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Hydrocarbon Potential and Depositional Environment of the Lower Cretaceous Garbutt Formation, Liard Basin, Canada

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Summary

This study presents organic matter (OM) characterization, thermal maturity, hydrocarbon potential and paleo-redox sedimentary conditions of the Lower Cretaceous Garbutt Formation in the Liard Basin in British Columbia. The study compares outcrop samples from western edge of the basin to subsurface core samples from the eastern margin. Lower Garbutt lithology varies from coarse-grained siltstone (mean = 51.9µm) in the west to shaley facies in the eastern part of the basin. The major OM constituents of western outcrop samples are vitrinite and inertinite macerals (kerogen Type III) that are mainly reworked. Minor amounts of migrabitumen have filled intergranular porosities. In contrast core samples from near the eastern basin margin consist of kerogen Type II, dominantly composed of liptinite group macerals (alginite) with lower abundance of vitrinite and intertinite group macerals. Total organic carbon (TOC) content of outcrop samples is significantly lower (mean: 1.21 wt. %) than subsurface core samples (mean: 4.2 wt. %). Outcrop samples are at the end of oil window while the maturation of core samples varies from onset of the oil window to the condensate zone with a gradual north to south increase in thermal maturity. Inter-crystalline porosity associated with framboidal pyrite and microfossil interskeletal porosity host free oil in the core samples, whereas, intergranular porosity forms the major pore spaces in silty outcrop samples. These results indicate that the Garbutt Formation near the eastern margin of the Liard Basin in British Columbia could potentially be an excellent target for unconventional oil and wet gas exploration.

Paleo-redox trace element (i.e., Mo and U) enrichment factor (EF) of subsurface samples relative to average shale is higher by two orders of magnitude. In contrast outcrop samples have no significant EF. The predominance of terrestrial OM (kerogen Type III), coarser grain size, and higher detrital mineral contents of outcrop samples in comparison to the mainly marine OM (kerogen Type II, liptinite group), finer grain sediments and significantly higher TOC content and paleo-redox trace elements concentrations suggest the primary source of sediment for the Garbutt Formation was from the west. The trace elements record of core samples show small scale variation in the basin redox condition.

Introduction

The Liard Basin of northeastern British Columbia, southwestern Northwest Territories, and southeastern Yukon Territory (Fig. 1) contains significant unconventional shale gas resources in Devono-Mississippian shales and are being actively explored for in British Columbia (Adams, 2014). Lower Cretaceous shales of the basin are known to have shale gas potential (Chalmers and Bustin, 2008a, b; Ferri et al., 2011; McMechan et al., 2012) but remain unexplored (Adams, 2014). This study suggests the Lower Cretaceous

Garbutt shales of Liard Basin in northeastern British Columbia may be a promising exploration target due to their organic richness, lateral extent and thickness.

The Garbutt Formation consists of black, silty shale and mudrock containing centimetre to decimetre-thick sideritic beds. It was deposited during the major marine transgression in the Western Canada Sedimentary Basin (Kauffman and Calwell, 1993; Leckie and Potocki, 1998). Basal shale or siltstone of the Garbutt Formation either conformably overly sandstones of the Chinkeh Formation or lie directly above the regional sub-Cretaceous unconformity (Stott, 1982; Leckie and Potocki, 1998; Fig. 2). Garbutt Formation rocks were deposited in a marine environment, largely below the storm wave base (Leckie and Potocki, 1998). This study integrates the results from organic petrology, Rock-Eval and trace element analyses for outcrop samples of western margin of Liard Basin (Ferri et al., 2011) and cores from near the eastern margin of the basin. Samples are from three wells located in a north to south direction at depths ranging from 1200 to 1400m (Fig. 1).

Method

Representative chip samples were collected every 1 meter from the cores. Acquired samples were split, with one group analyzed for whole-rock, trace and rare earth element abundances by inductively coupled plasma mass spectrometry (ICPMS) with four acid digestion methods at Acme Analytical Laboratories (Vancouver, BC), and a second group analyzed for organic geochemistry by Rock-Eval analysis at the Geological Survey of Canada (Calgary, Alberta). Organic petrology was carried out on selected samples using polished blocks made with a cold-setting epoxy-resin mixture. The resulting sample pellets were ground and polished, in final preparation for microscopy using an incident light Zeiss Axio Imager II microscope system equipped with fluorescent light sources and the Diskus-Fossil system for reflectance measurements.

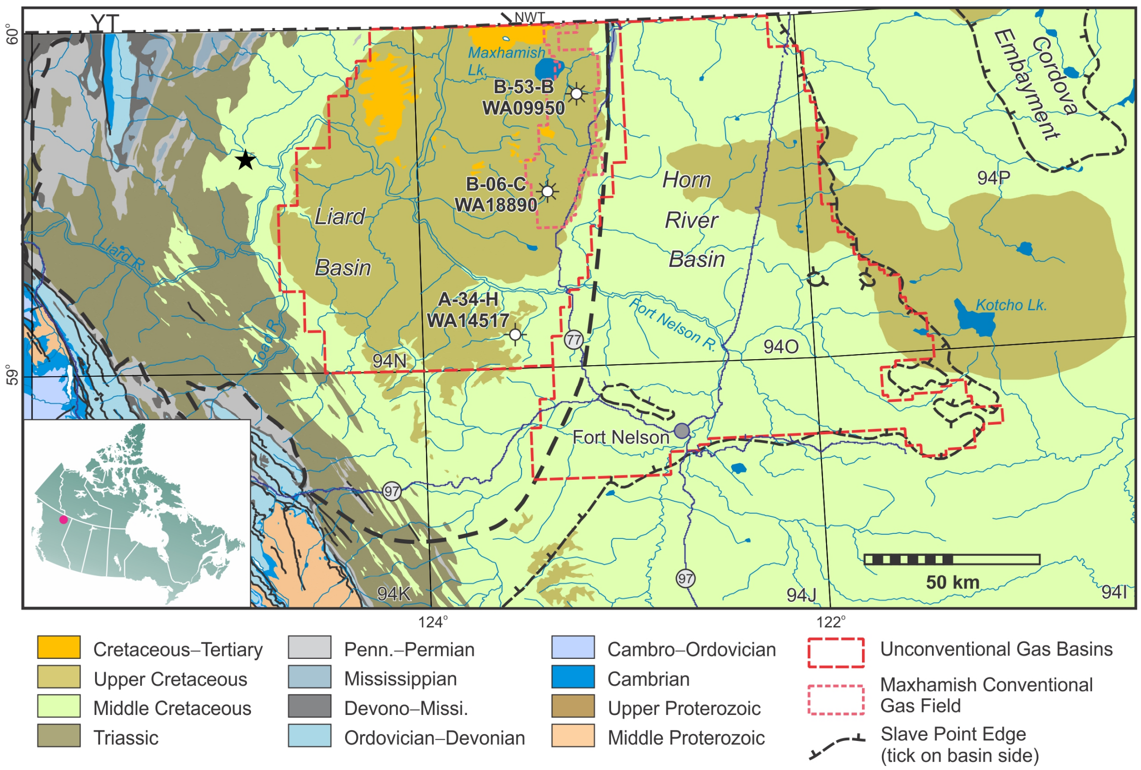

Figure 1. Regional geological setting of the study area and the location of studied wells (AEC Maxhamish B-053-B/94-O-14, WA09950; ECA ECOG Maxhamish B-006-C/94-O-11, WA18890; Tsoo A-13-H/94-O-4, WA14517) and surface section (star).

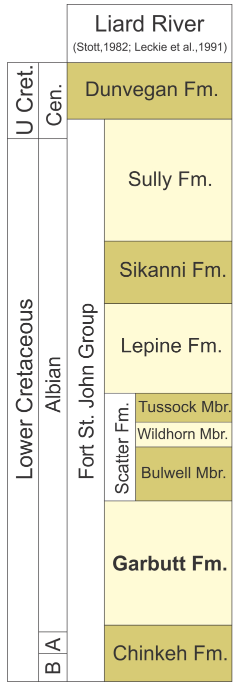

Figure 2. Stratigraphic framework for Cretaceous strata in the Liard Basin, northeast British Columbia. Modified after Ferri et al. (2011).

Results and Discussion

The average grain size of the Garbutt Formation decreases from a coarse-grained siltstone (mean: 51.9 µm) to a shale from west to east across the Liard Basin. The outcrop samples of Garbutt Formation from the western margin of basin have TOC content ranging from 0.67 to 1.67 wt.% (mean: 1.21%), while, the subsurface samples from the eastern margin have excellent TOC content ranging from 1.1 to 10.3% (mean: 4.3%). The current TOC content of subsurface and outcrop samples consist of an average of 88% and 92% residual carbon (RC), respectively. Kerogen type in the western margin of the basin is dominantly Type III, terrestrial kerogen, with abundant reworked vitrinitic and intertinitic macerals, and migrabitumen filled intergranular porosity. Samples from the eastern part of basin contain mainly marine kerogen Type II, dominantly composed of liptinite group macerals (alginite) with lower abundance of vitrinite and intertinite group macerals. Inter- and intraskeletal porosities in the eastern core samples filled with exudatinite.

The T_{max} values obtained from the Rock-Eval analysis of outcrop samples ranges from 454 to 479°C which represent the onset of dry gas window, while T_{max} values for core samples ranges from 432 to 470°C which brackets the oil window and up to the onset of dry gas window. Higher temperatures occur toward the south. The Hydrogen Index (HI) of core samples decreases significantly with increasing thermal maturity from north to south. Core samples in the oil window have high S2 values (up to 25.9 mg HC/g TOC) and exude oil under fluorescent light. The majority of oil in the lower maturity (i.e., oil window) samples fills the intercrystalline porosity of framboidal pyrites or pores in the microfossil skeletons.

Random vitrinite reflectance (VRo) was measured in outcrop and core samples. In outcrop samples (T_{max} = 454 – 479°C) VRo ranges from 0.88 to 1.1% which suggests the end of oil window and onset of wet to dry gas window. Core samples exhibit a slight variation in thermal maturity compared to T_{max} values. Samples with lower maturity (T_{max} = 432 – 450°C) show two distinct vitrinite populations, one with an average peak of ~0.751 % (σ = 0.219), the other with an average peak of ~1.081 % (σ = 0.183). These two populations are thought to represent the original, Cretaceous vitrinites (lower maturity) and reworked vitrinites from older formations with a much greater average maturity. Within samples of higher maturity (T_{max} = 463 – 469°C), these two populations are far closer, and display overlapping measurement distributions, with peaks at ~1.311 % (σ = 0.378) and ~1.495 % (σ = 0.280), respectively. Core samples from north to south also show a red shift in the liptinite group fluorescence color which is consistent with an increase in the thermal maturity and is in accordance with the other thermal maturity indicators (i.e., T_{max} and VRo).

The bulk concentration of paleo-redox trace element proxies (i.e., Mo and U), and the percentage of framboidal pyrite, significantly increase from west to east. The mean Mo enrichment factor (EF) of outcrop samples in is 2.6, while core sample shows EF values up to two orders of magnitude (97.4) higher than the average shale which indicates prevailing euxinic conditions in the eastern part of the basin. U also shows the same trend with lower EFs than Mo. Mineralogical analysis also show higher concentration of quartz in the outcrop samples (mean: 79.9%) in comparison to the core samples (mean: 37.4%) from the eastern part of the basin. The decrease in grain size and significant increase in TOC content, paleo-redox trace elements concentration, framboidal pyrite content, and change in type of kerogen from west to east indicates that the sediment were sourced from the west and that the basin deepened toward the east. Among the core samples, the middle core (i.e., WA 18890; Fig. 1) has the highest average Mo concentration (63.6 ppm) and framboidal pyrite content (up to 15%) in comparison to the other two wells. This suggests a more restricted environment in this part of the basin.

Conclusions

Rock-Eval analysis and organic petrography indicate that outcrop samples of the Garbutt Formation from western Liard Basin are in the onset of dry gas zone, while core samples along the eastern margin of the basin show a range of thermal maturity from onset of oil window to onset of dry gas window along a north-south transect. Core samples from the eastern margin of the basin have higher TOC content than their outcrop equivalents in the west. In addition, core samples with higher percentage of pyrolysable carbon (20%) in comparison to outcrop samples (8%) have a further potential for hydrocarbon generation. This makes Garbutt Formation an excellent target for oil and wet gas exploration and production in the eastern margin of the basin.

The predominance of terrestrial organic matter (Type III kerogen), coarser grain size, and higher detrital mineral contents of outcrop samples in comparison to predominance of marine organic matter (Type II kerogen, liptinite group), finer grain sediments and significantly higher TOC content and paleo-redox trace elements concentrations in subsurface samples in the east indicates that the source of sediments for Garbutt Formation was from the western margin of Liard Basin. Trace element variations among core samples show small scale variation in basin redox conditions.

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