Petrographic characterizations of the "Nordegg" (Gordondale) Member of the Fernie Formation in West Central Alberta, Using Scanning Electron Microscopy & Organic Petrology

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Summary

The Gordondale member of the Fernie Formation, also termed "Nordegg", in West Central Alberta has recently come to light as the focus of many unconventional exploration activities due to its high hydrocarbon potential and the improvement in drilling, completion and stimulation techniques that have allowed reserves of its qualities – tight (low permeability and porosity) organic rich shales, to be exploited.

This study highlights the organic matter characteristics and associations of the Gordondale, as well as its implications for the hydrocarbon potential and reservoir quality using scanning electron microscope (SEM) and organic petrography.

Preliminary results show that the samples are generally organic rich (up to 13 wt. % TOC) and within the oil generation window (eq. VR_o=0.9%). The organic petrology indicates the presence of bitumen as the dominant organic maceral within the samples. Bitumen in the samples exhibit an invasive nature as they dominate the entire matrix of the samples and fill most intergranular pore spaces within organic and inorganic fractions of the rock. Bitumen also occurs in the form of vacuole and fracture filling migrated bitumen.

In general, two main types of bitumen (matrix bitumen and solid bitumen) can be summarized based on their mode of occurrence, maturity and physical accumulation. Results indicate that fluorescing matrix bitumen and exsudatinite are contained within aggregates of clay minerals – most commonly kaolinite aggregates. The bitumen and exsudatinite in these clay aggregates rapidly breakdown and release light hydrocarbons (oil) within the samples. Solid bitumen is associated with zooclast (bivalve and belemnite fossil remains) and irregularly shaped diagenetic calcites, which are bi-products of bacterial sulphate reduction.

Introduction

The Gordondale is one of the richest oil-prone source rocks in the Western Canada Sedimentary Basin. It is a fine-grained, organic-rich, fossil-rich, phosphatic, calcareous

mudstone, and has been described as a shelf facies deposited in the lower Jurassic, specifically Hettangian to Toarcian in age, based on coccolith & ammonite biostratigraphy. A formal name – Gordondale, was proposed for this facies (Asgar-Deen et al. 2004), and has been adopted for this study.

Deep anoxic restricted bottom water conditions facilitated the deposition of the Gordondale, which occurred in two transgressive cycles separated by a regressive cycle. The depositional mechanisms are evident in the Gordondale in the form of three units described in previous Gordondale studies (Riedeger et al. 1990; Riedeger and Bloch 1995; Asgar-Deen et al. 2003).

In this work, we perform a detailed study of a 30m Gordondale core between 1845m - 1880m. An approximate location of the core within the areal extent of the Gordondale Member is shown in Figure 1.

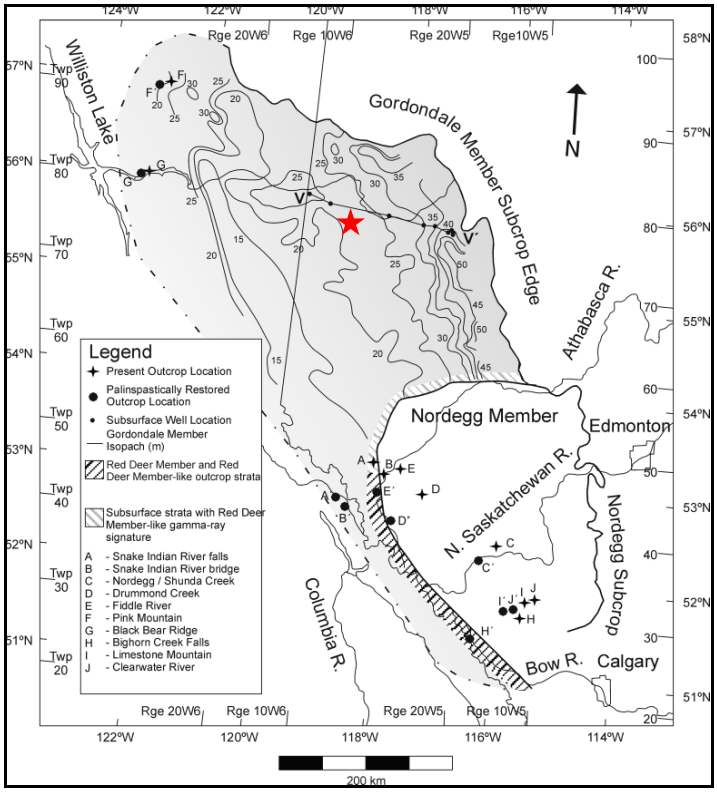

Figure 1: Map showing the areal extent of Gordondale Member (in grey), and the approximate location of the core studied (red star). Modified from Asgar-Deen et al, 2004.

Methodology

Scanning electron microscopy with energy dispersive x-ray (EDX) mapping, and optical petrography, were used to examine the core samples. Thirty-eight diamond-polished thin sections and thirty rock chip pellets were made from various depths for SEM and organic petrography respectively.

EDX maps of key elements were compared to photomicrographs. Petrographic analysis was conducted with a reflected white light and ultra-violet/blue light irradiation microscope. Nanoscale spot reflectance measurements were conducted on mainly bitumen macerals. Bitumen random reflectance was converted to equivalent vitrinite random reflectance, using the Jacob's (1989) equation (VR_o (%) = 0.618*BR_o+0.40) for thermal maturity determination.

Results & Discussions

Two main types of bitumen were recognized within the Gordondale core studied. The bitumen were classified and recognized based on their reflectance range, mode of occurrence and containment associations within various intervals in the core.

1. ***Matrix bitumen*** – This is the dominant form of bitumen and exsudatinite observed in the Gordondale. It is disseminated within the mainly porous clay matrix. Its size ranges from very fine to fine-grained (<1 µm-4 µm) and it is characterized by BR_o averaging 0.8% - in the oil window, and a yellow-brown to brown-red fluorescence. The small surface area of matrix bitumen makes it challenging to measure. Matrix bitumen is evident in EDX profiles as intergranular pore-filling bitumen in a variably calcareous (coccolith remnants) and argillaceous-rich matrix. Occasionally within the core, rounded sponge-like aggregates of clay minerals (mostly kaolinite) occur. Matrix bitumen likely accumulates in micro pore spaces in-between individual plate-like kaolinite crystals. Preliminary fluorescence work shows that the bitumen and exsudatinite in these clay aggregates degrade rapidly and release a significant amount of light hydrocarbons (which have a bright blue fluorescence) after a few seconds of exposure to ultraviolet light. In some circumstances, matrix bitumen might also be associated with apatite, a calcium phosphate mineral that has been noted at various intervals in the Gordondale. EDX profiles indicate that this mineral, which occurs in form of bedding parallel nodules, is rich in carbon - mainly in the form of fine-grained matrix bitumen.

2. ***Solid bitumen*** – These are solid granular bitumen of often larger accumulations (up to 10 µm in size) contained mostly within larger isolated pore spaces, cavities, and micro fractures. It tends to have slightly higher measured BR_o (0.8 – 1.1%), and does not fluoresce. This form of bitumen likely represents migration and accumulation of bitumen from the matrix into nearby micro fractures, large pore spaces, and vacuoles in zooclast (calcitized fragments of bivalves & belemnites) and char particles. Solid bitumen also occurs in association with diagenetic calcite. Bitumen associated with these calcites accumulates around the edges of irregularly formed calcite, or accumulate in larger masses in very close proximity to the diagenetic calcite. These calcites are speculated to be the bi-products of early bacterial sulphate reduction (BSR). Solid bitumen in this core has attained a higher reflectance range than matrix bitumen likely due to the chemical degradation during BSR and migration into micro fractures. The larger accumulation and hence surface area of solid bitumen makes it easier and perhaps more accurate to measure compared to matrix bitumen.

Conclusions

The combination of organic petrography and scanning electron microscope study of the Gordondale, reveal two main types of bitumen and exsudatinite present – matrix and solid forms. The bitumen trapped within clay (mostly kaolinite) aggregates could be a significant source of light hydrocarbons due to their rapid degradation and release of oil when thermally induced. Each type of bitumen along with their modes of containment and their reflectance and fluorescence characteristics could influence the reservoir properties along the length of the core, especially with respect to release of hydrocarbons at the micro to nano scale. The findings of this study may aid decisions in targeting specific hydrocarbon intervals within the Gordondale.

References

Asgar-Deen M, Hall R, Craig J, Riediger C. 2003. New biostratigraphic data from the Lower Jurassic Fernie Formation in the subsurface of west-central Alberta. Canadian Journal of Earth Sciences, 40(1): 45-53.

Asgar-Deen M, Riediger C, Hall R. 2004. The Gordondale Member: designation of a new member in the Fernie Formation to replace the informal “Nordegg Member” nomenclature of the subsurface of west-central Alberta. Bulletin of Canadian Petroleum Geology. 52(3): 201-214.

Jacob H. 1989. Classification, structure, genesis, and practical importance of natural solid bitumen (“migrabitumen”). International Journal of Coal Geology, 11: 65-69.

Riedeger C, Fowler M, Snowdon L, Goodarzi F. 1990. Source rock analysis of the Lower Jurassic "Nordegg Member" and oil-source rock correlations, northwestern Alberta and northeastern British Columbia. Bulletin of Canadian Petroleum Geology. 33A: 236-249.

Riedeger C.L, Coniglio, M. 1992. Early diagenetic calcites and associated bitumens in the "Nordegg Member": implications for Jurassic paleogeography of the Western Canada Sedimentary Basin. Bulletin of Canadian Petroleum Geology. 40(4): 381-394.

Riediger C. 1994. Migration of “Nordegg” oil in the Western Canada Basin. How much and how far?. Bulletin of Canadian Petroleum Geology. 42(1):63-73.

Riediger C, Bloch J. 1995. Depositional and diagenetic controls on source-rock characteristics of the Lower Jurassic “Nordegg Member”, western Canada. Journal of Sedimentary Research. 65(1): 112-126.