Government of
Northwest Territories

# Horn River and Exshaw Formations Unconventional Play Summary

## Liard Basin, Northwest Territories

Golata (foreground) and Mattson (distant background) formations at Etanda Lakes, Northwest Territories (copyright NTGS).

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NORTHWEST TERRITORIES
GEOLOGICAL SURVEY

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## Liard Basin, Northwest Territories

## Summary

The Liard Basin exploration region hosts two organic-rich shale horizons within the Devonian to Mississippian Besa River Formation. These shales, known as the Exshaw and Horn River formations, have been the focus of recent successful exploration and development in northeastern British Columbia where they form both source and reservoir for significant accumulations of natural gas (NTGS et al., 2016). This pamphlet presents an overview of these unconventional shale gas resource plays where they extend into the Northwest Territories.

## Introduction

The Liard Basin occupies the southwest corner of the Northwest Territories (NT) and extends into both Yukon Territory (YT) and northeastern British Columbia (NEBC; Figure 1). It is considered to be a part of the northern extension of the Western Canada Sedimentary Basin (Morrow et al., 2006). In NT, the Liard Basin can be accessed via an all-weather road that connects the southwestern part of the territory to NEBC. The Liard River separates the regional centre of Fort Liard from the Pointed Mountain gas field to the west.

The Liard Basin in NT hosts conventional and unconventional natural gas plays associated with Middle Devonian carbonates and Middle Devonian to Mississippian organic-rich shales, respectively. Conventional natural gas was first discovered in structural traps associated with Laramide thrust fault-related features with structural closure. The natural gas was sourced from the organic-rich shales of the Horn River Formation (Hannigan, 2011). A total of five conventional gas pools have been discovered in the Paleozoic units of the Liard Basin in NT. Since 1969, the overall cumulative gas production to date has been approximately 469 Bcf (NEB, 2014). There has been no gas production from the Liard Basin north of 60° since 2012. However, there is a gas pipeline connecting the historical gas fields to NEBC infrastructure (Figures 1 & 11).

There are two Paleozoic unconventional shale gas plays in the Liard Basin: the Horn River Formation and the Exshaw Formation (NTGS et al., 2016; Rocheleau & Fiess, 2017). The Middle Devonian age Horn River Formation is prospective for shale gas in NT and YT, and is the source rock for conventional gas in the Liard Basin (Figure 2). This shale gas play is being produced in the Horn River Basin of NEBC, where, as of 2016, more than 500 wells have been permitted (NTGS et al., 2016). The Late Devonian to Mississippian age Exshaw Formation (Figure 2) became a target for shale gas exploration in NEBC portion of Liard Basin as early as 2009. This shale gas play was defined after exploration and drilling by Apache Corporation between 2009 and 2012. Cumulative production from the Exshaw Formation to February of 2018 was 55.5 Bcf (M. Hayes, pers. comm., 2018). More than 400 wells have been drilled in NEBC to date, targeting the 'Besa River' shale gas play (Exshaw Formation). Since 2004, no new wells have been drilled to test either unconventional play north of 60°. In 2012, Lone Pine Resources recompleted an existing wellbore in the Pointed Mountain South Pool at 300/L-68-60-12345/0 and successfully tested sweet dry gas from the Horn River Formation. Gas flow rate data supports a potential deliverability of 12 mmcf/d (Market Wired, 2013).

# Location Map & Middle Devonian to Mississippian Stratigraphy

In the Liard Basin, shales of the Horn River Formation disconformably overlie the carbonate rocks of the Nahanni Formation (Figure 2), which are the stratigraphic equivalent of the Dunedin Formation in NEBC (Thompson, 1989). The Horn River Formation thins at the eastern margin of the basin near the Slave Point edge. The Horn River Formation is conformably overlain by gray shales of the Fort Simpson Formation, which are the stratigraphic equivalent of the Imperial Formation in the Central Mackenzie Valley (Moore, 1993). The Fort Simpson Formation contains the basinward facies of the Tetcho Formation and some of the Kotcho Formation carbonates (Moore, 1993). The contact between the Fort Simpson and Exshaw formations is gradational (Figure 2). The Exshaw Formation was divided into three unofficial members following the work of Ferri et al. (2015): the upper Exshaw, lower Exshaw, and Patry. The Patry member is considered to be equivalent to the upper part of the Kotcho Formation carbonates and may represent a basinal facies transition to calcareous shale. The Exshaw Formation is disconformably overlain by calcareous shales of the Banff Formation and younger Carboniferous rocks. In some literature, these Middle Devonian to Mississippian stratigraphic units are included in a diachronous regional shale unit, the Besa River Formation (Moore, 1993; Morrow, 2012).


Figure 1: Location of the Liard Basin (red outline) in the Northwest Territories (cross-hatched), Yukon Territory, and northeastern British Columbia. Existing unused gas pipeline infrastructure connects the abandoned Pointed Mountain and Liard fields to Fort Nelson, British Columbia (see Figure 11).

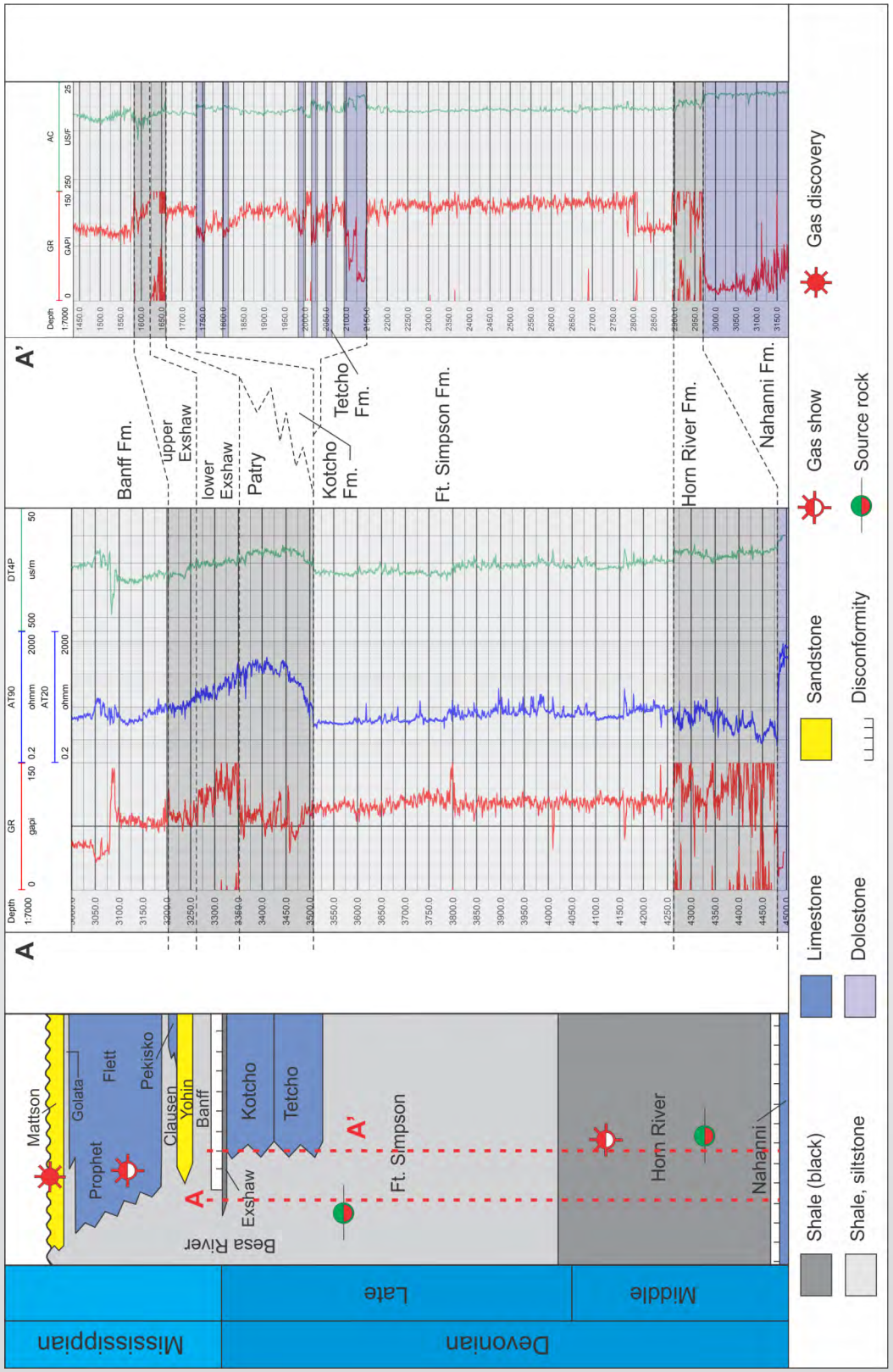
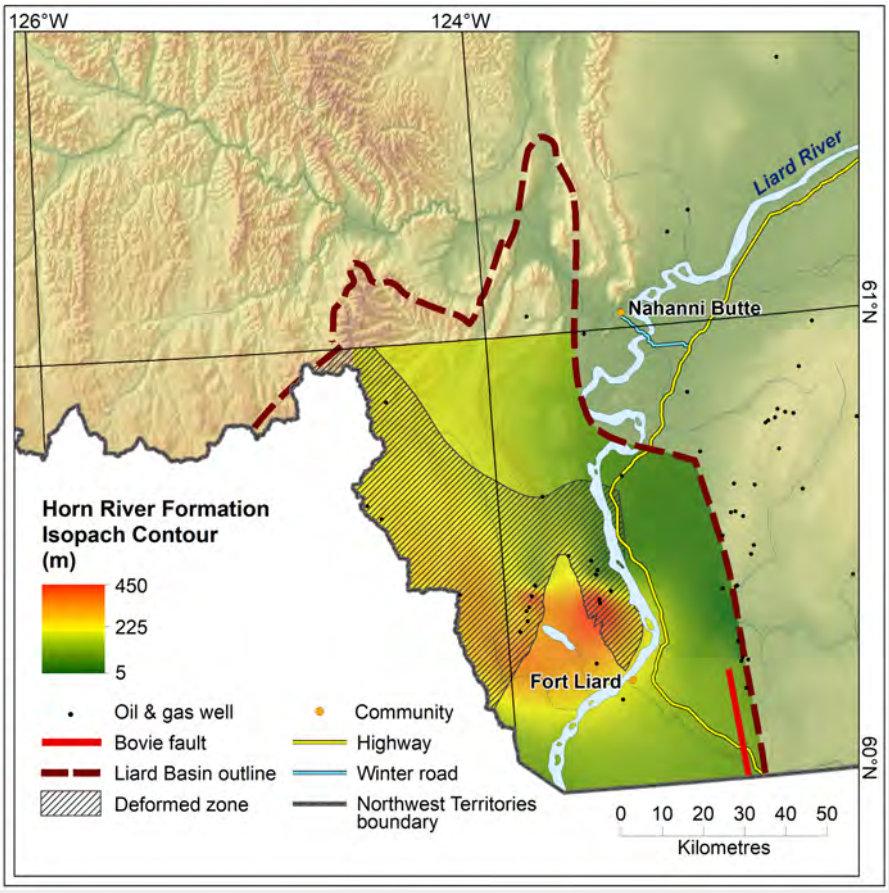
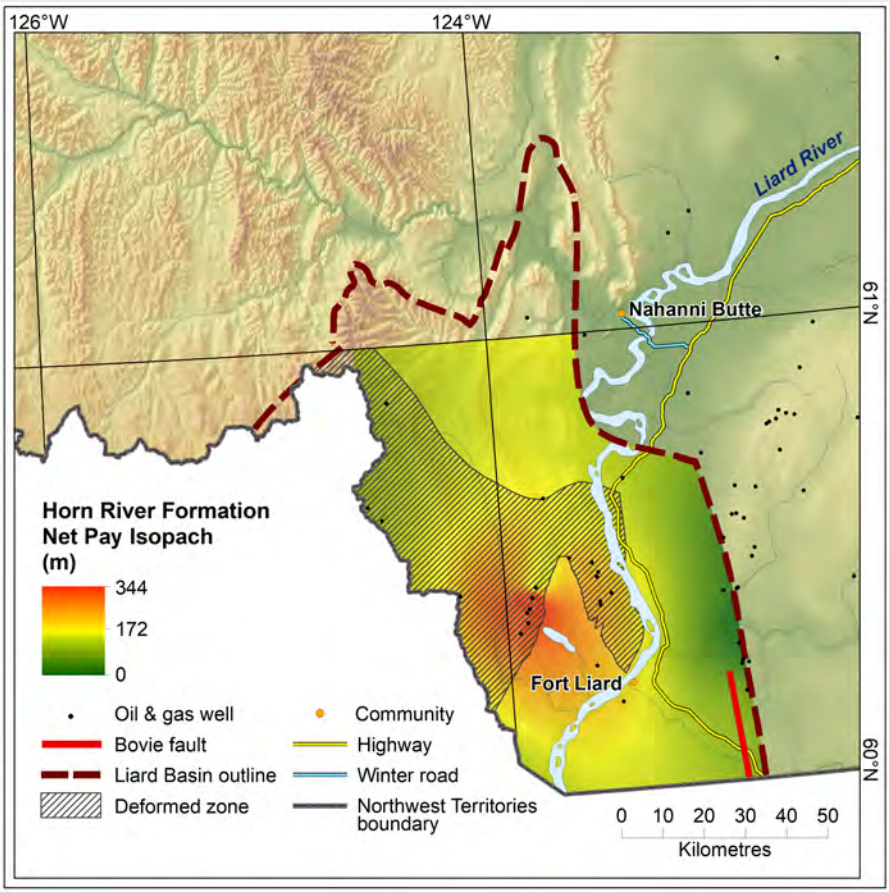



Figure 2: Stratigraphic correlations between the Mount Coty 2K-02 (A) and Bovie Lake J-72 (A') wells. Left: Middle Devonian to Carboniferous stratigraphy of the Liard Basin in the Northwest Territories (modified from Rocheleau & Fiess, 2014), showing interpreted relative positions of the two wells. Formation tops by the Northwest Territories Geological Survey (NTGS; extrapolated from Ferri et al., 2015) are displayed on the well logs. Cross-section line A-A' is shown in Figure 11.



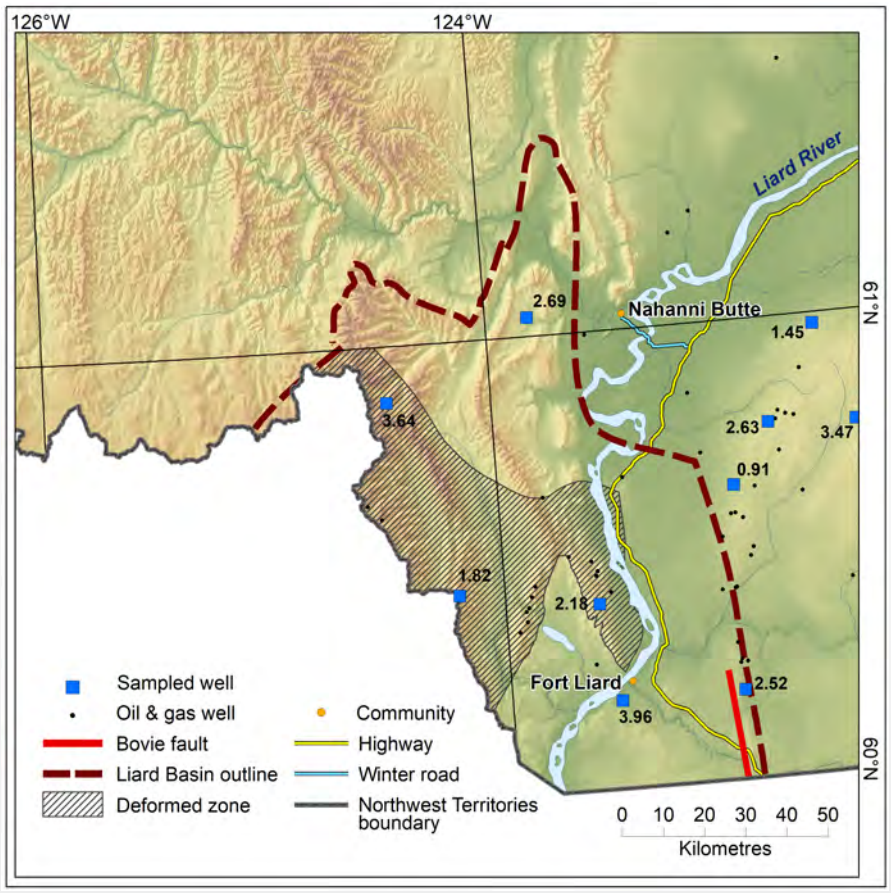

## Horn River Gross Isopach (m)

Figure 3: Gross thickness of the Horn River Formation in the Liard Basin varies from 5 m to 450 m between 60°N and 61°N. The Horn River Formation overlies Nahanni Formation carbonate rocks that form the reservoir for conventional natural gas in the Pointed Mountain and Liard fields (see Figure 11). The Horn River Formation is thickest near Pointed Mountain and thins abruptly east of the Bovie fault.



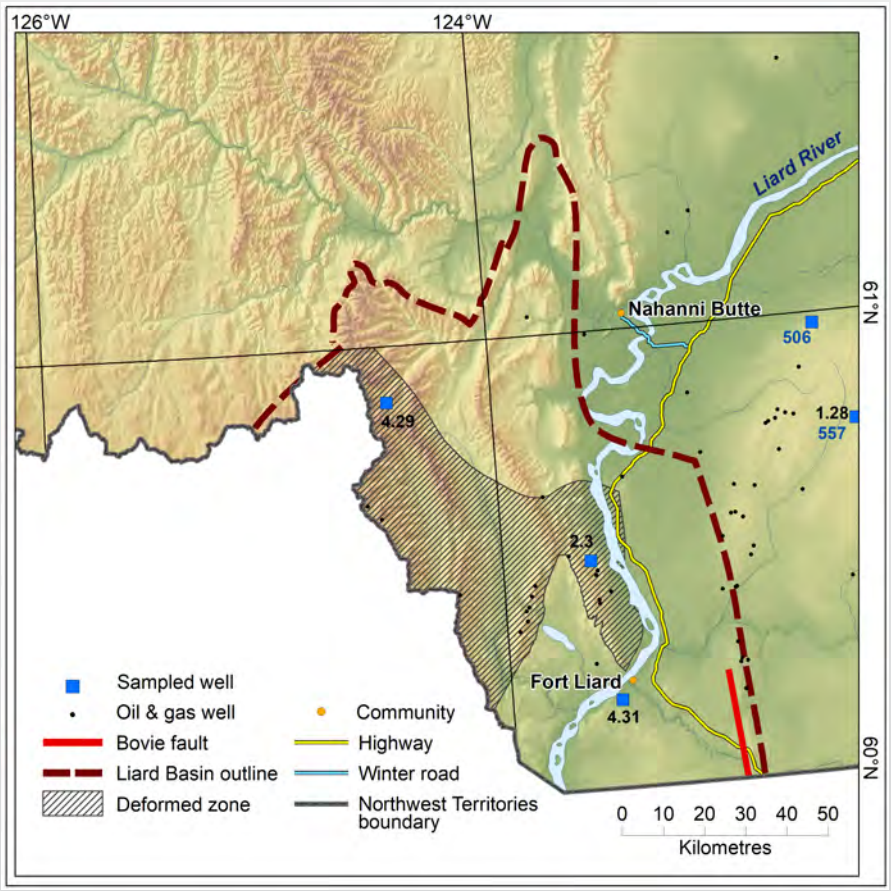

## Horn River Net Shale (m)

Figure 4: Net shale thickness of the Horn River Formation varies from 0 to 344 m in the study area. The thickest net pay is at the Pointed Mountain gas field (see Figure 11) and thins rapidly to the north and east. Net pay was determined using a 10 Ω-m cut-off on resistance logs.



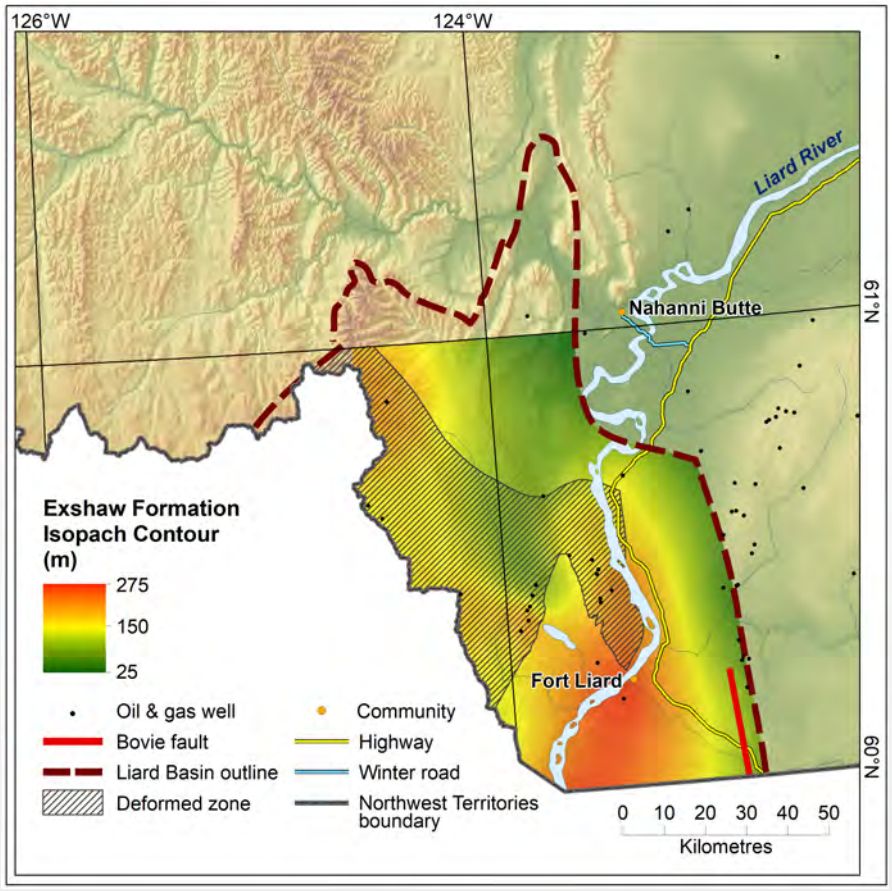

## Horn River TOC (wt. %)

Figure 5: Organic richness of the Horn River Formation in average weight percent total organic carbon (TOC) from sampled wells. Data are limited and there are no apparent TOC trends within the Liard Basin. TOC data were obtained from wells sampled by the NTGS and the Geological Survey of Canada (GSC; Potter et al., 2000; Feinstein et al., 1988).



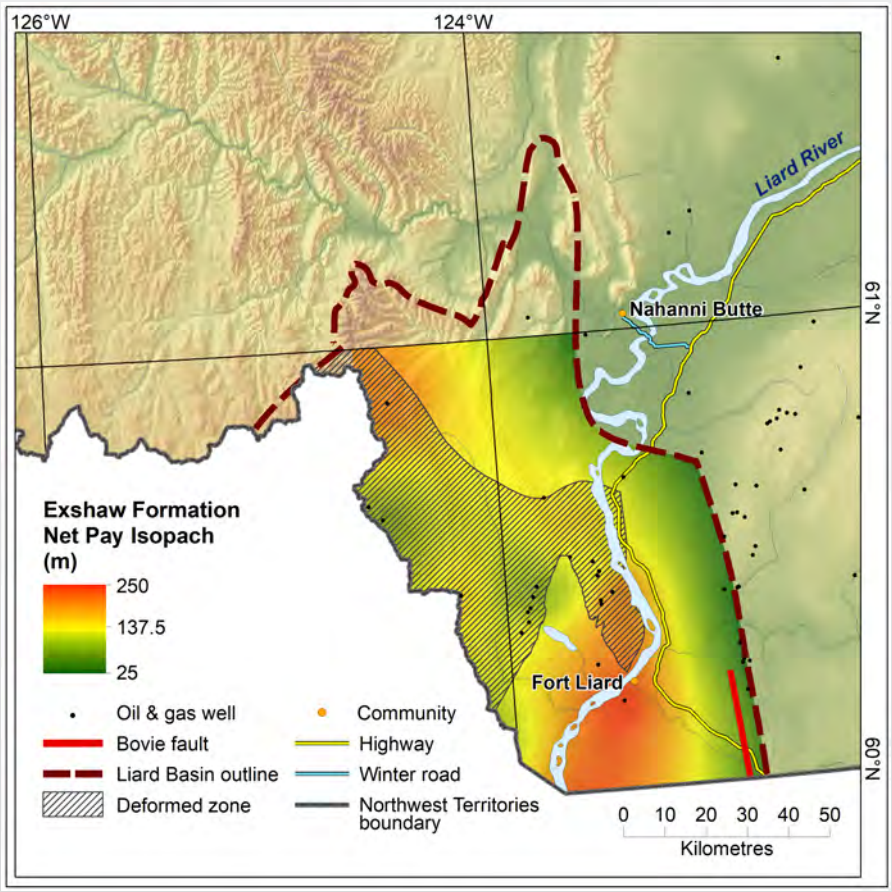

## Horn River Maturity Indicators

Figure 6: Average $T_{max}$ (blue) and $\%R_o$ (black) for the Horn River Formation from sampled wells. Values indicate overmature to dry gas in the Liard Basin whereas there is an apparent decrease in formation maturity outside the basin. Data were obtained from wells sampled by the NTGS and the GSC (Potter et al., 2000; Feinstein et al., 1988).



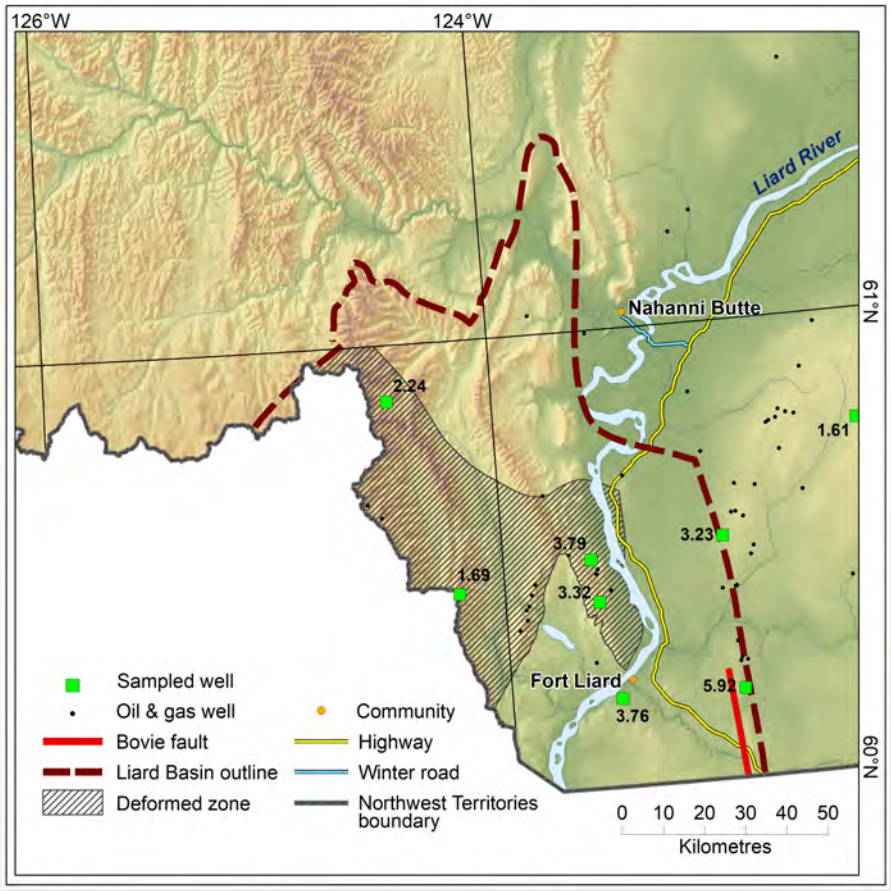

## Exshaw Gross Isopach (m)

Figure 7: Gross thickness of the Exshaw Formation (including Patry member) in the Liard Basin varies from 25 to 275 m between 60°N to 61°N. The Exshaw-Patry shales conformably overlie those of the Fort Simpson Formation, except at the eastern edge of the basin where the Patry member undergoes a lateral facies change into part of the Kotcho Formation. The Exshaw Formation is thickest at the BC-NT border and in the northwestern part of the study area. Note that in the eastern part of the basin the thickness contours parallel the Bovie fault trend, which is where the Exshaw thins abruptly and drapes the Kotcho Formation.



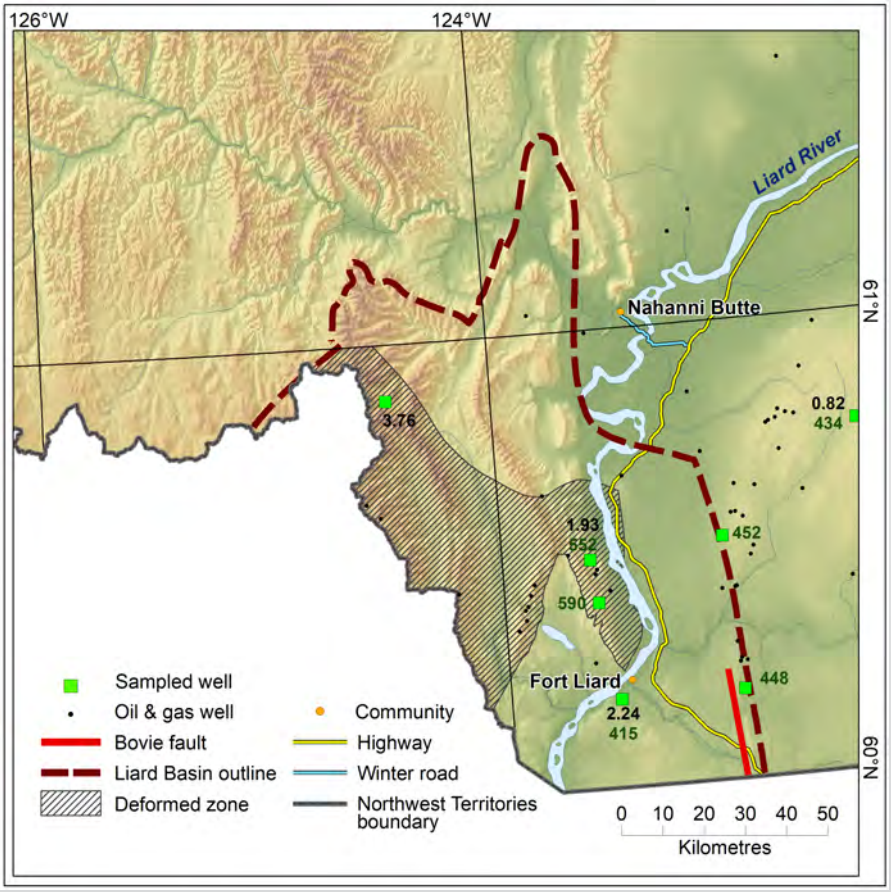

## Exshaw Net Shale (m)

Figure 8: Net pay thickness of the Exshaw Formation varies from 25 to 250 m in the study area. The thickest areas of net shale are in the Liard gas field, the southern end of the Pointed Mountain gas field, and at the northwestern edge of the study area (see Figure 11 for gas field locations). Net pay was determined using a 10 Ω-m cut-off on resistance logs.




## Exshaw TOC (wt. %)

Figure 9: Organic richness of the Exshaw Formation in average weight percent total organic carbon (TOC) from sampled wells. Although data are limited, there is an apparent trend of increasing TOC from west to east within the Liard Basin. TOC data were obtained from wells sampled by the NTGS and the GSC (Potter et al., 2000; Feinstein et al., 1988).




## Exshaw Maturity Indicators

Figure 10: Average $T_{max}$ (green) and $\%R_o$ (black) for the Exshaw Formation from sampled wells. Values in the deformed zones indicate dry gas whereas data for the eastern margin of the Liard Basin suggests the possibility of a liquid phase. Data were obtained from wells sampled by the NTGS and the GSC (Potter et al., 2000; Feinstein et al., 1988).

# Liard Basin - Oil and Gas Rights

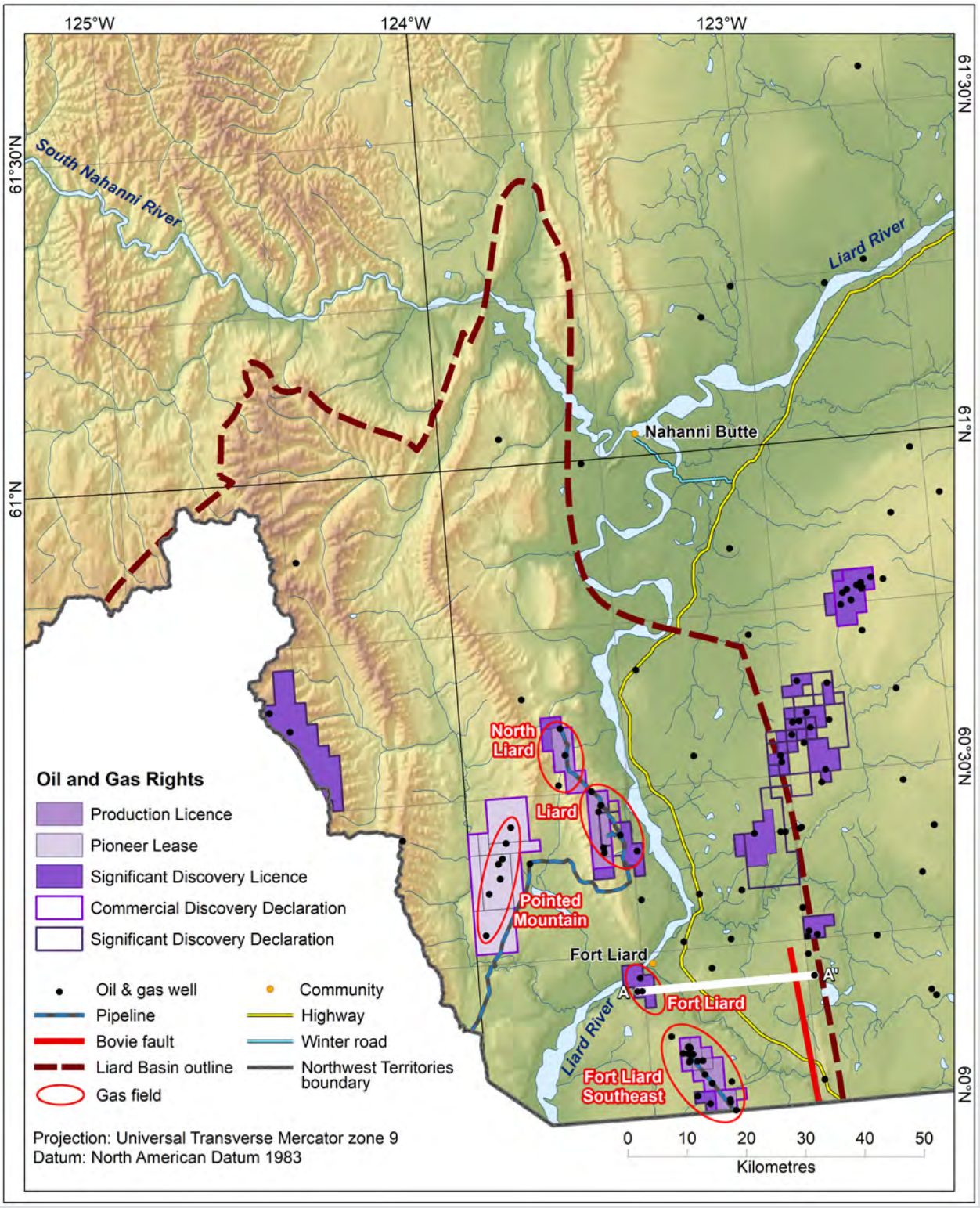



Figure 11: Current land disposition, well locations, and gas fields in the Liard Basin of NT. There has been no recent activity in NT in the previous five years and all gas fields are currently abandoned or suspended. The white bar shows the cross-section line used in Figure 2.

# Play Summary, Mapping, and Resource Potential

There are two shale gas plays in the Liard Basin of NT: the Middle Devonian Horn River Formation, and the Late Devonian to Mississippian Exshaw Formation (Figure 2). Both formations are self-sourcing black shales within the diachronous Besa River Formation. The Besa River Formation is a historical geologic unit that incorporates the distal basinal equivalents of the Horn River, Fort Simpson, Kotcho, Exshaw, Banff, Prophet, and Golata formations (Figure 2). The Horn River Formation in the Liard and Horn River basins is approximately age-equivalent to the Horn River Group in the Central Mackenzie Valley. It is interpreted to have been deposited in deep, oxygen-poor waters of the Northern Starved Basin (Moore, 1993). The Exshaw Formation marks the Devonian-Carboniferous boundary and is stratigraphically equivalent to portions of the Bakken Formation in Saskatchewan. Similar to the Horn River Formation, it is interpreted to have been deposited in an anoxic basin below storm wave base (Richards et al., 1993).

The gross thickness of the Horn River Formation varies from 450 m in the Pointed Mountain area to 5 m at the eastern margin of the Liard Basin (Figure 3). The greater thickness in the central part of the basin is attributed to thrust repetition of the Horn River and Nahanni formations (Rocheleau & Fiess, 2017). The Horn River shales thin to the east where they interfinger with the carbonates of the Slave Point and Keg River formations (Ferri et al., 2015). The net shale thickness of the Horn River Formation ranges from 344 m at Pointed Mountain to 0 m at the Bovie fault (Figure 4). Net shale was determined using a 10 Ω-m cut-off on resistance logs (NTGS et al., 2016). The Horn River Formation decreases in depth northward from approximately 4200 m at 60°N to 470 m at 61°N. There is also an abrupt decrease in depth east of the Bovie fault. The Horn River Formation shales contain a high proportion of silica (66 % on average) and have a mean total organic carbon (TOC) value of 2.5 wt. % (Rocheleau, unpublished data). Vitrinite reflectance (and vitrinite equivalent from pyrobitumen) ranges from 2.3 to 4.63 $\%R_o$ throughout the Liard Basin (Figures 5 & 6).

The gross thickness of the Exshaw Formation ranges from 275 m is the southern part of the basin to 25 m in the north and east (Figure 7). Net shale thickness varies from 250 m to 25 m with the greatest thickness found primarily in the south-central region (Figure 8). The Exshaw Formation is up to 4500 m deep at the southwest corner of the study area and shallows to 1600 m at the Bovie fault and 500 m at 61°N. The Exshaw Formation shales contain a high proportion of silica (65-85%) and an average TOC value of 3.4 wt. % (Rocheleau, unpublished data). Vitrinite reflectance values of 2.2 and 1.9 $\%R_o$ from the south and central areas contrast with a single valueof 3.8 $\%R_o$ in the northwest (Figures 9 & 10).

The shale gas resource in place was estimated using mapped geological data and an analysis of historical production data from the Liard Basin (NTGS et al., 2016). In NT, part of the Liard Basin is considered to be a "deformed area", where higher risk factors could prevent the recovery of any marketable gas (Figures 3-7). The expected volumes of gas in place are 187 Tcf and 318 Tcf for the Horn River and Exshaw formations, respectively (NTGS et al., 2016). The potential area for shale gas exploration in NT is approximately 50 km wide by 100 km long in a north-south trend west of the Bovie fault (Figures 3-10).

# Unconventional Play Attributes

Table 1: Unconventional Play Attributes of the Horn River and Exshaw formation shales. Data compiled from various subsurface (core) and field studies.

| | Exshaw Formation | Horn River Formation |
|---|---|---|
| Porosity (vol. %) | 4-9% (highest in organic-rich horizons) [1] | Expected porosity = 0.506*TOC%+3.55 [1] |
| TOC (wt. %) | 1.5-6.0% [1] | 0.32-6.01% [2] |
| VR and Vre (%Ro) | 1.95-2.45 (south-central), 1.86-2.01 (north-central), 3.62-3.80 (northwest edge). [2] | 4.14-4.44 (south central), 4.14 - 4.58 (northwest edge). [2] |
| Tmax (°C) | Dry gas in central part of the basin, overmature at NW end.[2] | Dry gas to overmature. [2] |
| Kerogen Type | Type I & II [2] | Type I & II [2] |
| Thickness (m) | 20-200 m (thickest at basin centre)[1] | 75-375 m (structural thickening)[2] |
| Silica content (wt. %) | 65-85%[1] | 66.24% (average)[2] |

[1]NTGS et al., 2016.
[2]Rocheleau,unpublished data.

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