# Lower Carboniferous Banff Formation - New Insights about Petroleum Migration and Rocky Mountains Scenery from a Preliminary Petroleum & Organic Matter Characterization

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## Introduction

The Lower Carboniferous Banff Formation of Western Canada Sedimentary Basin (WCSB) is a widespread and up to 800 m thick mixed siliciclastic-carbonate succession deposited on the cratonic platform in the northwestern margin of ancestral North America (Chatellier, 1992; Richards et al., 1994). The Banff Formation is extensively drilled. However its role in the petroleum system of WCSB is poorly understood. A detailed basin-wide oil-source correlation study suggests that the petroleum generated by the underlying Devonian to Carboniferous in age Exshaw Formation migrated through the Banff Formation to charge the overlying sedimentary units including Athabasca Oil Sands Deposit (Adams et al., 2013). However, the mechanism of petroleum migration through the mostly tight Banff Formation is poorly understood (Adams et al., 2013). Although, the Banff Formation hosts diverse play types such as (i) detrital plays, (ii) hydrothermal dolomites (i.e. Ferrier gas field), and (iii) clastic reservoirs (i.e. DeTree project), etc. no significant petroleum accumulations have been encountered.

The Banff Formation is well exposed in the Front Ranges of the Canadian Rockies. Repeated stratigraphy, caused by Mesozoic thin-skinned thrusting (Cook et al., 1988), allows for examination of sections representing proximal to distal depositional settings over relatively short distances along an east–west transect. In outcrops, the Banff Formation is easily recognizable by its distinct beige to light brown, weathered color (Fig. 1). The Banff Formation forms relatively gentle slopes compared to the underlying dark grey, cliff-forming Palliser Formation and overlying light grey Rundle Group (Fig. 1). Increased shale and/or silt content are commonly invoked to explain enhanced erosion of the Banff Formation rocks. However, with the exception of the lowermost mixed carbonate siliciclastic unit (Upper Bakken equivalent; Smith and Bustin, 2000) which is argillaceous, the Banff Formation in road cut exposures and subsurface cores is usually described as non-argillaceous dark colored carbonate succession. Rare argillaceous fragments are described as wind-blown silt and clay size material. These observations provoke two questions: (i) why the Banff Formation rocks appear to be dark, tight and hard in road cuts, cores, and thin sections, and rather weak, earthy, and locally fissile in outcrops; and (ii) why the rocks of the Banff Formation tend to form slopes that are gentler than those of overlying and underlying carbonate units.

Inspired by high total organic carbon (TOC) percentages in several wells from central Alberta (GSC Open File Reports), this study aims to identify and characterize organic matter and petroleum occurrences in subsurface cores and outcrop sections. The ultimate goal is to attempt to improve the understanding of [i] petroleum migration paths and/or migration mechanism through the deposits of the Banff Formation; [ii] its self-source potential; and [iii] the potential relationship between organic matter content, petroleum migration paths, and increased erodibility of Banff Formation rocks in outcrops.

## Theory and/or Method

Subsurface studies of two short cores from intervals characterized by high TOC (drill cuttings analysis) include:
(i) Core description, facies identification, and depositional environment interpretation;
(ii) Petrography and EDS elemental study of thin sections and rough samples;
(iii) Source rock evaluation using RockEval and qualitative organic petrography (fluorescence);
(iv) Hydrocarbon molecular composition analysis using gas-chromatography - mass spectrometry (GC-MS).

Outcrop studies include outcrop slope measurements and analysis of single weathered outcrop sample from Canyon Creek near the town of Bragg Creek:

(i) Raman Spectroscopy

(ii) Petrography and organic petrography of thin sections

Data and results are integrated and interpreted in contexts of the petroleum system and geomorphology.

## Examples

<u>Core Sample:</u> Data and observations from cores show carbonate dominant lithology with rare siliceous fragments. There is also evidence of multistage dolomitization and silica precipitation, initial porosity reduction, and limited secondary nano-scale porosity development. In contrast to high organic matter concentration (1-6% TOC wt%) recorded in drill cuttings, core samples display low TOC content ( ~0.2 TOC wt%). Although rocks appear to be non-porous in thin sections, SEM and organic petrography shows evidence of live oil in micropores and microfractures. The organic matter is present but is immature in studied samples. Biomarkers clearly show two distinct types of source rocks: marine shale (Exshaw Type, sensu Adams et al., 2013) and carbonate (i.e. Madison Group Type, sensu Jiang et al., 2002).

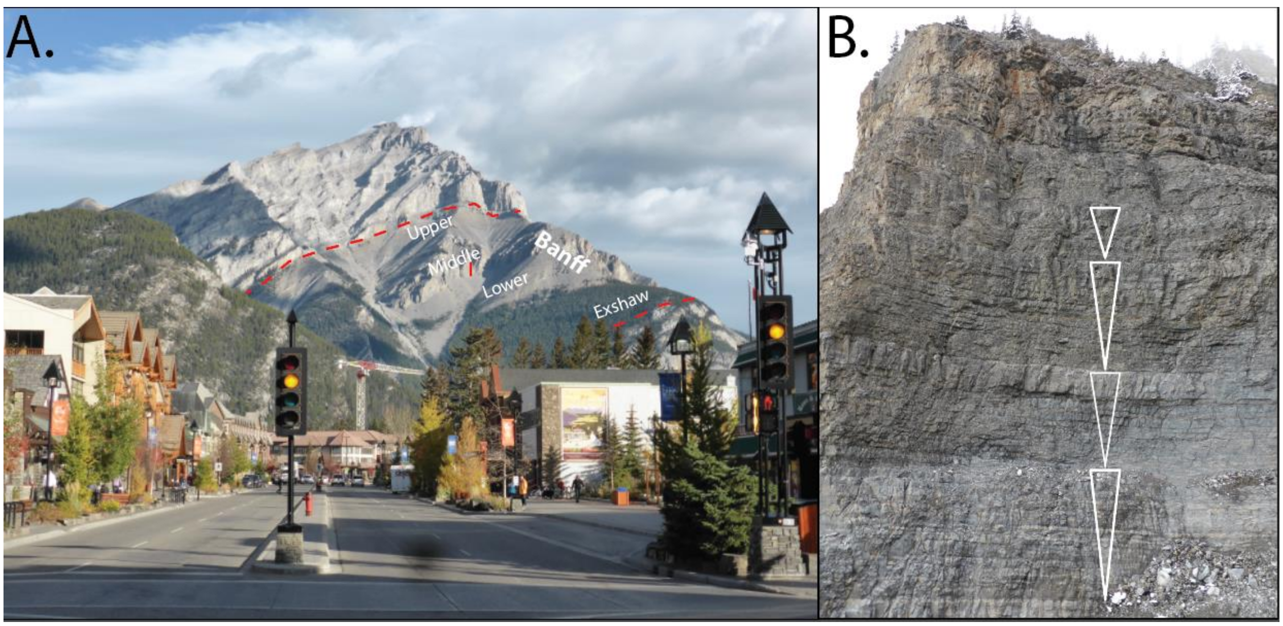


**Figure 1.** **A.** Exshaw-Banff succession at Cascade Mountain, Banff, Alberta, Canada. The Exshaw Formation is covered by vegetation. Note: the Banff Formation is sub-divided into lower, middle (erosion resistant), and upper members**. B.** Close up view of Banff Formation exposure (approximate location vertical red line at the base of Middle Banff in A.) photograph showing conformable succession of coarsening-upward sedimentary cycles of genetically related bedsets bounded by marine flooding surfaces (bases of triangles), interpreted as prograding clinoform parasequences.

<u>Outcrop Sample:</u> Raman spectrometry analysis of outcrop sample shows strong carbonate and organic matter peaks as well as silicate peak. Petrographic analysis shows that the lithology ranges from fine-grained laminated to moderately bioturbated carbonate (calcisiltites, lime mudstones) to quartz-dominated siltstones with calcareous matrix; there is also evidence of multistage dolomitization and localized chert formation; the organic matter fills inter- granular/crystalline pore spaces in fine- to medium crystalline calcareous rocks. The silica might be biogenic.

## Conclusions

Our limited data allow us to make provisionary ideas for numerous conclusions and future studies:

(i) Elevated TOC obtained from RockEval of drill cuttings is not representative of actual TOC content in the Banff Formation. Recorded high TOC values are probably caused by coal cavings and/or organic additives during drilling.

(ii) Identified organic matter in all studied samples may contribute to dark color and infered reduced hardness and consequently enhanced weathering and erodibility. Enhanced erodibility results in lesser slope angles than those of the carbonate units underlying and overlying the Banff Formation.

(iii) Finer-grained bases of intra-formational coarsening upward parasequences may locally thicken and have higher TOC concentrations implying potential source rock potential.

(iv) The widely accepted belief that petroleum migrates via narrow migration paths comprised of porous carrier beds or paths is challenged by the presence of Exshaw sourced oil in examined Banff Formation tight carbonates.

(v) Dispersed occurrences of migrated live oil in tight non-reservoir rock units may represent significant, yet poorly understood petroleum losses during migration.

In summary, the origin of dispersed organic matter and migrated oil within Banff Formation tight rocks, their role in the petroleum system, and the impact on rock mechanical properties of surface and subsurface rocks needs to be better understood.

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