# Assessing the Organic Composition and Mineralogy of the Tipton Member Shale of the Green River Formation Utilizing Petrological Analysis

Boone Pickens School of Geology
Oklahoma State University

Joshua M.A. Bedell
Jack Pashin, PhD
Ahmed Ismail, PhD

# Table of Contents

**Title** **Page**

Introduction…….1

Methodology…….……..……1

Thin Section Analysis..……..……..3

Reflected Light Microscopy...……..…….....6

Scanning Electron Microscope...…..……..……...8

Conclusion……..…….…….....10

References..…….……11

## Introduction

Historically the Green River formation (GRF) has been a unique point of interest for geologists as it consists of paleo-logical anomalies, including the largest deposit of trona in the world, which is a non-marine evaporite mineral, as well as consisting of large amounts of natural resources, especially hydrocarbons (Trudell et al, 1983). It is estimated that there is enough resource potential in the GRF to provide energy for the United States for the next 100 years (Trudell et al, 1983). Although there is an abundant amount of hydrocarbons within the kerogen-rich shales in the GRF, the shales typically do not allow the "easy" extraction of these resources (Pashin, 2016-17). This is likely due to not only the extremely low porosity and permeability of these shales but also the relatively immature levels of organic matter (OM) within the shales (Pashin, 2016-17). Therefore, it is important to further examine the lithological and mineralogical properties of the GRF's shales in an effort to advance our knowledge of these types of highly unconventional reservoirs. A better understanding of these rocks could lead to the eventual development of the contained hydrocarbons, resulting in a potentially self-sustaining nation, which is ever more important amidst unstable political landscapes.

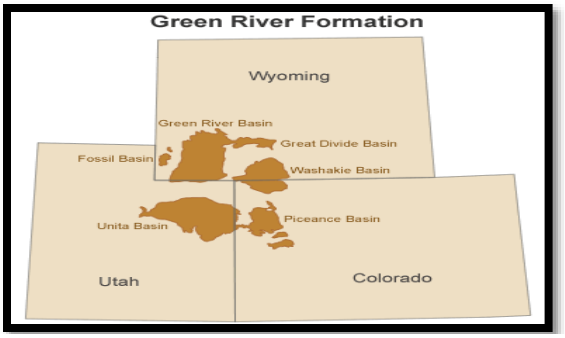

*Figure 1: Green River Formation and basin map.*

Moreover, it will shed new light on the mineralogy, porosity, and organic matter within the rock. The GRF has not been characterized to the extent and with the technologies that this project proposes (Pashin, 2016-17). This study will facilitate a new geological perspective of the region which would aid in resource development, environmental protection, and understanding of important episodes of Earth's geologic past.

## Methodology

This project began with a field investigation and rock sample collection along primarily two outcrops between the towns of Rock Springs, Wyoming and Green River, Wyoming. While here, a general survey was taken of the outcrops in an effort to develop an overview of the lithology and clues to the depositional environment. The first outcrop was 0.25 miles west of mile marker 96 on Interstate 80, between Rock Springs and Green River (Figure 1, 2, and 3). Here we collected three samples of dark grey to dark brown organic rich appearing shales (Figure 3). The second outcrop was within the town of Green River alongside a river bank (Figure 1, 2, and 4). Here four samples were collected including dark brown and dark grey shales, as well as shales that appeared to contain significant amounts of trona crystals which are very prevalent throughout the Green River Formation (Figure 4). It should be noted that at both locations there was substantial rain the night before that resulted in the shales appearing darker than their actual color. At each outcrop the general geology was noted and appeared to be in

compliance with the lacustrine type deposits as the literature suggests (King, 2015). Organic rich shales, inorganic shales, carbonate rocks, and evaporate minerals were common place throughout the outcrops.


*Figure 2: Google Earth view of outcrops 1 and 2.*

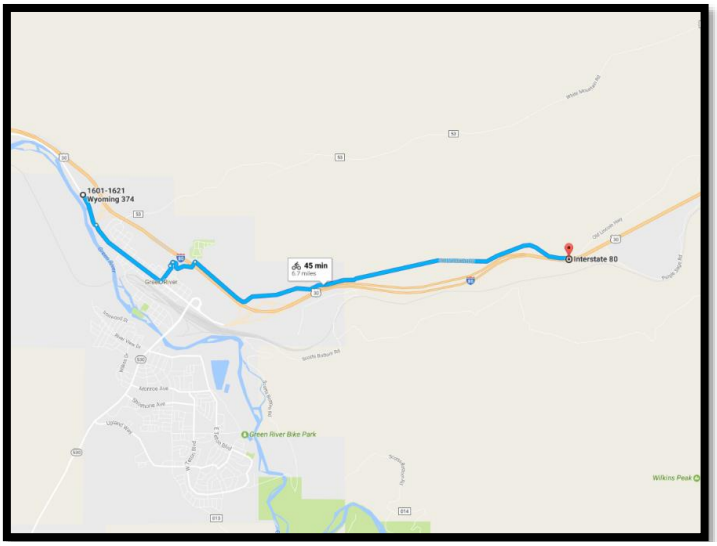


*Figure 3: Google Maps view of outcrops 1 and 2.*

*Figure 4: Dr. Pashin examining dark brown to black shale samples at outcrop 1.*

*Figure 5: Josh Bedell collecting dark brown and dark grey shales containing trona crystals at outcrop 2.*

After the samples were collected, all seven of them were cut and polished and sent to a commercial laboratory to which was to make thin sections. We requested for all seven samples to be cut to 20 microns and to be blue epoxy and vacuum impregnated and were to be later viewed under a polarizing microscope for mineral identification and texture studies. For samples 1, 4, and 5 we also requested for additional 80 micron thin sections that were vacuum impregnated and polished and were to be later utilized for reflected light microscopy (Davies, 2014).

Once the samples were returned, we began the process of identifying minerals and qualifying the amount of organic matter by using a common polarizing microscope with an attached live camera which allowed us to image the samples as shown below. Each of the 20 micron thin sections were studied thoroughly by using a grid pattern to view the sample. Images were taken at regular intervals as well as on anything of special interest. Samples were viewed and imaged in magnifications ranging from 5x to 20x.

Upon completion of the regular thin section study, reflected light microscopy was then utilized. As mentioned earlier, samples 1, 4, and 5 we had thicker polished thin sections made which were to be used for the reflected light microscopy work. We labeled these samples 1A, 4A, and 5A respectively in order to keep them separate from the other associated samples. The added thickness allowed us to work with the same microscope and not have to be as concerned with the issue of light bleed, which would have been the case if we would have used the thinner thin sections. The additional polish promoted the better image quality which was required for the reflected light and fluorescent light work. The samples were prepared by mounting them onto steel plates with mounting putty, this would guarantee that no additional light would come in from below the thin section. We utilized oil emerging optical lenses with 100x magnification to allow us to see on a very fine scale the inner workings of the crystalline structure as well as the type of organic matter.

Furthermore, all seven samples were also cut and readied for the Scanning Electron Microscope (a microscope that uses focused high beams of electrons that derives signals from a sample) (Swapp, 2015). The samples were further prepared by being polished under the argon ion mill which is where a machine uses argon gas ions that are accelerated into the sample and removes the outermost layer. Thus, leaving a small clean surface in the middle of the sample. After being milled, the samples were coated with a conductive gold palladium layer which increases image quality by inhibiting charging, reducing thermal damage, and improving the secondary electron signal required for topographic examination in the SEM. The SEM was then utilized to further determine the texture of the rocks and crystalline structure of the minerals that make up any given sample. Additionally, the resulting images displayed the pore system of the rock sample, which allowed us to quantify the average pore size within the samples.

**Thin Section Analysis**

Overall, the samples were all of similar mineralogy, each sample contained significant amounts of calcite, quartz, clay minerals, and trona. What set the samples apart though, was their grain size and the amount of organic matter that they contained. As shown in the image below, samples 1, 2, 3, and 5 contained primarily very fined grained silt and clay sized grains (Figure 6) while samples 4, 6, and 7 contained much coarser grained silt sized grains

and contained large trona crystals as well (Figure 7). All of the samples contained large amounts of clay, at least 50%, qualifying this rock as a true shale. All of the samples also contained several grain sizes, samples 1, 2, 3, and 5 contained pockets of coarser grains and vice versa for the other samples. The majority of the samples contained some amount of organic matter but samples 1, 2, 3, 4, and 6 contained significant to dominating amounts of organic matter (Figure 8) while samples 5 and 7 contained very little to no organic matter. Interestingly, samples 1, 2, and 3 contained numerous specimens of a  type of mineral or a piece of organic material that had a sprawling finger like structure and appeared black under plane polarized light and cross polarized light and bright green under a combination of reflected and transmitted light (Figure 9 and 10). Another notable aspect of several of these thin sections is the fining upward and coarsening upward sequences that are widespread throughout the samples (Figure 11). This is a classic example of how a fissile shale might normally appear in thin section.

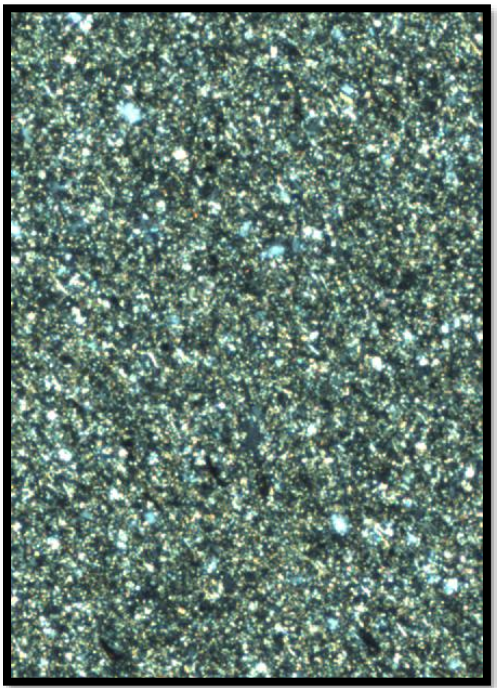

*Figure 6: Sample 1 at 5X magnification under xpl displaying very fine grained silt to clay sized grains.*

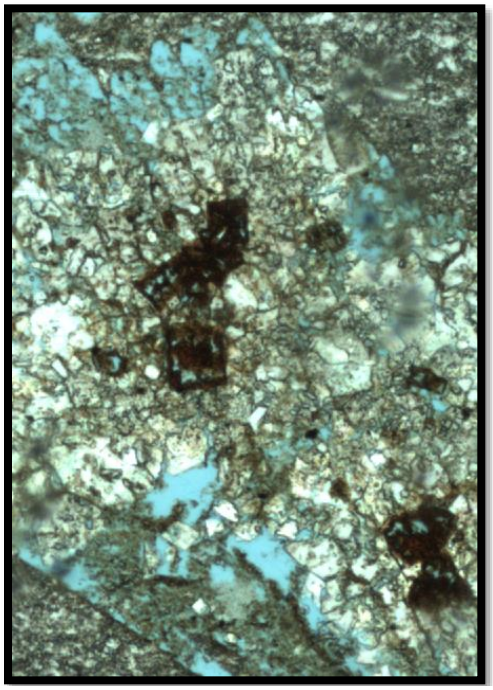

*Figure 7: Sample 7 at 5X magnification under xpl displaying coarse grained surrounded by pores and clay.*

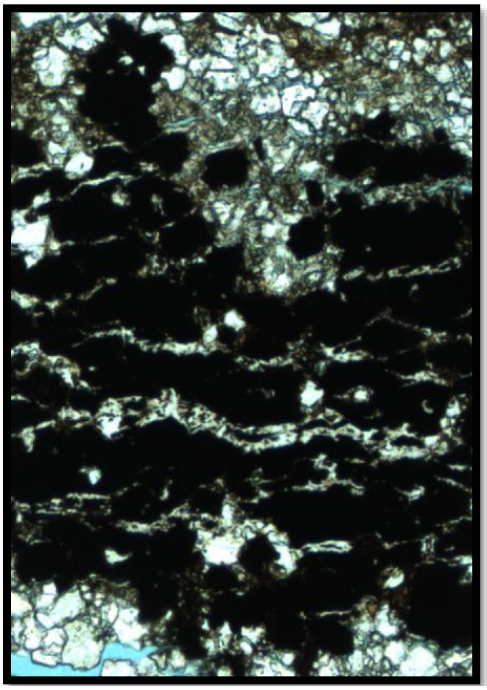

*Figure 8: Sample 3 at 5X magnification under ppl displaying significant amounts of OM.*

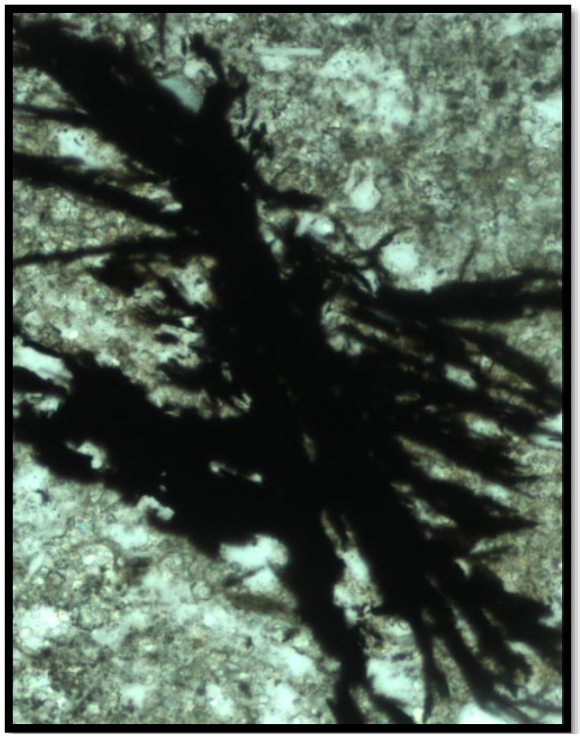

*Figure 9: Sample 3 at 20X magnification under cross polar, displaying a unique mineral or organic matter.*

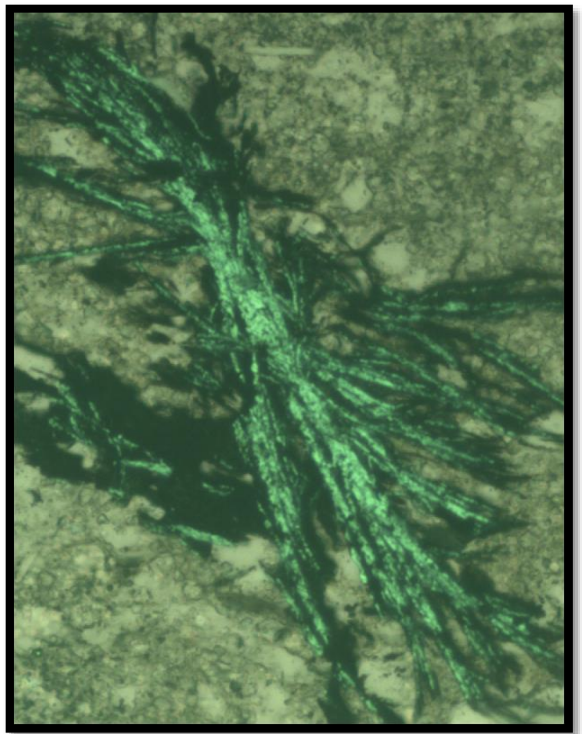

*Figure 10: Sample 3 at 20X magnification under reflected and transmitted light, displaying a unique mineral or organic matter.*

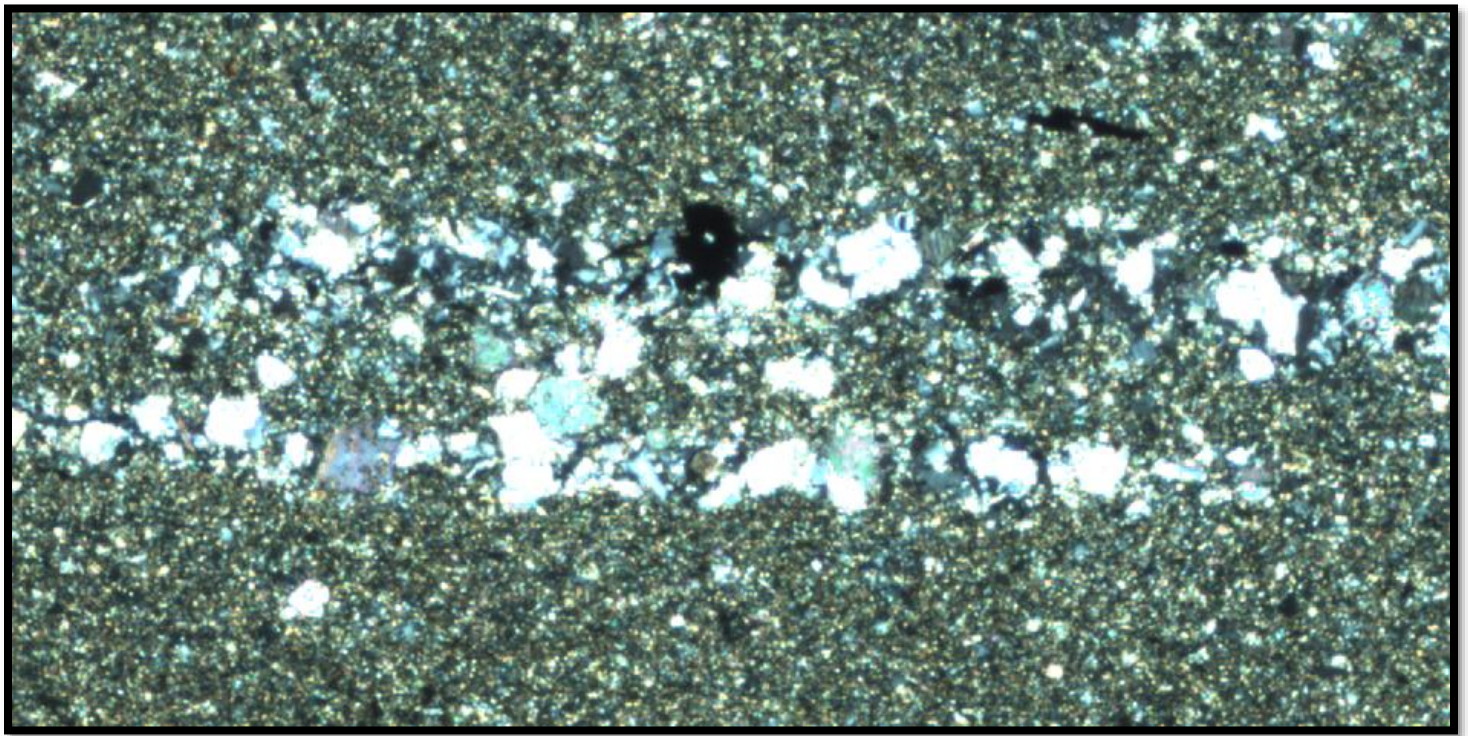

*Figure 11: Sample 1 at 5X magnification under xpl displaying several coarsening and fining upward sequences.*

**Reflected Light Microscopy**

Sample 1A was dominated by the finger like structures previously noted. Under fluorescent light the structures were black and were surrounded by a white grey matrix (Figure 12). Under reflected light, the structure was bright white with a green tint surrounded by dark material (Figure 13). This indicates that the object is actually inorganic.

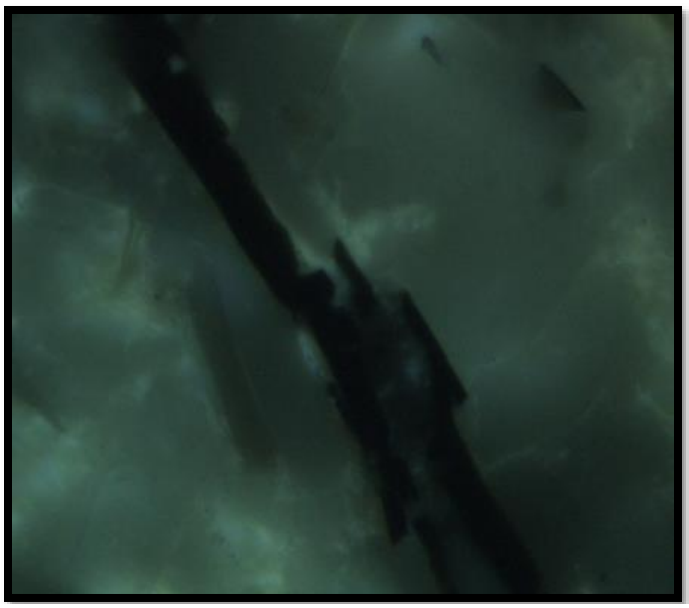

*Figure 12: Sample 1A at 100X magnification under fluorescent light displaying the dark finger like structure previously noted.*

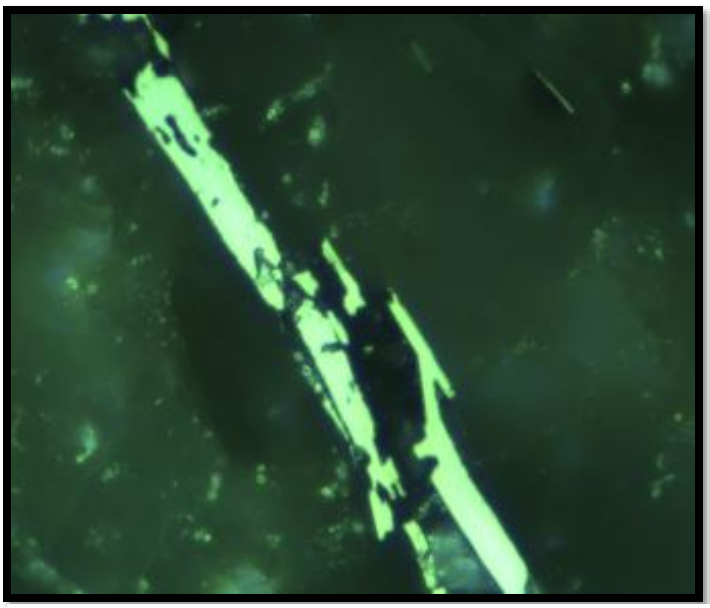

*Figure 13: Sample 1A at 100X magnification under reflected light displaying the dark finger like structure previously noted.*

Sample 4A appeared to contain circular lobe like organic matter which were coalesced together into globs. When the image was viewed in fluorescent light, the OM was black in appearance and the matrix consisted of grey, moderately sorted, sub rounded grains of varying composition (Figure 14). Under reflected light, the organic material was a light grey and was entrained with bright white minerals, which may have been trona crystals (Figure 15).

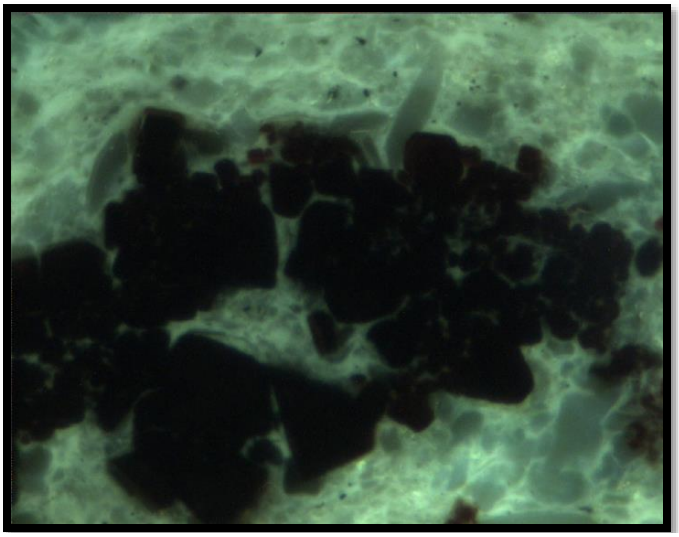

*Figure 14: Sample 4A displaying organic matter globs.*

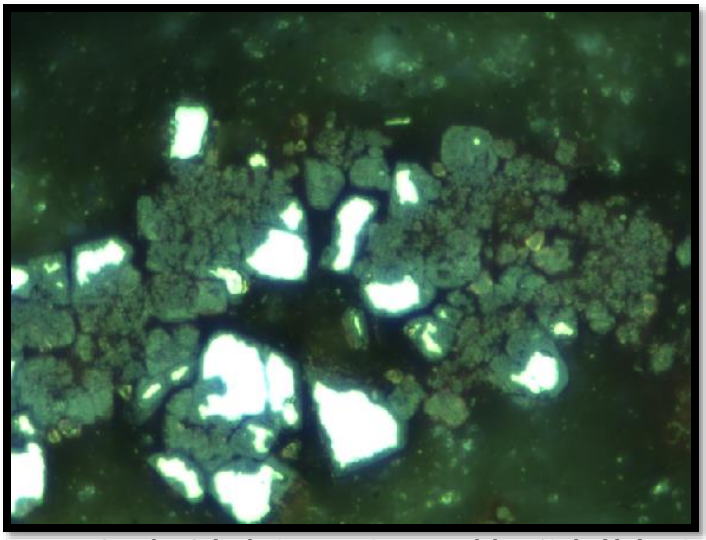

*Figure 14: Sample 4A displaying organic matter globs w/ in bedded grains.*

Sample 5A unfortunately, did not display very much organic matter. The organic matter that was visible was very fine silt sized to clay sized chunks. The fluorescent light revealed a light grey matrix with sub angular to sub rounded grains and small patches of OM (Figure 15). Under reflected light, the entire sample appeared dark green with light grey minerals, and black spots which appeared to be organic matter (Figure 16). Although, little organic matter was seen in sample 5A, there was an exceptional mineral with its full crystalline structure on display as shown in figure (Figure 17) and could only be seen using the reflected light method. This was by far the largest crystal throughout the entire sample which was dominated by very fine silt and clay sized grains. All the samples viewed under reflected light and fluorescent light only displayed what appeared to be pre-oil kerogen (Type I and Type II) which did not fluoresce or show any signs of thermal maturity.

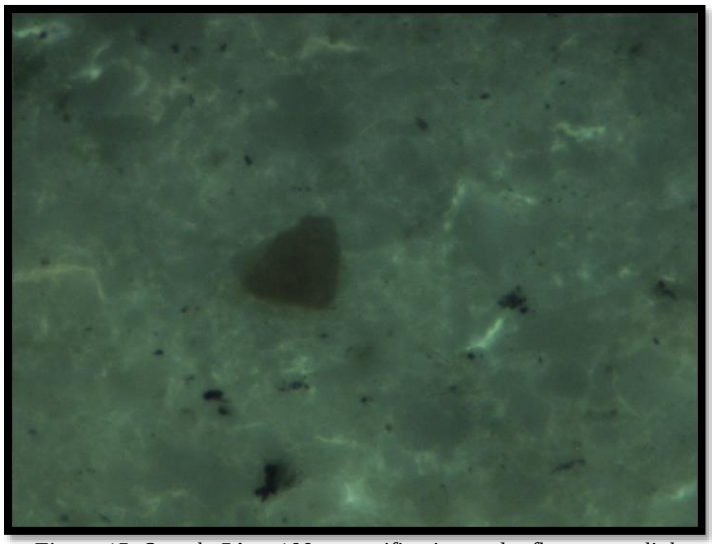

*Figure 15: Sample 5A at 100x magnification under fluorescent light displaying the matrix and clay sized pieces of organic matter.*

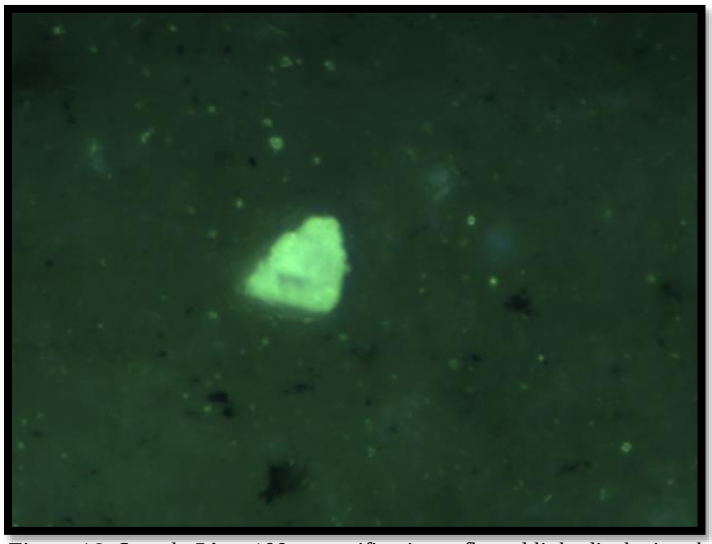

*Figure 16: Sample 5A at 100x magnification reflected light displaying the matrix and clay sized pieces of organic matter.*

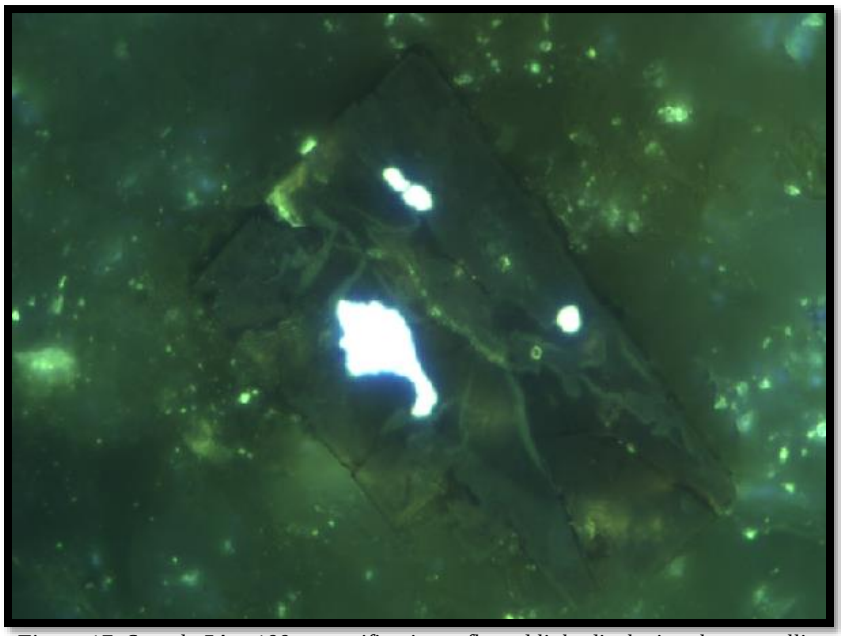

*Figure 17: Sample 5Aat 100x magnification reflected light displaying the crystalline structure of mineral.*

**Scanning Electron Microscope**

The samples all displayed wide ranges of pore size which is likely do to the presence of trona crystals that had either broken off or that had been dissolved due to the passage of fluids. Pore sizes ranged from 400nm to 10microns, and several other larger which were fractures or the remnants of trona crystals which ranged between 0.1mm and 1mm. Samples 1, 2, 3, and 5 appeared to be much finer grained and had no visible trona crystal sized pores under the milled viewing area, but did contain pores on the scale of 400nm (Figure 18). Samples 4, 6, and 7 contained significant amounts of trona sized pores, that resulted from the breaking/dissolution of trona crystals, as well as the smaller range of pores previously mentioned (Figure 19). The organic matter was difficult to distinguish under the SEM but sample 6 had large dark organic appearing locations that were common throughout the milled viewing area (Figure 20). Sample 2 contained a very unique piece of organic matter or mineral that had a sprawling finger like appearance which contained small micro to nano fractures along its frame (Figure 21). This is the same type of object that was noted in several of the thin section studies mentioned previously (i.e. Figure's 9, 10, 12, and 13).

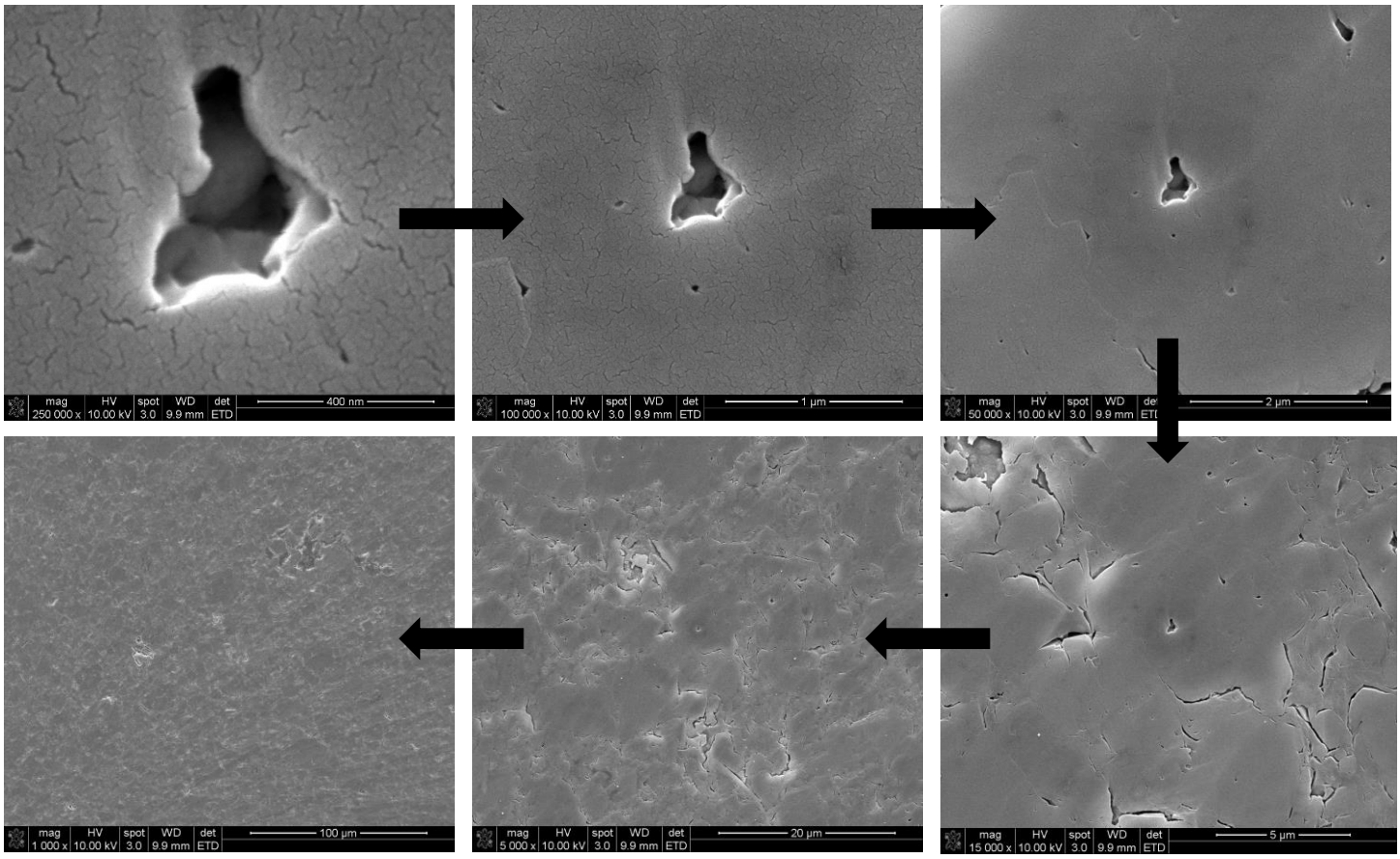


*Figure 18: Sample 5 with pore sizes as small as 400nm ranging from 250,000X magnification to 15,000X magnification.*

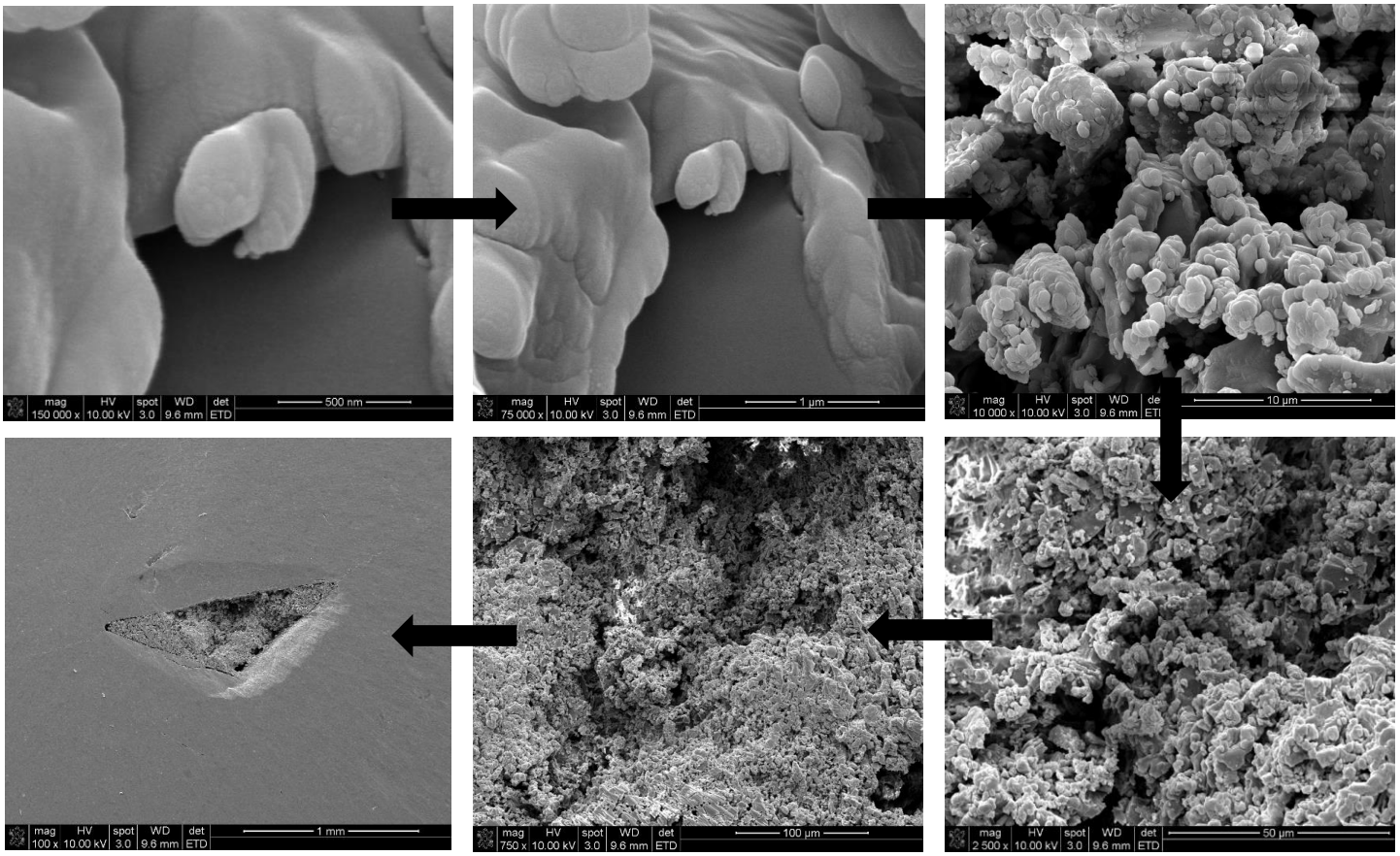


*Figure 19: Sample 6 with pore sizes as small as 1000nm within a broken trona crystal and up to 1mm where the trona crystal has either completely broken away or has been dissolved. Magnification ranges from 150,000X to 10,000X.*

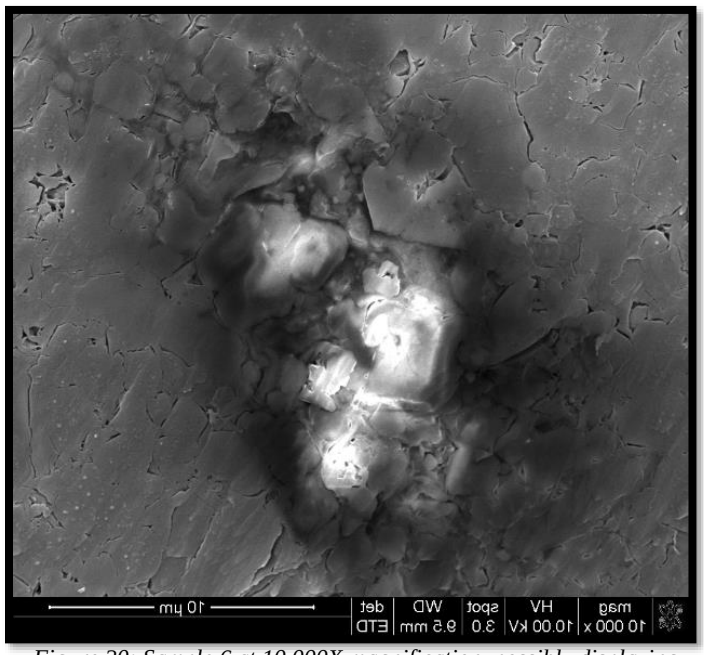

*Figure 20: Sample 6 at 10,000X magnification, possibly displaying organic matter.*


*Figure 21: Sample 2 at 1000X magnification, displaying fractures along the structure of the mineral or OM.*

## Conclusion

This project was beneficial to the overall study of the Green River Formation in that it sheds new light on the mineralogical and organic composition of some of the thermally immature pre-oil shales that dominate the Green River Formation. Although, this study further validates previous studies' claims that the kerogen within the Green River shales is thermally immature, it also promotes a new understanding of the scale of pore sizes as well as the dominating presence of trona crystals which dramatically increase porosity throughout most of rocks they are within. At the present time, the only way to reasonably extract hydrocarbons from Green River oil shales is to apply the in-situ retorting methods which have been applied by previous researchers (Carpenter et al, 1972). This method utilizes high powered electrodes which are inserted into the ground overlying thermally immature organic rich rocks, and then sends electrical currents into the subsurface which heats the kerogen and artificially matures it over a several year time period (Carpenter et al, 1972). Once the organic matter is thermally matured it then contains hydrocarbons which can be extracted by common drilling methods. Unfortunately, this is uneconomic with the current price of oil so new, more efficient methods are still being sought after.

Future research over the Green River Formation's pre-oil shales would benefit by running samples through the X-ray diffraction machine to form an even more detailed description of the mineralogical and chemical makeup of the shales (Dutrow, 2015). Furthermore, it would be helpful to establish the shales relative permeability's and quantitative values for total porosity versus just pore size. This would aid in understanding how fluid flow effects the dissolution of the trona cyrstals as well as the other common minerals in the Green River shales.

In conclusion, the Green River pre-oil shales' mineralogical composition is dominated by calcite, quartz, clay, trona, and significant amounts of thermally immature pre-oil kerogen. The pore size ranges from 400nm to 10microns and also contains several larger pores which appear to be the result of dissolved or broken trona crystals or micro fractures and range from 0.1mm to 1.0mm.

**References**

Davies, Bathan. (February, 2014) "Thin Section Analysis." Antarctic Glaciers. University of London, Retrieved from Web. 15 Jan. 2016.

Dutrow, Barbara L. (June, 2015)"X-ray Powder Diffraction (XRD)." Techniques. Carleton College. Retrieved from Web. 5 Dec. 2015.

Carpenter H.C., Burwell E.L., Sohns , H.W., (January 1972) Evaluation of an In-Situ Retorting Experiment in Green River Oil Shale. Retrieved from Web. 10 May 2017.

Hillier, Stephen. (February, 2014)"Clays and Minerals." X-ray Diffraction. James Hutton Institute, Retrieved from Web. 15 Jan. 2016.

King, Hobart. (January, 2015) "Green River Formation Fossils." GRF Fossil Fish, Insects, Plants and More. Geology.com. Retrieved from Web. 17 Jan. 2016.

Pashin, J. (2015 September 15 - 2016 Febuary 3). Personal Interviews.

Swapp, Susan. (June, 2015) "Scanning Electron Microscopy (SEM)." Techniques. Carleton College, Retrieved from Web. 21 Dec. 2015.

Trudell, L.g., J.w. Smith, T.n. Beard, and G.m. Mason. (1983) "Primary Oil-shale Resources of the Green River Formation.", Retrieved from Web 2016.