Facies Analysis and Ichnology of the Upper Montney Formation in Northeastern British Columbia

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Introduction

The Lower Triassic Montney Formation is a world-class unconventional hydrocarbon reservoir hosted primarily in low-permeability siltstone and to a lesser extent, very fine grained sandstone. To date, most published research has focused on conventional plays in the eastern part of the basin, such as the Montney Formation turbidite interval and shoreface clastic and bioclastic units proximal to the Triassic subcrop edge (Davies et al., 1997; Moslow, 2000; Zonneveld et al., 2010a). These targets have been explored since the 1950s (Zonneveld et al., 2010a), whereas the low-permeability siltstone that constitutes the bulk of the Montney Formation was largely overlooked. Over the past decade, however, advances in horizontal drilling and multi-stage hydraulic fracturing made it possible to exploit hydrocarbons from this unconventional siltstone reservoir (National Energy Board et al., 2013). As a result, British Columbia has become a leading province in the exploration and development of unconventional gas resources (BC Oil and Gas Commission, 2012). The Montney Formation is the foremost gas-producing formation in BC and is believed to house 449 trillion cubic feet of marketable natural gas along with high volumes of gas liquids and condensate (National Energy Board et al., 2013).

The processes that control reservoir characteristics in this western unconventional trend are less well known than for plays situated to the east. Despite the relatively restricted grain size, the sedimentary facies of the Montney Formation are very heterogeneous. This refers to the several sedimentological and ichnological factors that result in highly variable reservoir characteristics (e.g., Clarkson et al., 2012; Wood, 2013). Subtle changes in the rock fabric both laterally and vertically result in the compartmentalization of resources within zones of distinctly different porosity and permeability values. Another controlling factor on reservoir properties is the occurrence of bioturbation. Biogenic permeability is important to reservoir properties because it has the ability to either enhance or reduce permeability or porosity (Pemberton and Gingras, 2005; Baniak et al., 2015). Bioturbation can influence the porosity and permeability by changing the distribution of grains and affecting the geochemistry thus affecting diagenetic processes (Gingras et al., 2012). A study done by Wood (2013) identified the degree of bioturbation in relation to the water saturation in the Montney Formation. Upper Montney Formation samples with a higher degree of bioturbation had a higher vertical permeability and water saturation (Wood, 2013). Bioturbated fabrics tend to enhance the permeability and vertical transmissivity of the rock (Pemberton and Gingras, 2005).

The purpose of this study is to understand the variability in bioturbated intervals in the Montney Formation and its affect on the porosity and permeability of this siltstone reservoir. This study will integrate sedimentology, ichnology and petrography from core studies with various petrophysical analyses to develop predictive models.

Regional Setting and Stratigraphy

The Montney Formation was deposited during the early Triassic on the western margin of Pangea (Davies, 1997). The Montney Formation succession in the study area is dominated by fine-grained clastic sediment as a result of an arid climate and long transport distances during the Triassic

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(Zonneveld et al., 2011). The Montney Formation is dominated by siltstone and very fine grained sandstone and determining depositional environments is challenging due to this restriction in grain size (Zonneveld et al., 2011). The Montney Formation is laterally extensive, spanning across Alberta and northeastern BC (Figure 1). It reaches thicknesses of over 300 m in the west and thins to 0 m at the subcrop edge in the east (Davies et al., 1997). Armitage (1962) defined Texaco's NFA Buick Creek No. 7 well (L.S. 6, Sec. 26, Twp. 87, Rge. 21, W 6^{th} Mer) as the type well for the Montney Formation. From this well, the Montney Formation was originally described as dark argillaceous siltstone and interbedded shale. It has been interpreted that the Montney Formation in the study area represents deposition in an offshore, basin-centred setting (Gibson and Barclay, 1989; Edwards et al., 1994; Davies et al., 1997). Core studies do not support this interpretation and the upper Montney Formation shows evidence of deposition in a shallow marine environment with most deposition occurring within a couple hundred metres of maximum water depth (Zonneveld et al., 2011).

Different workers have formally and informally assigned the Montney Formation, and units within it, to different stratigraphic levels. Also, correlations can differ significantly across the Alberta and BC border. Thus far no lithostratigraphic subdivision has been widely accepted but for the purpose of this research, the Montney Formation in the study area is divided into the upper and lower Montney Formation (Figure 2). The upper Montney Formation spans from the informally named mid-Montney marker (MMM) to the base of the Doig phosphate zone. The MMM is interpreted as a flooding surface and it approximates the Smithian–Spathian boundary (Golding et al., 2014). It is easily identifiable on well logs as a sharp increase in gamma-ray levels. The Doig phosphate zone has a very high signal on gamma-ray logs as result of phosphate-rich siltstone (Golding et al., 2014).

Ichnology

The Montney Formation includes the earliest Triassic strata in the subsurface of the Western Canada Sedimentary Basin and provides valuable information about life during the recovery interval after the end of the Permian mass extinction (Zonneveld et al., 2010b). Trace fossils provide a record of in situ activities of infaunal and epifaunal organisms (Zonneveld et al., 2010b). Environmental conditions during this time were stressed and as a result the ichnofossil assemblages observed are characterized by low diversity, high abundance and reduced body size (Zonneveld et al., 2010b).

Bioturbation is important to reservoir properties because it has the ability to either enhance or reduce permeability or porosity (Pemberton and Gingras, 2005; Baniak et al., 2015). In recent literature, ichnology of the Montney Formation has been discussed, however, its affects on reservoir properties has received little attention. Analyzing bioturbated intervals includes the identification of fossil traces, assessment of bioturbation intensities and burrow size (Figure 3).

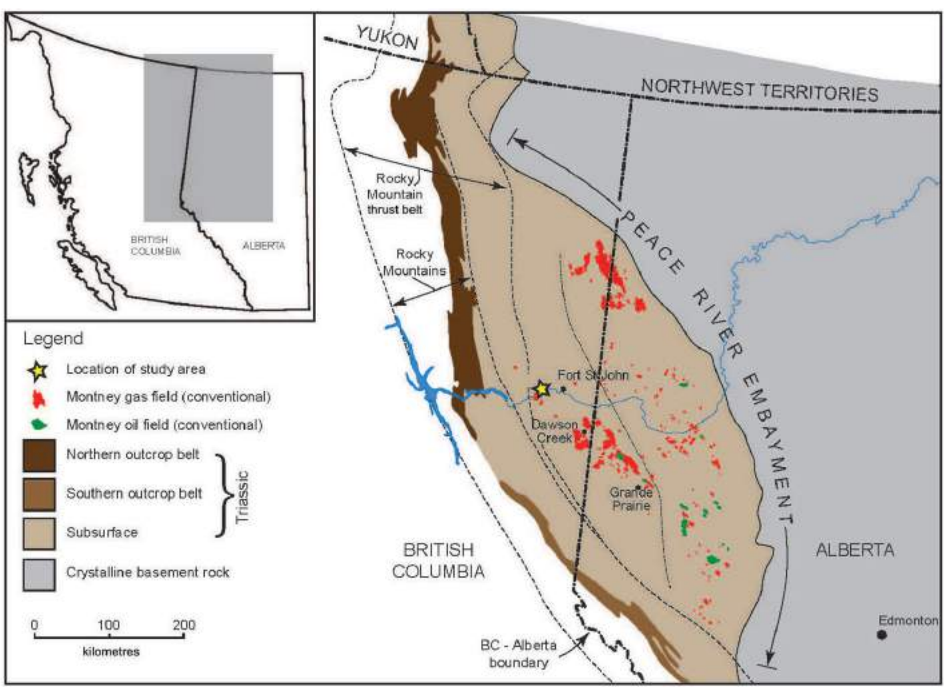

Figure 1. Regional map indicating the extent of Triassic strata in the Western Canada Sedimentary Basin. Montney Formation oil fields, unconventional gas fields and location of the study area are indicated. Figure modified from Zonneveld et al. (2011).

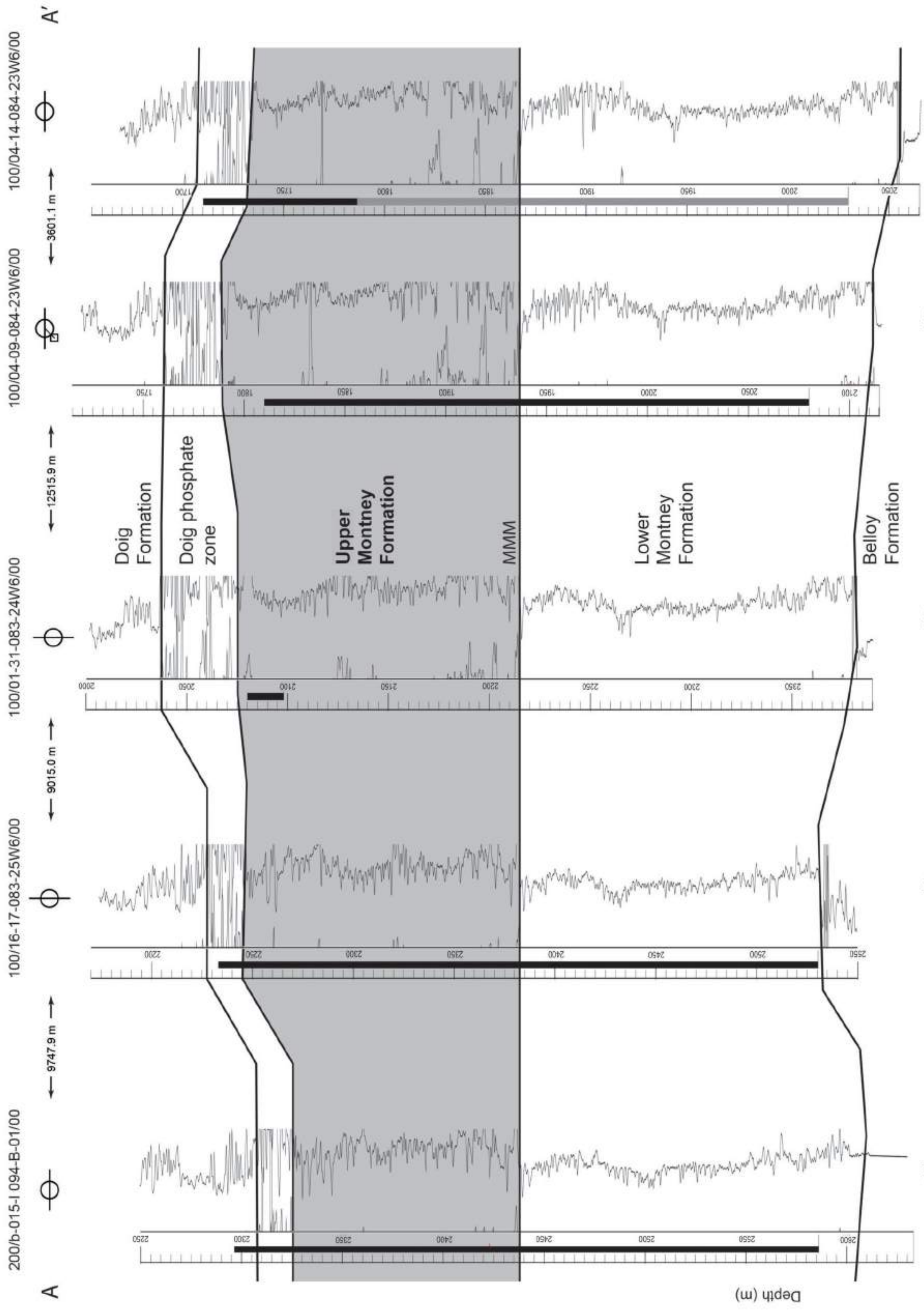

Figure 2. Well-log cross-section through study area indicating log picks informally designating the upper Montney Formation, northeastern British Columbia. See Figure 4 for cross-section location. Abbreviation: MMM, mid-Montney marker.

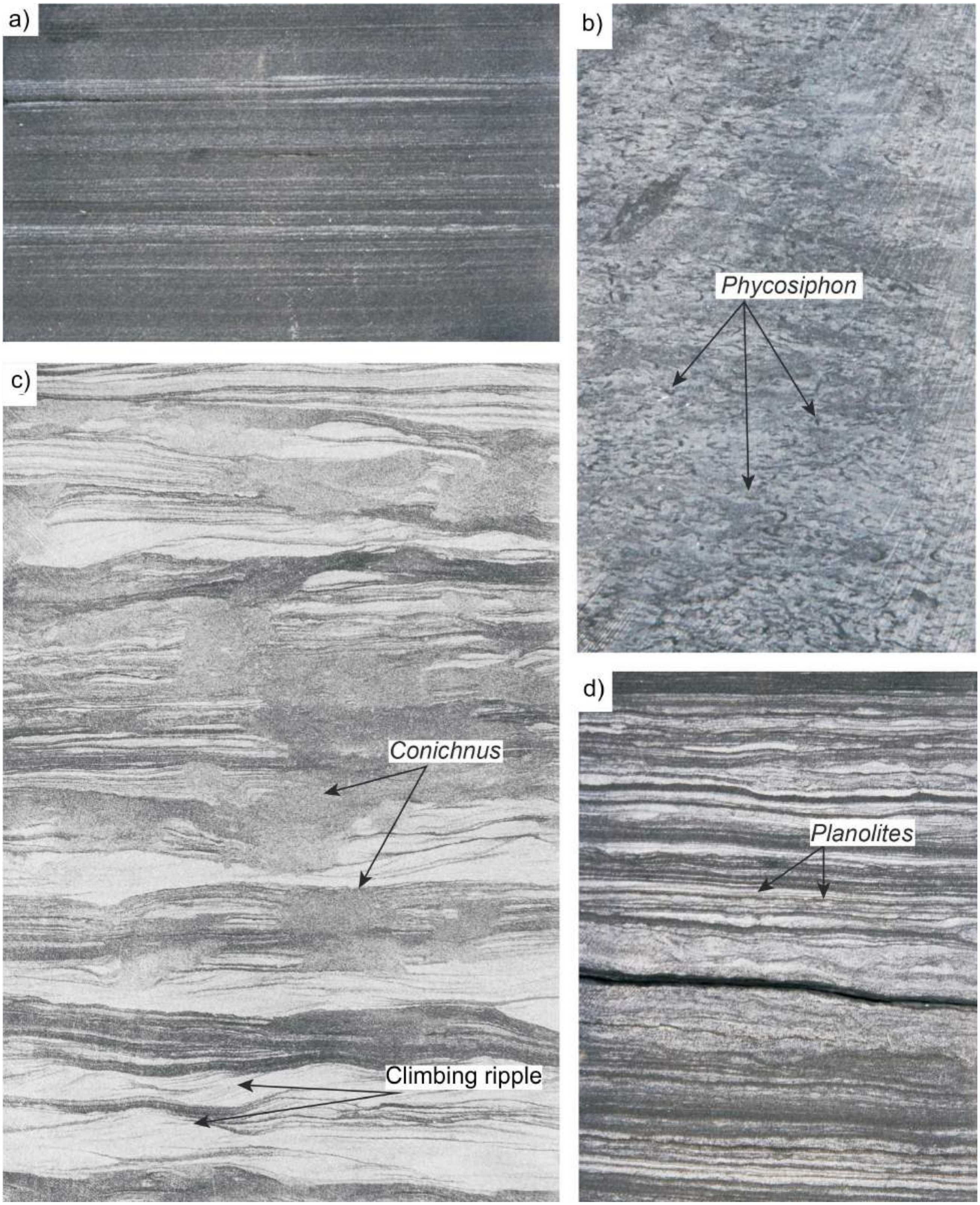

Figure 3. Example images of different bioturbated facies: **a)** parallel laminated siltstone, no bioturbation present, in well C-033-C/094-B-09 at 2226.40 m; **b)** sample of bioturbated fabric completely dominated by *Phycosiphon*, in well C-024-K/094-B-08 at 2229.70 m; **c)** *Conichnus* traces interpenetrate and disrupt the sedimentary structures, climbing ripples are present, in well D-067-J.094-B-09 at 1901.70 m; and **d)** bioturbated fabric with small diminutive traces of *Planolites*, in well C-033-C/094-B-09 at 2202.40 m.

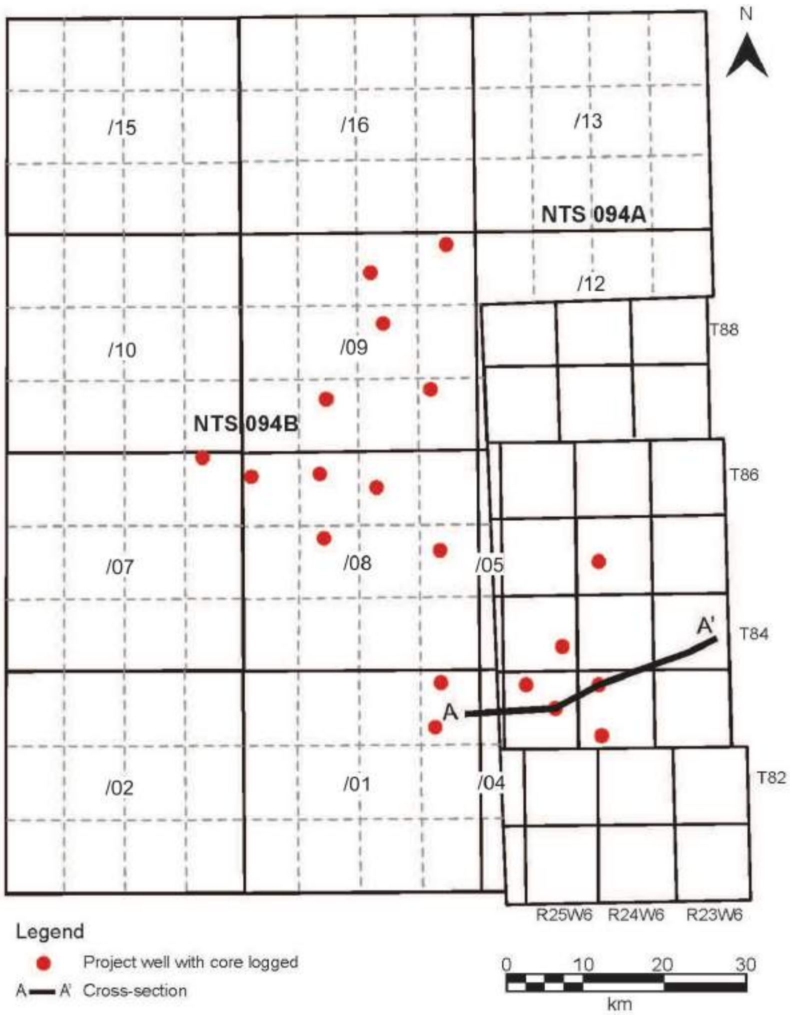

Figure 4. Map of study area, northeastern British Columbia. The red dots indicate the location of wells from which core of the upper Montney Formation has been sampled and analyzed in detail.

Study Area

The study area is commonly referred to as the northern Montney within the Montney play trend and is part of the dry gas fairway (BC Oil and Gas Commission, 2012). The Montney Formation in this northern region has not been extensively studied and facies distributions and relationships to the rest of the basin are not well understood. The area of interest lies within Twp. 82 to 84, Rge. 24 to 25, W 6th Mer. and includes areas on NTS map areas 094A and 094B (Figure 4). There are approximately 1900 wells that penetrate the top of the Montney Formation over this 10 300 km^2 area. Within the upper Montney Formation, there are 87 wells that have cores preserved and stored at the BC Oil and Gas Commission Core Research Facility in Fort St. John. A subset of 19 wells has been described in detail and provides the primary data for this study (Table 1).

Project Work

To develop a predictive geological model of reservoir characteristics and quality, this study will integrate the results of sedimentological, ichnological and petrographic analysis. This work will be completed over an 18-month period, with the results to be reported as an M.Sc. thesis.

Table 1. List of wells from which core of the upper Montney Formation was analyzed. See Figure 4 for map of the well locations.

Location (UWI)	Well name	Pool name	Year drilled
200/b-017-I 094-B-01/00	CANBRIAM HZ W FARRELL B-017-I/094-B-01	Farrell	2009
200/c-085-I 094-B-01/00	PROGRESS ET AL ALTARES C-085-I/094-B-01	Altares	2008
200-d-094-I 094-B-07/00	PROGRESS ET AL GRAHAM D-094-I/094-B07	Graham	2012
200/c-065-F 094-B-08/00	PROGRESS ET AL GRAHAM C-065-F/094-B-08	Graham	2013
202/c-003-H 094-B-08/00	CANBRIAM HZ ALTARES B-B034-H/094-B-08	Altares	2012
200/c-007-J 094-B-08/00	PROGRESS HZ ALTARES C-007-J/094-B-08	Altares	2011
200/c-024-K 094-B-08/00	PROGRESS HZ GRAHAM C-024-K/094-B-08	Graham	2011
200/c-006-L 094-B-08/00	PROGRESS ET AL GRAHAM C-006-L/094-B-08	Graham	2013
200/d-048-A 094-B-09/00	SUNCOR PC HZ KOBES D-048-A/094-B-09	Kobes	2006
200/c-033-C 094-B-09/00	CNRL GRAHAM C-033-C/094-B-09	Graham	2009
200/c-074-G 094-B-09/00	SUNCOR PC HZ KOBES C-074-G/094-B-09	Kobes	2008
200/b-093-I 094-B-09/00	SHELL HZ BLUEBERRY B-093-I/094-B-09	Blueberry	2011
200/d-067-J 094-B-09/00	PROGRESS KOBES D-067-J/094-B-09	Kobes	2009
100/04-20-084-24W6/00	ARCRES HZ ALTARES 04-20-084-24	Altares	2011
100/01-31-083-24W6/00	CANBRIAM FARRELL 01-31-083-24	Farrell	2008
100/05-05-083-24W6/00	CANBRIAM FARRELL 05-05-083-24	Farrell	2008
100-01-32-083-25W6/00	PROGRESS ET AL HZ ALTARES A01-32-083-25	Altares	2011
100-12-36-083-25W6/02	PROGRESS ET AL HZ ALTARES 12-36-083-25	Altares	2011
100/16-17-083-25W6/00	PROGRESS ET AL ALTARES 16-17-083-25	Altares	2009

Abbreviation: UWI, unique well identifier.

The specific research methods to generate inputs to the model are outlined below:

- analyzing the core, focusing on sedimentological and ichnological characteristics (bioturbation intensities, mineralogy, sedimentary structures, biogenic structures, body fossils and grain size), work completed this past season;
- mapping the distribution of bioturbated fabrics, stratigraphically and regionally;
- analyzing the thin sections to study lithology, porosity and trace fossils;
- obtain permeability measurements using a Core Laboratories pressure-decay profile permeameter;
- identifying log signatures associated with specific ranges of porosity and permeability; and
- correlating core data with downhole wireline logs and extrapolate information to wells that are underrepresented with core.

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