PS Characterization of the Porosity Distribution within the Clinton Formation, Ashtabula County, Ohio by Geophysical Core and Well Logging*

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Abstract

A combination of cores and geophysical logs were used to correlate the Clinton Formation in Ashtabula County and to help with an environmental analysis and porosity distribution as a means of evaluating its suitability as a target for Ohio Division of Natural Resources (ODNR) and Department of Energy (DOE) for enhanced oil/gas recovery and/or carbon sequestration.

Reflectance data was measured on one set of cores corresponding to well 408, producing mineral composition and depositional patterns. Thirty-nine geophysical well logs were correlated using Geographix, with help from SPSS 17.0 factor reduction analytical tool. Plugs were measured for porosity and permeability. Thin sections were created to analyze porosity, permeability and composition.

The Clinton Formation in Ashtabula County, Ohio deepens towards the southeast (towards the Appalachian Basin), and thickens towards the southeast. This is consistent with previous findings on the Clinton Formation in Ohio. The Clinton Formation in Ashtabula County is fine-grained sandstone, consisting mainly of quartz grains. Shale is found in different locations throughout the formation, consisting of glauconite, with red staining present on different sections of the Clinton Formation. The red staining is goethite. Calcite grains are located sparingly throughout the sandstone, with some calcium carbonate cement, as noted in the thin sections. Plugs were taken from core 908 at 13 locations within the core, producing 11 samples that were able to be measured for porosity and permeability. The porosity ranged from 4.2% to 9.2%, with an average of 6.0%. The permeability ranged from 0.0007 mD to 0.809 mD, averaging 0.128 mD. Reflectance and principle component analysis (PCA) were used to determine minor minerals throughout the formation. The red tinting on the sandstone is caused by goethite, and the green tint is caused by chlorite and amphibole. The PCA also produced a third component, correlating negatively with various clay minerals. This third component also highly correlates with the porosity measurements at the same depth, allowing interpretation of this component to be the

siliciclastic porosity of the Clinton Formation. An equation from the linear trend of the porosity vs. component 2 was used to extrapolate porosity throughout the entire Clinton Formation core, giving a mean porosity of 6.02%, with ranges from 0.0% to 25.1%. The porosity distribution, along with the geophysical logs, were used to establish five sub-sections within the Clinton Formation that were correlated across one cross section line from East Ashtabula County to West Ashtabula County in the center of the county, indicating distribution of shale within the formation. Being able to identify shale and low porosity within the formation may help with further oil and gas exploration and enhanced oil recovery operations in the future.

CHARACTERIZATION OF THE POROSITY DISTRIBUTION WITHIN THE CLINTON FORMATION, ASHTABULA COUNTY, OHIO BY GEOPHYSICAL CORE AND WELL LOGGING

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Special Thanks To:

ABSTRACT

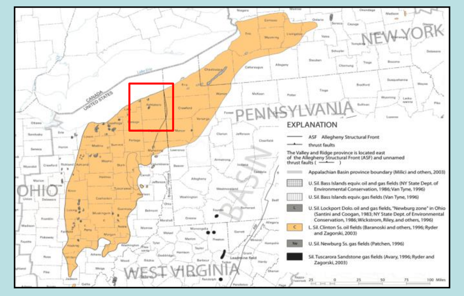
A combination of cores and geophysical logs were used to correlate the Clinton Formation across Ashtabula County and to help with an environmental analysis and porosity distribution. Reflectance, thin sections, porosity and permeability measurements, and geophysical logs helped to correlate sequences found within the Clinton Formation, along with reinforcing the known environmental interpretation of the Clinton Formation, and further regional information about the formation in Ashtabula County.

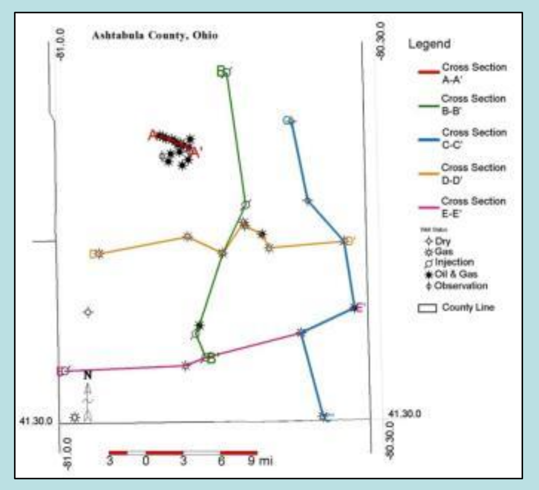
The Clinton Formation in NE Ohio is fine grain, semi- angular to semi-round, moderately sorted, quartz sandstone interbedded with shale. The sandstone contains silica cement, although calcite is found sparingly in the cement. Plugs were taken from core 908 at 13 locations within the core, producing 11 samples that were able to be measured for porosity and permeability. The porosity ranged from 4.2% to 9.2%, with an average of 6.0%. The permeability ranged from 0.0007 mD to 0.809 mD, averaging 0.128 mD. Reflectance and principle component analysis (PCA) were used to determine minor minerals throughout the formation. The red tinting on the sandstone is caused by goethite and hematite, and the green tint is caused bya combination of chlorite , illite and glauconite. The PCA also produced a third component, correlating negatively with various clay minerals. This third component also highly correlates with the porosity measurements at the same depth, allowing interpretation of this component to be the siliciclastic component of the Clinton Formation. An equation from the linear trend of the porosity vs. component 2 was used to extrapolate porosity throughout the entire Clinton Formation core, giving a mean porosity of 6.02%, with ranges from 0.0% to 25.1%. The porosity distribution, along with the geophysical logs, were used to establish five sub-sections within the Clinton Formation that were correlated across one cross section line from East Ashtabula County to West Ashtabula County in the center of the county, indicating distribution of shale within the formation. Being able to identify shale and low porosity within the formation may help with further oil and gas exploration and enhanced oil recovery operations in the future.

INTRODUCTION

The Clinton Formation oil and gas plays extend from New York, through Pennsylvania down to West Virginia (Figure 1) and is a major oil and gas producer in the Appalachian Basin [1].The Clinton Formation consists of interbedded Silurian sandstones, carbonates and shales, with individual beds varying in thickness depending on location [1] and it lies between the Ordovician Queenston Shale and Silurian Packer Shell Limestone[2] (Figure 2). The Clinton Formation is a stratigraphic trap because of this variation within the Clinton, and the ability to depict the less porous (i.e., shale) layers is important for hydrocarbon production. Thirty wells from Ashtabula County, OH were used to better understand the Clinton Formation stratigraphic and porosity variation.

Figure 1. Location map of oil/gas plays in the Clinton Formation, Appalachian Basin[3] (below). The study area is in Ashtabula County, OH (left) and consists of 32 oil/gas wells, with emphasis on five cross sections created to observe variations within the subsurface.





WELL LOGGING

Geographix is geological software designed by LMRK, allowing for organization and mapping of wells. Well logs were uploaded from ODNR in LAS format. After data was entered, a location map was compiled (Figure 1). Cross-sections were interpreted in various directions and length (Figure 3 and 4). The Clinton Formation was divided into 5 geotechnical units, based upon core logging and interpreted shale locations from the well logs. Finally, isocore maps were made, consisting of Clinton Formation thickness and Clinton Formation depth (Figure 5 and 6). The Clinton Formation in NE Ohio agrees with previous studies on thickness(114 ft/ 34.7 m) and depth (shallows towards the NW, with depths ranging from 3049 ft to 2086 sub sea level). It thins and shallows towards the northwest. Small anomalies are present in the center of the study area, but this is due to the limited size of the study area and local variations in the depositional environment.

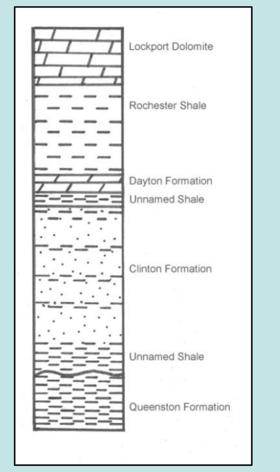
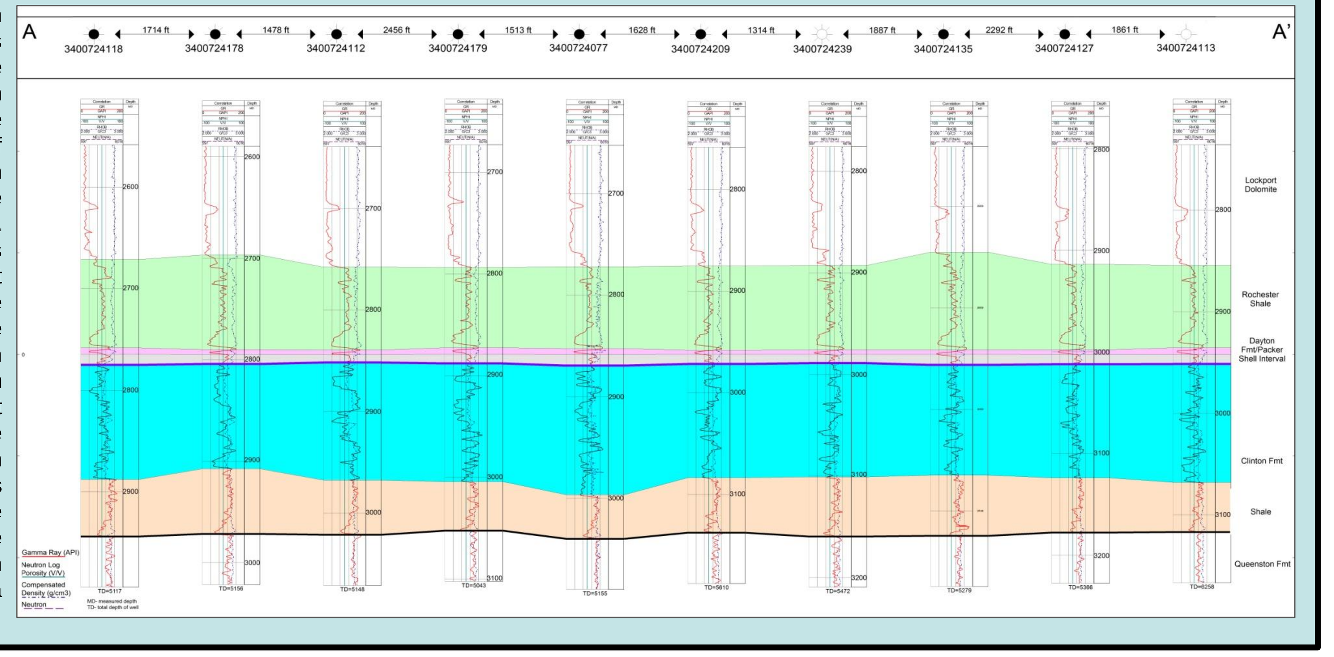


Figure 2. Generalized stratigraphic column of the Clinton Formation and surrounding units that were mapped in cross section.

Figure 3. Cross section A-A' includes 10 wells from the Northwest to the Southeast. It is located in the cluster of wells in the Northwest section of Ashtabula County, with wells ranging in distance from 1478 ft to 2456 ft. The cross section shows relatively constant thickness within the Clinton Formation. The thickness of the Clinton Formation ranges from 103.31 to 127.10 ft. At well 3400724077, there is slight thickening, with the total thickness reaching 127.10 ft. The average thickness of the Clinton Formation within the cross sectional area is 113.54 ft.



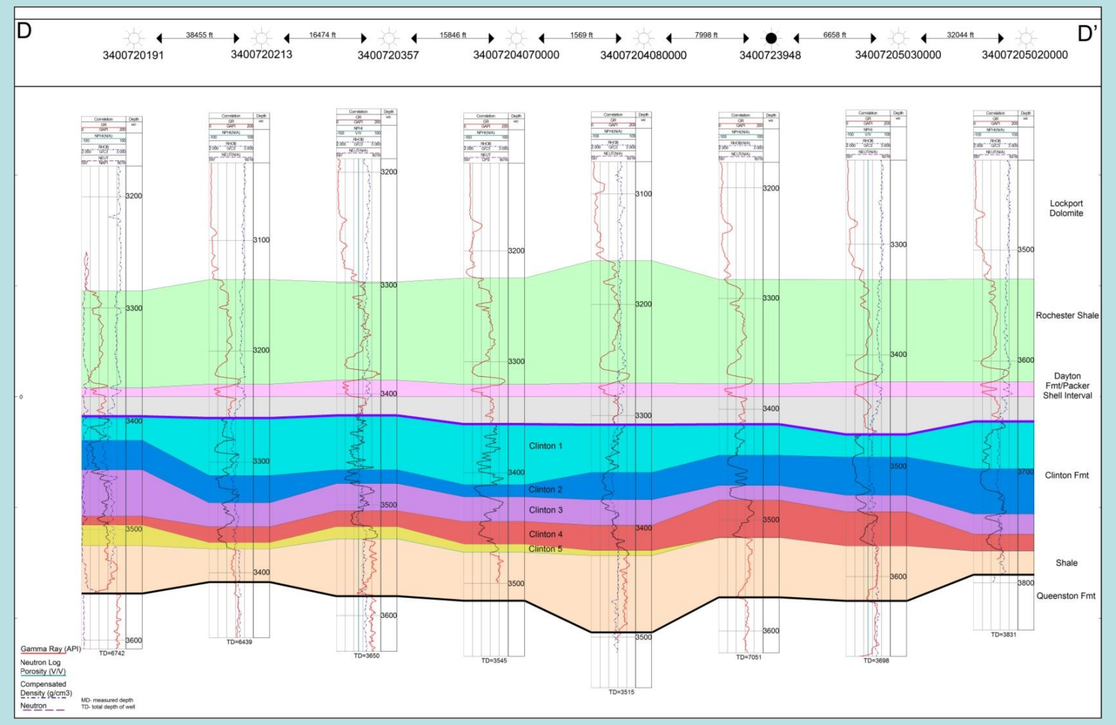


Figure 4. Correlations within the Clinton Formation were made amongst the eight wells in cross section D-D'. Cross section D-D' is located through the center of the county, trending west to east. A pattern of (1) clastic interval, (2) white sandstone, (3) interbedded sandstone and shale, and (4) shale repeats five times within the Clinton Formation Core 908. This is also recognized in Stark County Clinton Formation correlations, where five mappable units are correlated within the Canton Oil Field[14]. These five sequences from well 3400720408 (corresponding to core holding 908) are able to be identified in the well logs by the repeating gamma ray log pattern. Well 3400720408 was the focus of the correlation because of the ability to verify the logging interpretation with the core.

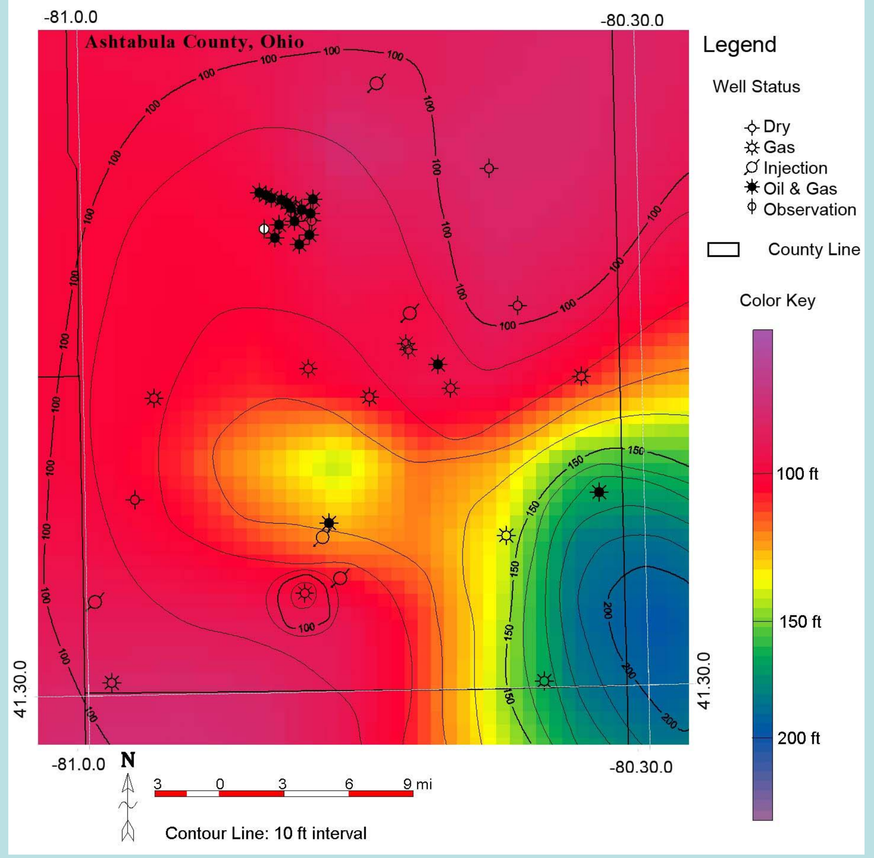


Figure 5.Clinton Formation thickness contour map. Contour interval in 10 ft increments. General trend is thinning towards the west (away from the Appalachian Basin). This is consistent with findings in Ryder (1995)[1].

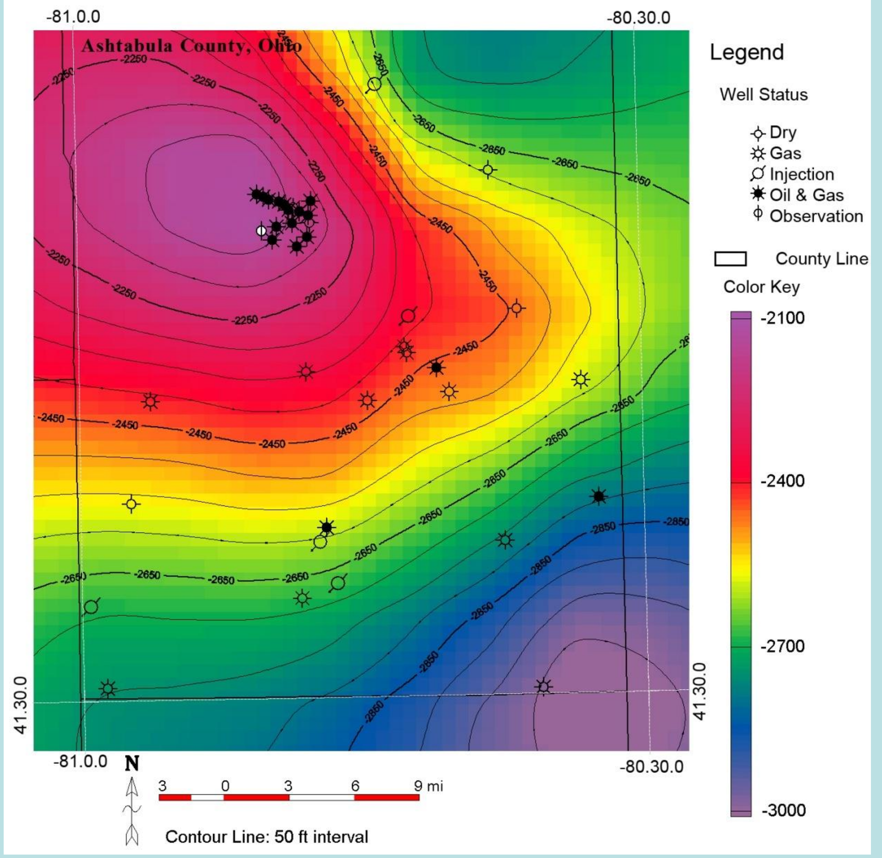


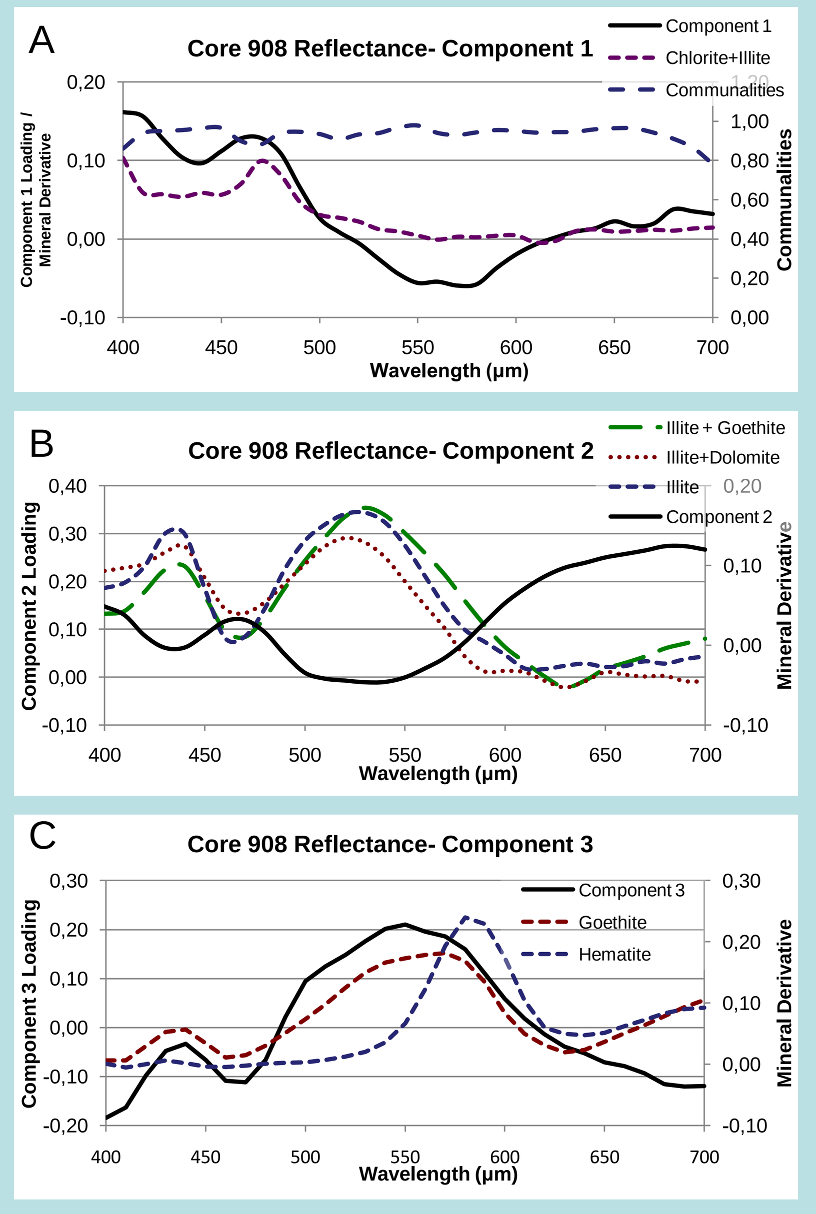
Figure 6. Top depth of the Clinton Formation, subsea level with contours at 50 ft increments. General trend shows shallowing towards the Northwest.

CORE LOGGING USING REFLECTANCE

Reflectance data was measured on one set of cores corresponding to well 408 with a Minolta CM-2600D, a portable spectrophotometer. It produces an unbiased color interpretation, which can be used for mineral interpretation[5,6,7,8] . A sample is taken over a small area (3 mm diameter at 1 cm sampling interval), with L* (brightness), a* (red-green contrast), b* (yellow-blue contrast) and reflectance as a function of wavelength (every 10μm from 400-700 μm) is measured. Cracks in the core caused low reflectance measurements because of the low amount of light received reflected from the core to the instrument, resulting in a biased reflectance spectrum. To reduce the noise created from the cracks, the reflectance data was filtered by first calculating the slope of the reflectance data and removing data with slopes below 0.0008. Reflectance data were then uploaded into SPSS 17.0 for Principle component analysis (PCA) for interpretation. PCA was run with Varimax Rotation and Kaiser Normalization on the first derivative of the reflectance spectra. PCA produces orthogonal axes, and the Varimax Rotation keeps the axes orthogonal following rotation. The Varimax Rotation produces component loadings that are independent of one another and maximizes the component loadings. Loadings were calculated and compared to known minerals and mineral combinations[9, 10].

Three components were extracted from the reflectance data. Component 1 shows influence from chlorite+illite clay minerals (Figure 7A). Correlation of Component 2 data with derivatives of various minerals shows a strong negative correlation with clay minerals (illite+goethite, illite, illite+dolomite, smectite+chlorite+dolomite) (Figure 7B). The negative correlation may indicate that component 2 represents the siliciclastic matrix of the Clinton Formation. Component 3 shows influence from goethite (FeO(OH)) (Figure 7C).

To verify the clay minerals identified when the dataset was run in its entirety, individual boxes were run (~ 122 cm each). Glauconite was also found within box 14, with a correlation to Component 1 of 0.962 (Figure 7D). Although hematite is commonly found in the Clinton Formation in Ohio[1,11, 12], goethite appears to be the dominant red mineral in the Clinton Formation in Ashtabula County (Figure 7B). PCA on individual boxes was also used to further refine the iron oxide mineral, showing that although goethite is a major contributor to the Clinton Formation, hematite is also present in the Clinton Formation (Figure 7E).



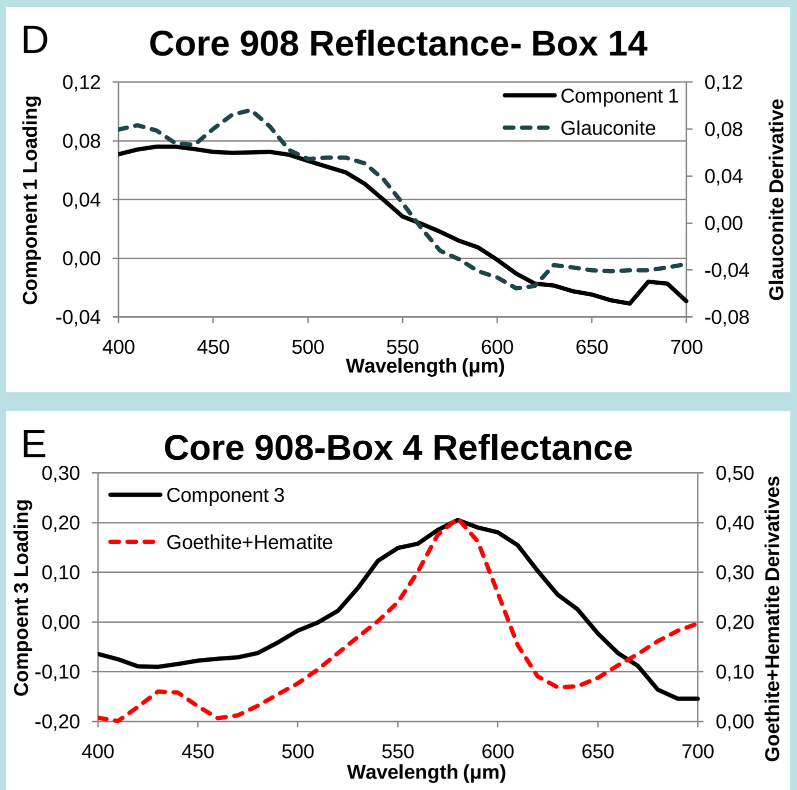


Figure 7. (A) Graph of reflectance data, with Varimax rotation and Principle Component Analysis (PCA), showing the Component 1 Loadings extracted from the data. Chlorite+Illite derivative, from a known data base, is graphed to show similarities in the two curves. (B) Graph of reflectance data showing Component 2 Loadings extracted from the data. Clay minerals and dolomite derivatives are plotted on the secondary axis, all showing negative correlations with Component 2. (C) Graph of reflectance data showing Component 3 Loadings extracted from the data. Component 3 shows strong correlation with goethite. To further explain mineral variations and correlations, individual boxes were analyzed. Box 14 (D) Component 1 shows a strong correlation with galuconite, which was not a dominant mineral when the whole core was analyzed. Also, Box 4 (E) shows influence from Hematite.

REFLECTANCE TO INTERPOLATE POROSITY

The porosity from the lab measurements were plotted with the VPCA component score (Figure 8A). An r^2 value of 0.64, was calculated, indicating a moderately strong linear correlation with primary formation porosity and the corresponding component scores. With an r^2 value of 0.64, r= 0.80 with the given N=11 and degrees of freedom (df) = 9[13], indicating statistically significant correlation between porosity and reflectance measurements because r_{crit}= 0.74[13]. The formula of the line from the VPCA component scores and porosity correlation was used to calculate porosity for the Clinton Formation Core 908 (Figure 8B). The average value for interpolated porosity is 6.0%, which corresponds well to average measured porosity in this study (6.1%) and to average typical porosity found within the Clinton Formation (5%)[1].

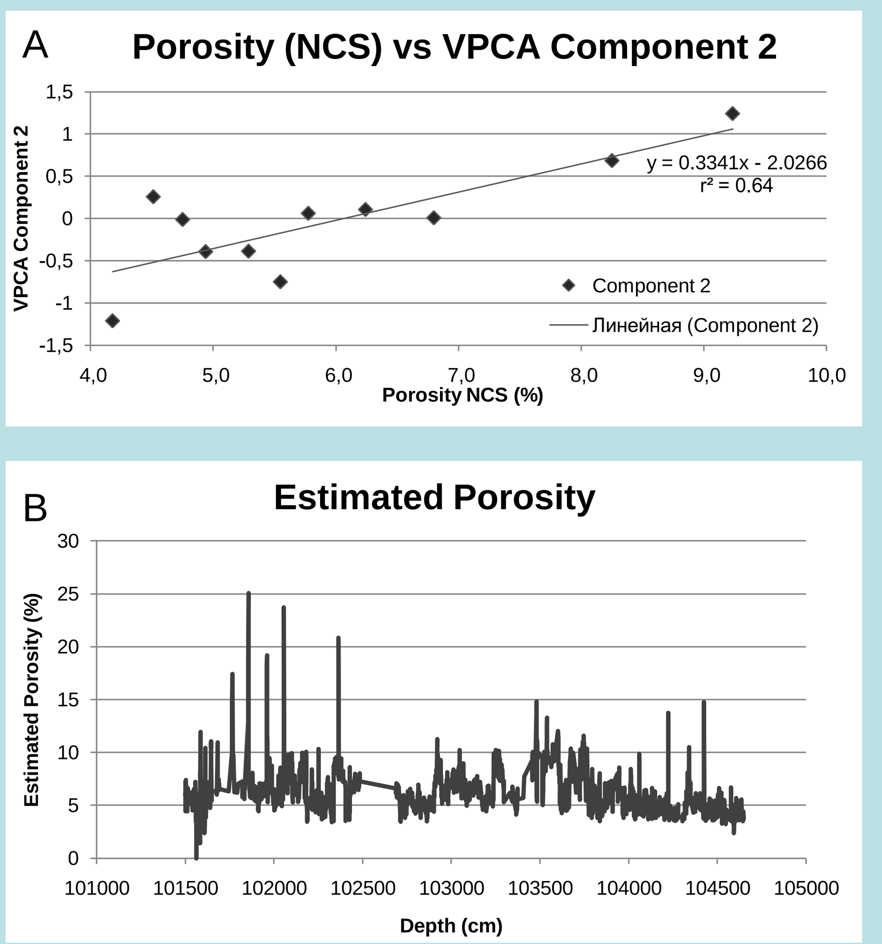


Figure 8. (A) VPCA Component vs. Porosity NCS (%). Linear trends between Component 1 and 3 with porosity are weak (r^2= 0.00 and -0.01, respectively). The linear trend between Component 2 and porosity is much stronger, with r^2= 0.64. (B) Estimated porosity of the Clinton Formation Core 908, estimated from the laboratory porosity measurements and reflectance data, Component 2. Component 2 is the siliciclastic component of the Clinton Formation.

FUTURE RESEARCH

The r^2 value could be improved upon with further porosity measurements from core 908, and porosity and reflectance measurements with other cores from the Clinton Formation. Also, this may allow for correlation to occur between reflectance, porosity and logging data, as the current data set do not have correlations amongst the data. This is also due to the lack of well logging data (only gamma ray and density are available for well 3407204080000/core holding 908).

DISCUSSION

The Clinton Formation consists of alternating clastic unit, white sandstone, interbedded shale and sandstone and shale, which can be interpreted as being minor (local) transgressive-regressive cycles. The transgressive-regressive cycles suggest a littoral marine setting, which is consistent with findings in Ryder (1995)[1]. Each can represent a different environment during the transgressive-regressive cycles: (1) clastic sandstone represents a period of low sea level, where the unit was exposed and causing erosion; (2) grey/white sandstone represents the deltaic environment, where low to moderate energy was depositing relatively clean sands, with mud drapes during times of low energy; (3) the interbedded shale and sandstone represent a transition from deltaic to lagoonal; and (4) shale represents lagoonal setting with reducing conditions.

The Clinton Formation within Ashtabula County, Ohio is relatively consistent in thickness averaging 113.98 ft. Anomalies are present, with thicker and thinner zones at various sites within the formation. The thickness variations can be attributed to two reasons: (1) deposition within the coastal setting was not equal at all points along environment; (2) erosion may have had different rates during exposure of the formation. Correlations of the five Clinton sequences proved to be difficult. The thickness varies within the five sequences, and the shale content appears to vary within each sequence.

The shale will cause the porosity and permeability to greatly vary throughout the Clinton Formation, and the abundance of mud laminations throughout the Clinton Formation will greatly reduce the porosity. Also, the porosity and permeability measured in the laboratory suggest low primary porosity and permeability present through much of the formation, with a few locations having moderate (~9%) porosity. Results of the study conducted by the Ohio Geology Survey[14], which demonstrated enhanced recovery of hydrocarbon by CO_2 sweeping suggest that the hydrocarbon and CO_2 sweeping fluids were moving through secondary, fracture porosity, consistent with the fractures encountered while generating data for the reflectance study.

One method to estimate the primary porosity and permeability conditions in Core 908 is to extrapolate from the porosity data and reflectance data correlation. The estimated porosity data has an average porosity of 6.0%, with a maximum of 25.1% and minimum of 0.0%. This method has flaws associated with the interpretation, but if more laboratory data were to be collected, a better estimate could be obtained. The average porosity, however, is very close to the laboratory measurement average. Although the absolute values may not be indicative of the true porosity, the estimates could be used for observing the variance of the porosity with depth.

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