Canol Formation and Bluefish Member Shale Play Summary

Central Mackenzie Valley

Summary

Organic rich Devonian shales of the Canol Formation in the Central Mackenzie Valley (CMV) exploration region sourced the oil at the Norman Wells oil pool and are potentially world class unconventional self-sourcing reservoirs. Exploration in recent years in the CMV indicates that the Canol shales may host a significant amount of oil estimated to total 145 billion barrels of oil-in-place (ITI-PRD, 2015), and the resource has shown the potential for production following recent well test results. This pamphlet outlines the history of exploration and development in the CMV and current play and resource potential, with an emphasis on the shales of the Canol Formation.

Introduction

The CMV (Figure 1) is the eastern part of the Mackenzie Arc exploration region within the Northern Canadian Mainland Sedimentary Basin (Morrow et al., 2006; Pyle et al., 2014). The elongated area of the CMV follows the Mackenzie River (Figure 1). Norman Wells is the regional center in the CMV, and can be reached by airplane, barge (summer), or winter road (Figure 1).

The CMV has historically been a target for conventional oil and gas exploration. The Norman Wells oil pool, which has been in production since the 1920s, is a conventional oil play that to date has produced 274 million barrels (NEB, 2015). The reservoir rock of the pool is the reef-carbonate Kee Scarp Member of the Ramparts Formation, and is sourced from the younger Canol Formation (Snowdon et al., 1987; Pyle et al., 2014). Although declining, development from the pool has an estimated 5-10 years production life left (CBC News, 2016), with output totaling 3.62 million barrels in 2015 (ITI-PRD, 2015). The oil is transported from Norman Wells to Zama, AB, through an 869 km long pipeline (Figure 1) with a 50,000 barrel per day capacity (ITI-PRD, 2015; Enbridge, 2011). The current usage of the pipe is approximately 10,000 barrels per day (ITI-PRD, 2015).

More recently, the Canol Formation in the CMV has been the focus of exploration as a new unconventional resource play. In particular, two significant organic-enriched black shale deposits contained within Middle and Upper Devonian strata of the Horn River Group (interpreted to be a thick basinal depositional succession) are the main targets. The two main stratal units of interest are the Bluefish Member of the Hare Indian Formation and the Canol Formation (Figure 2). Both consist of organic rich shales deposited during starved basin conditions (Morrow and Geldsetzer, 1988; Pyle et al., 2014). Fourteen exploration licenses have been granted since 2011 in the CMV (Figure 7), for a total of $627.5 million in work-bid commitments (Aboriginal Affairs and Northern Development Canada, 2013; NEB, 2015). A total of seven exploration wells, including two horizontal and five vertical, have been drilled since 2011 to test the Canol unconventional hydrocarbon play (Figure 7). The recent drilling has resulted in two significant discovery declarations for the Canol play in the CMV (OROGO, 2015, 2016).

Location Map

Figure 1: Location of the CMV in the Northwest Territories (Mackenzie Plain). The CMV is flanked to the east by the Franklin Mountains, to the west and south by the Mackenzie Mountain Arch and to the north by the Peel Plain and Plateau. Norman Wells can be reached by airplane, barge (summer) and a winter road. The existing pipeline infrastructure that connects Norman Wells to Zama City, Alberta has a capacity of 50,000 barrels per day (Enbridge, 2011). The red box highlights the map area shown in Figures 3-7.

Middle to Upper Devonian Stratigraphy - Horn River Group

In the Mackenzie Plain area the Horn River Group overlies platform carbonates of the Hume Formation (Williams, 1986a, b) and is in turn overlain by marine siliciclastic deposits of the Imperial Formation (Pugh, 1983, Morrow and Geldsetzer, 1988) (Figure 3). The Horn River Group comprises the Hare Indian, Ramparts, and Canol formations (Pugh, 1983). The basal Bluefish Member of the Hare Indian Formation and the Canol Formation are interpreted to have been deposited in starved-basin conditions, while the upper Bell Creek member of the Hare Indian Formation represents a siliciclastic bank with periodic carbonate influx. The Ramparts Formation comprises carbonate bank/reef deposits and contains the reef carbonates of the Kee Scarp Member that forms the conventional reservoir at Norman Wells. Oil in this reservoir is sourced from the adjacent Canol Formation (Snowdon et al., 1987).

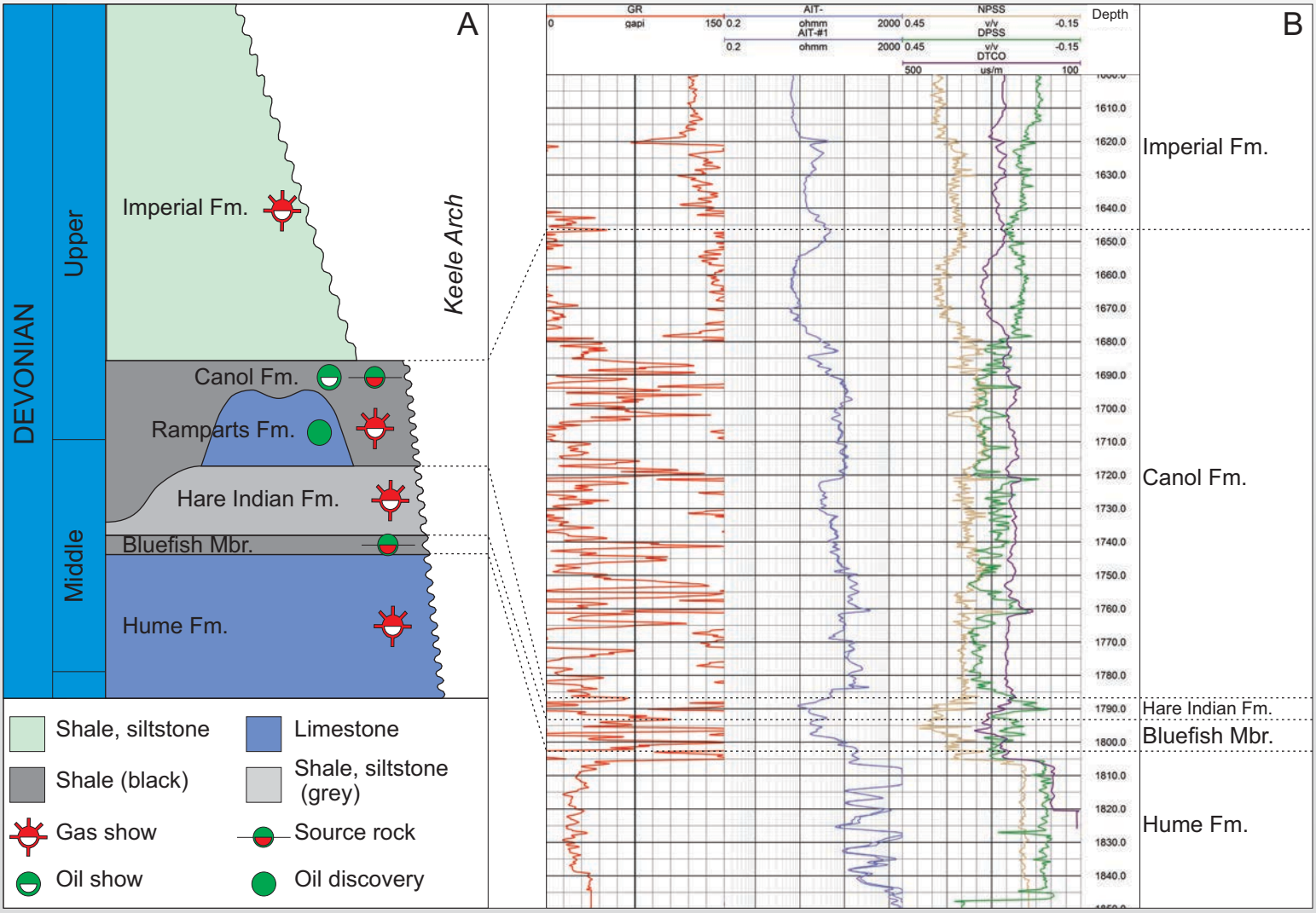
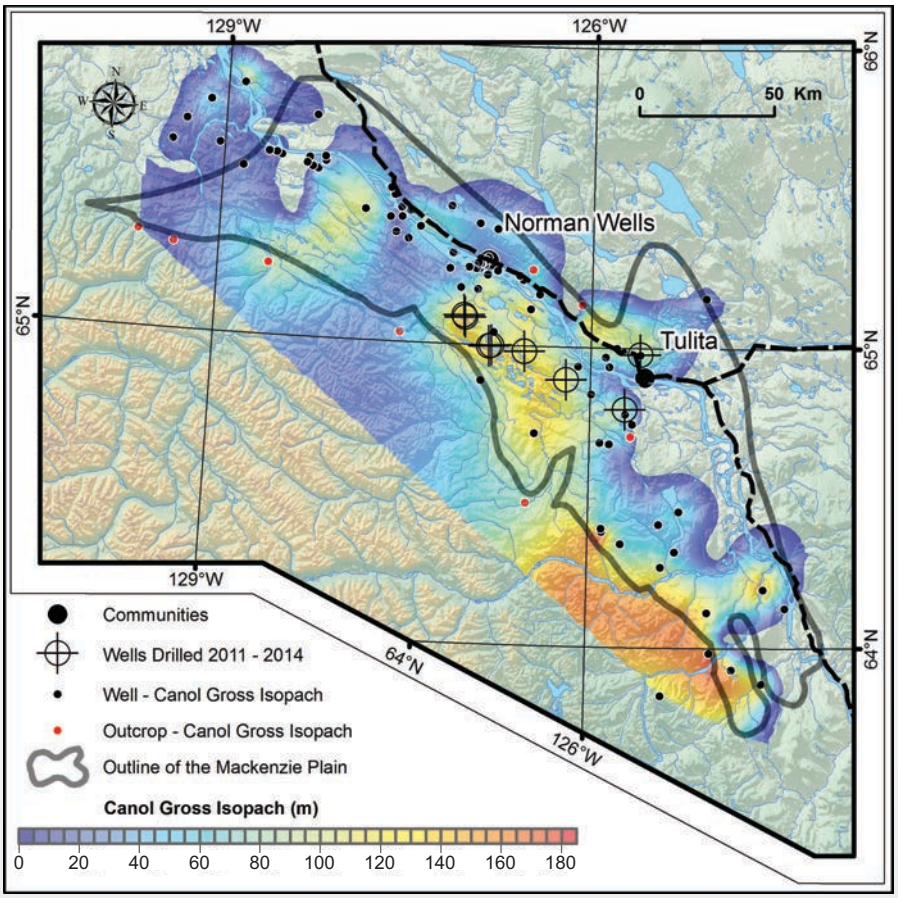
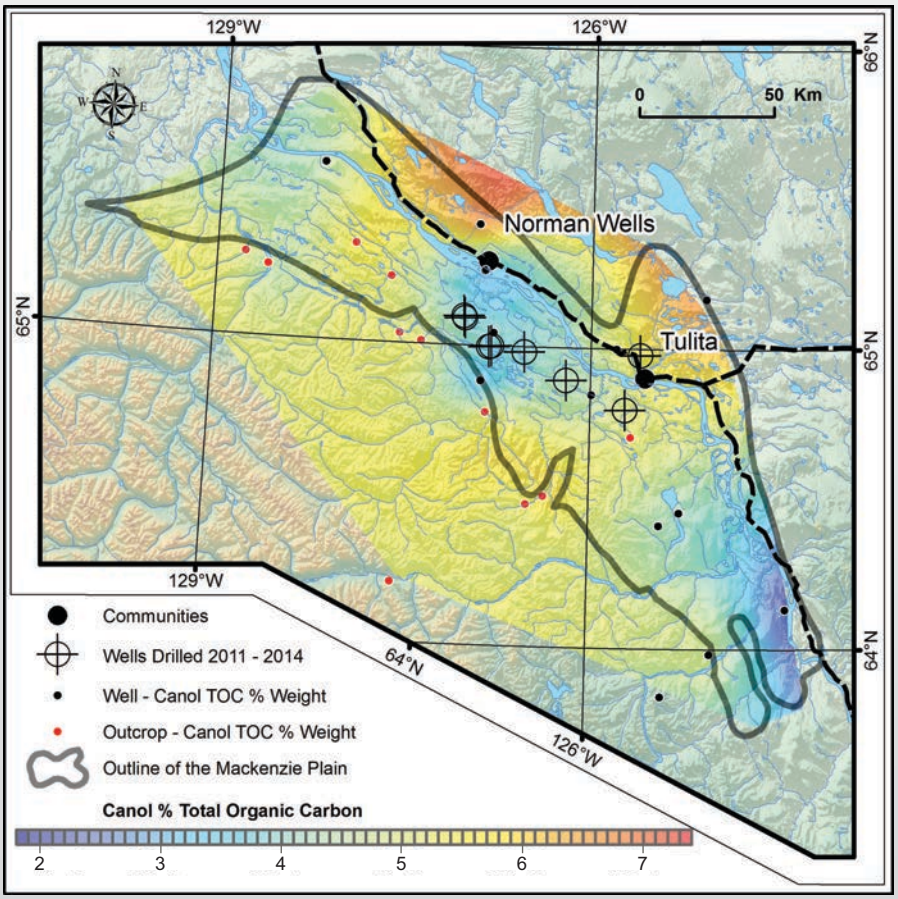


Figure 2: (A) Stratigraphy of the Middle and Upper Devonian Horn River Group in the Mackenzie Plain, and Peel Plateau and Plain areas (modified from MacLean and Cook, 1999). (B) gamma-ray, resistivity, delta-time compressional, neutron and density porosity logs from ConocoPhillips Canada Resources Corp's (COPRC) Loon Creek O-06 well of the Horn River Group in the CMV. Formation tops by COPRC are displayed on the well-logs. In the CMV the Horn River Group consists of the Hare Indian, Ramparts and Canol formations. The Bluefish Member of the Hare Indian Formation and the Canol Formation are potential unconventional hydrocarbon targets.



Canol Gross Isopach (m)

Figure 3: Thickness of the Canol Formation varies from 0 to 175 m in the CMV. The Canol Formation overlies the Hare Indian Formation across much of the CMV, but drapes the Ramparts Formation where the Ramparts Formation is present (Figure 2A). The Ramparts Formation is present near Norman Wells and toward the southwest, and as a result here the Canol Formation is thinnest. The thickness of the Canol shales increases away from the Ramparts Formation both toward the northwest and southeast, where it is typically >100 m thick. Although the Canol Formation is thickest in the southern CMV and into the Mackenzie Mountains, it drastically thins to 0 m just south of Tulita.

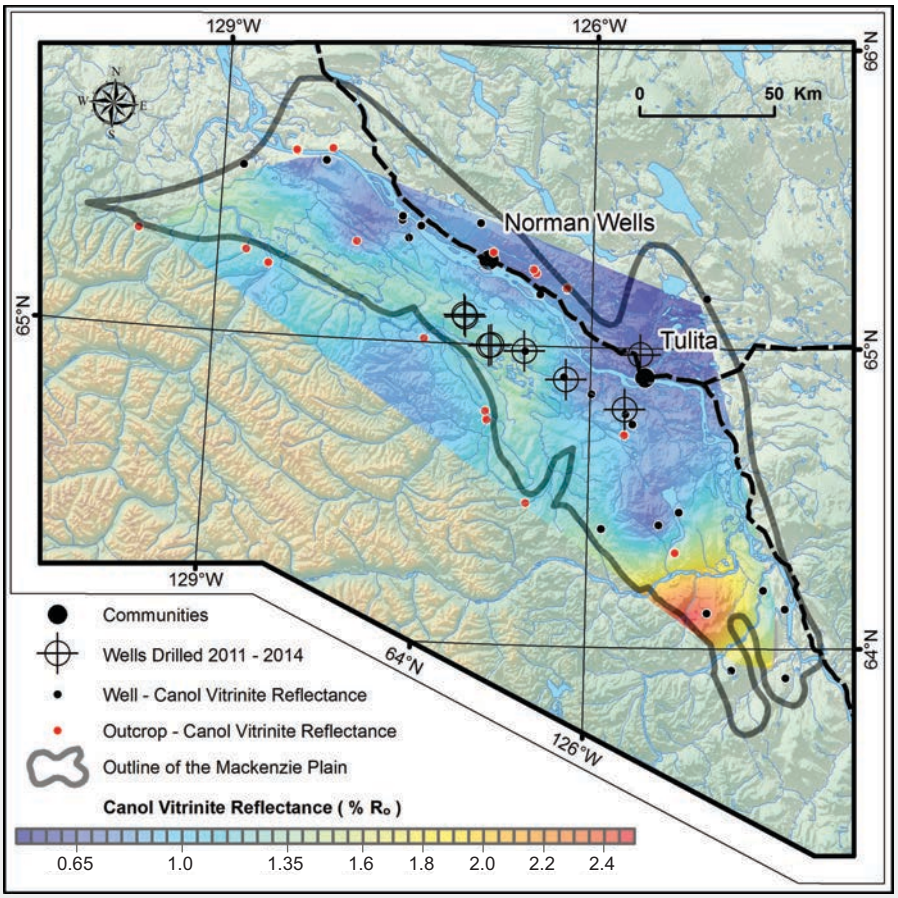


Canol TOC (wt. %)

Figure 4: The entire areal extent of the Canol shale is characterized by high total organic carbon (TOC) content, ranging from "good" to "excellent" (1 - >5 wt. %) on the source-rock petroleum potential classification of Peters and Cassa (1994).

In the area directly south of Norman Wells, TOC ranges from 2.5-5 wt. %; in COPRC's Loon Creek O-06 well, TOC in the Canol Formation ranges from 1.8 - 4.8 wt. %, also indicated by high gamma-ray counts (see the Canol Formation interval in Figure 2B).

From the Norman Wells area, TOC increases toward the southeast, west, and northwest to ~5.5 wt. %, but diminishes again toward the far southeast of the CMV to <2 wt. %.

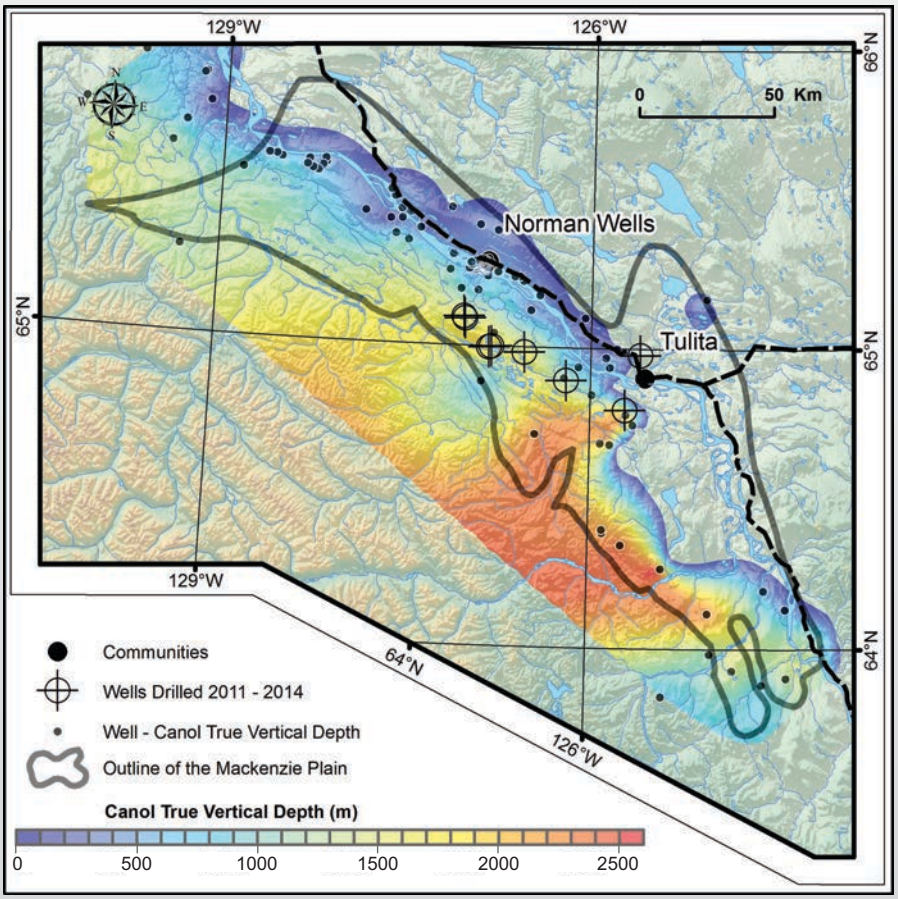


Canol VR and VRe (%R_o)

Figure 5: Mean vitrinite reflectance (VR) or vitrinite reflectance equivalent[1] (VRe) %R_o map. Generally, reflectance values are lower (0.5-0.8 %R_o) toward the north and northwest, suggesting that these areas are primarily in the oil zone and locally in the wet gas zone.

Reflectance values gradually increase toward the west and south. Along the western edge of the CMV, VR and VRe values typically range from 1.0-1.2 %R_o, indicating that these areas are dominantly in the wet gas zone, but locally in the oil window.

Although VR and VRe values are lower south of Tulita, at the far southern end of the CMV a region with high reflectance values up to 2.5 %R_o is present, suggesting that this area is in the dry gas zone or is locally overmature.



Canol Depth to Formation (m)

Figure 6: The Canol Formation exists in the subsurface under most of the CMV. There is a general deepening trend from the northeast to the southwest. In the far northern end of the CMV and north, east, and south of Tulita, Canol shales are exposed at the surface, or have been eroded and are absent.

In the central portion of the CMV, the Canol Formation dips gently; in the far east of the CMV it is exposed at surface and in the subsurface true depth to top-of-formation increases from 0 m east of the Mackenzie River to 1500-1800 m. Southwest of Tulita, formation dip is considerably steeper, with depth ranging from 0 m to >2400 m. It should be noted that in the western regions, thrust faulting has affected total thickness and depth of the Canol Formation.

[1] Vitrinite Reflectance Equivalent (VRe): Jacob (1989) described a linear relationship between vitrinite and bitumen at concentrations between <0.1% and 3.0 % BR_o, with a standard deviation of ± 0.06%. VRe = R_o = 0.618(BR_o) + 0.4

Central Mackenzie Valley - Recent Land & Drilling Activity

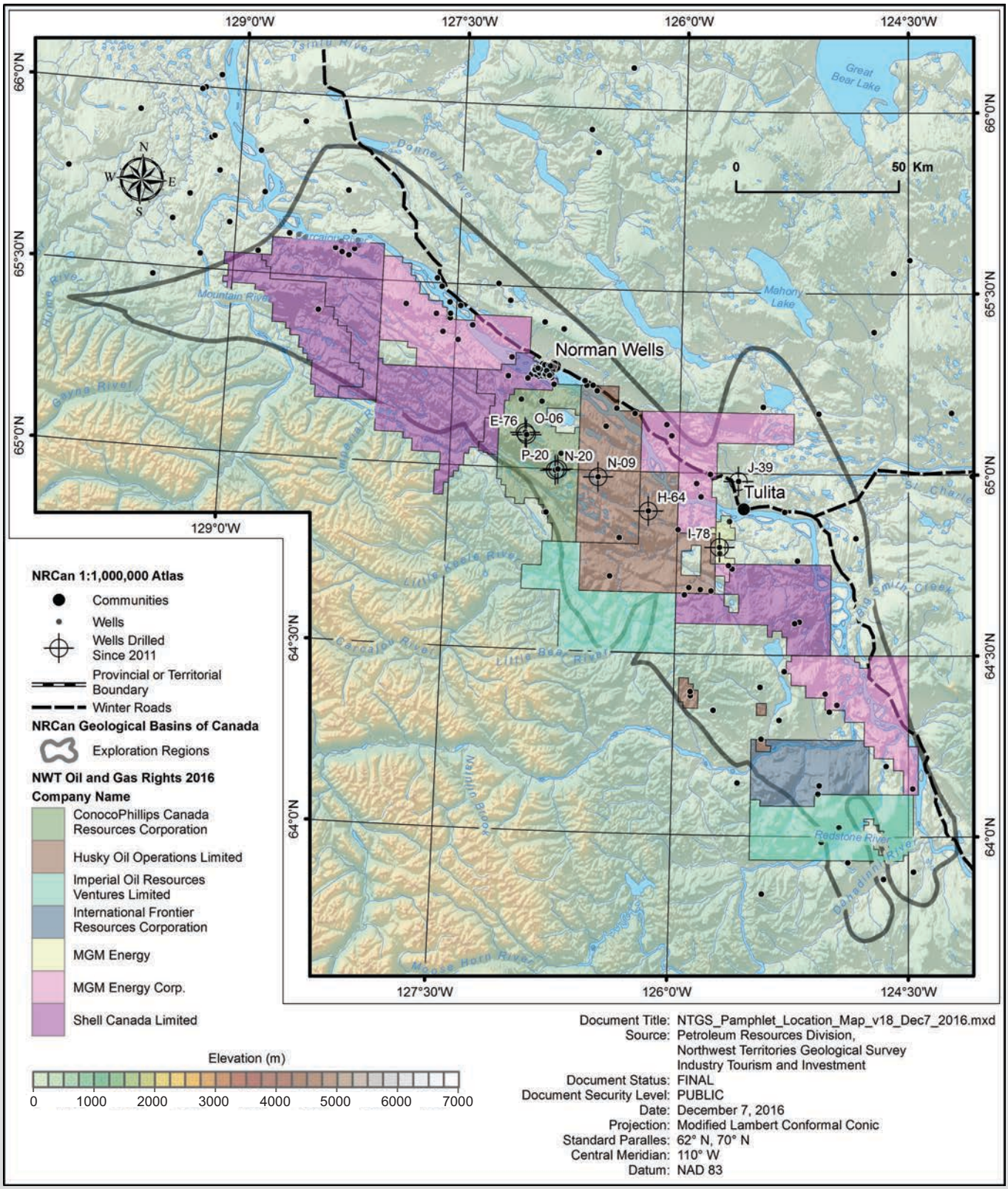


Figure 7: A total of seven exploration wells, including two horizontal and five vertical, have been drilled since 2011 in the CMV to test the Canol unconventional hydrocarbon play. The two horizontal wells, E-76 and P-20, were drilled by COPRC. Each horizontal well was hydraulically fractured in the lower portion of the Canol Formation and flowed hydrocarbons from the stimulated intervals. The well identified as J-39 was not a Canol Formation test well.

Play Summary, Mapping and Resource Potential

The Middle and Upper Devonian unconventional play of the CMV consists of two self-sourcing black shales: the Bluefish Member of the Hare Indian Formation and the Canol Formation. Although stratigraphically predating the Canol Formation, the shale-gas prospects in the Horn River Basin and Cordova Embayment of northeast British Columbia are thought to have been deposited in a similar, starved and poorly circulated deep-water environment adjacent to a shallow-water carbonate reef (B.C. Ministry of Energy and Mines and NEB, 2011). The Canol Formation is slightly older, but similar to the Duvernay Formation in Alberta, a current unconventional shale hydrocarbon play under assessment by industry. The potential area for oil exploration is approximately 70 km wide by 200 km long in NW trend parallel to the Mackenzie River (Figures 1, 3, 4, 5, 6, and 7). The Bluefish shale is typically only a few meters thick, but is up to 62 m thick locally, and forms a smaller prospect than the Canol Formation (NEB, 2015). The Canol Formation is few meters to up to 175 m thick (Figure 3). Both formations extend beyond the bounds of the CMV. The Canol Formation is thinnest to the west of Norman Wells where it overlies the Ramparts Formation (Figures 2 and 3). The Canol shales contain significant (60-90 wt. %) amounts of silica (Pyle et al., 2014; Rocheleau et al., in press), have typical TOC values up to over 6 wt. % (Figure 4; Pyle et al., 2014; Rocheleau et al., in press), and porosities of 8 % and higher (Energy Briefing Note, 2015; but also note neutron and density porosity logs in Figure 2). Vitrinite reflectance and vitrinite reflectance equivalent values range from 0.7 to 1.4 $\%R_o$ in much of the CMV, although higher values up to >2 occur in the southern region (Figure 5; Pyle et al., 2014; Rocheleau et al., in press). The Canol Formation is locally exposed at surface, but is up to 2500 m deep at the southwestern end of the CMV (Figure 6).

In-place resource volumes were estimated using a simplified single oil phase model, based on vitrinite reflectance values that straddled the oil window for the mapped areas included in the resource assessment (NEB, 2015). The estimated volume of oil-in-place for the Bluefish Shale is 46 billion barrels, and that for the thicker Canol Shale is 145 billion barrels. The amount of marketable oil has not been estimated to date (NEB, 2015), but the Significant Discovery Declaration (SDD) suggests an accumulation that has potential for sustained production (OROGO, 2016).

Approximately 40 years of seismic data were acquired starting in the 1970s. Although the data provide significant areal coverage, they exist as separate and disparate datasets, and is in an irregular grid with variable datum and quality (Hogg, 2015).

Unconventional Play Attributes

Table 1: Unconventional Play Attributes of the Canol Formation shale interval. Data compiled from various subsurface (core) and field studies.

Porosity (vol. %)	8% and above (NEB, 2015)
TOC (wt. %)	3.7-6.8% (median values; Pyle et al., 2014; Rocheleau et al., in press); >6% in large areas of the play.
VR and VRe ($\%R_o$)	~0.6 in the Norman Wells area, increasing toward the west and southeast to ~1; >>1 in the far southeast (Figure 5; Pyle et al., 2014; Rocheleau et al., in press).
Tmax (°C)	Immature to the east of Norman Wells, increasing maturity toward the west. Mostly mature (435-470°C range) in the main CMV, but overmature toward the far west near the Mackenzie Mountains (Pyle et al., 2014; Rocheleau et al., in press).
Kerogen Type	I and II dominant, minor III (Pyle et al., 2014)
Thickness (m)	The Canol Formation is 1-174.5 m thick in the CMV; it is thin when overlying the Ramparts Formation, but rapidly thickens to >100 m thick south of Norman Wells (Figure 3).
Silica content (wt. %)	60-90% (Pyle et al., 2014; Rocheleau et al., in press)

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