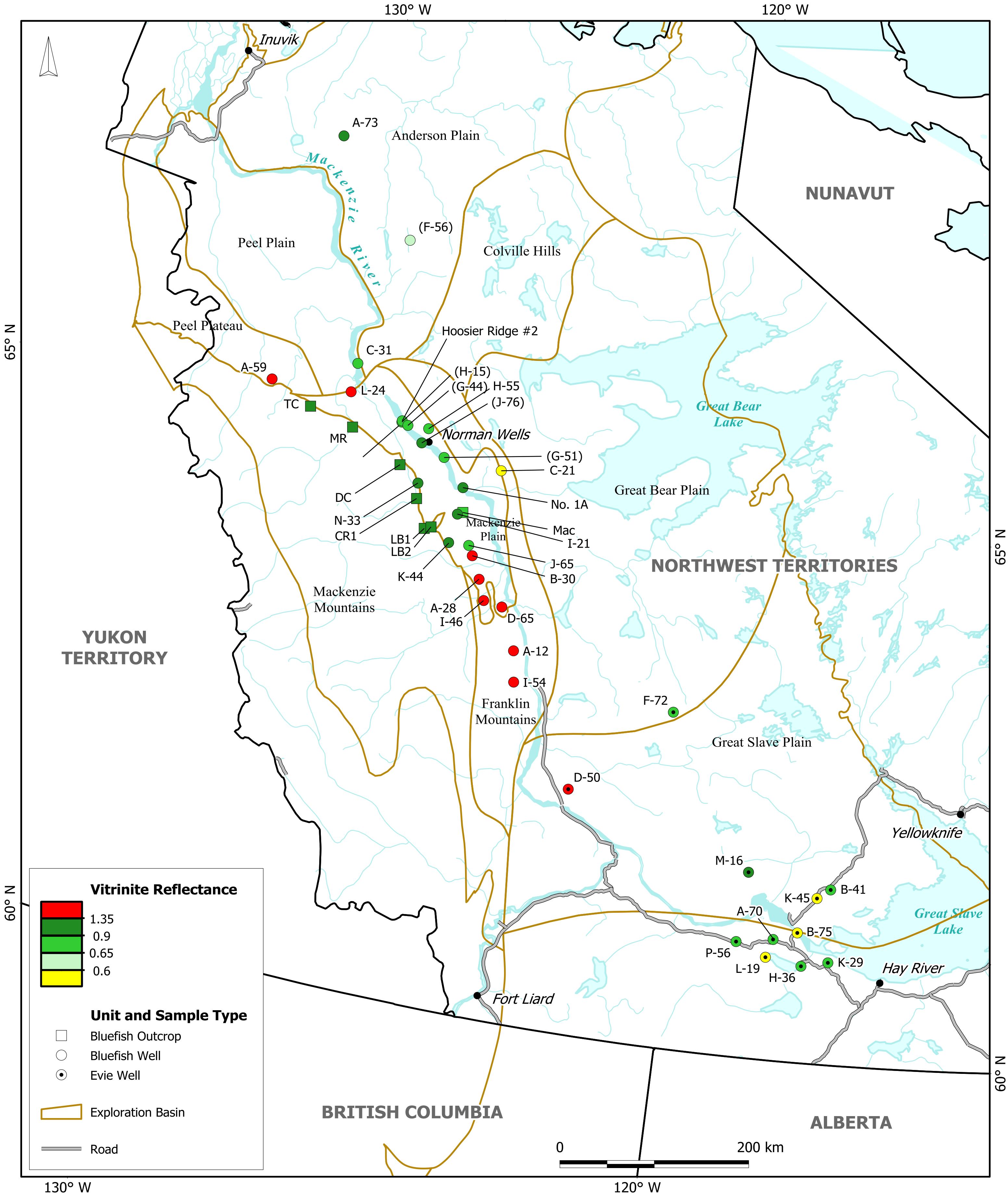

130° W
120° W
65° N
60° N
Inuvik
A-73
Anderson Plain
Mackenzie River
F-79
NUNAVUT
Peel Plain
Colville Hills
K-04
Peel Plateau
C-31
L-24
BCW
MR
H-55
Norman Wells
Great Bear Lake
C-21
DC
Great Bear Plain
No. 1A
CR1
I-21
Mackenzie Plain
LB1
LB2
G-18
J-65
K-44
NORTHWEST TERRITORIES
Mackenzie Mountains
YUKON TERRITORY
A-12
G-60
Franklin Mountains
Great Slave Plain
I-23
A-31
J-05
O-27A
M-70
Yellowknife
G-24
G-24
C-10
Great Slave Lake
(I-48)
Hay River
B-16
Fort Liard
Vitrinite Reflectance
1.35
0.9
0.65
0.6
Unit and Sample Type
Bell Creek Outcrop
Bell Creek Well
Hare Indian Well
Horn River Well
Exploration Basin
Road
BRITISH COLUMBIA
ALBERTA
0
200 km

Figure 19



130° W
120° W
Inuvik
A-73
Anderson Plain
Mackenzie River
(F-56)
Colville Hills
Peel Plain
NUNAVUT
Peel Plateau
65° N
Hoosier Ridge #2
C-31
A-59
(H-15)
(G-44)
H-55
(J-76)
L-24
TC
MR
Norman Wells
Great Bear Lake
(G-51)
C-21
Great Bear Plain
DC
No. 1A
N-33
CR1
Mackenzie Plain
Mac
I-21
LB1
LB2
J-65
B-30
K-44
NORTHWEST TERRITORIES
Mackenzie Mountains
A-28
I-46
D-65
YUKON TERRITORY
A-12
I-54
Franklin Mountains
F-72
Great Slave Plain
D-50
Yellowknife
M-16
K-45
B-41
A-70
B-75
Great Slave Lake
P-56
L-19
H-36
K-29
Hay River
Fort Liard
60° N
Vitrinite Reflectance
1.35
0.9
0.65
0.6
Unit and Sample Type
Bluefish Outcrop
Bluefish Well
Evie Well
Exploration Basin
Road
BRITISH COLUMBIA
ALBERTA
0
200 km

Figure 20

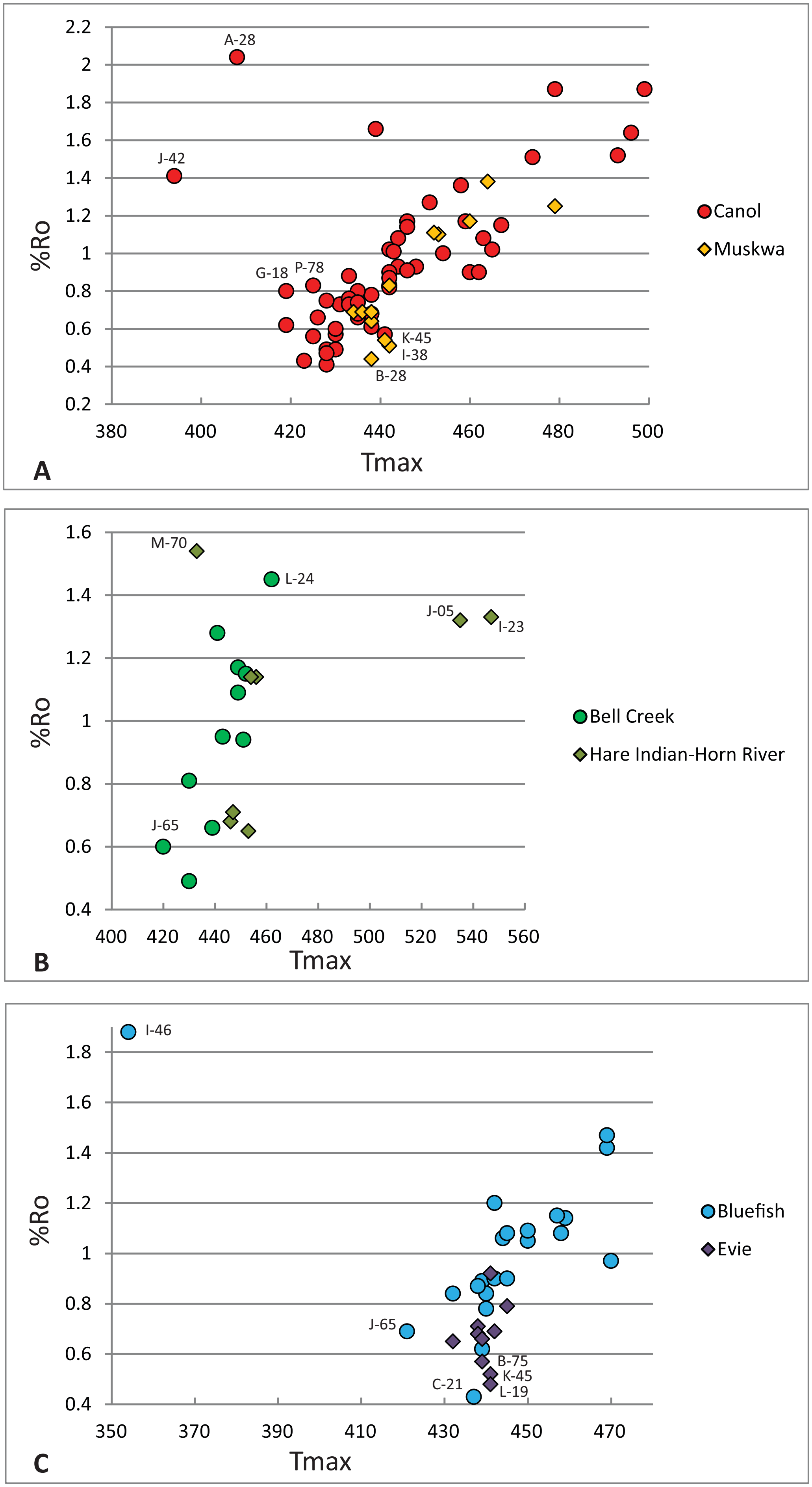
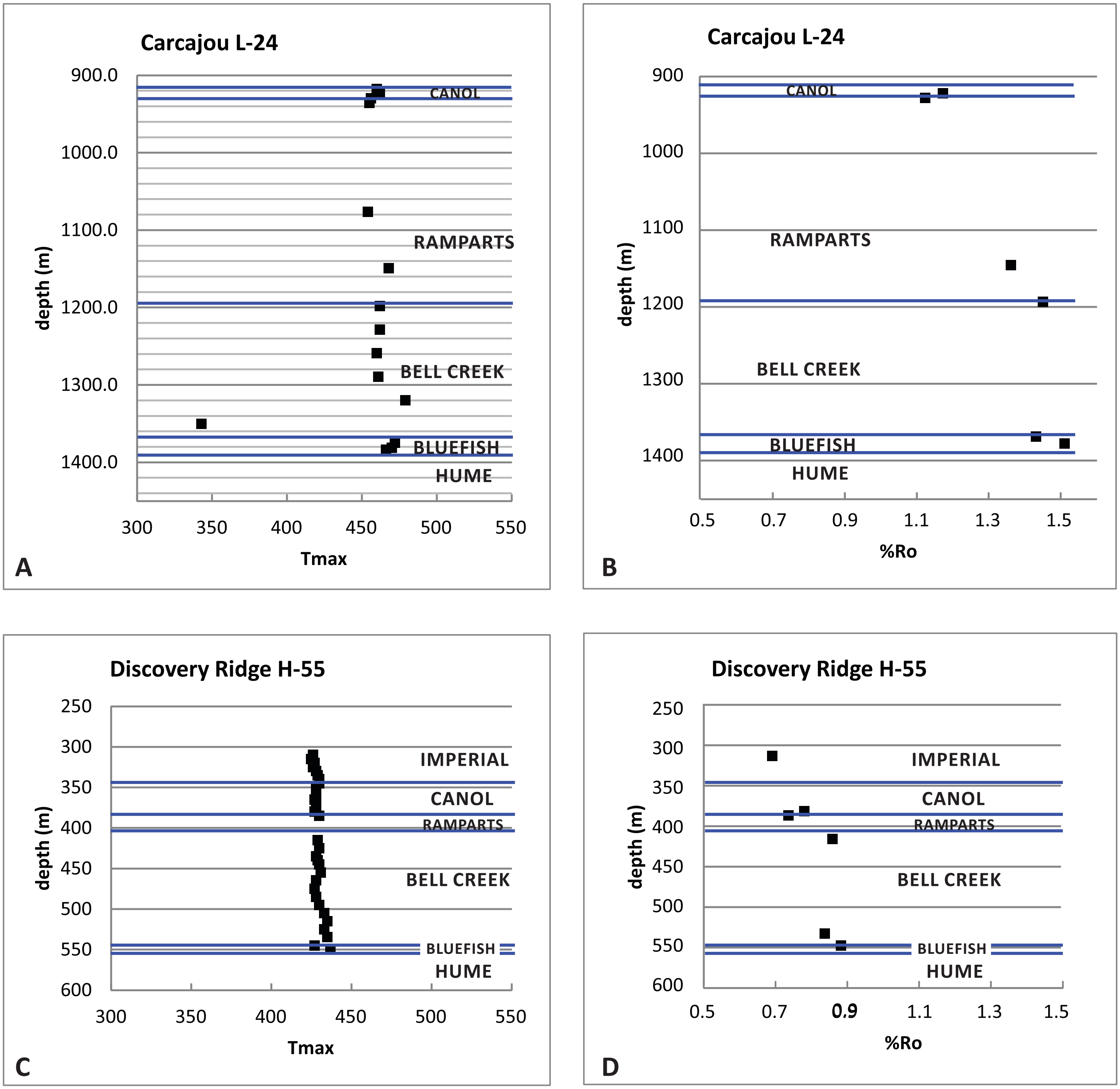

2.2
2
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
%Ro
380
400
420
440
460
480
500
Tmax
A
A-28
J-42
G-18
P-78
K-45
I-38
B-28
Canol
Muskwa
1.6
1.4
1.2
1
0.8
0.6
0.4
%Ro
400
420
440
460
480
500
520
540
560
Tmax
B
M-70
L-24
J-05
I-23
J-65
Bell Creek
Hare Indian-Horn River
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
%Ro
350
370
390
410
430
450
470
Tmax
C
I-46
J-65
B-75
K-45
L-19
C-21
Bluefish
Evie

Figure 21



Carcajou L-24
900.0
1000.0
1100.0
1200.0
1300.0
1400.0
depth (m)
CANOL
RAMPARTS
BELL CREEK
BLUEFISH
HUME
300
350
400
450
500
550
Tmax
A
Carcajou L-24
900
1000
1100
1200
1300
1400
depth (m)
CANOL
RAMPARTS
BELL CREEK
BLUEFISH
HUME
0.5
0.7
0.9
1.1
1.3
1.5
%Ro
B
Discovery Ridge H-55
250
300
350
400
450
500
550
600
depth (m)
IMPERIAL
CANOL
RAMPARTS
BELL CREEK
BLUEFISH
HUME
300
350
400
450
500
550
Tmax
C
Discovery Ridge H-55
250
300
350
400
450
500
550
600
depth (m)
IMPERIAL
CANOL
RAMPARTS
BELL CREEK
BLUEFISH
HUME
0.5
0.7
0.9
1.1
1.3
1.5
%Ro
D

Figure 22

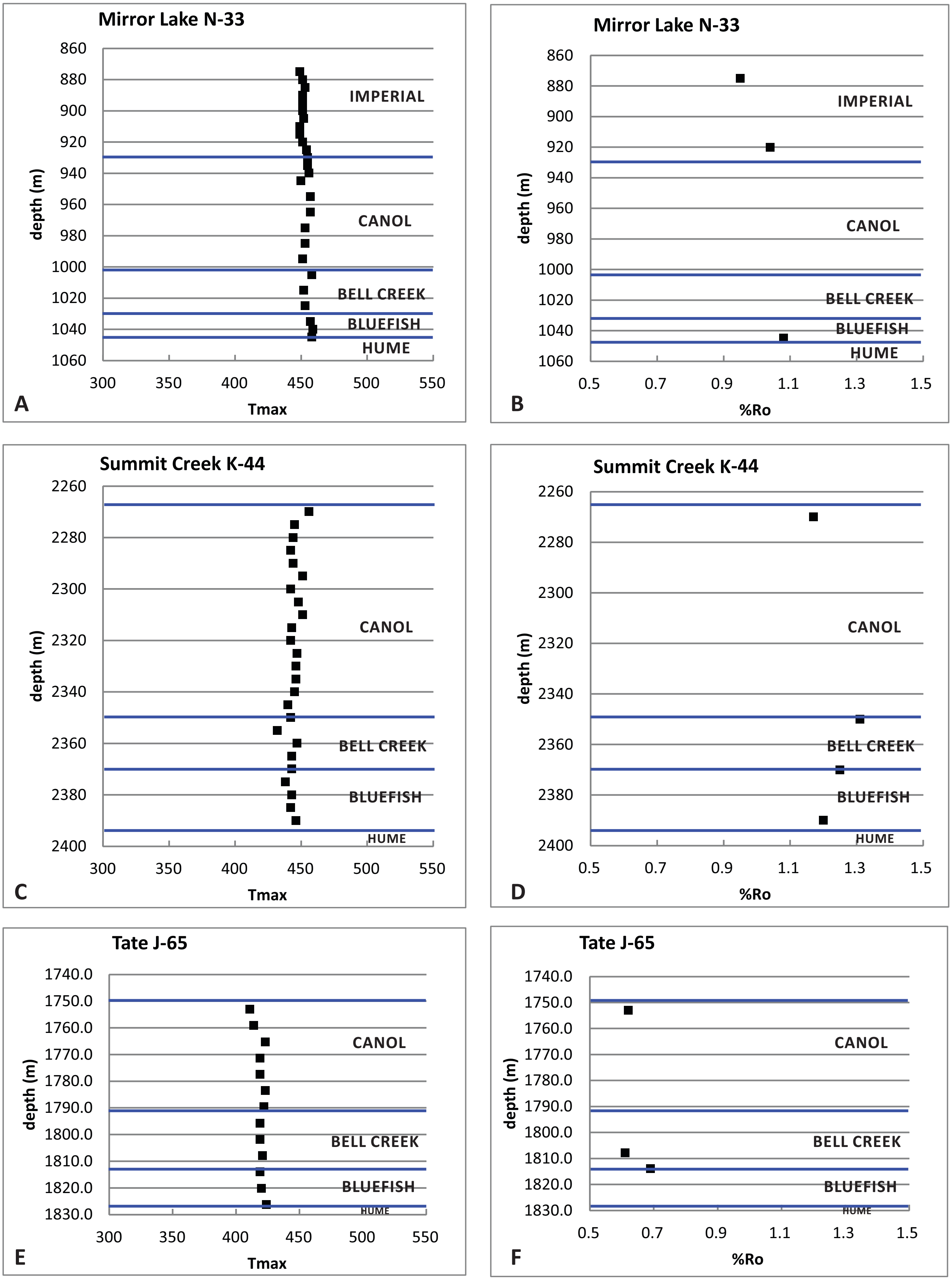

Mirror Lake N-33
depth (m)
Tmax
IMPERIAL
CANOL
BELL CREEK
BLUEFISH
HUME
A
Mirror Lake N-33
depth (m)
%Ro
IMPERIAL
CANOL
BELL CREEK
BLUEFISH
HUME
B
Summit Creek K-44
depth (m)
Tmax
CANOL
BELL CREEK
BLUEFISH
HUME
C
Summit Creek K-44
depth (m)
%Ro
CANOL
BELL CREEK
BLUEFISH
HUME
D
Tate J-65
depth (m)
Tmax
CANOL
BELL CREEK
BLUEFISH
HUME
E
Tate J-65
depth (m)
%Ro
CANOL
BELL CREEK
BLUEFISH
HUME
F

Figure 23