

## The Evolution of Petrophysical Properties During Pyrolysis: Examples from the Montney Formation and Duvernay Formation, Alberta, Canada

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### Summary

Rock Eval pyrolysis is a standard technique used to evaluate the hydrocarbon-generating potential of a formation by quantifying its organic content and thermal maturity. By utilizing a new Rock Eval procedure, in which the heating rate is slowed down over an extended temperature range, previous studies (Sanei et al. 2015) indicate that different hydrocarbon components can be distinguished based on enhanced peak resolution. It is the aim of this project to observe the evolution of organic matter *and* petrophysical properties of tight formations during pyrolysis, and to determine the effects of differing hydrocarbon components on the pore network and reservoir quality. This is carried out by utilizing various geological/reservoir characterization methods to make both quantitative and qualitative observations of the changes that occur in the samples over the course of the thermal treatment.

### Introduction

Due to the importance of porosity on formation evaluation, it is essential that the effects of thermal treatment on rock samples be examined for alterations in the pore network. Rock Eval pyrolysis is a standard procedure that involves steadily heating the rock and measuring the amount of hydrocarbons released at different stages in time, providing important information on the total organic matter content (TOC) and maturity of the sample, which in turn provides a quantitative measure of the source rock's total potential to generate petroleum (Nunez-Betelu and Baceta 1994). One limitation of this analysis, however, is that it does not address how the thermal treatment, which includes increasing temperature to volatilize hydrocarbons and pyrolyze kerogen, may be affecting the pore network of the samples. It is likely that petrophysical properties (ex. porosity, permeability, pore size distribution, etc.) change during each thermal treatment cycle due to the release of various components of organic matter making up the total organic carbon, along with other pore fluids, but to date this has not been studied.

This research project aims to investigate the effect of thermal treatment on the pore network of the Montney Formation and Duvernay Formation, unconventional plays in the Western Canadian Sedimentary Basin (WCSB) of Alberta and British Columbia, Canada. The evolution of petrophysical properties during pyrolysis is quantified by performing measurements and applying imaging techniques before and during the various stages of the thermal treatment.

### Method

The study utilizes an adapted method of Rock Eval, termed extended slow heating cycle pyrolysis (ESH), which is better suited for the pyrolysis of tight reservoirs (Sanei et al. 2015). ESH was developed to characterize the various components of organic matter in the Montney Formation by slowing the heating rate down to 10°C over an extended temperature range of 150° to 650°C, allowing volatile-free hydrocarbons to be evolved from the samples and various organic matter fractions to be identified. Major organic matter components of the rock can be distinguished due to improved S1 and S2 peak resolution,

which refer to hydrocarbons already present in the rock and hydrocarbons thermally induced through pyrolysis, respectively. The ESH method allows three different peaks to be characterized during pyrolysis: S1) free light oil; S2a) fluid-like hydrocarbon residue; and S2b) solid bitumen (Sanei et al. 2015).

ESH results are used to determine the temperatures at which each hydrocarbon component is pyrolyzed. This information in turn is used in the thermal treatment of batch samples placed in an inert, atmosphere-controlled muffle furnace. After each thermal treatment step, the samples are subject to a suite of petrographical, geochemical, and petrophysical analysis including: mineralogical and organic matter petrography (O-PET), scanning electron microscopy (SEM), x-ray diffraction (XRD), x-ray fluorescence (XRF), shale matrix permeametry (SMP), helium pycnometry (He-PYC), and low-pressure adsorption (LPA).

## Examples

The study includes characterizing organic matter and pore spaces of the formations at each stage, and relating properties such as mineralogy, texture and diagenetic features to porosity and permeability measurements. The effects of differing thermal maturities, total organic content values and mineralogy on the pore network is also being examined. Preliminary results from the thermal treatment of the Duvernay Formation (Figure 1) indicate that the migration of free hydrocarbons within the sample does not impact the pore network. Following ESH pyrolysis, the sample was placed in an oven and thermally treated to 150°C, which corresponds to the S1 peak. Porosity and permeability measurements did not significantly change from the As-Received sample to that heated to S1. When placed back in the oven and heated to 400°C, the fluid-like hydrocarbon residue (FHR) was pyrolyzed, causing porosity and permeability to rise by a couple percent. The FHR fraction generally resides as a thin film surrounding the grains, as well as filling in some pore space. Existing microfractures in the organic matter became widened, possibly indicating an occurrence of FHR along the microfractures within the organic matter. Solid bitumen mainly occurs in the pore spaces, and after the pyrolysis of the sample to the S2a peak, it was still remaining. For the third thermal treatment stage, the sample was heated to 550°C, corresponding to the S2b peak and characterized by the pyrolysis of the remaining organic matter in the sample. SEM observations reveal the underlying mineralogy of the sample, as no organic material is remaining once the sample is heated to the S2b peak. Porosity increased nearly 4% between S2a and S2b thermal cycles, with the largest change in petrographic properties occurring with the pyrolysis of the solid bitumen in the sample.

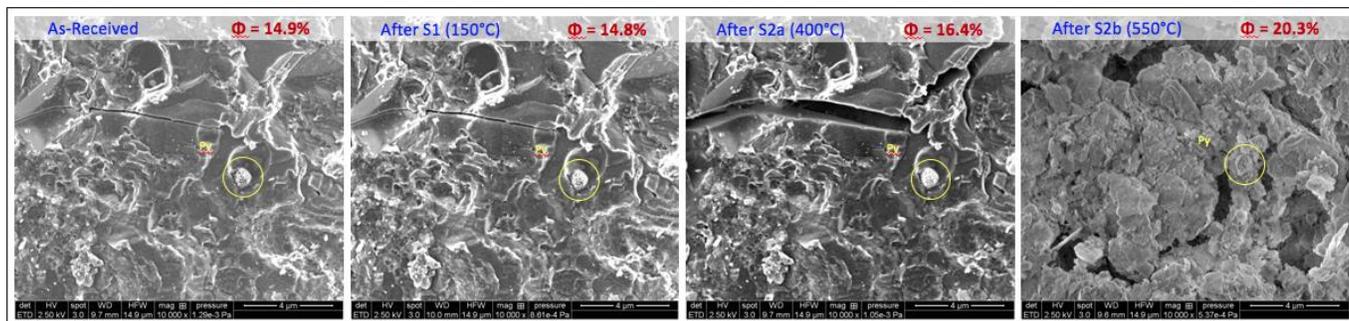


Figure 1: SEM photomicrographs of the Duvernay Formation, showing the evolution of organic matter during thermal treatment (from image left to right). Each image is taken during a different thermal cycle, but is in the same location in the sample (see the circled Pyrite grain for reference). *As-Received*: image taken before the thermal treatment began; most of the image is of organic matter. *After S1*: the sample is subjected to 150°C, causing the free hydrocarbons to evolve; notice that there is no change in porosity or observed texture. *After S2a*: the sample is subjected to 400°C, pyrolyzing the fluid-like hydrocarbon residue (FHR); notice an increase in porosity of 1.5%, and the widening of a pre-existing microfracture in the organic matter, as well as the propagation of a crack tip (upper right). *After S2b*: after being subjected to 550°C, the remaining kerogen was pyrolyzed, revealing the underlying mineralogical framework and causing another increase in porosity of nearly 4%.

## Conclusions

The evolution of petrographic properties during thermal treatments is important for isolating the effects of different kinds of organic matter and entrained fluids on reservoir quality. This study utilizes a newly developed and adapted method for Rock Eval analysis, called the extended slow heating cycle (ESH), to first determine the various hydrocarbon components that evolve during thermal treatment. This information is then used to thermally treat batch samples whose petrographic and petrophysical properties are evaluated after various thermal treatments steps. SEM imaging is also used to qualitatively tie observations of pore structure evolution to reservoir quality evolution.

Preliminary results using a Duvernay sample suggest that a fairly significant change in the rock fabric occurs after the S2a peak, which corresponds to the pyrolysis of the pervasive, fluid-like hydrocarbon residue (FHR). A more significant change occurs with the pyrolysis of the remaining organic matter (solid bitumen) in the sample, which corresponds to the S2b peak. The latter reveals the nature of the mineralogical framework initially obscured by the presence of organic matter seen in SEM images.

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