Carbon Capture Utilization and Storage Opportunities in Pennsylvania

Appalachian Reservoir Core and Thin Section Analysis

Clarissa W. Miller



Senior Comprehensive Project

Allegheny College, Geology Department

May 2024

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In Partial Fulfillment of the Requirements for a Bachelor of Science Degree in Environmental Geology

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I hereby acknowledge that I have fulfilled my responsibilities, as defined by the Honor Code, and maintained the integrity of both myself and the college community as a whole.

Clarissa W. Miller

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ACRONYMS AND ABBREVIATIONS

CCUS	Carbon Capture Utilization and Storage
CAP	Central Appalachian Partnership for Carbon Storage Deployment
DOE	U.S. Department of Energy
EPA	U.S. Environmental Protection Agency
MMt	Million Metric Tonnes
MRCI	Midwest Regional Carbon Initiative
MRCSP	Midwest Regional Carbon Sequestration Partnership
PAGS	Pennsylvania Geological Survey
SEM	Scanning Electron Microscope
SEM_TSC#B#_#	Scanning Electron Microscope Thin Section Core # Box # Image #
TSC#B#_#	Thin Section Core # Box # Image #
UIC	Underground Injection Control
XRD	Standard powder X-Ray Diffraction

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ABSTRACT

Carbon capture utilization and storage (CCUS) research has been growing regionally as a method to decrease carbon emissions. Pennsylvania has been one of the states at the forefront of this research since 2003. The last two decades have continued this research which has led to the most recent project being the Central Appalachian Partnership (CAP) for Carbon Storage Deployment. This project focuses on the Appalachian Basin Rome Trough region for continued research and development of large-scale CCUS implementation.

The Helderberg Group was chosen as the unit of interest to study caprock capabilities within the proposed carbon storage systems. The Helderberg Group lies beneath the Oriskany Sandstone and above the Medina Group. The Oriskany Sandstone has been targeted for research as a potential carbon storage unit making the underlying Helderberg Group a potential caprock. The selected rock core was chosen for multiple analytical techniques which included physical descriptions, XRD analysis, and petrographic microscope and SEM analysis.

Following the analysis, it was determined that the rock core was a sample from the Huntersville Chert and Oriskany Sandstone, not the Helderberg Group as originally thought. The core description analysis, located fully in Appendix I, included a variety of testing methods that led to the initial conclusion that the upper unit was the Mandata Shale, and the lower unit was Corriganville Limestone. This portion of the research included photos of all sections of core to create a comprehensive workbook, located in Appendix II, that allowed for continued reference throughout the project. The bulk mineralogy analysis that was conducted, located in Appendix III, led to the conclusion that the intervals should be revised to the Huntersville Chert and Oriskany Sandstone. Geophysical logs and completion reports, located in Appendix IV, from the

original drilling site highlight the potential inconsistencies of where the core was measured, solidifying the revisions made.

1.0 INTRODUCTION AND PURPOSE

1.1 Geologic Carbon Sequestration Research in the Appalachian Basin

Geologic carbon sequestration research has been in progress in Pennsylvania for more than two decades. This research has been conducted both at the state level and throughout the larger Appalachian and Mid-Atlantic regions. The Midwest Regional Carbon Sequestration Project (MRCSP) has had three phases: Phase I (characterization), Phase II storage capacity potential overview (validation), and Phase III regional geologic characterizations (development). Phase I ranged from 2003-2005, Phase II from 2005-2011, and Phase III from 2014-2019.

Phase I focused on geological storage potential to create a background to build the next phases on. The results from this included the identification of potential reservoir sites within four major categories: deep saline formations, oil and gas fields, unmineable coal beds, and shales. The information derived from this concluded that Mt. Simon, St. Peter, and Rose Run sandstones were the most likely to be the region's largest assets for carbon storage reservoirs (National Energy Technology Laboratory, n.d.).

Phase II included five subtasks to expand geologic knowledge of the region and fill the data gaps found in Phase I. These five subtasks as stated in the MRCSP Phase II—Storage Capacity Potential Overview:

"(1) A Regional Geologic Characterization and Assessment of Geologic Carbon Sequestration Opportunities in the Upper Cambrian Mount Simon Sandstone in the Midwest Region, with Addendum – Cambrian

(2) Characterization of Geologic Sequestration Opportunities in the MRSCP Region: Middle Devonian–Middle Silurian Formations

(3) MRCSP Phase II—Reassessment of CO_2 Sequestration Capacity and Enhanced Gas Recovery Potential of Middle and Upper Devonian Black Shales in the Appalachian Basin

(4) Storing and Using CO_2 for Enhanced Coalbed Methane Recovery in Unmineable Coal Beds of the Northern Appalachian Basin and Parts of the Central Appalachian Basin

(5) Evaluation of CO_2-Enhanced Oil Recovery and Sequestration Opportunities in Oil and Gas Fields of the MRCSP Region (Ball, 2010)."

These subtasks were created for the purpose of detailed geologic characterization for carbon storage potentials. Phase II also indicated quantities of storage potential as well as location sites. The assessment concluded storage quantities in the MRCSP region to be around 52,640 to 234,245 Million Metric tonnes (MMt) in deep saline formations and 8,510 MMt in existing and depleted oil and gas fields leaving a total of approximately 63,378 to 244,985 MMt in the entire region (Ball, 2010).

Phase III continued the research done in Phases I and II to enhance the knowledge of these potential reservoirs. Phase III included regional cross section analysis, regional geology capstone report, and enhanced recovery opportunities. These MRCSP reports created a more comprehensive understanding of carbon storage in the region allowing for the future development of commercial-scale carbon sequestration.

The Midwest Regional Carbon Initiative (MRCI) ran from 2019-2024. The new initiative added 10 more states to the research leading to a total of 20 states involved. These 20 states were separated into primary and contributing. Primary states were the organizers consolidating data for research on Carbon Capture Utilization and Storage (CCUS) and contributing states provided supporting data. The primary states are Illinois, Indiana, Kentucky, Ohio, Michigan, West Virginia, Pennsylvania, Maryland, Delaware, New Jersey, and New York. Contributing states are

Wisconsin, Iowa, Missouri, Vermont, New Hampshire, Connecticut, Massachusetts, Rhode Island, and Maine (Young, 2022). This work has identified five major CCUS systems: Cambrian Mount Simon, Cambrian-Ordovician, Silurian-Mississippian, Late Triassic-Early Jurassic, and Late Jurassic to Late Cretaceous (Young, 2022). This work is still incomplete and the full MRCI report will be released in late 2024.

The newest federally funded project for Pennsylvania and West Virginia is the Central Appalachian Partnership (CAP) for Carbon Storage Deployment that was launched in January 2024 and will continue through early 2026. This project is funded by the U.S. Department of Energy (DOE). The use of the Exploration and Development Well Information Network (EDWIN) has centralized data allowing for easily accessible information on the subsurface geology of the state. Part of the scope of the Central Appalachian Partnership (CAP) Project includes a compilation of data that will be provided through a free, online web-tool. The CAP Project focuses on the development stage of CCUS implementation by closing data gaps in research and compiling a database to provide resources for the U.S. Environmental Protection Agency (EPA) Underground Injection Control (UIC) permitting efforts (Cooney, 2023). This focused specifically on the Rome Trough region shown in Figures 1 and 2.

1.2 Statement of the Problem

Decarbonization efforts focused on mitigating climate change have been in the works for decades, but the recent stream of federal funding to support and accelerate the evaluation of CCUS opportunities at the sub-regional, state and site scales has offered Pennsylvania substantive opportunities to better evaluate and compile its subsurface geologic information for CCUS considerations. These efforts initially began as pilot projects to determine the feasibility

of geologic carbon storage and are now moving toward commercial-scale implementation. Advances have been made in these endeavors with a large task force working on commercial-scale implementation in the Midwest/Atlantic region. These projects were inaugurated by the MRCSP followed by continued research done by the MRCI. The CAP Project is the most recent of these research projects and will continue through 2026. While the MRCSP and MRCI were large regional projects, Pennsylvania paved the way for the CAP Project through the state's extensive research and continued development within these regional projects. The FOA 002799 requirements on building regional initiatives and focus on state-sponsored activities that could best inform entities looking to permit Class VI injection wells for carbon sequestration were all met by the CAP Project (Department of Energy, FOA 002799, n.d.).

This research is critical to the region as there are currently no carbon storage projects in Pennsylvania and no imminent executable commercial-scale projects in the larger Appalachian region (Cooney, 2023). In both MRCSP and MRCI research, data gaps were reported that indicated the need for more detailed datasets on porosity and permeability of reservoir targets, geomechanical studies of confining intervals, and spatial identification of pre-regulatory oil and gas wells that require location, characterization, and potential mitigation before sites can be cleared for geologic storage projects (Cooney, 2023).

1.3 Research Objective and Relevance

The objective of this current research is to describe the lithological, mineralogical, and porosity conditions of the Lower Devonian Helderberg Group using rock core extracted from a deep gas well in Somerset County, Pennsylvania. This work has included both physical descriptions of the chosen core samples as well as a suite of laboratory analyses to evaluate the

potential of Helderberg Group carbonate rocks to serve as a caprock interval between possible shallower and deeper carbon sequestration reservoirs.

The current research is part of a larger effort by the CAP Project to address data gaps in our understanding of subsurface geologic conditions and to facilitate decision-making at CCUS project areas in the Pennsylvania portion of the Appalachian Basin. This research builds on previous regional CCUS-based efforts (Lewis et al., 2009).

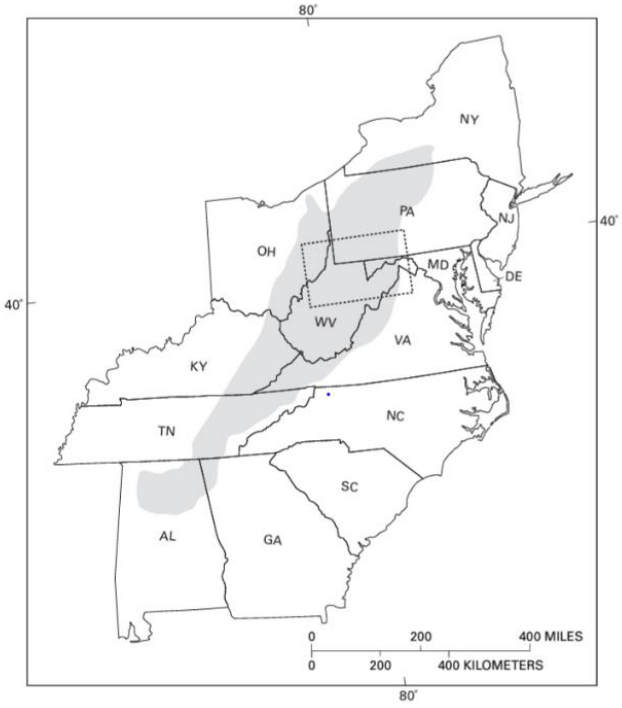


Figure 1 Location of the Appalachian Basin; Area of Study.

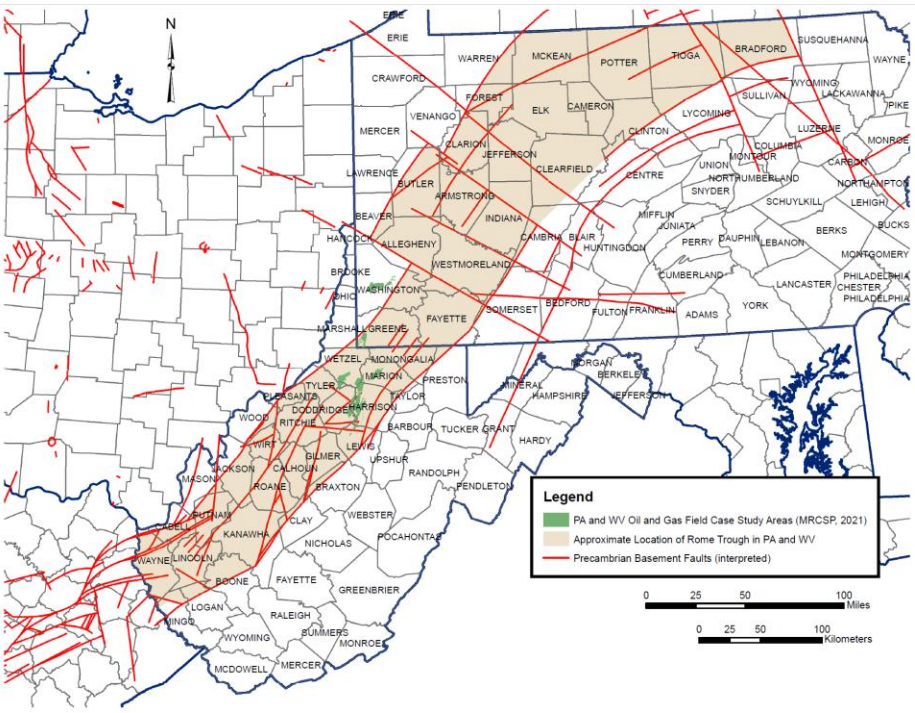


Figure 2 Rome Trough Area in the Appalachian Basin.

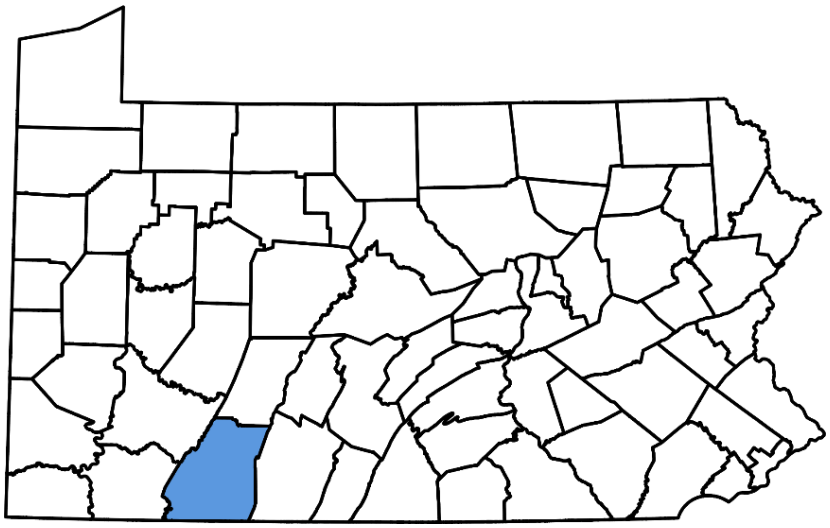


Figure 3 Location of Coring Sample; Sipe Well No.1 (API #37-111-20087), Somerset County, PA.

2.0 REGIONAL GEOLOGY CONSIDERATIONS

2.1 Oil and Gas Development in Pennsylvania

The history of oil and natural gas in Pennsylvania has been one of the main resources for current CCUS development. Oil and gas production has been present in the commonwealth for more than 200 years (Shultz, 1999). The world's first commercial oil well was drilled in Titusville, Pennsylvania in 1859. Early exploration for hydrocarbons started after the discovery of the Drake Well, which expanded oil production activities in multiple geologic formations.

Exploration for oil in Pennsylvania continued due to money driving an increase in hydrocarbon production. An increase in production between 1975-1985 came from a dramatic increase in worldwide oil and gas prices from the founding of the Organizational of Petroleum Exporting Countries (OPEC) in 1973 (Shultz, 1999). The quality of crude oil in Pennsylvania kept the oil production in the region a significant resource even through the development of large oil and gas fields in Texas and other booming oil regions in the United States.

Current production in shallow oil and gas fields remain active in northwestern and north-central Pennsylvania with oil production existing primarily in the northwestern region and natural gas production existing primarily in the central-western part of the state (Shultz, 1999). These reservoirs are notoriously low-porosity and low-permeability sandstones that require stimulation for production. The state's most important reservoirs tend to of Devonian age.

Figure 4 gives a visualization of oil and gas fields in Pennsylvania. These fields are undergoing research for potential repurposing into carbon storage reservoirs. The data that has been collected throughout the years of oil and gas drilling —geophysical logs, completion reports, cutting samples, and core samples—has allowed for more thorough research to be performed on the capabilities of CCUS. This research is done through rock core, petrographic evaluations, and geophysical log calculations (Kostelnik and Carter, 2009).

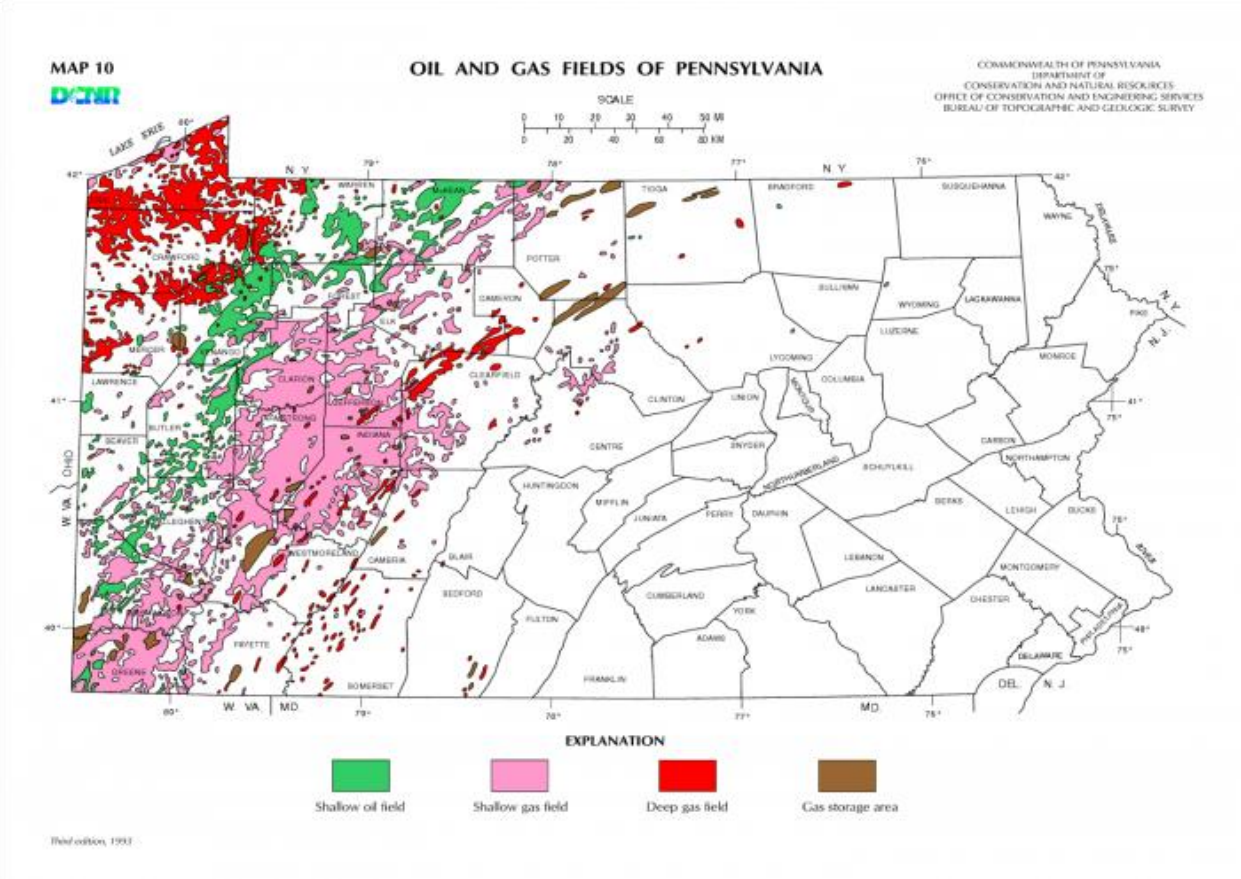


Figure 4 Oil and Gas Fields in Pennsylvania.

The Rome Trough, as shown in Figures 1 and 2, passes through many of the oil and gas fields shown in Figure 4. This project focuses on the Rome Trough region in Southwestern PA which has many shallow gas fields interspersed with a few deep gas fields. Subsurface reservoirs have successfully been converted into natural gas reservoirs and into natural gas storage units. Knowing this, researchers have taken the initiative to investigate the capability of using these reservoirs for CO_2 storage as well. With the strong history of oil and natural gas exploration in Pennsylvania, the potential for the conversion of these depleted reservoirs to be repurposed is very strong, leading to continued research on the topic.

2.2 Pennsylvania's Subsurface Lithostratigraphy

The rocks present in the Devonian system primarily consist of Lower Devonian marine carbonates, cherts, and shales (Shultz, 1999). The Upper Devonian consists of marine to non-marine, coarse- to fine-grained rocks deposited in the Catskill deltaic system (Shultz, 1999). Lower Devonian rocks consist of strata ranging from carbonates to coarse-grained sandstones. The Helderberg Group is typically comprised of limestone and includes minor amounts of shale, chert, and detrital quartz.

The basal unit of the Devonian system, the Keyser Formation, consists of New Creek and Corriganville limestones and the Mandata Shale. The limestones are distinguished from the underlying Keyser by the lighter color, lower chert content, and more massive bedding (Shultz, 1999). The Keyser-New Creek was generally described disconformable throughout central Pennsylvania but in later years was not substantiated (Shultz, 1999). The New Creek Limestone is typically coarse-grained, massive- to thick-bedded, and has fragmental biosparite from 3-10 feet (ft). The New Creek grades into the Corriganville Limestone, which is finely crystalline, thick- to thin-bedded at 10-30 ft thick. The New Creek is generally more fossiliferous. The Mandata Shale is dark grey to black with layers of interbedded chert and limestone ranging from 20-100 ft thick. This grades into the Licking Creek Limestone which is part of the Deerparkian Stage (Shultz, 1999). The Licking Creek Limestone is about 90 ft thick in south-central Pennsylvania.

The Licking Creek Limestone grades into the Oriskany Sandstone, which is one of the most productive reservoirs in Pennsylvania until the Marcellus Shale play. The Oriskany Sandstone consists of lithologies ranging from calcareous, fine-grained sandstone to noncalcareous conglomerate with the dominant lithology consisting of white to light-grey, medium-grained, silica-cemented, quartzose sandstone (Shultz, 1999). Western Pennsylvania has

the Huntersville Chert overlying the Oriskany Sandstone. This formation is dark grey, slightly calcareous, and ranges as thick as 250 ft in some areas (Shultz, 1999).

The Oriskany Sandstone is a formation that is being looked at for carbon storage. The Helderberg Group underlies the Oriskany Sandstone making it a potential caprock of a larger carbon storage system. The effectiveness of the Helderberg as a carbon seal has been studied using geophysical, seismic, and core data as well as with previous outcrop data (Lewis et al., 2009). The Mandata Shale of the Helderberg Group was thought to be the seal as shales are often good caprocks due to low porosity and permeability. The Helderberg was deemed as low permeability, which initially suggests that it would be a suitable caprock. The long-term data suggests that the calcite in the formation would dissolve after interaction with the injected supercritical CO_2 (Lewis et al.,2009). Many samples of the Helderberg that were taken and analyzed via thin sections showed calcite-filled fractures. Most microfractures found in the section studied had secondary calcite precipitation that filled these fractures (Lewis et al., 2009). Based on a study done on mineralogy impact on caprocks, calcite-rich caprocks can withstand chemical perturbations and be reliable seals (Spokas et al., 2018). However, these calcite-rich caprocks do better with bands of less reactive minerals running perpendicular to the potential flow paths of the supercritical CO_2 (Spokas et al., 2018). The consensus of these projects indicates that further research is required to determine the viability of individual carbon storage systems with carbonate caprocks.

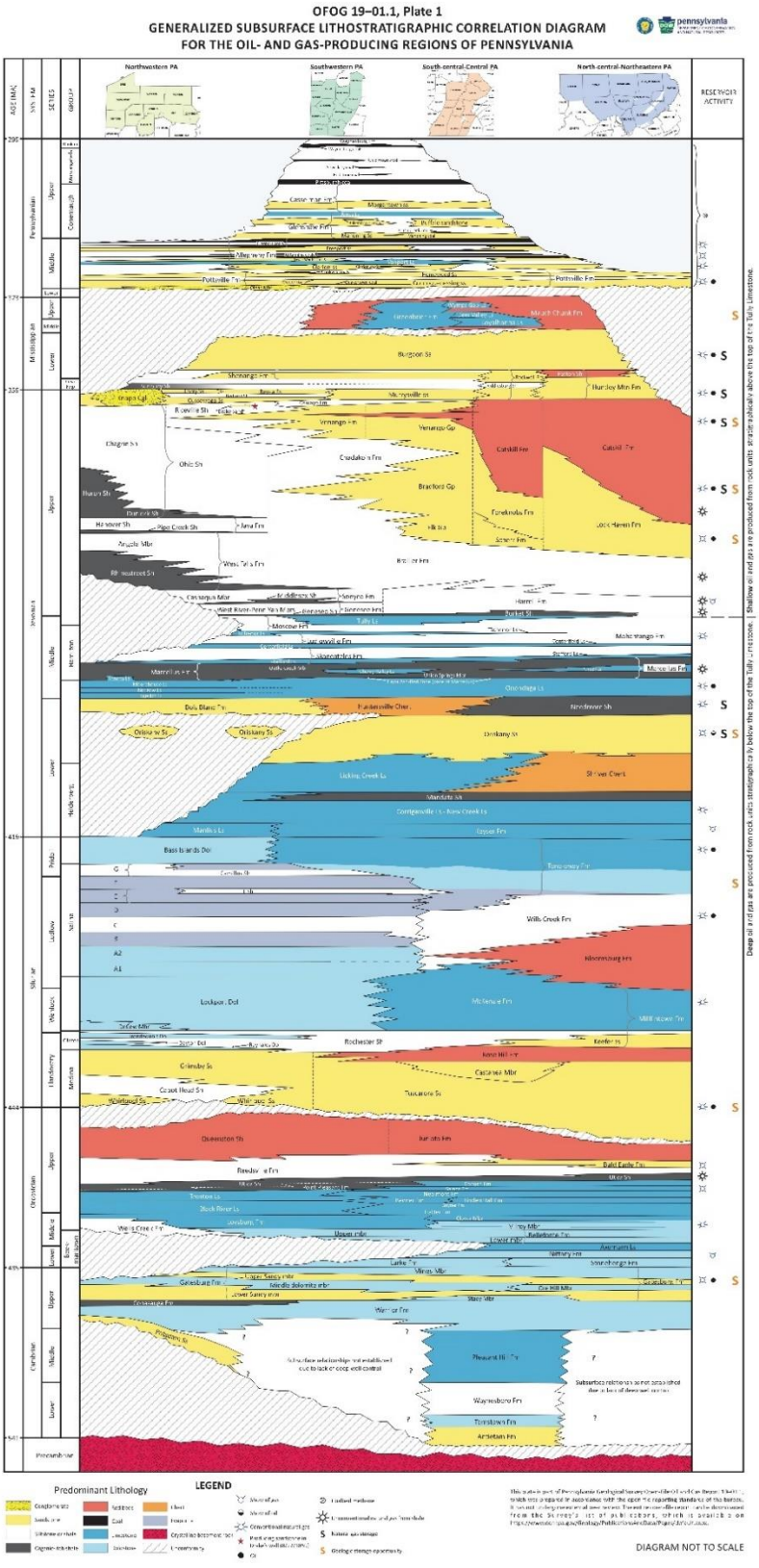


Figure 5 Pennsylvania Lithostratigraphic Correlation Chart for the Oil and Gas Regions.

2.3 Devonian System

The Devonian system is located above the older Silurian system and below the Mississippian system. The system name is based on the exposures of the Devonshire marine rocks in England (Shultz, 1999). The New York Geological Survey noted that the Devonian section in New York was less complex and stratigraphically more complete making the New York outcrop belt a more correct systemic type section than the British Devonshire section (Shultz, 1999). The Devonian system in Pennsylvania is thicker and more extensive than that in New York and thins as it moves westward (around 2,400 ft in Erie County and over 12,000 ft in Eastern Pennsylvania).

The primary formation type in the Devonian system is mudrocks; however, there are formations of chert and limestone in the lower half, and siltstones, sandstones, and conglomerates in the upper half. The upper and lower boundaries are primarily conformable with notable exceptions (Shultz, 1999). In northwestern Pennsylvania and the lower boundary is disconformable and in eastern Pennsylvania the upper boundary is disconformable. The stratigraphy of the Devonian System places the marine carbonates, cherts, and shales in the Lower Devonian with the marine to nonmarine terrigenous rocks in the Upper Devonian (Shultz, 1999).

Lower Devonian rocks have strata that ranges from bioclastic shelf carbonate to very coarse detrital sandstones. The Helderbergian Stage rocks are typically limestones with a few appearances of shale, chert, and detrital quartz. The Helderbergian stage consists of the New Creek and Corriganville Limestones and the Mandata Shale. The Deerparkian Stage rocks are mostly comprising of quartz sandstones, siltstones, and shales with limestones and cherts in

central and eastern Pennsylvania. The basal Devonian unit in Pennsylvania is the Keyser Formation. The Keyser-Helderberg boundary is distinguished by the lighter-colored limestones, lower chert content, and thicker bedding presiding in the Helderberg (Shultz, 1999). The New Creek Limestone is typically a coarse-grained, thick bedded, fragmental biosparite. The New Creek grades into the Corriganville Limestone, which is finely crystalline, thick- to thin-bedded limestone. The Mandata Shale is dark grey to black, splintery, and thin-bedded. There are interbedded chert and limestone layers, and it grades into the Corriganville (Shultz, 1999).

Middle Devonian

Group	Formation	Named Unit	Informal and Drillers' Names Used by Industry	Reservoir Activity
Hamilton	Moscow	Tichenor Limestone	Driller's Tully	
	Skaneateles	Skaneateles Fm	Part of "organic-rich Marcellus" in southwestern PA	
	Mahantango	Mahantango Fm	Chaneysville	Conventional natural gas production
	Marcellus	Oatka Creek Member	Upper Marcellus	Unconventional natural gas production from shale
		Cherry Valley Limestone	Purcell	
		Union Springs Member	Lower Marcellus	Unconventional natural gas production from shale
		Purcell Limestone	Cherry Valley	
		Marcellus Fm		Unconventional natural gas production from shale
	Onondaga	Onondaga Limestone		Conventional oil/natural gas production

Lower Devonian

Group	Formation	Named Unit	Informal and Drillers' Names Used by Industry	Reservoir Activity
	Bois Blanc	Bois Blanc Fm		Conventional natural gas production
	Huntersville	Huntersville Chert		Conventional natural gas production, natural gas storage
	Oriskany	Oriskany Sandstone		Conventional natural gas production, show oil, natural gas storage, geologic storage opportunity
Helderberg	Keyser	Keyser Fm		Show gas
		Helderberg Gp		Conventional natural gas production

Table 1 OFOG Middle and Lower Devonian System Formations and Reservoir Activities.

2.4 Defining Carbon Storage Systems

Carbon storage systems are defined by the Department of Energy (DOE) as a subsurface series of rocks that will hold Carbon Dioxide (CO_2) safely and permanently (DOE, National Energy and Technology Laboratory, n.d.). There are five formation types labeled by the DOE as

potential carbon storage units: saline formations, oil and natural gas reservoirs, unmineable coal seams, organic-rich shales, and basalt formations.

These formations require specific characteristics including storage resources, injectivity, integrity, and depth. Storage resources is the volume of storage available in a potential carbon storage system based on pore volume or porousness and permeability. Injectivity is the rate at which CO_2 can be injected into the storage system. This is directly correlated with permeability of the geologic formation of the potential unit. Integrity refers to the ability to confine the CO_2 in the potential storage system. A storage system or "complex" requires one or more confining zones that seal above injected formations that are intact and with no leakage pathways (DOE, National Energy and Technology Laboratory, n.d.). The storage complex must also have sufficient depth to maintain the correct pressure to keep the CO_2 in a supercritical state.

3.0 METHODS

3.1 Rock Core Analysis

3.1.1 Core Sample Selection

The initial selection process considered 316 cores in a specified region relevant to the CAP Project. Out of these 316 cores, there are both cores of carbon storage units and caprock units. These cores were organized by the formation that they exist in along with notes on the formation's potential for reservoir or caprock qualities. The choosing to do an analysis for a caprock unit narrowed the core to a select few units within the initial database. The stratigraphic unit chosen for analysis was the Helderberg Group, located between two potential carbon storage units. After the Helderberg Group had been chosen as the sample for analysis, it narrowed the core samples to a few selections. After discussion, the core chosen was from the Sipe Well (API

37-111-20087) in Somerset County, Pennsylvania. This core ranges from 8830 to 8903 ft and contains 28 boxes for analysis.

3.1.2 Core Description Work

The initial portion of the core analysis involved wetting with water to compare the rock core to 322 standardized color chips from the Rock-Color Chart with Munsell color chips. Following the steps from the Midwest Geosciences Group Field Guide, an analysis of the sediment size, sorting, and texture was performed. This same guide was used to analyze the fracture analysis and completion of the core samples. Succeeding the previous analysis, laminations, mineral intrusions or veins, and fossils are notated. The final step in the analysis process was testing potential calcite in the chemical composition of the core. This was tested using 10% HCl for a chemical reaction.

3.2 XRD Mineralogy

3.2.1 Sample Selection

Rock core samples were selected at 2-ft intervals along the entire length of the core. As there was 80 ft of core in the Sipe Well, the sample selection intends to allow for multiple Standard X-ray powder diffraction (XRD) samples from each box as there was variety in the physical characteristics from the top to the bottom of core boxes in some instances.

3.2.2 Sample Preparation

Rock chips were taken from Sipe No. 1 core sample at 2 ft intervals. The shallowest interval was at approximately 8,835 ft and the deepest was at approximately 8,898 ft. XRD was

used to determine the bulk mineralogy of the core. The samples were ground with a mortar and pestle until they reached the consistency of talcum powder to be analyzed.

3.2.3 XRD Analysis

The XRD analysis was run by PAGS (Middletown). Bulk mineralogy was determined by powder XRD using a PANalytical Empyrean X-ray diffractometer and HighScore Plus software. For this study, the Rietveld method was used to determine the mineralogy of the core samples. The Rietveld method is conducted by fitting a calculated diffraction pattern to the observed data (Misture et al., 2001). This method allows the creation of reasonable estimates of mineralogical data within the selected sample, rounded to the nearest tenth of a percent.

3.3 Thin Sections

3.3.1 Sample Selection

Samples were chosen based on interesting observations found during the rock core description of the Sipe well. These observations included fractures, laminations, vugginess, or fossiliferous layers. Three samples were chosen using the 148 photos of the core that were taken during the rock core description. These samples were from Core 1 Box 4 interval 8,838 ft, Core 2 Box 6 interval 8,868 ft, and Core 3 Box 8 interval 8,898 ft.

3.3.2 Thin Section Preparation

Samples taken from the Sipe Well were cut into thin section billets by the PAGS Middletown office and sent to Grindstone Laboratory LLC. Grindstone cut the bulk samples into 27 x 46 millimeter (mm) thin sections. These were turned into standard, single-side polished thin

sections. The samples were embedded with blue dye to allow visual observations of porosity. These thin sections were then sent directly to Allegheny College to be observed at the laboratory.

3.3.3 Thin Section Analysis

The three thin sections were selected based on visual noteworthiness and analyzed with both an optical microscope and Scanning Electron Microscope (SEM). The initial analysis was done using an optical microscope to determine the total optical porosity by using areal percentages. This was done by taking 9 points and calculating the average optical porosity of all points taken. Following the data analysis from the optical microscope, an analysis was performed on the SEM. The SEM analysis would take the same 9 points to be photographed and visually analyzed to determine factors affecting porosity. Porosity found in the optical microscope will be compared to the visual images taken by the SEM to provide qualitative assessments of mineralogy, mineral grain contacts, cements, and pore space characteristics.

4.0 RESULTS

4.1 Lithostratigraphy

This research effort focused on subsurface lithostratigraphic units from the Lower Devonian. This part of the section includes the Needmore Shale, Huntersville Chert, Oriskany Sandstone, and limestones and shales comprising the Helderberg Group (Figure 5). Both the Huntersville Chert and Oriskany Sandstone are notable gas producers in southwestern and south-central Pennsylvania (Kostelnik and Carter, 2009), and the underlying Helderberg Group carbonates have been considered as a potential seal to overlying and underlying carbon storage targets (Lewis et al., 2009).

When evaluating carbon storage systems, one of the most important components is the caprock. Caprocks overlie and underlie reservoir rocks and serve to keep reservoir fluids (or injected fluids) in place. Similarly, the Lower Devonian caprocks studied here include a mix of shale and limestones of the Helderberg Group.

4.2 Core Description

The interval of rock core described for this research included two primary lithologies. The first was observed at depths of 8,830-8,837 ft. This upper interval mostly consisted of very fine grains that were very well sorted. Certain sections on the described interval had laminations and mineral veins that can be assumed to be calcite based on the reaction to hydrochloric acid (HCl) that occurred. Figure 6 shows fracturing, very fine-grained 62-88 micrometers (μm) and is very well sorted. The color was interpreted as N2 grey-black. These descriptions, paired with the background geologic information for southwestern/south-central Pennsylvania leads to the hypothesis that this part of the core is comprised of the Mandata Shale.



Figure 6 Fig12_B3C1, 8,835 ft, N2 Grey Black, Shale (Chert, revised).

The lower, second interval was interpreted to be limestone based on the detailed core description of depths 8,837 to 8,903 ft. As the first interval was hypothesized to be the Mandata Shale, this would suggest these lower rock units would be the Corriganville Limestone-New Creek Limestone. The limestone interval is hypothesized to be interbedded with sandstone in sections that were less reactive or not reactive to HCl.

Figure 7, located at 8,837 feet, indicated no fracturing. This sample had color variation from N3 Light Grey to N8 Very Light Grey. There were interbedded fossils and variance in grain size between coarse 710-1000 μm and medium 350-500 μm. This specific sample was interpreted to be sandstone due to the variance in grain sizes and sorting. There were slight reactions to HCl potentially indicating carbonate cementing. Figure 8, at 8853 ft, is hypothesized to be a limestone interval with N4 Medium Dark Grey coloration. The grains are fine 177-250 μm and well sorted. There were laminations throughout and the fossiliferous layer near the top of the section had medium sorting. Figure 9 located at 8863 feet is another sample of limestone.

The coloration was N3 Dark Grey, very fine grains 88-120 μm, very well sorted, with some interbedded fossils. The core sample maintained a few of the most prominent features—grain size, sorting, laminations—that occur throughout the full depth, minus a few notable sections.



Figure 7 Fig17_B4C1, 8837 ft, N4 Medium Dark Grey, Limestone (Sandstone, revised).



Figure 8 Fig33_B10C1, 8853 ft, N4 Medium Dark Grey, Limestone (Sandstone, revised).



Figure 9 Fig43_B4C2, 8863 ft, N3 Dark Grey, Limestone (Sandstone, revised).

Figure 10 is one of the notable sections in the core interval. At 8,868 ft, the sample is interpreted as a sandstone interval due to larger grain sizes and no reaction to HCl. The coloration ranges from N8 Very Light Grey in the primary/central portion to N3 Dark Grey near the top and bottom of this core section. This section also has very notable fossil layers and was collected for SEM analysis.



Figure 10 Fig48_B6C2, 8868 ft, N8 Very Light Grey in primary and N3 Dark Grey in top and bottom, Sandstone.

Figure 11 at 8,880 ft is another typical example of limestone within the rock core. This section is near the bottom and is very similar to what is found at most of the lower unit in the core sample. The coloration is N3 Dark Grey, slightly reactive to HCl, and fine grained. There is some variation here with laminations and interbedded fossils as well as minor fracturing.



Figure 11 Fig56_B1C3, 8880 ft, N3 Dark Grey, Limestone (Sandstone, revised).

The overall conclusion from the physical analysis of the rock core was that the upper portion of the core sample consisted of the Mandata Shale while the lower portions consisted of Corriganville Limestone-New Creek Limestone. Appendix I contains descriptions from the entirety of the rock core and Appendix II contains all corresponding images.

4.3 Mineralogy

The bulk mineralogy of samples taken from the rock core interval was an important component in confirming or otherwise determining the lithologies in the core interval. The physical description of the interval gave a good initial picture of the types of sedimentary rocks in the core and what some of the geologic formations may be, but the bulk mineralogic analysis was integral to testing the initial hypotheses regarding these formations.

Bulk mineralogy results are reported by depth in Appendix III and graphically displayed in Figure 12. As shown in Figure 12, the major mineralogic composition is dominated by quartz and calcite, with other, much less concentrated minerals including dolomite, lizardite, and clay minerals. The pie chart in Figure 13 is another way of demonstrating that these rocks are

primarily comprised of calcite and quartz. Averaging the bulk mineralogy along the entire rock core interval clarified what some of the lithologies (and associated formations) most likely are. Based on the physical descriptions as well as the mineralogy data, it can be determined that the initial observations hypothesizing the lithologies as shale and limestone should be revised to chert and sandstone. respectively.

The lack of clay minerals in the upper sections of the core sample indicates that there may have been an error in the initial determination of shale in the upper sections. Shale most often contains higher quantities of clay minerals while the mineralogical data suggests less than 20% is present. Pairing this with the core sample photographs and the physical descriptions, this initial analysis has been revised to suggest the presence of chert.

In the lower sections, the quantity of quartz and lack of calcite in the data suggests that while the sandstone reacts to HCl, it is not the majority mineral in the rock. The causation of the sandstone reacting to the HCl is likely due to carbonate cement in the sandstone. While there are some sample depths with greater percentages of calcite, overall, the bulk mineralogy results for these deeper sample depths still suggest that the primary lithology is sandstone.

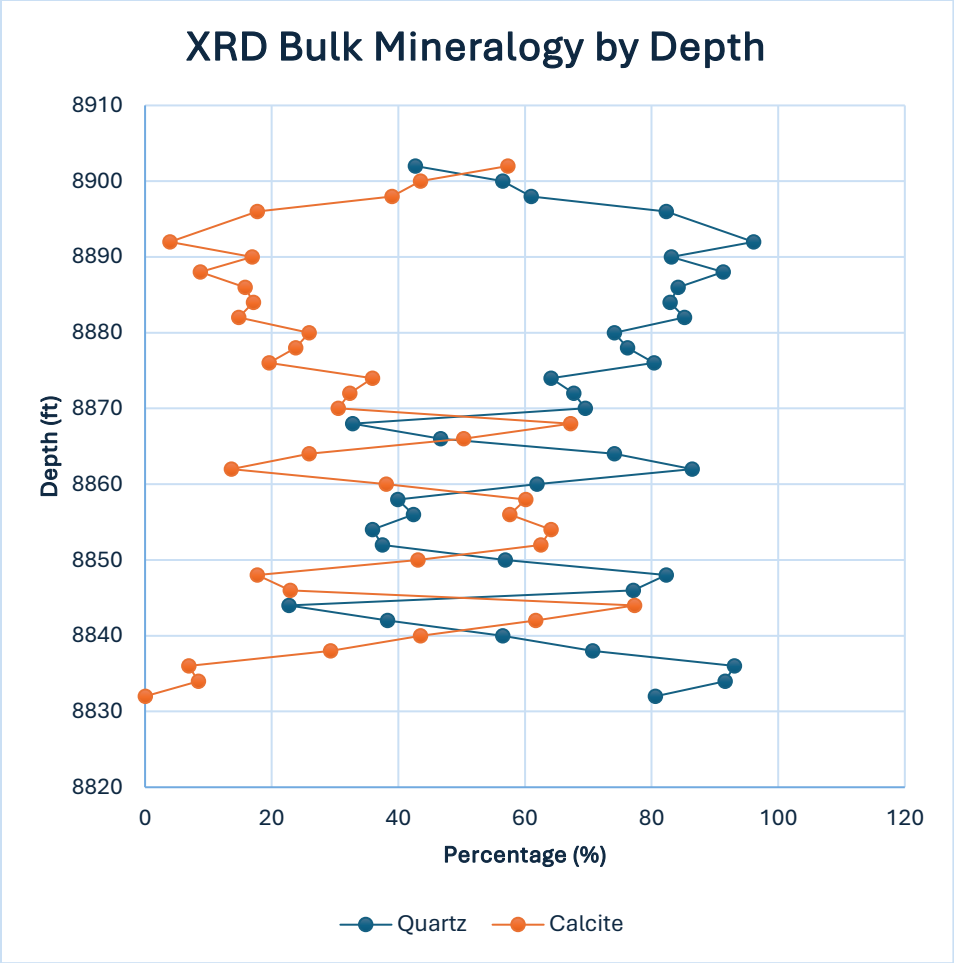


Figure 12 XRD Bulk Mineralogy by Depth

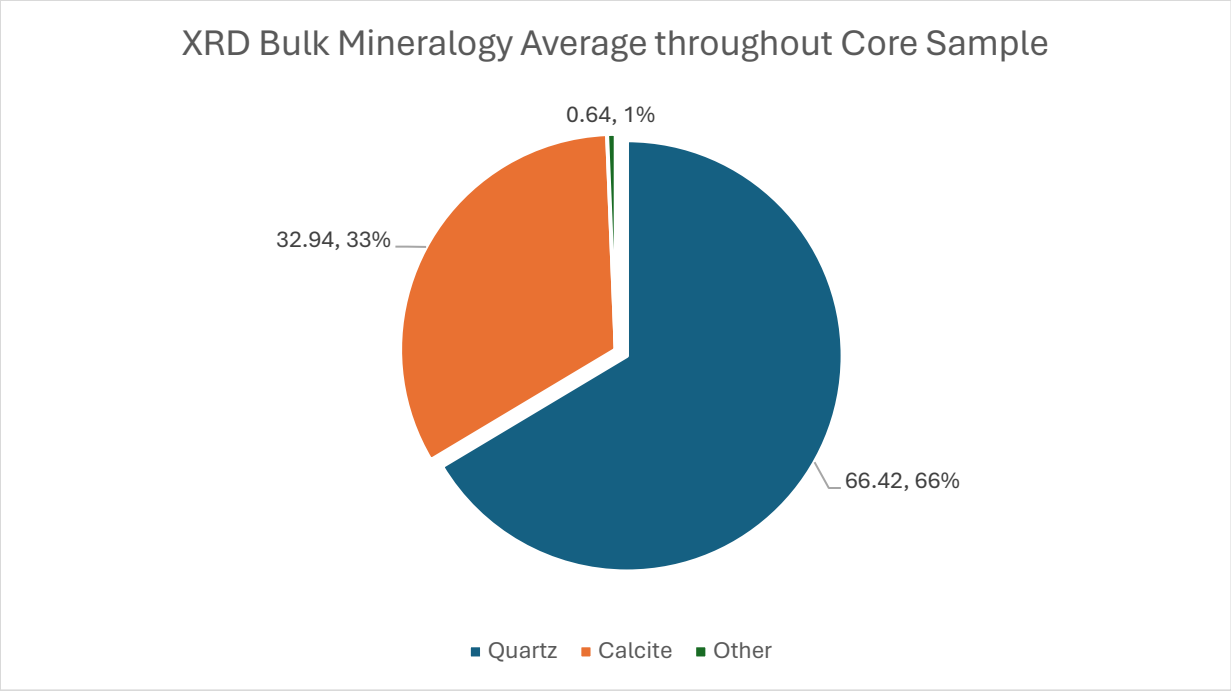


Figure 13 XRD Bulk Mineralogy Average for Entire Rock Core Sample

4.4 SEM Analysis

An SEM analysis was performed on three samples at different intervals throughout the core sample. The analysis was performed using a pairing of petrographic microscope work and the SEM. The petrographic analysis was performed by taking 9 images of the thin section to observe mineral grains and cement. These 9 images were notated using a grid system drawn onto the thin section samples.

The thin sections were placed into the SEM machine and oriented to find the grid that was used during the petrographic system. The 9 grid sections chosen for the petrographic microscope were then oriented in the SEM to take photographs within the same grid sections.

Pulling the data from the XRD for the three thin sections and comparing it to the images taken on both the petrographic microscope and the SEM allowed for a deeper analysis of the mineralogy from each section through visually analyzing the mineral shapes and sorting.

The first thin section was taken from Core 1, Box 4 at depth 8,838 ft. Thin section one is mostly composed of quartz with a 91.6% quartz composition and 8.4% calcite. This is shown in Figure 14 and images from the petrographic microscope and SEM can be found in Appendix V. This thin section had the most uniform grain sizes of all three thin sections taken as shown in petrographic microscope photos (Figures 15 and 16) and SEM photos (Figures 17 and 18).

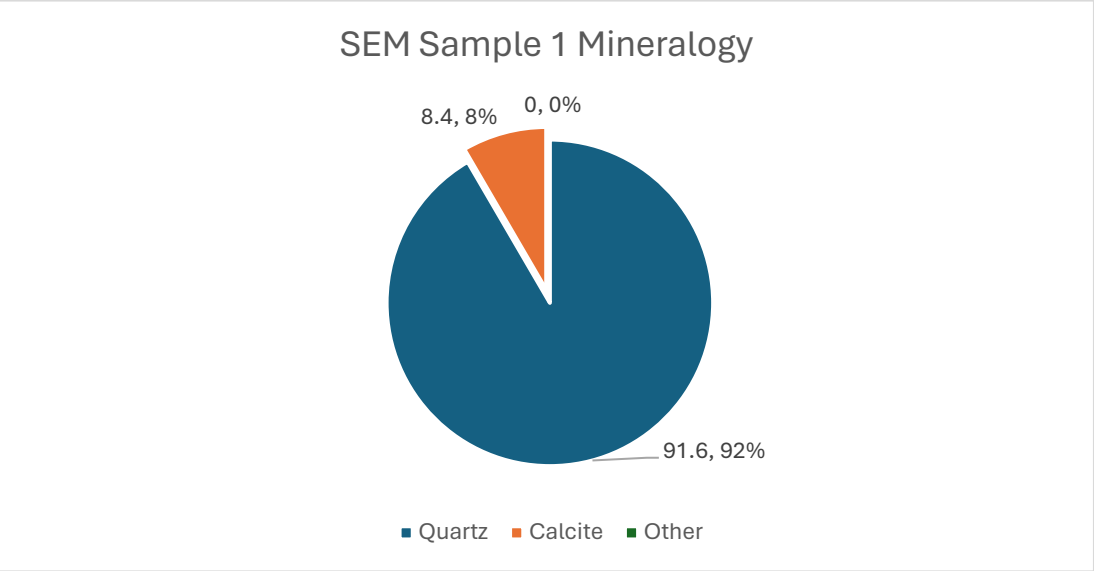


Figure 14 Thin Section 1 Associated XRD Mineralogy

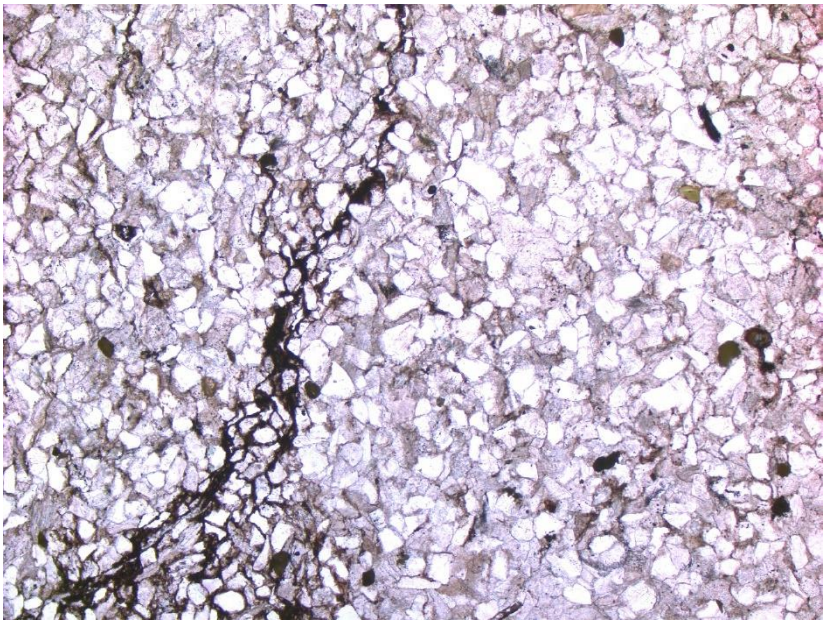


Figure 15 Petrographic 40 mm; Thin Section 1, Image 2

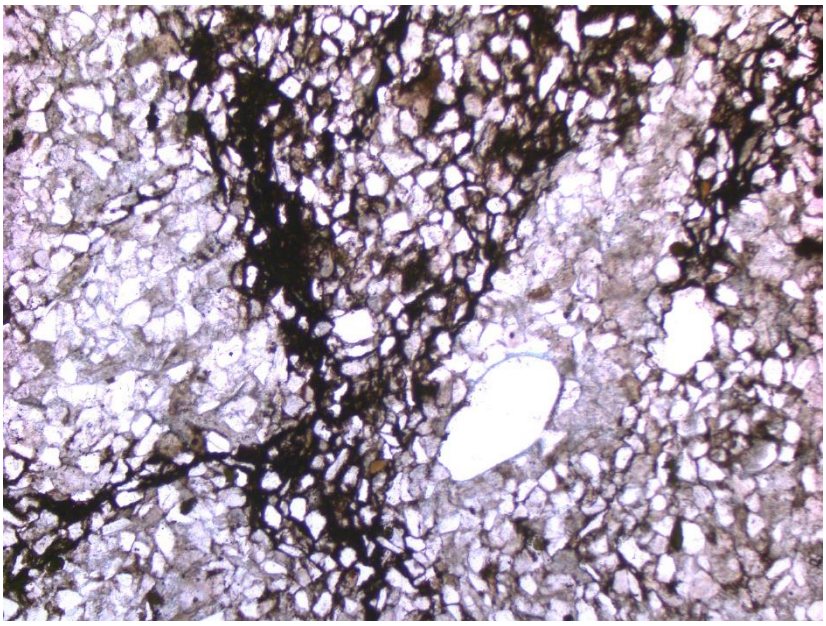


Figure 16 Petrographic 40 mm; Thin Section 1, Image 7

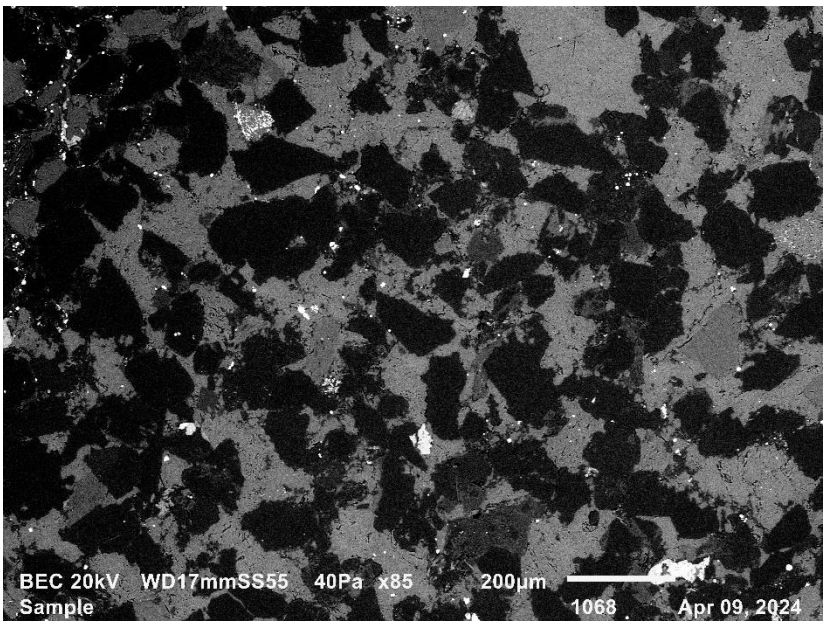


Figure 17 SEM; Thin Section 1, Image 2

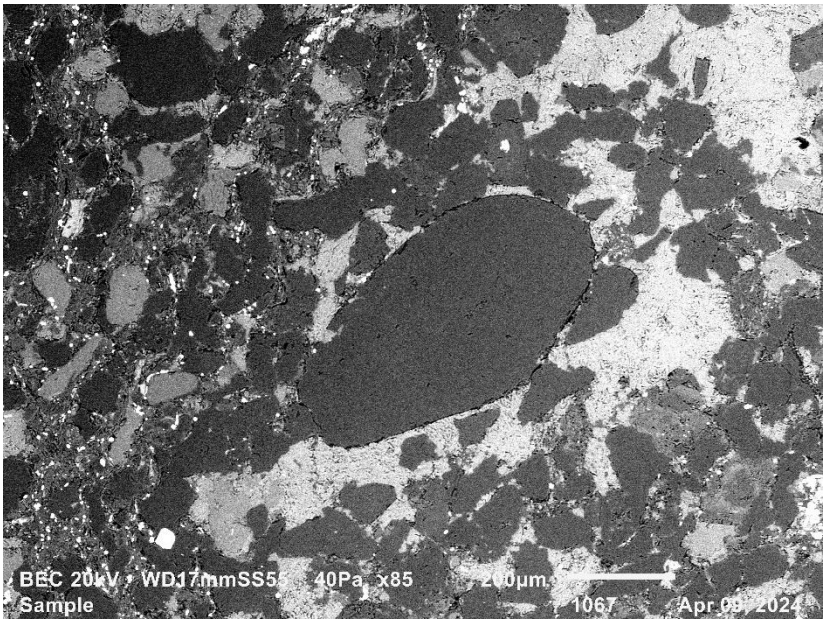


Figure 18 SEM; Thin Section 1, Image 7

Thin section two was taken from Core 2, Box 6, at depth 8,868 ft. This thin section is also mostly comprised of quartz with 69.5% quartz and 30.5% calcite. This section seemingly has more carbonate cement, making calcite more prominent than in thin section one. Thin section two had larger grains of quartz and more cement between grains as shown in Figures 20 and 21. Figures 23 and 24 show SEM imaging of the same portion of the thin section showing more detail on the cement between grains.

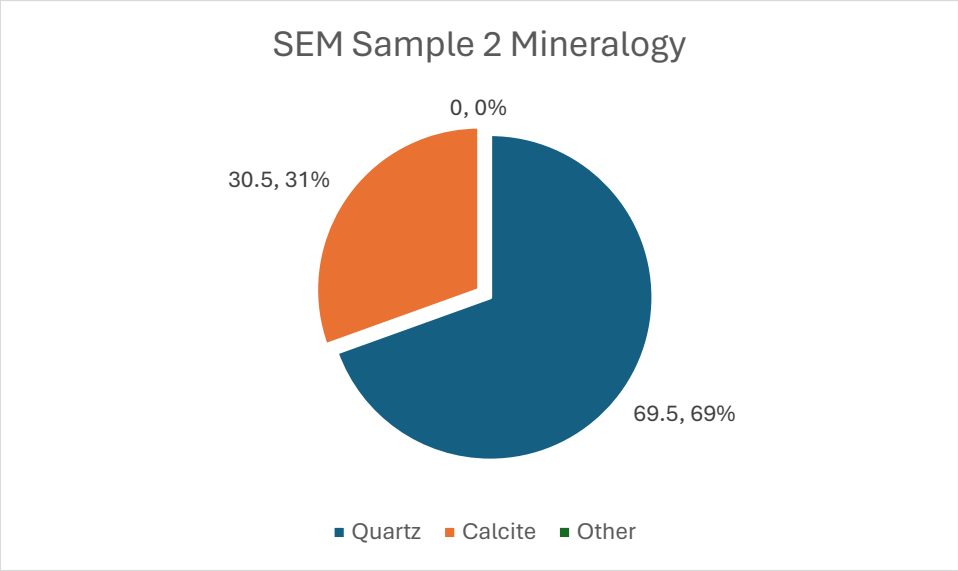


Figure 19 Thin Section 2 Associated XRD Mineralogy

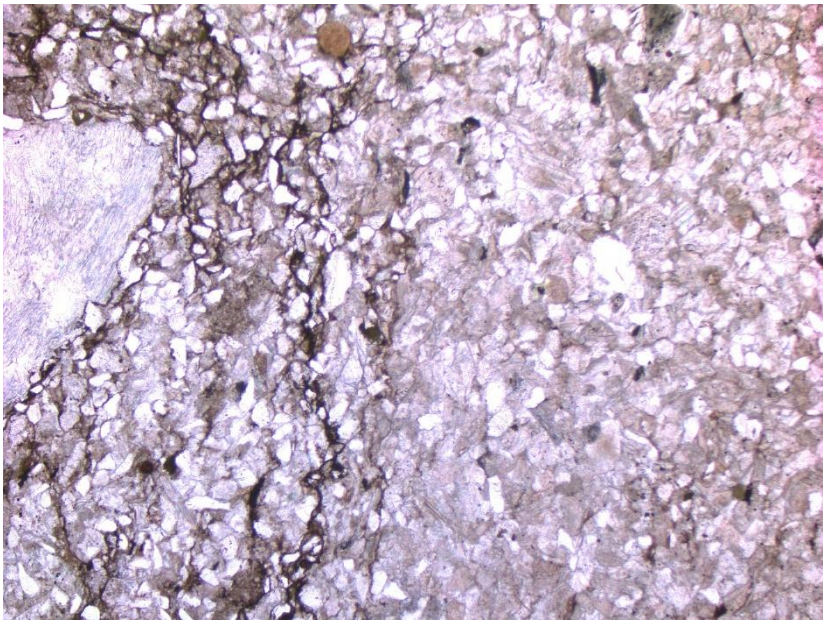


Figure 20 Petrographic 40 mm; Thin Section 2, Image 2

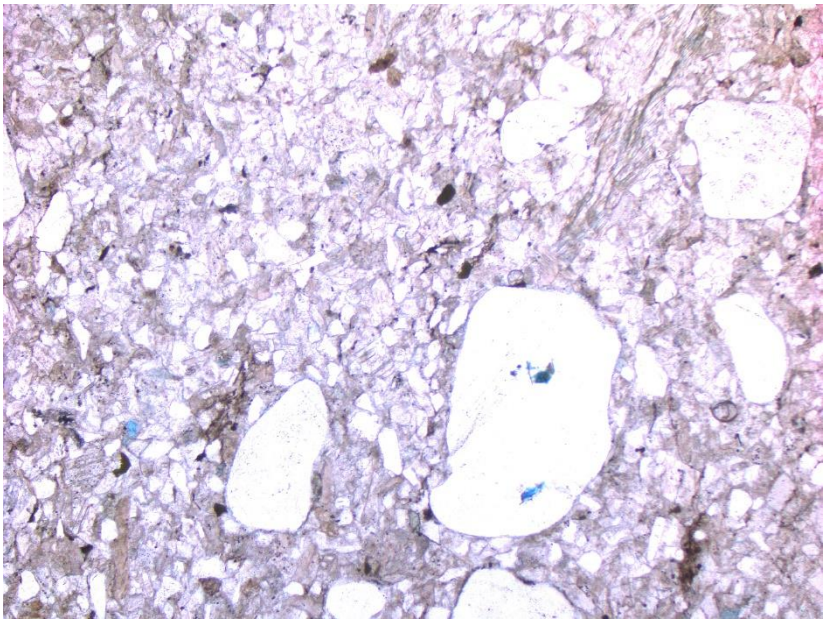


Figure 21 Petrographic 40 mm; Thin Section 2, Image 6

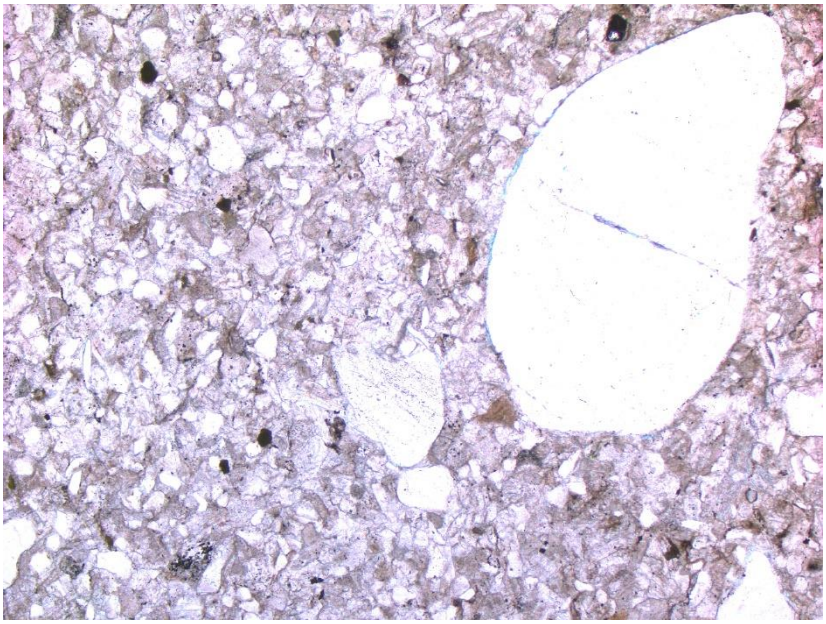


Figure 22 Petrographic 40 mm; Thin Section 2, Image 9

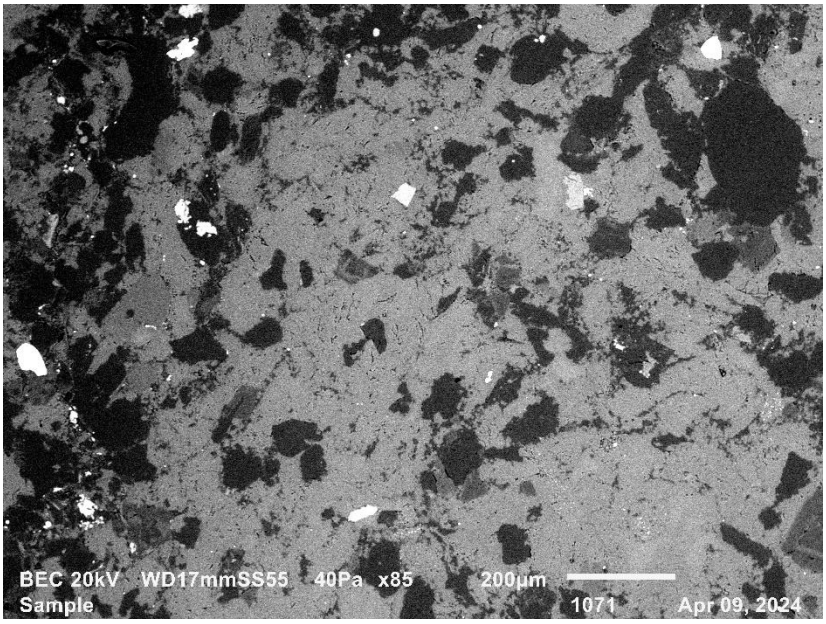


Figure 23 SEM; Thin Section 2, Image 2

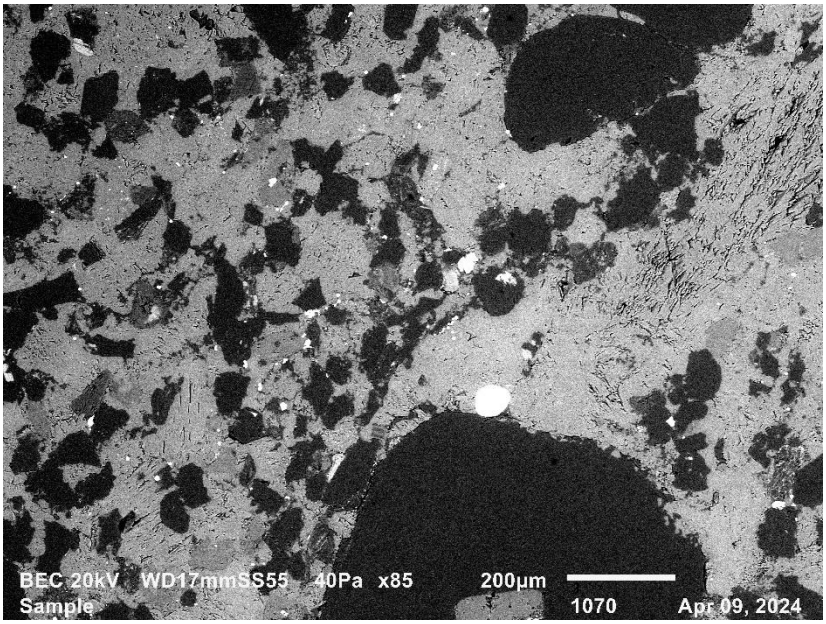


Figure 24 SEM; Thin Section 2, Image 6

Thin section three was taken from Core 3, Box 8 at a depth of 8,898 ft. This thin section had the largest calcite composition showing 39% calcite and 61% quartz. While quartz was still the largest composition overall, the increase in calcite shows more carbonate cement and a larger concentration of calcite mineral veins. This is shown in the petrographic microscope photos from Figure 26 and 27 and the SEM photos Figures 28 and 29.

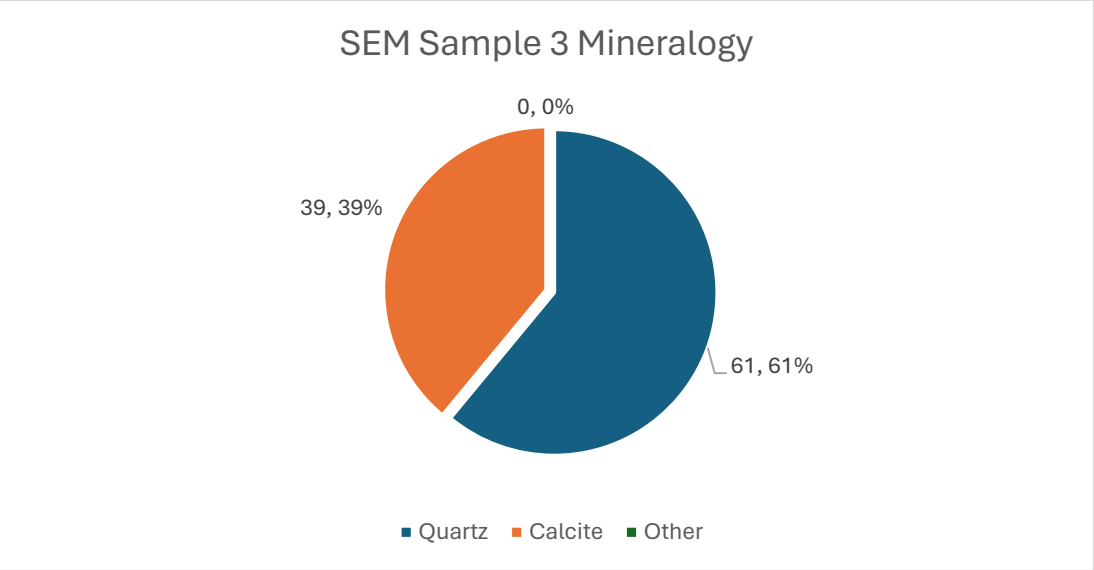


Figure 25 Thin Section Three Associated XRD Mineralogy

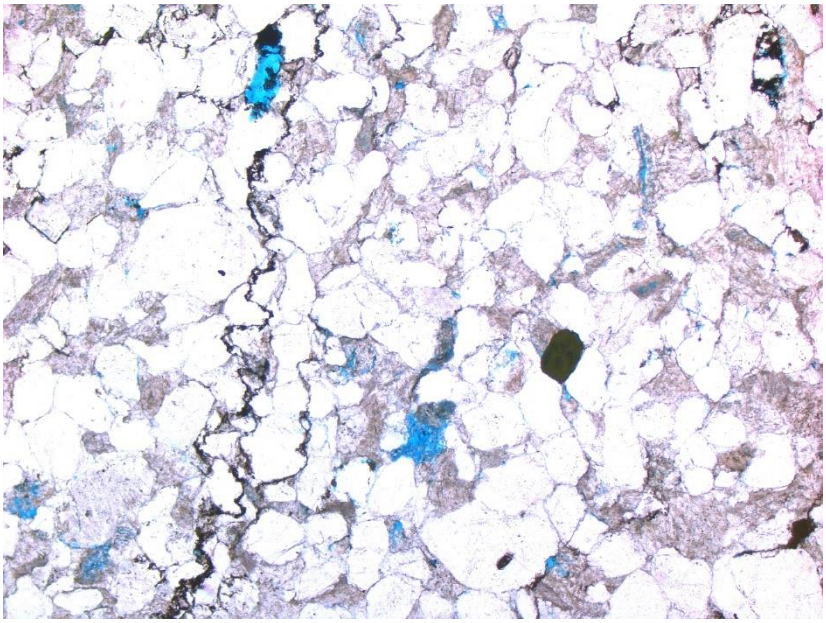


Figure 26 Petrographic 40 mm; Thin Section 3, Image 5

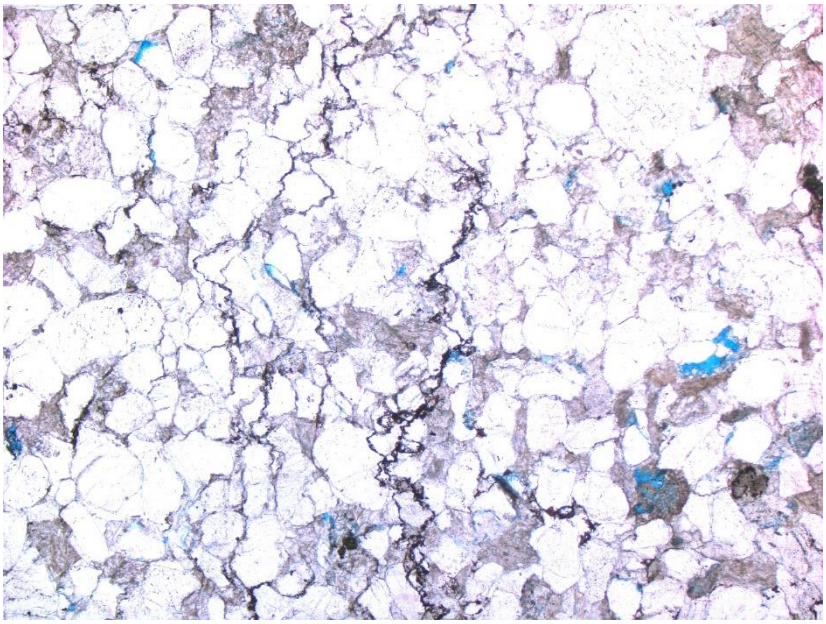


Figure 27 Petrographic 40 mm; Thin Section 3, Image 9

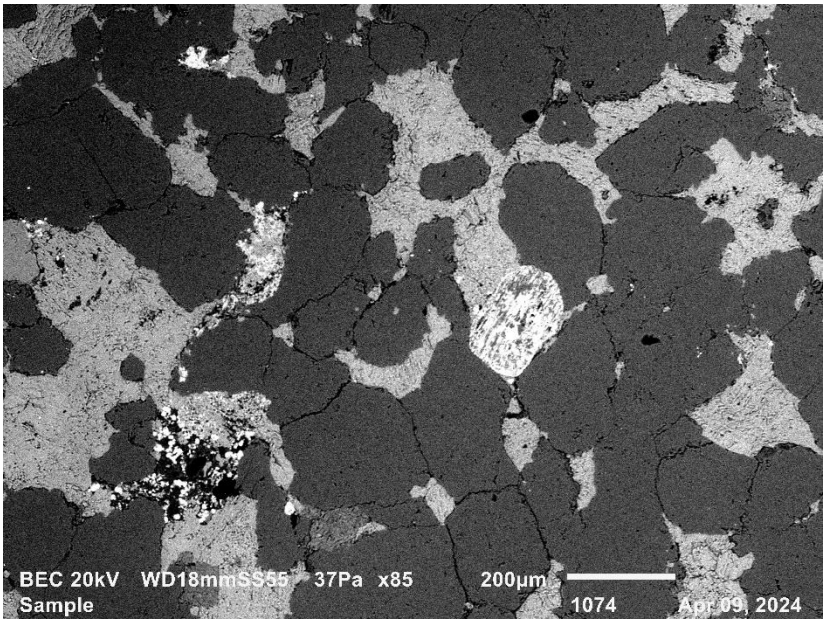


Figure 28 SEM; Thin Section 3, Image 5.1

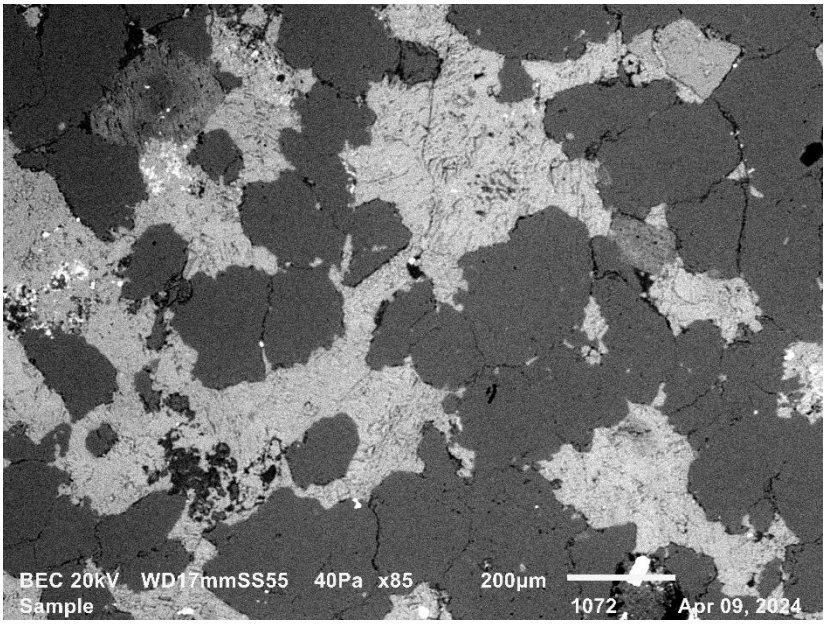


Figure 29 SEM; Thin Section 3, Image 9

4.4.2 Porosity Estimations

Initial observations of porosity measurements from thin sections showed that there was very little blue dye, and the grains were very tightly packed. Thin section three had the largest amount of pore space while remaining under 1% throughout the entire thin section. With seemingly low percentages of pore space, this would not make a good carbon storage reservoir due to the tightly packed grains and extensive cement.

5.0 DISCUSSION

5.1 Rock Core Selection and Physical Descriptions

The rock core selected for this work was intended to determine the caprock capabilities of the Helderberg Group. The rock core was selected from a spreadsheet that provided characteristics by the PAGS core library. Within the spreadsheet there were a variety of

formations including both potential carbon reservoirs and caprocks. The Oriskany Sandstone is one of the largest contenders for carbon storage reservoirs which led to the choosing of the Helderberg Group to study caprock potential. Many samples within the rock core selection included the Helderberg Group, but the Sipe No. 1 Well was ultimately selected for study. It is located in Somerset County, Pennsylvania from depths 8,830-8,903 ft. The rock units originally thought to be represented in this well were from the Helderberg Group starting with the Mandata Shale going into the Corriganville and New Creek Limestone.

The initial analysis done on this project was the physical description of the core done by analyzing the grain size, sorting, roundness, and reaction to HCl. The observation of fossil intervals, mineral veins, and vugginess was also noted in order to look at differences between intervals; this work performed for all 80 ft of core. During this process, photographs were also taken from each box of core to provide additional documentation and allow for continued observation and review.

The top few boxes of the core were dark in color (primarily N2 grey-black) with small, well-sorted grains. The range of depths was from 8,830-8,837 ft making it a relatively small portion of the overall rock core. This section was very fractured and many of the core sections were incomplete. It did not react to HCl except in the mineral veins and fossils that occurred throughout the section. Because of the initial assumptions of the lithology and location, this was observed to be a shale interval; specifically, the Mandata Shale.

The lower boxes of the core from depths 8839-8903 ft were much more varied throughout. While the coloration of this section was primarily N3 dark grey and N4 greyish black there was more variation. The grains were well sorted with sizes varying from very small to medium sized. There was some mineral veining and fossil intervals throughout the portion

of this core. This section was very reactive to HCl throughout which indicated high presence of calcite. This was concluded to be the Corriganville and New Creek Limestone as it is the interval that underlies the Mandata Shale.

5.2 Determination of Rock Units in Sampled Interval

The original determination of the rock units in the sampled interval was based solely on the physical descriptions of the core. The core was then sent to the PAGS and for XRD analysis to determine the mineralogy. The primary mineral found from the XRD bulk mineralogy was quartz with 66.42%. The other mineral composition of the rock core was 32.94% calcite and 0.64% other minerals (lizardite, dolomite, and clay minerals). The mineral analysis indicates that the initial conclusion of the rock core being shale and limestone was inaccurate. The high amount of quartz indicates that the primary composition of the rock core is likely to be sandstone. The presence of calcite throughout the rock core suggests that the sandstone is carbonate-cemented. After the determination that the core sample was sandstone and not limestone, the lithology has been determined to be the Oriskany Sandstone.

Because of the revised conclusion that the assumed limestone (revised sandstone) was determined to be the Oriskany Sandstone, it can be said the lithology overlaying the sandstone was the Huntersville Chert. After this conclusion was made, revisiting the images and the descriptions of the rock core led to new conclusions that show previous errors in the conclusion of shale as the top interval. While fracturing was indicated, this interval fractured conchoidally and was not flakey or soft like shale. The top layer of mineralogy was comprised mostly of quartz and lacks calcite, which paired with the physical descriptions, suggests the chert is likely of the flint variety.

Pairing the conclusions of the mineralogy data and associated lithology, assumptions can be made about the drilling of the Sipe Well. The Sipe Well was drilled to investigate gas potential and came up as a dry well. Knowing this, the assumption that the drilling stopped before reaching the caprock interval is a sound conclusion as it was the reservoir space being investigated. It is also likely that the depth was measured from the Kelly Bushing (KB) and not the Derrick Floor (DF) or Ground Level (GL). This could lead to inconsistencies potentially occurring in the field as field work is not always consistent to reported data.

5.3 Benefit of Multiple Analytical Techniques

Multiple analytical techniques were necessary for this research. If conclusions were made based on the initial physical data observations, clear answers would not have been reached as the initial conclusions were incorrect. The benefit of using multiple techniques is that it allowed for double-checking the research that was done by comparing different sets of data to come to a clear conclusion.

6.0 CONCLUSIONS

The work that was done in this project created comprehensive datasets for continued research to benefit the CAP Project. The integrated analysis allowed for these comprehensive data to be collected and added to the PAGS rock core library. This research signifies the importance of multiple analytical techniques when doing subsurface geological analysis because of errors that can occur in singular data analysis. This project also clearly shows the importance of not relying heavily on previously collected data when leaning into a project as it can skew initial data analysis. Following this work, future research should be done for both the porosity and storage capabilities of the Oriskany Sandstone as well as deeper subsurface research doing a

caprock analysis of the Helderberg Group. Continued research on the Oriskany is important, as it is one of the largest potential carbon reservoirs in the Appalachian region.

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Appendix I.

Formation	Formation (revised)	Member	Member (revised)	Box #	Top (box, ft)	Base (box, ft)	Top (section, in)	Base (section, in)	Lithology	Lithology (revised)	Color	Description	Figures	SEM	XRD depth intervals
Helderberg Grou	Lower Devonian	Mandata Shale	Huntersville Chert	1	8830	8831	0	3.6	shale	chert	N1 black	very fine 62-88 µ, very well sorted, no fractures	Fig 1		2 feet
Helderberg Grou	Lower Devonian	Mandata Shale	Huntersville Chert	1	8830	8831	3.6	7.6	shale	chert	N1 black with 5 YR 3/4	very fine 62-88 µ, very well sorted, fractured, potential oxidation creating a moderate brown color that fizzes with HCl indicating potential calcite presence, some lineations of calcite	Fig 2		
Helderberg Grou	Lower Devonian	Mandata Shale	Huntersville Chert	1	8830	8831	7.6	13.35	shale	chert	N2 grey black	very fine 62-88 µ, very well sorted, minor fractures, laminations occuring periodically through core, lineations of calcite	Fig 3		
Helderberg Grou	Lower Devonian	Mandata Shale	Huntersville Chert	1	8830	8831	13.35	22.6	shale	chert	N2 grey black	very fine 62-88 µ, very well sorted, no fractures, lineations of calcite	Fig 4		
Helderberg Grou	Lower Devonian	Mandata Shale	Huntersville Chert	1	8830	8831	22.6	28.35	shale	chert	5 YR 2/1 olive black with 5 YR 3/4	very fine 62-88 µ, very well sorted, fractured, larger quantity of lineations of minerals, circular vugs, potential oxidation with moderate brown coloration	Fig 5	*	
Helderberg Grou	Lower Devonian	Mandata Shale	Huntersville Chert	2			0	3	shale	chert	N3 dark grey, 5 Y 2/1 olive black for some chunks	very fine 88-125 µ, very well sorted, laminations throughout, fractures, very flakey	Fig 6		
Helderberg Grou	Lower Devonian	Mandata Shale	Huntersville Chert	2			3	6.8	shale	chert	5Y 2/1 olive black	very fine 88-125 µ, very well sorted, fractured	Fig 7		
Helderberg Grou	Lower Devonian	Mandata Shale	Huntersville Chert	2b	8834	8835	6.8	12.3	shale	chert	N2 grey black	very fine 62-88 µ, very well sorted, fractured, mineral lineations of calcite	Fig 8	*	
Helderberg Grou	Lower Devonian	Mandata Shale	Huntersville Chert	2b	8834	8835	12.3	22.3	shale	chert	N2 grey black	very fine 62-88 µ, very well sorted, fractured, mineral lineations of calcite, vugs	Fig 9	*	
Helderberg Grou	Lower Devonian	Mandata Shale	Huntersville Chert	3	8835	8836	0	5.5	shale	chert	N2 grey black	very fine 62-88 µ, very well sorted, fractured, very flakey	Fig 10		
Helderberg Grou	Lower Devonian	Mandata Shale	Huntersville Chert	3	8835	8836	5.5	13.75	shale	chert	N2 grey black	very fine 62-88 µ, very well sorted, some fractures but mostly complete, veins of calcite	Fig 11	*	
Helderberg Grou	Lower Devonian	Mandata Shale	Huntersville Chert	3	8835	8836	13.75	19.75	shale	chert	N2 grey black	fracturing (on interior where cut is completed in the center) but mostly complete, very fine 62-88 µ, very well sorted	Fig 12		
Helderberg Grou	Lower Devonian	Mandata Shale	Huntersville Chert	3	8835	8836	19.75	26.75	shale	chert	N2 grey black	very fine 62-88 µ, very well sorted, calcite veins	Fig 13		
Helderberg Grou	Lower Devonian	Mandata Shale	Huntersville Chert	3	8835	8836	26.75	31.25	shale	chert	N2 grey black	very fine 62-88 µ, very well sorted, complete, some fracturing, a bit vuggy but not reacting to HCl	Fig 14	*	
Helderberg Grou	Lower Devonian	Mandata Shale/New Creek Limestone	Huntersville Chert/Oriskany Sandstone	4	8837	8839	0	9.5	shale (top) to limestone (bottom)	chert/sandstone	N2 grey black (top) and N5 medium grey (bottom)	very fractured, flakey with laminations, bottom sections have dark veins, very limey at bottom but not top, fine 125-177 µ, some matric, well sorted	Fig 15	*	
Helderberg Grou	Lower Devonian	New Creek Limestone	Oriskany Sandstone	4	8837	8839	9.5	16.25	limestone	sandstone	N5 medium grey with N2 grey black veins and 5 YR 3/4 moderate brown throughout	very limey- entire portion fizzes with HCl, medium 250-350 µ, some matrix, mostly rounded, complete, large dark vein	Fig 16	*	
Helderberg Grou	Lower Devonian	New Creek Limestone	Oriskany Sandstone	4	8837	8839	16.25	20.5	dolostone	sandstone	N3 dark grey (top) and N8 very light grey (bottom)	contians fossils, slight reaction to HCl in veins but none/little reaction in matrix, coarse 710-1000 µ in some places, medium 350-500 µ in others, medium sorted, some matrix, complete	Fig 17		
Helderberg Grou	Lower Devonian	New Creek Limestone	Oriskany Sandstone	4	8837	8839	20.5	22.75	dolostone	sandstone	N6 medium light grey and N2 grey black veins	medium sorting, medium 350-500 µ, some fine matric, some reaction to HCl in veins, dark veins	Fig 18		
Helderberg Grou	Lower Devonian	New Creek Limestone	Oriskany Sandstone	4	8837	8839	22.75	26	dolostone	sandstone	mix of N6 medium light grey and N3 dark grey with N2 grey black veins	slightly limey, reacts in darker components of the matric, mostly well sorted, medium 250-350 µ	Fig 19		
Helderberg Grou	Lower Devonian	New Creek Limestone	Oriskany Sandstone	5	8840	8842	0	6	dolostone	sandstone	N3 dark grey	fossils, calcite vein with clear crystals appearing as vein widens toward the base, well sorted, fine 177-250 µ with some larger grains interspersed	Fig 20	*	
Helderberg Grou	Lower Devonian	New Creek Limestone	Oriskany Sandstone	5	8840	8842	6	12.75	dolostone	sandstone	N3 dark grey	continuing layers of fossils, continued mineral vein, well sorted, limey, medium 350-500 µ	Fig 21	*	
Helderberg Grou	Lower Devonian	New Creek Limestone	Oriskany Sandstone	5	8840	8842	12.75	23	dolostone	sandstone	N3 dark grey	interspersed fossils, slightly limey, mineral veins with visible crystals, well sorted, medium 350-500 µ	Fig 22		
Helderberg Grou	Lower Devonian	New Creek Limestone	Oriskany Sandstone	6	8843	8845	0	9.5	dolostone	sandstone	N3 dark grey	fossils, natrual fracture, well sorted, medium 350-500 µ, slightly limey, mineral veins	Fig 23	*	
Helderberg Grou	Lower Devonian	New Creek Limestone	Oriskany Sandstone	6	8843	8845	9.5	25.75	dolostone	sandstone	N4 medium dark grey	fossils in distinct grouping with a few sporatically throughout, mineral vein, very limey, dark veins/laminations, well sorted, medium 250-350 µ	Fig 24	*	
Helderberg Grou	Lower Devonian	New Creek Limestone	Oriskany Sandstone	6	8843	8845	25.75	30.75	limestone	sandstone	N3 dark grey	large mineral fossil, laminations, mineral vein, well sorted, medium 250-350 µ, very limey	Fig 25		
Helderberg Grou	Lower Devonian	New Creek Limestone	Oriskany Sandstone	6	8843	8845	30.75	35	limestone	sandstone	N3 dark grey matrix and N2 grey black laminations	dark laminations, mineral vein, very limey, fine 125-177 µ, well sorted, some mineral formations	Fig 26	*	
Helderberg Grou	Lower Devonian	New Creek Limestone	Oriskany Sandstone	7	8846	8847.4	0	28	limestone	sandstone	N3 dark grey	very limey, mineral vein, granite intrusion stemming perpendicular from mineral vein, thick mineral vein near bottom of core, slight fracturing throughout, fine 125-177 µ, well sorted	Fig 27	*	
Helderberg Grou	Lower Devonian	New Creek Limestone	Oriskany Sandstone	8	8848	8850	0	4.5	limestone	sandstone	N3 dark grey	fossils present, mineral vein, very limey, well sorted, medium 250-350 µ, some fractures	Fig 28		
Helderberg Grou	Lower Devonian	New Creek Limestone	Oriskany Sandstone	8	8848	8850	4.5	24.5	limestone	sandstone	N3 dark grey	a few fossils, some fracturing, very limey, medium 250-350 µ, well sorted, some variable in color due to matrix	Fig 29		

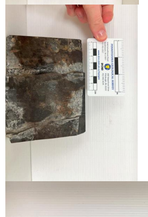
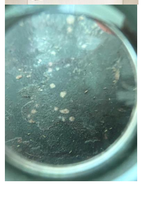
Helderberg Grou	Lower Devonian	New Creek Limestone	Oriskany Sandstone	8	8848	8850	24.5	30.75	limestone	sandstone	N3 dark grey	very limey, some fossils, well sorted moving to moderately sorted at bottom, medium 250-350 µ	Fig 30
Helderberg Grou	Lower Devonian	New Creek Limestone	Oriskany Sandstone	9	8851	8853	0	30.5	limestone	sandstone	N3 dark grey and % YR 8/1 pinkish grey laminations	medium sort, medium 250-350 µ, limey, indications of faint fossils	Fig 31
Helderberg Grou	Lower Devonian	New Creek Limestone	Oriskany Sandstone	10	8853	8854	0	6	limestone	sandstone	N3 dark grey	fossil layer, some fractures, very limey, well sorted, medium 250-350 µ	Fig 32
Helderberg Grou	Lower Devonian	New Creek Limestone	Oriskany Sandstone	10	8853	8854	6	16	limestone	sandstone	N4 medium dark grey	some fossils, some laminations, medium sort near fossil bed, well sorted, fine 177-250 µ	Fig 33
Helderberg Grou	Lower Devonian	New Creek Limestone	Oriskany Sandstone	10	8853	8854	16	20	limestone	sandstone	N3 dark grey	some darker laminations, fossil bed beginning near end of section, sorting gets medium with grain size medium 350-500 µ near fossils, sort is well in upper region and medium 250-350 µ	Fig 34
		Notes:	Grey indicates unknown sample interval										
			Green indicates where SEM samples were taken										

Formation	Formation (revised)	Member	Member (revised)	Box #	Top (box, ft)	Base (box, ft)	Top (section, in)	Base (section, in)	Lithology	Lithology (revised)	Color	Description	Figures	SEM
Helderberg Group	Lower Devonian	New Creek Limestone	Oriskany Sandstone	1	8855	8856	0	26	limestone	sandstone	N3 dark grey	limey, dark laminations, some fracturing, fine 125-177 mu, well sorted, subrounded, some fossils present, more fossils occuring on lower portions	Fig 36	
Helderberg Group	Lower Devonian	New Creek Limestone	Oriskany Sandstone	2	8857	8859	0	24	limestone	sandstone	N3 dark grey	very limey, very well sorted, very fine 88-125 mu, mineral vein, bottom 4 in- poorly sorted, fossils	Fig 37	
Helderberg Group	Lower Devonian	New Creek Limestone	Oriskany Sandstone	2	8857	8859	24	31.75	limestone	sandstone	N3 dark grey	very well sorted, very fine 88-125 mu	Fig 38	
Helderberg Group	Lower Devonian	New Creek Limestone	Oriskany Sandstone	3	8860	8862	0	22.5	limestone	sandstone	N3 dark grey, top section N4 medium dark grey	limey, well sorted, fine 125-177 mu, some fossil intervals, some laminations	Fig 39	
Helderberg Group	Lower Devonian	New Creek Limestone	Oriskany Sandstone	3	8860	8862	22.5	24	limestone	sandstone	N3 dark grey	lots of minerals, moderate sorting, medium 350-500 mu, limey	Fig 40	
Helderberg Group	Lower Devonian	New Creek Limestone	Oriskany Sandstone	3	8860	8862	24	28.5	limestone	sandstone	N3 dark grey	some moderate sorting, mostly well sorted, some fossils	Fig 41	
Helderberg Group	Lower Devonian	New Creek Limestone	Oriskany Sandstone	3	8860	8862	28.5	36.75	limestone	sandstone	N3 dark grey	well sorted, fine 135-177 mu, some laminations, limey	Fig 42	
Helderberg Group	Lower Devonian	New Creek Limestone	Oriskany Sandstone	3b	8860	8861	0	14.5	limestone	sandstone	N3 dark grey	laminations, ocasional fractures, some fossils and mineralization occuring, limey, well sorted, fine 177-250 µ	Fig 35	
Helderberg Group	Lower Devonian	New Creek Limestone	Oriskany Sandstone	4	8863	8865	0	30	limestone	sandstone	N3 dark grey	limey, some interbedded fossils near bottom third, very fine 88-125 mu, very well sorted, no/few fractures	Fig 43	
Helderberg Group	Lower Devonian	New Creek Limestone	Oriskany Sandstone	4	8863	8865	30	33.5	limestone	sandstone	N3 dark grey	limey, some laminations, very fine 88-125 mu, well sorted, a few fractures	Fig 44	
Helderberg Group	Lower Devonian	New Creek Limestone	Oriskany Sandstone	5	8866	8868	0	30	limestone	sandstone	N2 greyish black	limey, interbedded fossils in numerous sections, some small laminations, fine 125-177 mu, well sorted	Fig 45	
Helderberg Group	Lower Devonian	New Creek Limestone	Oriskany Sandstone	5	8866	8868	30	36.5	limestone	sandstone	N2 greyish black	limey, some fossils present, fine 125-177 mu, well sorted	Fig 46	
Helderberg Group	Lower Devonian	New Creek Limestone	Oriskany Sandstone	6	8868	8871	0	7.75	limestone	sandstone	N3 dark grey	limey, moves into more fossilized section near bottom, laminations, visible mineral crystals, fine 177-250 mu, well sorted moving into coarse 500-710 mu, moderate sorting	Fig 47	*
Helderberg Group	Lower Devonian	New Creek Limestone	Oriskany Sandstone	6	8868	8871	7.75	13.25	sandstone	sandstone	N8 very light grey in primary, N3 dark grey in top and bottom	highly fossilized section, moderate sorting, coarse 710-1000 mu, NOT limey	Fig 48	*
Helderberg Group	Lower Devonian	New Creek Limestone	Oriskany Sandstone	6	8868	8871	13.25	23.25	limestone	sandstone	N2 greyish black	limey, some laminations, well sorted, fine 177-250 mu	Fig 49	
Helderberg Group	Lower Devonian	New Creek Limestone	Oriskany Sandstone	6	8868	8871	23.25	32.25	limestone	sandstone	N3 dark grey	limey, well sorted, fine 125-177 mu	Fig 50	
Helderberg Group	Lower Devonian	New Creek Limestone	Oriskany Sandstone	7	8872	8874	0	27.5	limestone	sandstone	N2 greyish black	limey, fossil bed in lower third, laminations in top third, medium 250-350 mu, well sorted with a few coarse grains	Fig 51	
Helderberg Group	Lower Devonian	New Creek Limestone	Oriskany Sandstone	8	8874	8876	0	26	limestone	sandstone	N2 greyish black	limey, fossils throughout, few fractures, medium 350-500 mu, well to moderate sort, fossils are vuggy	Fig 52	*
Helderberg Group	Lower Devonian	New Creek Limestone	Oriskany Sandstone	8	8874	8876	26	31.5	limestone	sandstone	N3 dark grey	one fracture, limey, fossiliferous with well sorted coarcse 500-710 mu grain within fossil zone	Fig 53	
Helderberg Group	Lower Devonian	Limestone	Oriskany Sandstone	9	8876	8879	0	30	limestone	sandstone	middle and	fossil rich areas, limey, well sroted except through one bed of	Fig 54	*

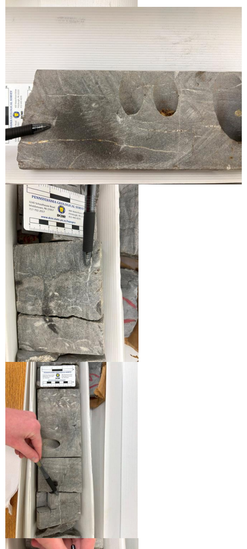
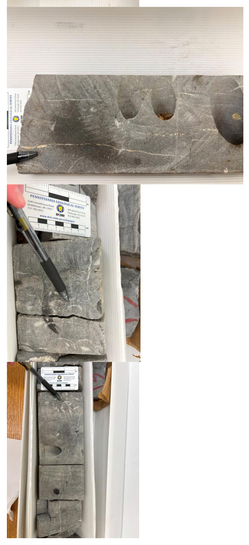
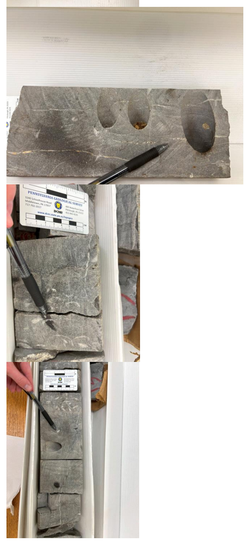
Notes: into Core 1 but doesn't

Formation	Formation (revised)	Member	Member (revised)	Box #	Top (box, ft)	Base (box, ft)	Top (section, in)	Base (section, in)	Lithology	Lithology (resvised)	Color	Description	Figures	SEM
Helderberg Grou	Lower Devonian	New Creek Limestone	Oriskany Sandstone	1	8880	8881	0	16	limestone	sandstone	N3 dark grey	limey, some fracturing, occasional fossils, slightly vuggy, well sorted, fine 177-250 mu, near bottom- color lightens with fossils, coarse 710-1000 mu, laminations	Fig 55	
Helderberg Grou	Lower Devonian	New Creek Limestone	Oriskany Sandstone	1	8880	8881	16	30	limestone	sandstone	N3 dark grey	limey, some fracturing, interbedded fossils, laminations, fine 177-250 mu, well sorted, near top- color lightens and grains are larger 710-1000 mu	Fig 56	
Helderberg Grou	Lower Devonian	New Creek Limestone	Oriskany Sandstone	2	8882	8884	0	27	dolostone	sandstone	N3 dark grey	only slightly reactive to HCl, fossiliferous, vuggy, some laminations throughout, mineralogy at top of core, medium 250-350 mu, well sorted, 16-18.5 in- larger very coarse grains 1420-2000 mu, moderately sorted	Fig 57	*
Helderberg Grou	Lower Devonian	New Creek Limestone	Oriskany Sandstone	3	8884	8886	0	15	dolostone	sandstone	N4 medium dark grey	incomplete, slightly reactive on top to HCl with increased reaction towards bottom, medium 250-500 mu, moderate sorting, some fracturing	Fig 58	
Helderberg Grou	Lower Devonian	New Creek Limestone	Oriskany Sandstone	4	8887	8889	0	11.25	dolostone	sandstone	N3 dark grey	only slightly reactive to HCl, moderate sorting, coarse 500-710 mu, some fossils, incomplete	Fig 59	
Helderberg Grou	Lower Devonian	New Creek Limestone	Oriskany Sandstone	4	8887	8889	11.25	26.25	dolostone	sandstone	N3 dark grey	only slightly reactive to HCl, moderate sorting, coarse 710-1000 mu, some fossils, incomplete	Fig 60	
Helderberg Grou	Lower Devonian	New Creek Limestone	Oriskany Sandstone	4	8887	8889	26.25	34	dolostone	sandstone	N3 dark grey	only slightly reactive to HCl, moderate sorting, coarse 710-1000 mu, fossiliferous, incomplete	Fig 61	
Helderberg Grou	Lower Devonian	New Creek Limestone	Oriskany Sandstone	5	8890	8892	0	24.5	dolostone	sandstone	N3 dark grey	minor reactions to HCl, fossils throughout, minor fracturing, well sorted, medium 350-500 mu, incomplete	Fig 62	
Helderberg Grou	Lower Devonian	New Creek Limestone	Oriskany Sandstone	5	8890	8892	24.5	31.75	dolostone	sandstone	N3 dark grey	practically no reaction to HCl, some fossils, minor fractures, well sorted, medium 350-500 mu	Fig 63	*
Helderberg Grou	Lower Devonian	New Creek Limestone	Oriskany Sandstone	7	8895	8897	0	30	limestone	sandstone	N2 greyish black	limey, some fossils, fractured, laminations near middle, medium 250-350 mu, well sorted	Fig 64	
Helderberg Grou	Lower Devonian	New Creek Limestone	Oriskany Sandstone	7	8895	8897	30	33.5	limestone	sandstone	N2 greyish black	limey, some fractures, medium 250-350 mu, well sorted	Fig 65	
Helderberg Grou	Lower Devonian	New Creek Limestone	Oriskany Sandstone	8	8998	8900	0	18	limestone	sandstone	N2 greyish black top, N3 dark grey bottom	limey, laminations, band of coarse grains at top of section, vuggy, well sorted, fine 177-250 mu	Fig 66	*
Helderberg Grou	Lower Devonian	New Creek Limestone	Oriskany Sandstone	8	8998	8900	18	20.5	limestone	sandstone	N5 medium grey	extremely limey, poorly sorted, very coarse 1410-2000 mu to medium 250-350 mu	Fig 67	*
Helderberg Grou	Lower Devonian	New Creek Limestone	Oriskany Sandstone	8	8998	8900	20.5	30	limestone	sandstone	N2 greyish black	slightly limey, laminations, well sorted, fine 177-250 mu	Fig 68	
Helderberg Grou	Lower Devonian	New Creek Limestone	Oriskany Sandstone	9	8901	8903	0	28	limestone	sandstone	N3 dark grey	completely fractured, multiple beds of fossils, vuggy, laminated, well sorted, fine 177-250 mu, sections of coarse 710-1000 mu, bottom 2 inches- all coarse grained	Fig 69	*
		Notes:	Boxes 7-9 were labeled one back (6-8) in the Figures											

Appendix II.

Top (box, ft)	Base (box, ft)	Box #	Figure #	Lithology	Revised Lithology	Images
8830	8831		1 Fig1	shale	chert	
8830	8831		1 Fig2	shale	chert	  
8830	8831		1 Fig3	shale	chert	   
8830	8831		1 Fig4	shale	chert	  
8830	8831		1 Fig5	shale	chert	     
8830	8831		2 Fig6	shale	chert	 
8830	8831		2 Fig7	shale	chert	
8834	8835	2b	Fig8	shale	chert	 
8834	8835	2b	Fig9	shale	chert	  

8835	8836	3 Fig10	shale	chert			
8835	8836	3 Fig11	shale	chert			
8835	8836	3 Fig12	shale	chert			
8835	8836	3 Fig13	shale	chert			
8835	8836	3 Fig14	shale	chert			
8837	8839	4 Fig15	shale/limestone	chert/sandstone			
8837	8839	4 Fig16	limestone	sandstone			
8837	8839	4 Fig17	limestone	sandstone			
8837	8839	4 Fig18	limestone	sandstone			

8837	8839	4 Fig19	limestone	sandstone	
8840	8842	5 Fig20	limestone	sandstone	
8840	8842	5 Fig21	limestone	sandstone	
8840	8842	5 Fig22	limestone	sandstone	
8843	8845	6 Fig23	limestone	sandstone	
8843	8845	6 Fig24	limestone	sandstone	
8843	8845	6 Fig25	limestone	sandstone	
8843	8845	6 Fig26	limestone	sandstone	
8846	8847.4	7 Fig27	limestone	sandstone	
					
					
					
					
					
					
					
					
					
					

8848	8850	8 Fig28	limestone	sandstone				
8848	8850	8 Fig29	limestone	sandstone				
8848	8850	8 Fig30	limestone	sandstone				
8851	8853	8 Fig31	limestone	sandstone				
8853	8854	10 Fig32	limestone	sandstone				
8853	8854	10 Fig33	limestone	sandstone				
8853	8854	10 Fig34	limestone	sandstone				

Top (box, ft)	Base (box, ft)	Box #	Figure #	Lithology	Revised Lithology	Images
8855	8856	1	Fig36	limestone	sandstone	  
8857	8859	2	Fig37	limestone	sandstone	 
8857	8859	2	Fig38	limestone	sandstone	 
8860	8862	3	Fig39	limestone	sandstone	
8860	8862	3	Fig40	limestone	sandstone	 
8860	8862	3	Fig41	limestone	sandstone	

8860	8862		3	Fig42	limestone	sandstone			
8860	8861	3b		Fig35	limestone	sandstone				
8863	8865		4	Fig43	limestone	sandstone				
8863	8865		4	Fig44	limestone	sandstone				
8866	8868		5	Fig45	limestone	sandstone				
8866	8868		5	Fig46	limestone	sandstone				

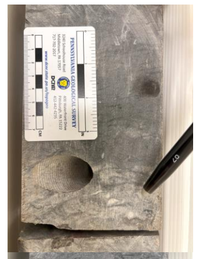
8868	8871	6	Fig47	limestone	sandstone				
8868	8871	6	Fig48	sandstone	sandstone				
8868	8871	6	Fig49	limestone	sandstone				
8868	8871	6	Fig50	limestone	sandstone				
8872	8874	7	Fig51	limestone	sandstone				
8874	8876	8	Fig52	limestone	sandstone				

8874	8876	8	Fig53	limestone	sandstone	
8876	8879	9	Fig54	limestone	sandstone	







Top (box, ft)	Base (box, ft)	Box #	Figure #	Lithology	Revised Lithology	Images
8880	8881	1	Fig55	limestone	sandstone	 
8880	8881	1	Fig56	limestone	sandstone	 
8882	8884	2	Fig57	dolostone	sandstone	 
8884	8886	3	Fig58	dolostone	sandstone	
8887	8889	4	Fig59	dolostone	sandstone	
8887	8889	4	Fig60	dolostone	sandstone	

8887	8889	4	Fig61	dolostone	sandstone	
8890	8892	5	Fig62	dolostone	sandstone	
8890	8892	5	Fig63	dolostone	sandstone	
8895	8897	6	Fig64	limestone	sandstone	 
8895	8897	6	Fig65	limestone	sandstone	
8998	8900	7	Fig66	limestone	sandstone	

8998	8900	7	Fig67	limestone	sandstone	
8998	8900	7	Fig68	limestone	sandstone	
8901	8903	8	Fig69	limestone	sandstone	







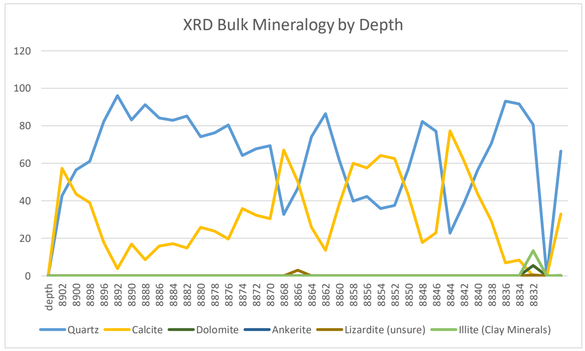
Appendix III.

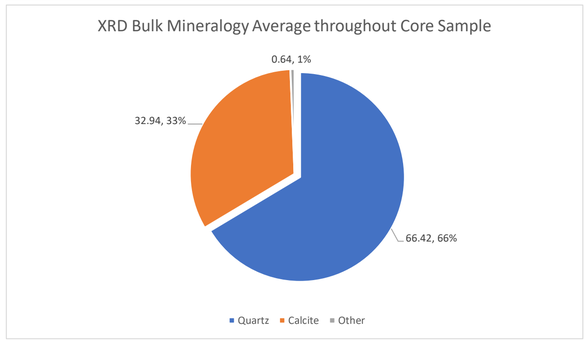
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43	8900	56.5	43.5	0	0	0	0
44	8898	61	39	0	0	0	0
45	8896	82.3	17.7	0	0	0	0
46	8892	96.1	3.9	0	0	0	0
47	8890	83.1	16.9	0	0	0	0
48	8888	91.3	8.7	0	0	0	0
49	8886	84.2	15.8	0	0	0	0
50	8884	82.9	17.1	0	0	0	0
51	8882	85.2	14.8	0	0	0	0
52	8880	74.1	25.9	0	0	0	0
18	8878	76.2	23.8	0	0	0	0
19	8876	80.4	19.6	0	0	0	0

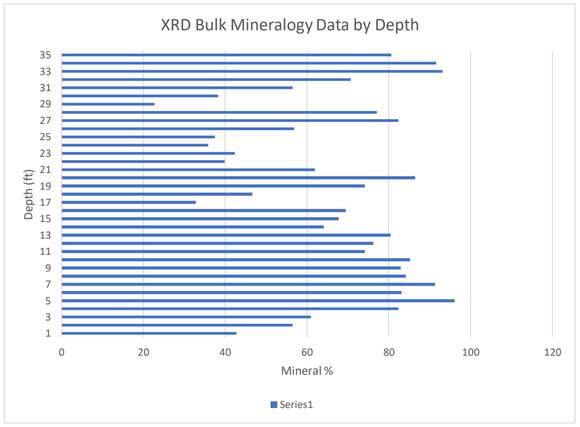
21	8874	64.1	35.9	0	0	0	0
20	8872	67.7	32.3	0	0	0	0
22	8870	69.5	30.5	0	0	0	0
23	8868	32.8	67.2	0	0	0	0
24	8866	46.7	50.3	0	0	3	0
25	8864	74.1	25.9	0	0	0	0
26	8862	86.4	13.6	0	0	0	0
27	8860	61.9	38.1	0	0	0	0
28	8858	39.9	60.1	0	0	0	0
29	8856	42.4	57.6	0	0	0	0
30	8854	35.9	64.1	0	0	0	0
31	8852	37.5	62.5	0	0	0	0
32	8850	56.9	43.1	0	0	0	0
33	8848	82.3	17.7	0	0	0	0
34	8846	77.1	22.9	0	0	0	0
35	8844	22.7	77.3	0	0	0	0
36	8842	38.3	61.7	0	0	0	0
37	8840	56.5	43.5	0	0	0	0
38	8838	70.7	29.3	0	0	0	0
39	8836	93.1	6.9	0	0	0	0
40	8834	91.6	8.4	0	0	0	0
41	8832	80.6	0	5.5	0	0.5	13.4

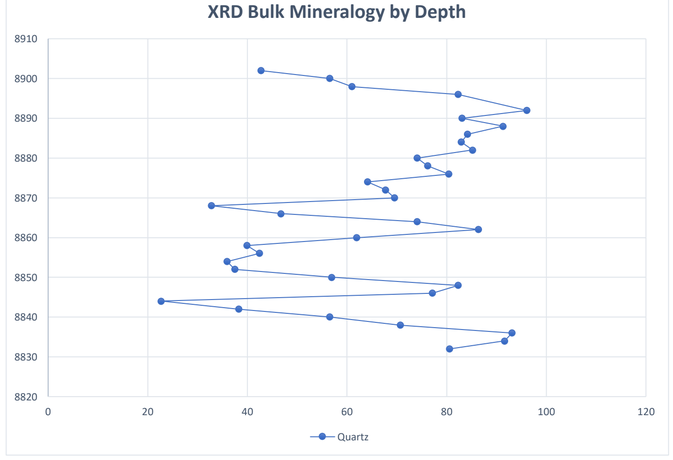
SEM Sample	XRD	depth	Quartz	Calcite	Dolomite	Ankerite	Lizardite (Unsure)	Illite (Clay Minerals)
1	40	8834	91.6	8.4	0	0	0	0
			Quartz	Calcite	Dolomite	Ankerite	Lizardite (Unsure)	Illite (Clay Minerals)
2	22	8870	69.5	30.5	0	0	0	0
			Quartz	Calcite	Dolomite	Ankerite	Lizardite (Unsure)	Illite (Clay Minerals)
3	44	8898	61	39	0	0	0	0

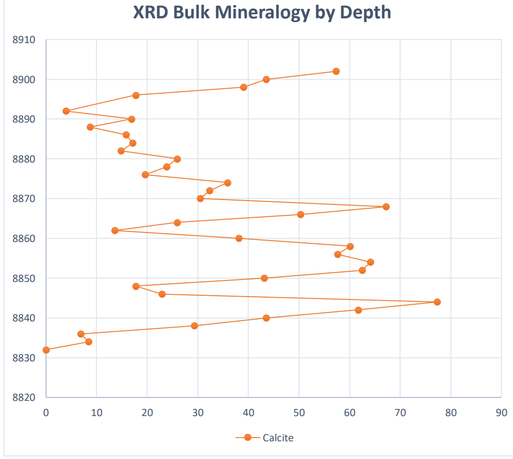
XRD	depth	Quartz	Calcite	Other	Dolomite	Ankerite	Lizardite (Unsure)	Illite (Clay Minerals)
42	8902	42.7	57.3	0	0	0	0	0
43	8900	56.5	43.5	0	0	0	0	0
44	8898	61	39	0	0	0	0	0
45	8896	82.3	17.7	0	0	0	0	0
46	8892	96.1	3.9	0	0	0	0	0
47	8890	83.1	16.9	0	0	0	0	0
48	8888	91.3	8.7	0	0	0	0	0
49	8886	84.2	15.8	0	0	0	0	0
50	8884	82.9	17.1	0	0	0	0	0
51	8882	85.2	14.8	0	0	0	0	0
52	8880	74.1	25.9	0	0	0	0	0
18	8878	76.2	23.8	0	0	0	0	0
19	8876	80.4	19.6	0	0	0	0	0
21	8874	64.1	35.9	0	0	0	0	0
20	8872	67.7	32.3	0	0	0	0	0
22	8870	69.5	30.5	0	0	0	0	0
23	8868	32.8	67.2	0	0	0	0	0
24	8866	46.7	50.3	3	0	0	3	0
25	8864	74.1	25.9	0	0	0	0	0
26	8862	86.4	13.6	0	0	0	0	0
27	8860	61.9	38.1	0	0	0	0	0
28	8858	39.9	60.1	0	0	0	0	0
29	8856	42.4	57.6	0	0	0	0	0
30	8854	35.9	64.1	0	0	0	0	0
31	8852	37.5	62.5	0	0	0	0	0
32	8850	56.9	43.1	0	0	0	0	0
33	8848	82.3	17.7	0	0	0	0	0
34	8846	77.1	22.9	0	0	0	0	0
35	8844	22.7	77.3	0	0	0	0	0
36	8842	38.3	61.7	0	0	0	0	0
37	8840	56.5	43.5	0	0	0	0	0
38	8838	70.7	29.3	0	0	0	0	0
39	8836	93.1	6.9	0	0	0	0	0
40	8834	91.6	8.4	0	0	0	0	0
41	8832	80.6	0	19.4	5.5	0	0.5	13.4
		Quartz	Calcite	Other	Dolomite	Ankerite	Lizardite (Unsure)	Illite (Clay Minerals)
Average:		66.42	32.94	0.64	0.157142857	0	0.1	0.382857143

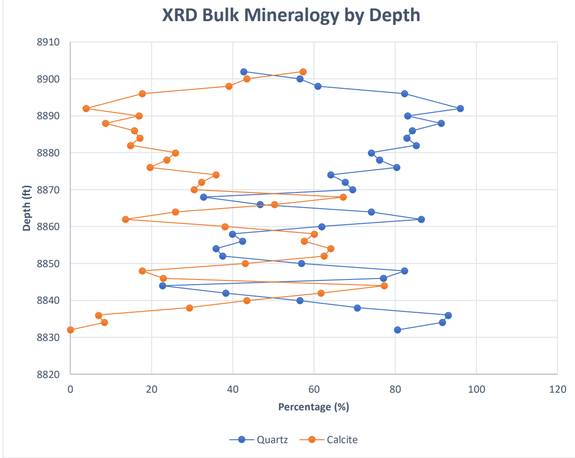






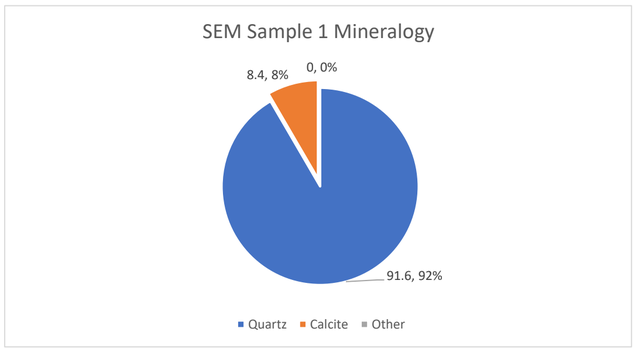


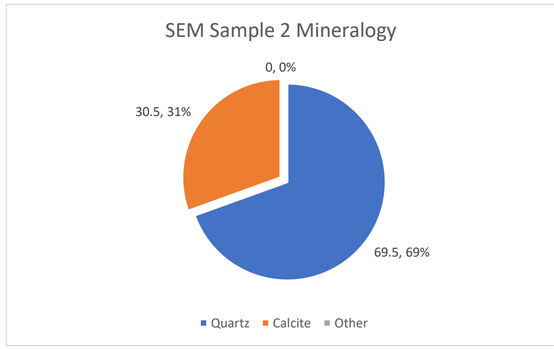


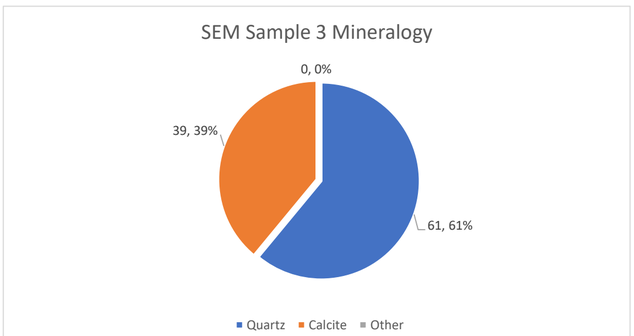


XRD	depth	Quartz	Calcite	Other	Dolomite	Ankerite	Lizardite (unsure)	Illite (unsure)
42	8902	42.7	57.3	0	0	0	0	0
43	8900	56.5	43.5	0	0	0	0	0
				0				
44	8898	61	39	0	0	0	0	0
				0				
45	8896	82.3	17.7	0	0	0	0	0
46	8892	96.1	3.9	0	0	0	0	0
47	8890	83.1	16.9	0	0	0	0	0
48	8888	91.3	8.7	0	0	0	0	0
49	8886	84.2	15.8	0	0	0	0	0
50	8884	82.9	17.1	0	0	0	0	0
51	8882	85.2	14.8	0	0	0	0	0
52	8880	74.1	25.9	0	0	0	0	0
18	8878	76.2	23.8	0	0	0	0	0
19	8876	80.4	19.6	0	0	0	0	0
21	8874	64.1	35.9	0	0	0	0	0
20	8872	67.7	32.3	0	0	0	0	0
22	8870	69.5	30.5	0	0	0	0	0
23	8868	32.8	67.2	0	0	0	0	0
24	8866	46.7	50.3	3	0	0	3	0
25	8864	74.1	25.9	0	0	0	0	0
26	8862	86.4	13.6	0	0	0	0	0
27	8860	61.9	38.1	0	0	0	0	0
28	8858	39.9	60.1	0	0	0	0	0
29	8856	42.4	57.6	0	0	0	0	0
30	8854	35.9	64.1	0	0	0	0	0
31	8852	37.5	62.5	0	0	0	0	0
32	8850	56.9	43.1	0	0	0	0	0
33	8848	82.3	17.7	0	0	0	0	0
34	8846	77.1	22.9	0	0	0	0	0
35	8844	22.7	77.3	0	0	0	0	0
36	8842	38.3	61.7	0	0	0	0	0
37	8840	56.5	43.5	0	0	0	0	0
38	8838	70.7	29.3	0	0	0	0	0
39	8836	93.1	6.9	0	0	0	0	0
40	8834	91.6	8.4	0	0	0	0	0
41	8832	80.6	0	19.4	5.5	0	0.5	13.4

SEM Sample	XRD	depth	Quartz	Calcite	Other	Dolomite	Ankerite	Lizardite (Unsure)	Illite (Clay Minerals)
1	40	8834	91.6	8.4	0	0	0	0	0
			Quartz	Calcite	Other	Dolomite	Ankerite	Lizardite (Unsure)	Illite (Clay Minerals)
2	22	8870	69.5	30.5	0	0	0	0	0
			Quartz	Calcite	Other	Dolomite	Ankerite	Lizardite (Unsure)	Illite (Clay Minerals)
3	44	8898	61	39	0	0	0	0	0







EPOG-4 Rev. 2/77

COMMONWEALTH OF PENNSYLVANIA
DEPARTMENT OF ENVIRONMENTAL RESOURCES
DIVISION OF OIL AND GAS
PITTSBURGH, PENNSYLVANIA 15222

Office Use Only

WELL RECORD

5 750 S 39° 57' 30" (E) 111-20087 ESD
2 250 W 79°10'00"

PERMIT NO. SOM-~~20087~~ PROJECT NO. DEEP TYPE OF WELL Dry Hole

Rockwood Field - Dev. Dry

WELL OPERATOR: Amoco Production Company
TELEPHONE NO.: 1-616-941-1100
ADDRESS: P. O. Box 1350, Traverse City, MI
ZIP: 49684
FARM NAME: Theodore C. Sipe Gas Unit
FARM NO.: #1
SERIAL NO.: ---
ACRES: 105
TOWNSHIP: Milford
COUNTY: Somerset
DRILLING COMMENCED: 8/10/79
DRILLING COMPLETED: 9/16/79
ELEVATION: 2081
QUADRANGLE: Rockwood (redacted) 7½' ☐ 15'

CASING AND TUBING RECORD

PIPE SIZE	AMOUNT IN WELL	MATERIAL BEHIND PIPE CEMENT (SKS.)	MATERIAL BEHIND PIPE GEL (SKS.)	PACKER TYPE	PACKER SIZE	PACKER DEPTH	DATE RUN
16"	100'	80 sx					7/27/79
8 5/8"	1508'	410 sx					8/13/79
4 1/2"	8982'	250 sx					9/19/79
		T.D. 8982	D.B. —	D.P.I. —	2.5 D	2 —	Lease 1

PERFORATION RECORD

DATE	INTERVAL PERFORATED FROM	TO
10/03/79	8874	8884
10/03/79	8903	8910
10/03/79	8932	8941

STIMULATION RECORD

DATE	INTERVAL TREATED	AMOUNT FLUID	AMOUNT SAND	INJECTION RATE
10/04/79	Those perfs on 10/03/79	150 gal acid		2 BPM
10/09/79	Those perfs on 10/03/79	100,000 Gal	325,000 pounds	14 BPM

NATURAL OPEN FLOW: N/A
NATURAL ROCK PRESSURE: N/A HRS. DAYS
AFTER TREATMENT OPEN FLOW: N/A
AFTER TREATMENT ROCK PRESSURE: N/A HRS. DAYS

REMARKS:

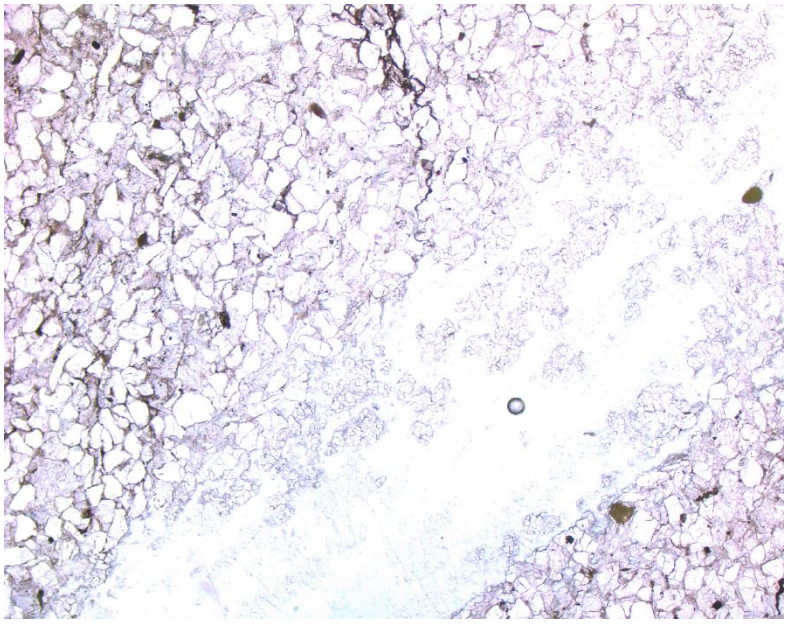
Well is being temporarily abandoned and held for future evaluation.

RECEIVED
FEB 15 1980
PA. GEOLOGIC SURVEY
Oil & Gas Division

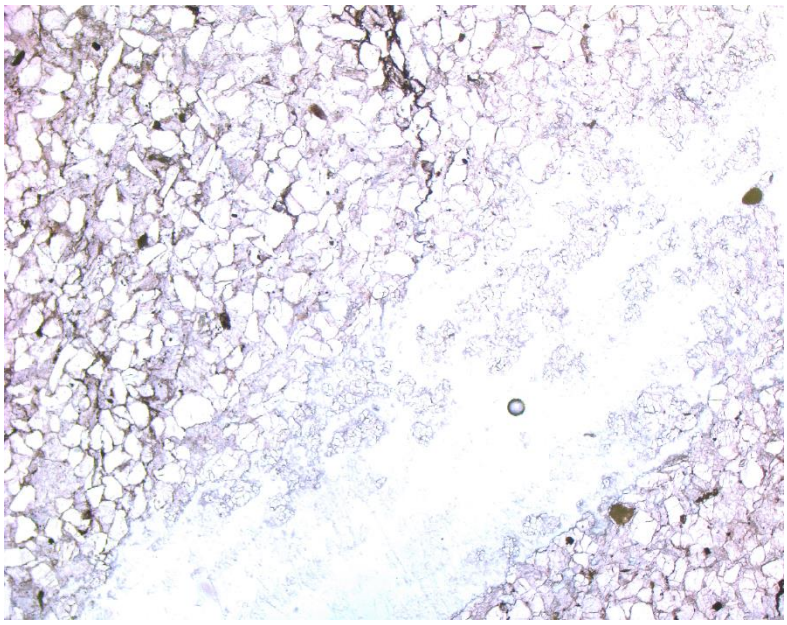
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(FORMATION ON REVERSE SIDE)

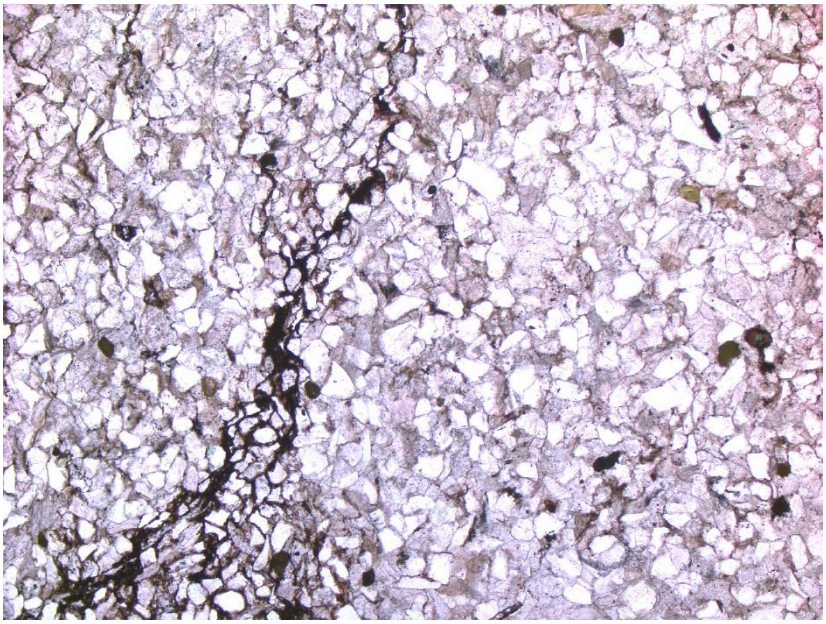
Appendix V



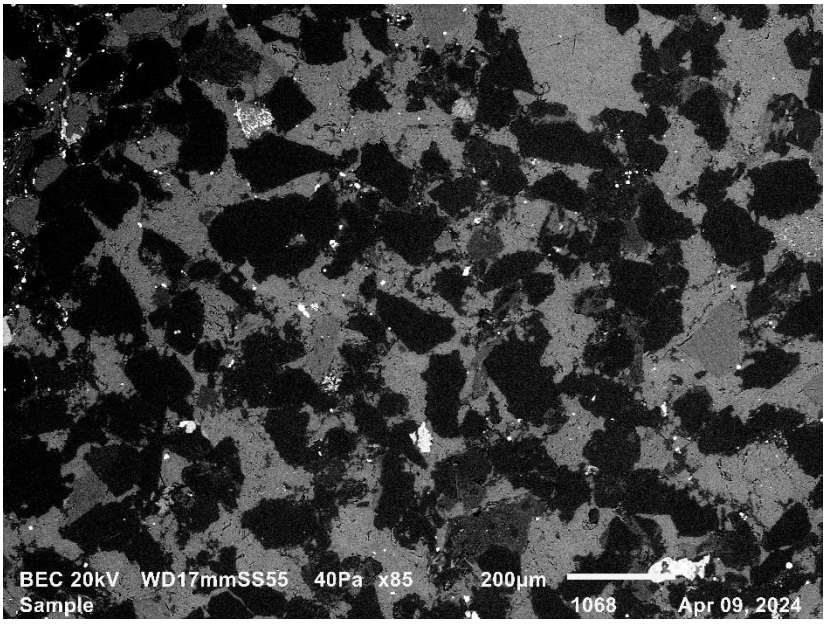
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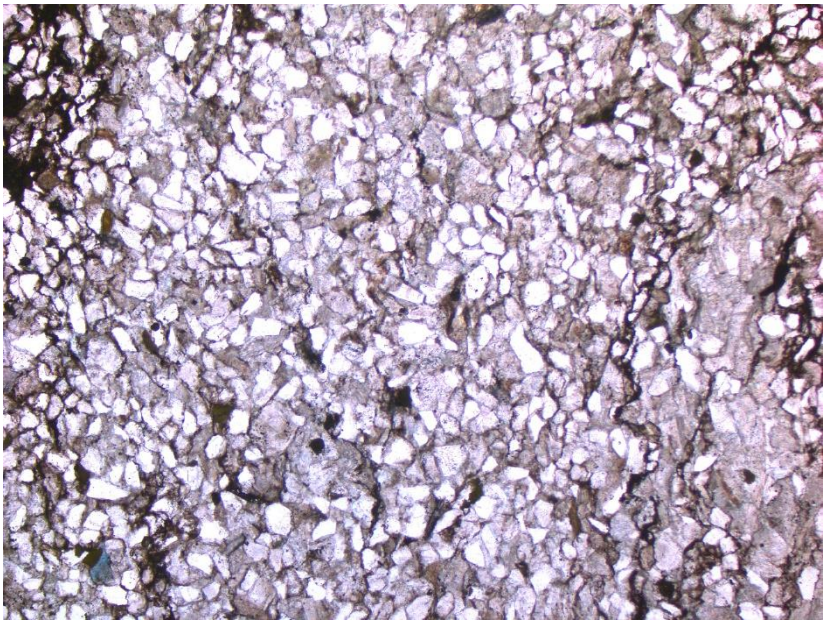
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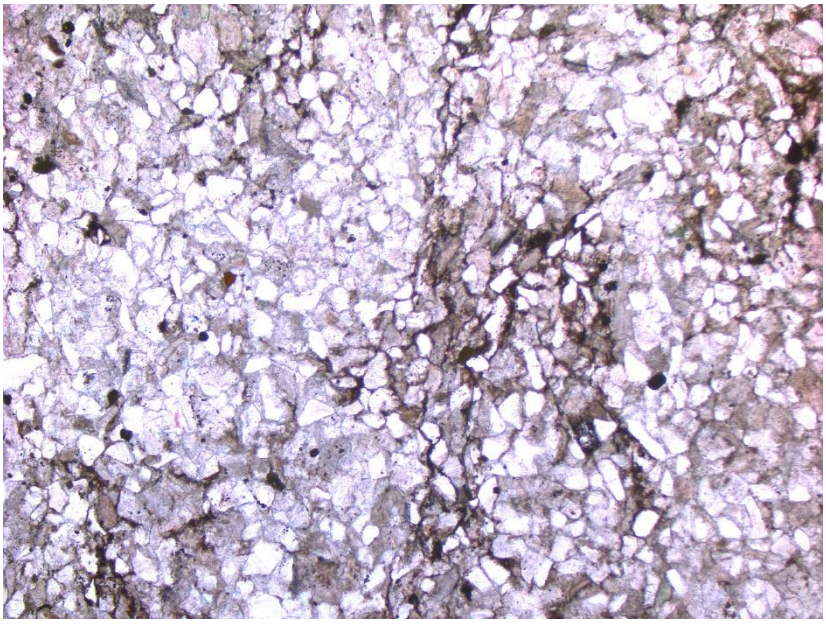
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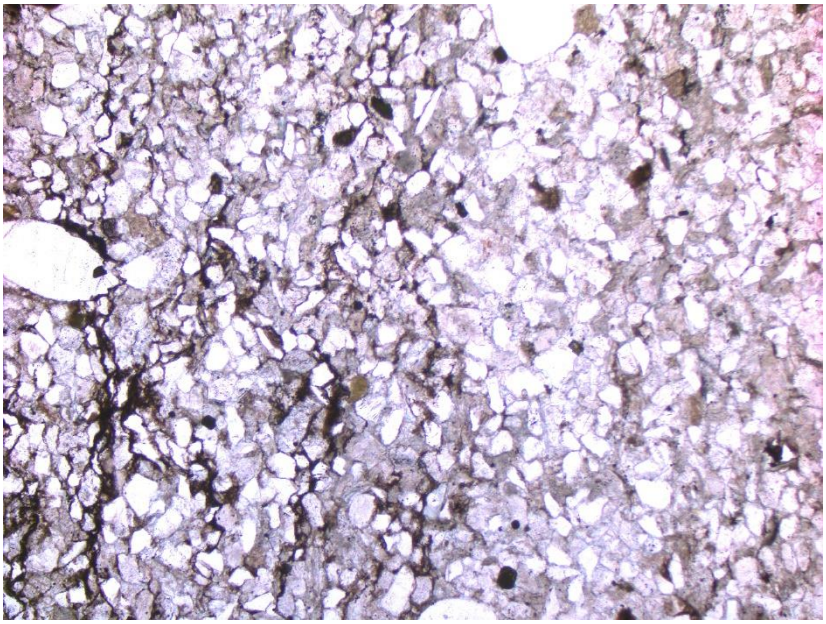
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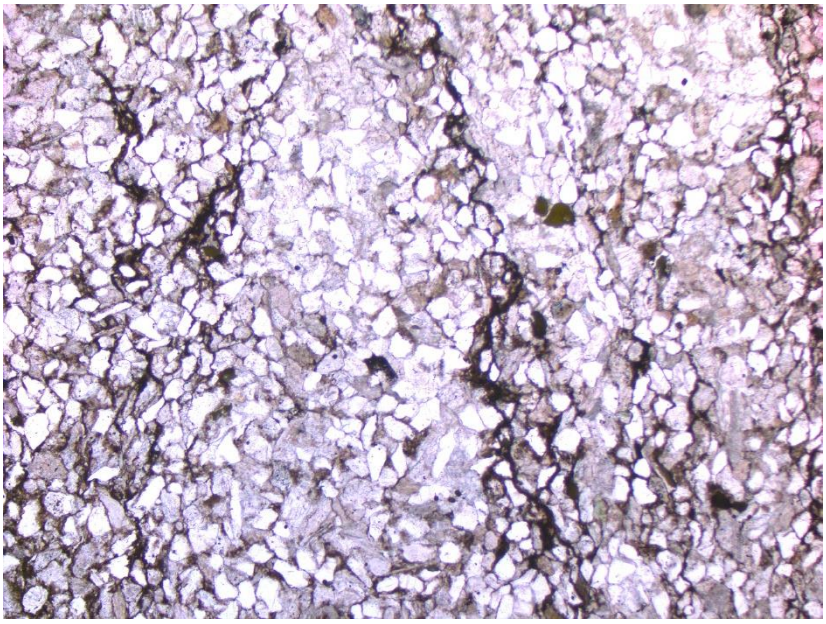
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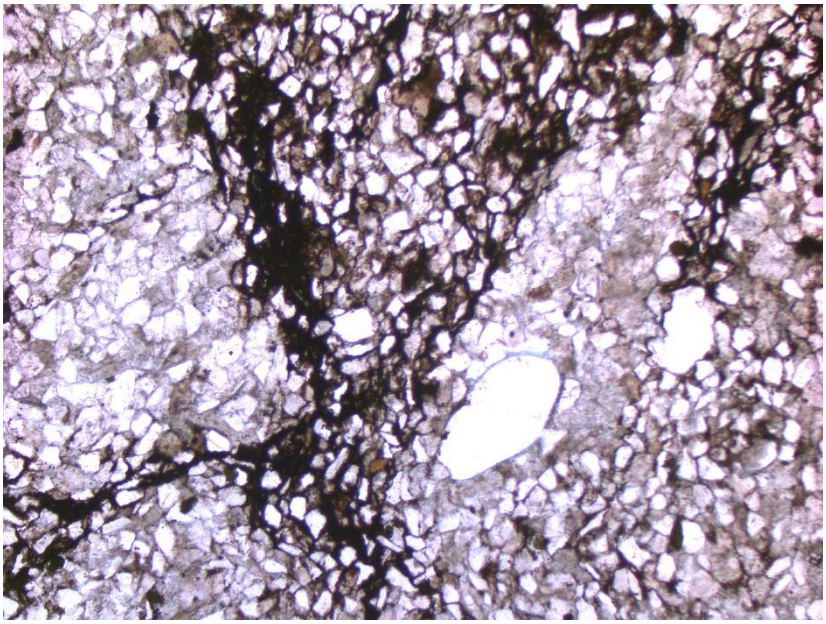
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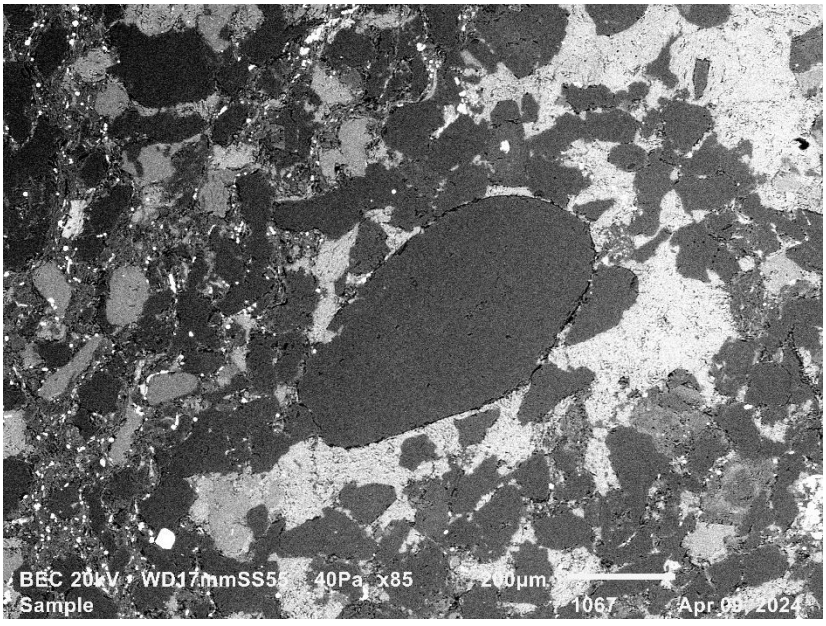
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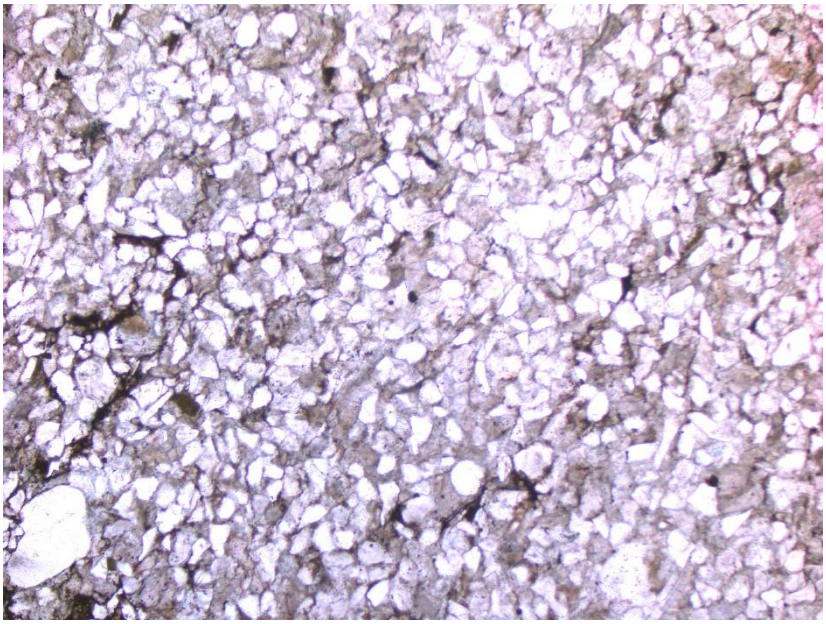
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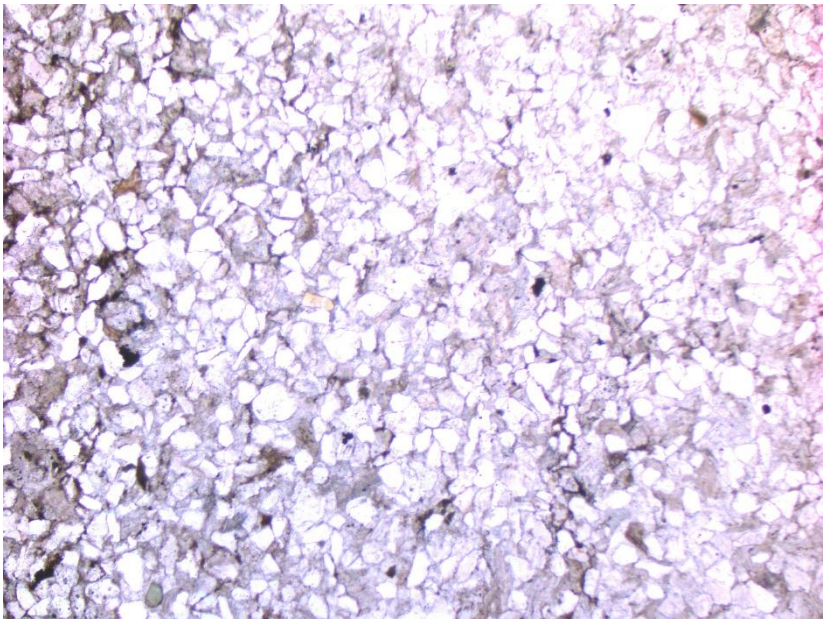
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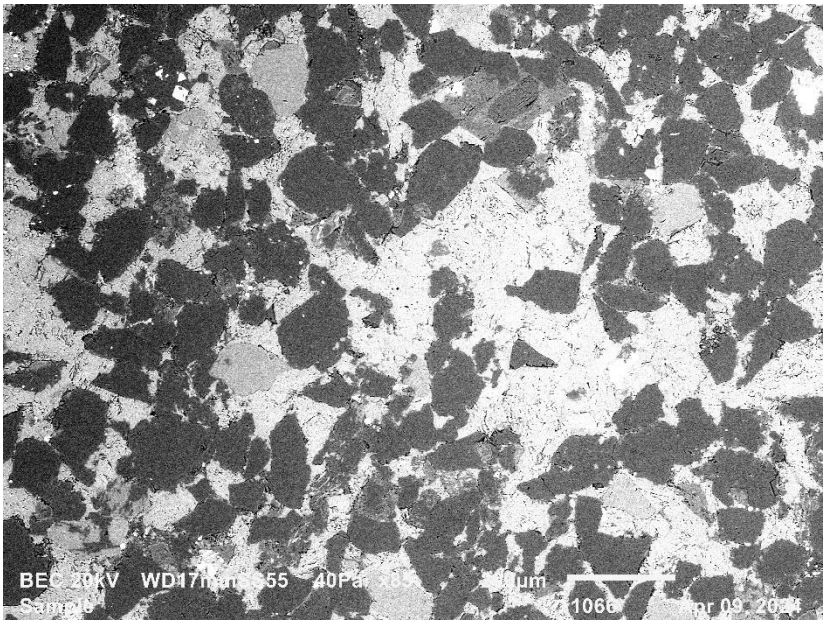
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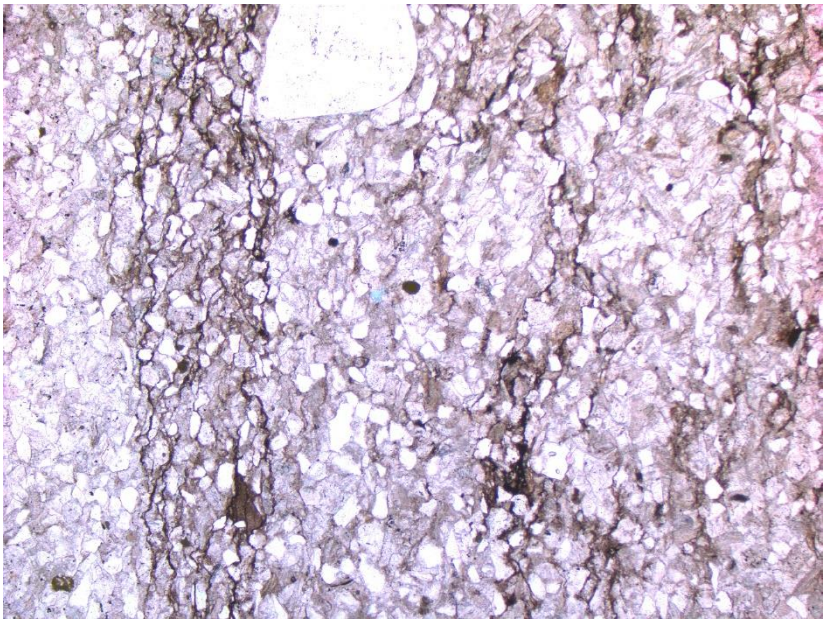
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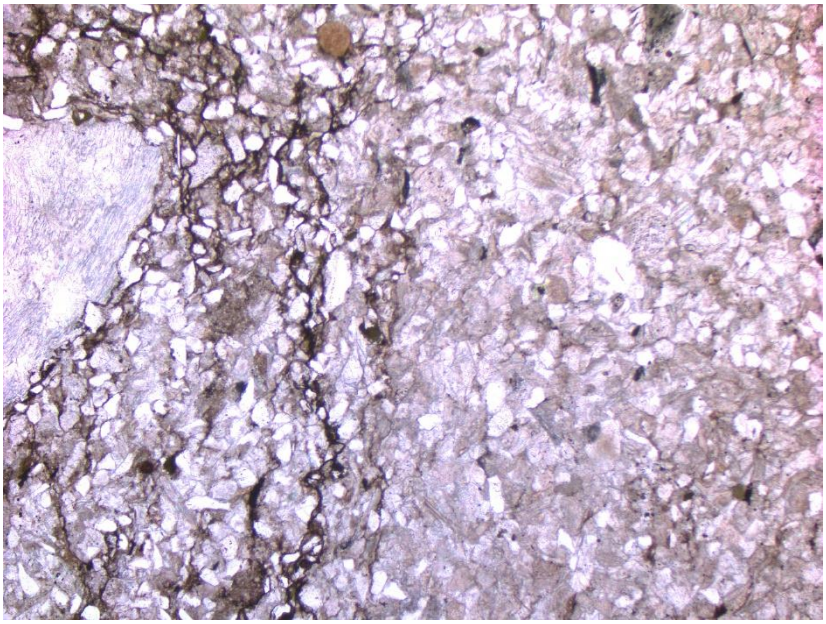
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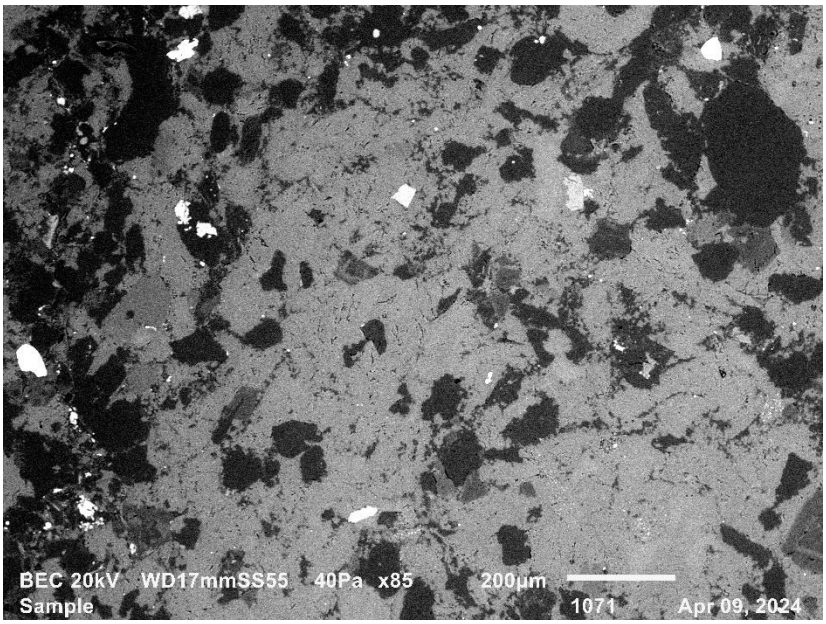
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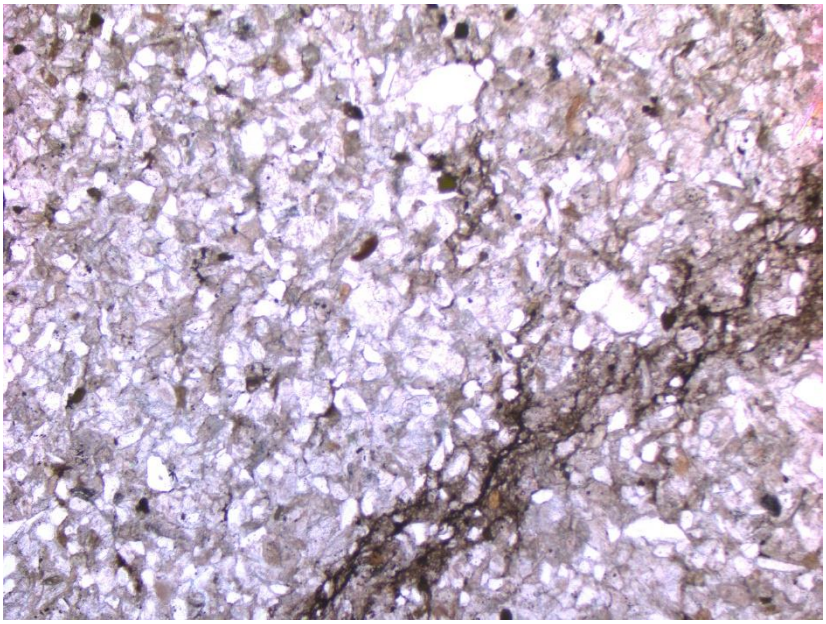
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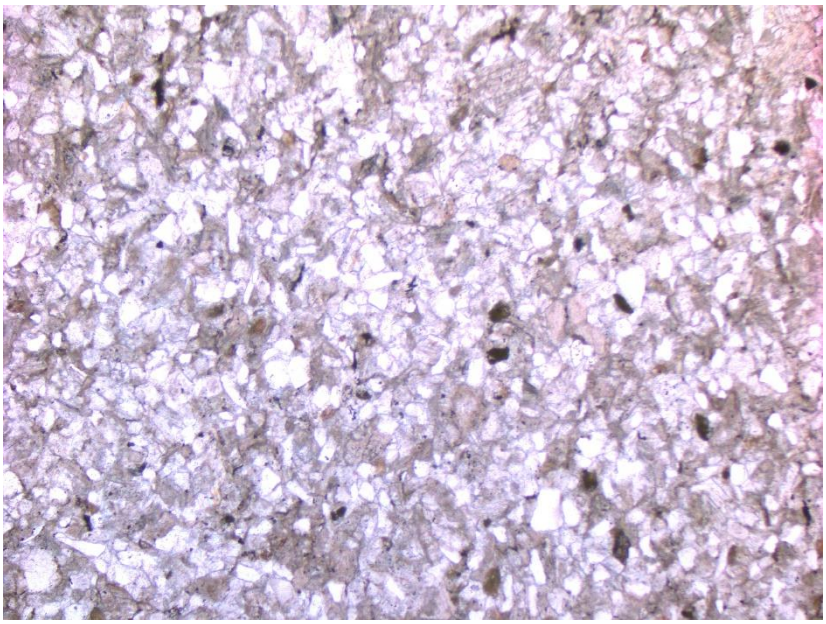
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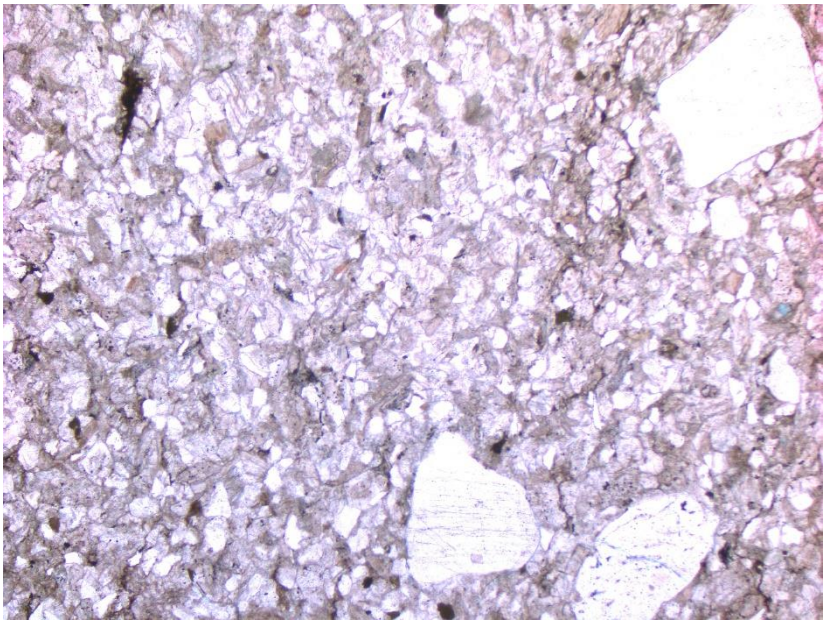
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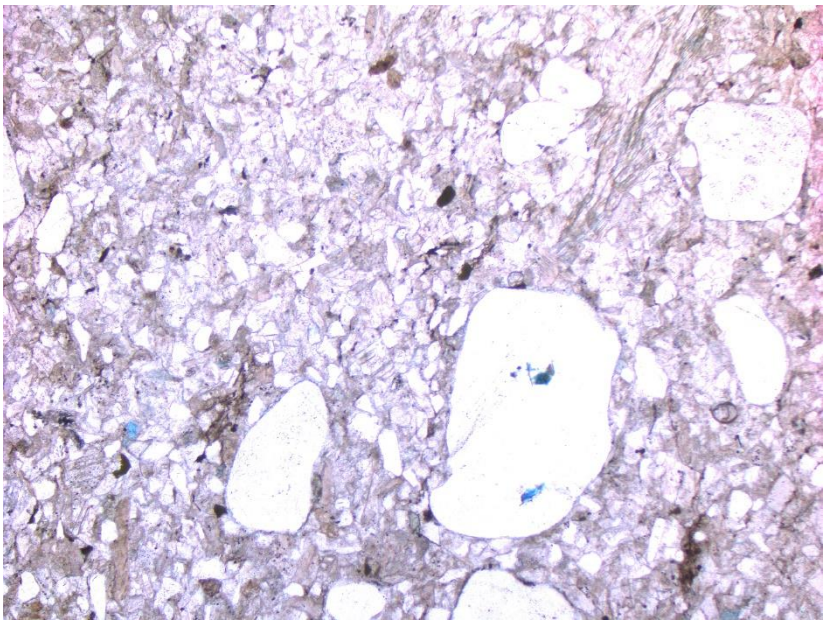
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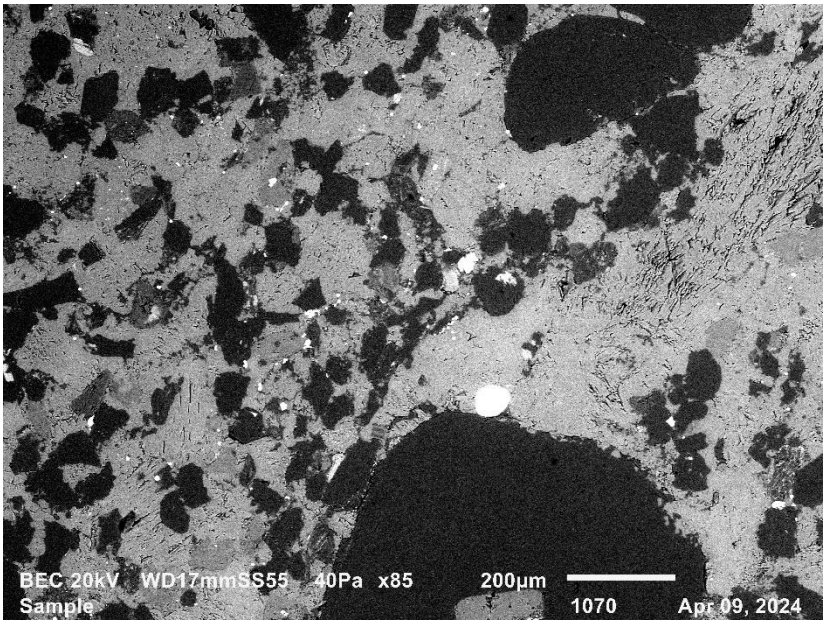
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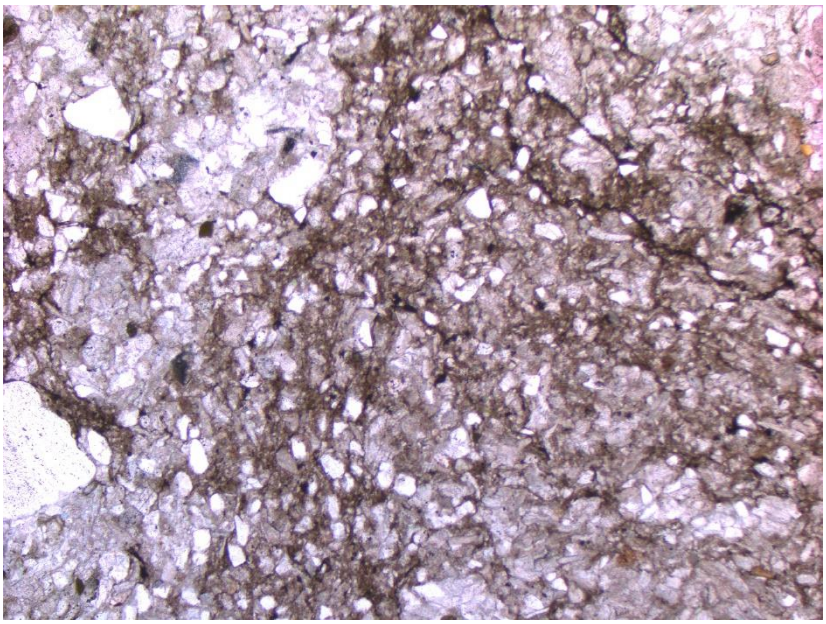
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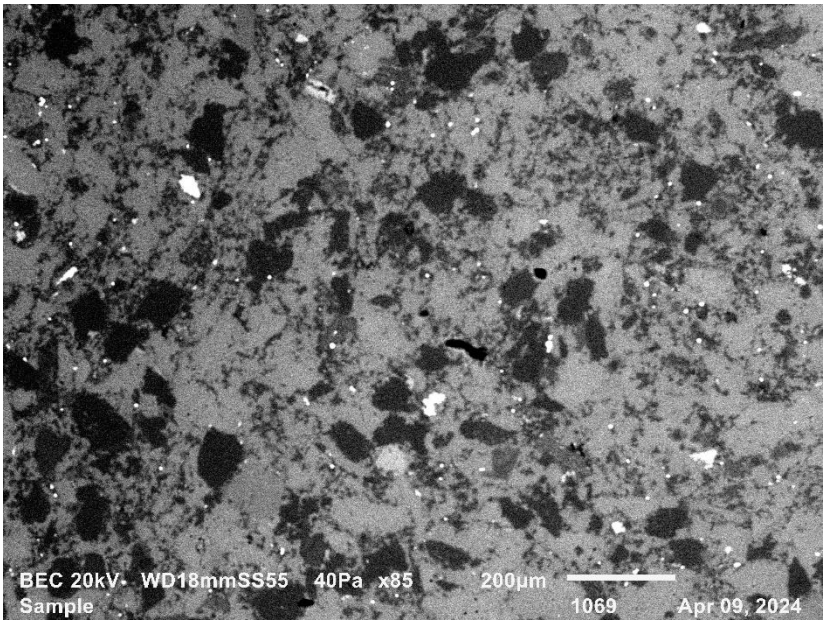
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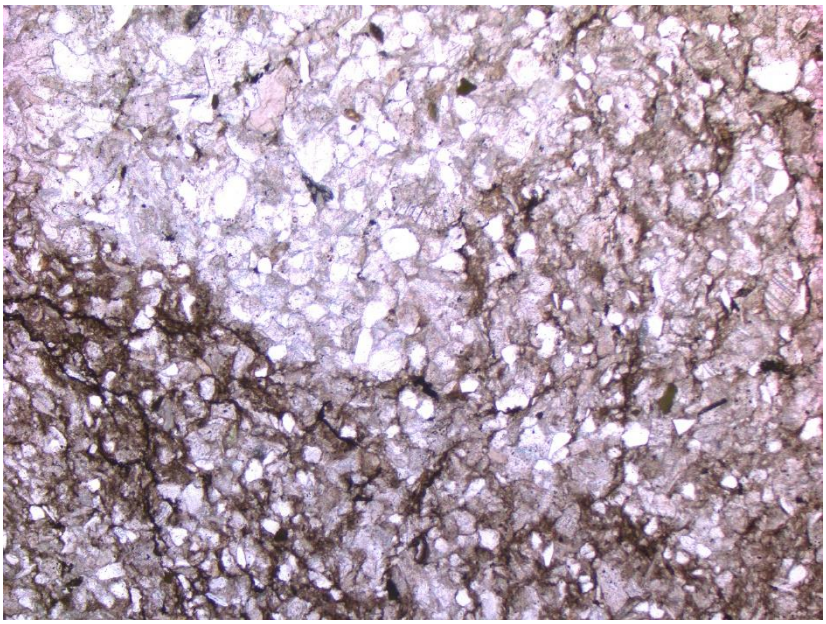
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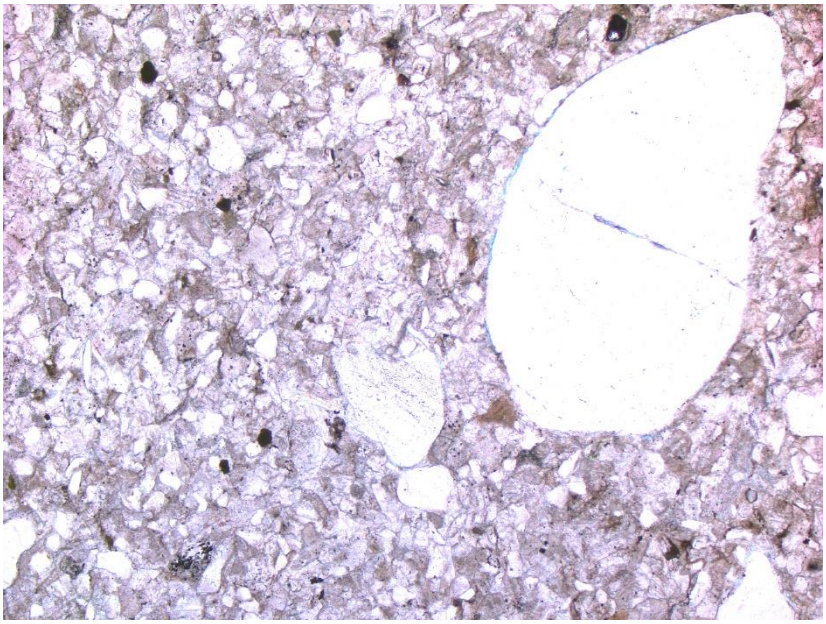
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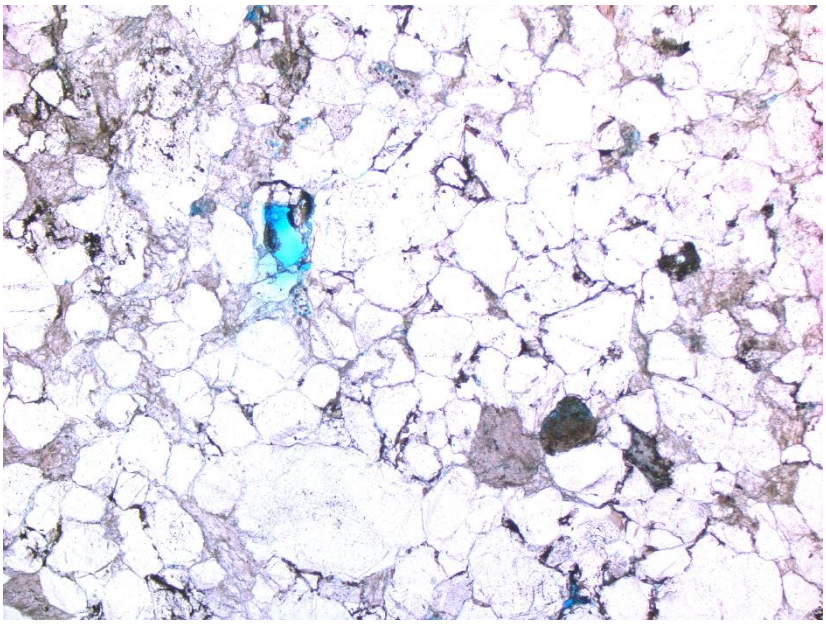
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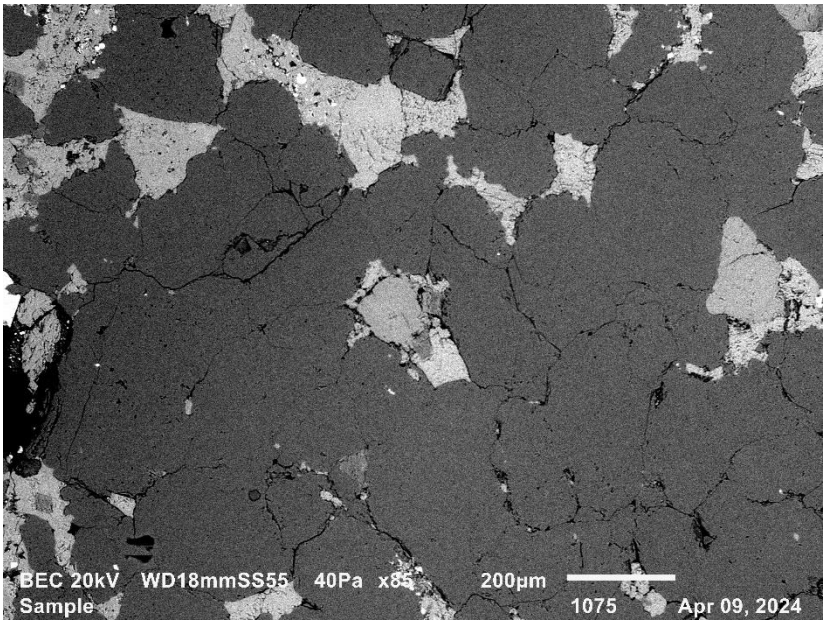
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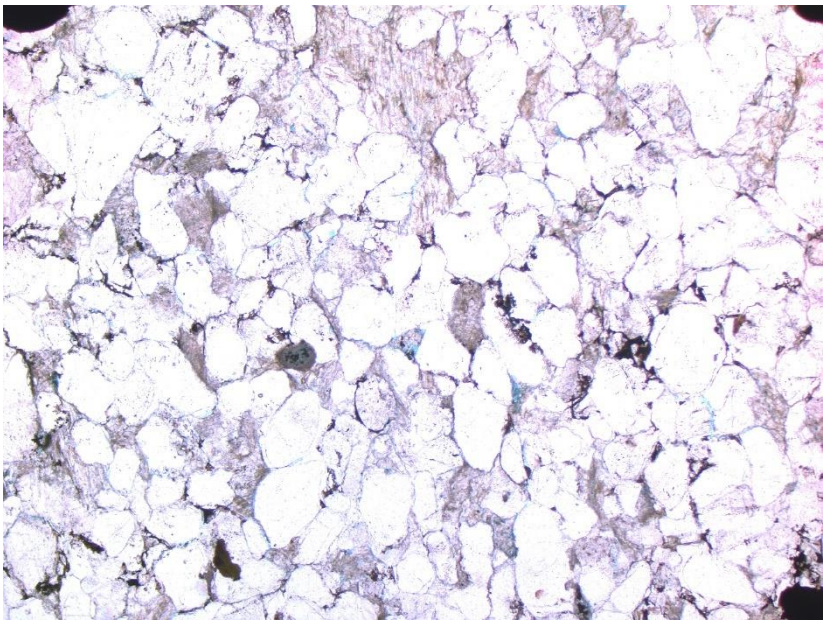
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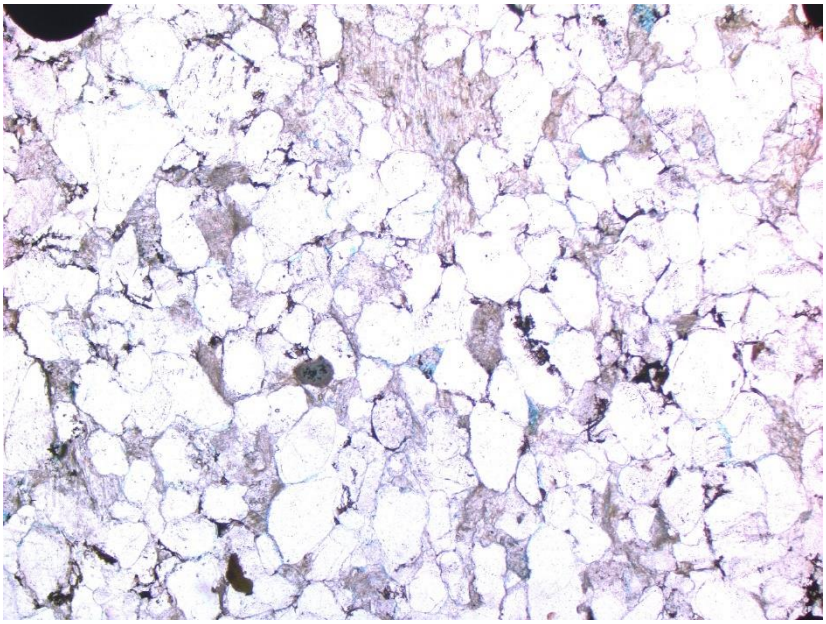
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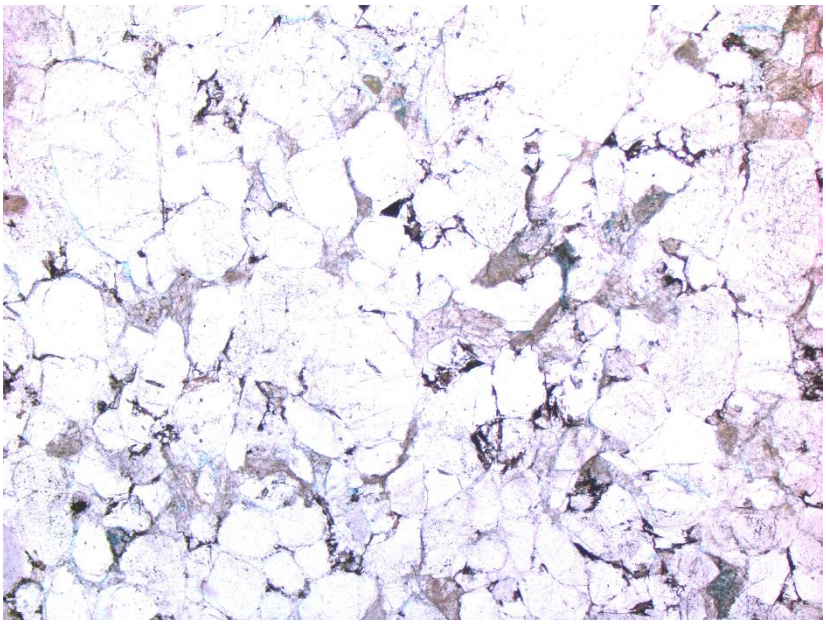
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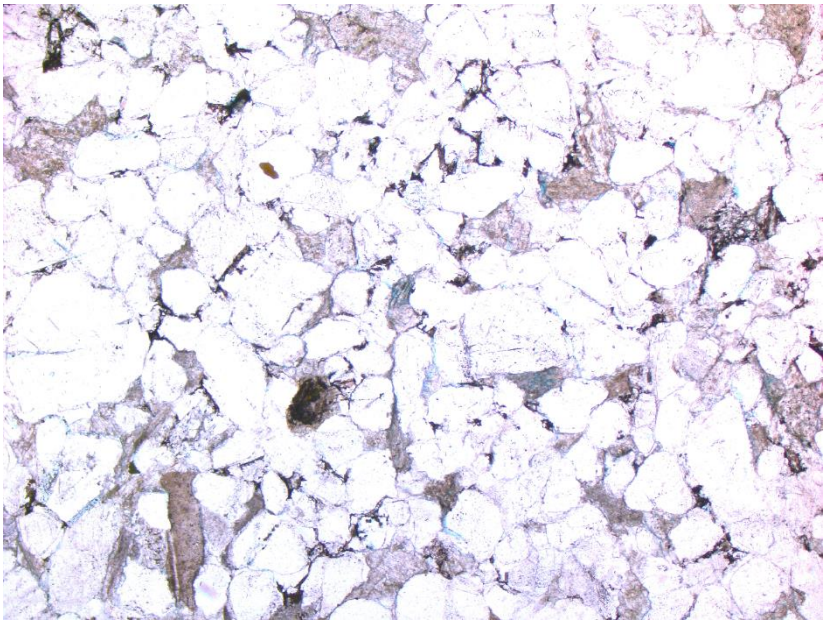
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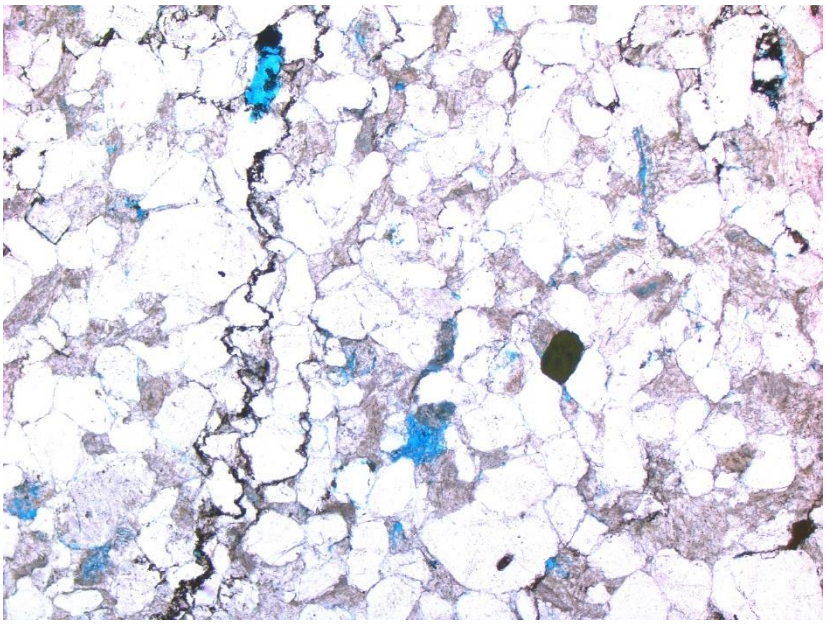
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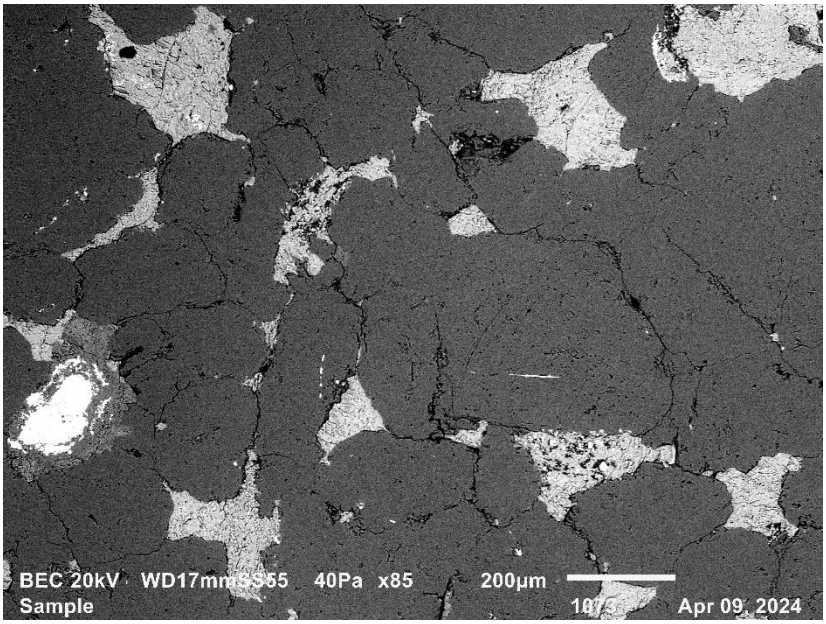
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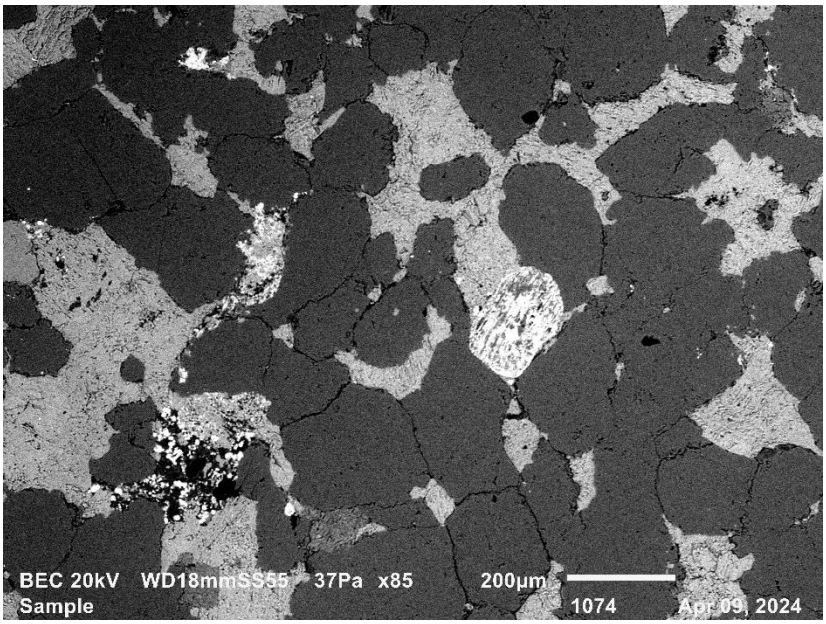
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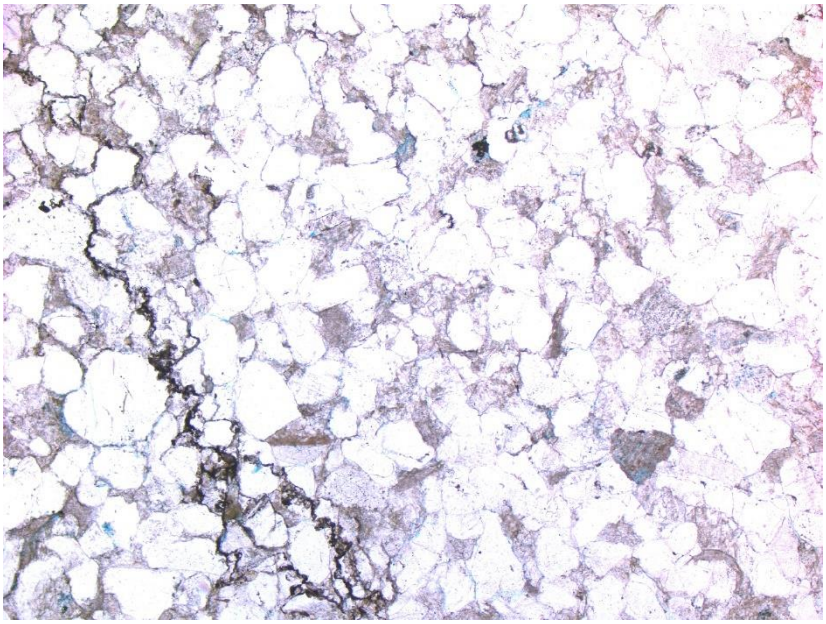
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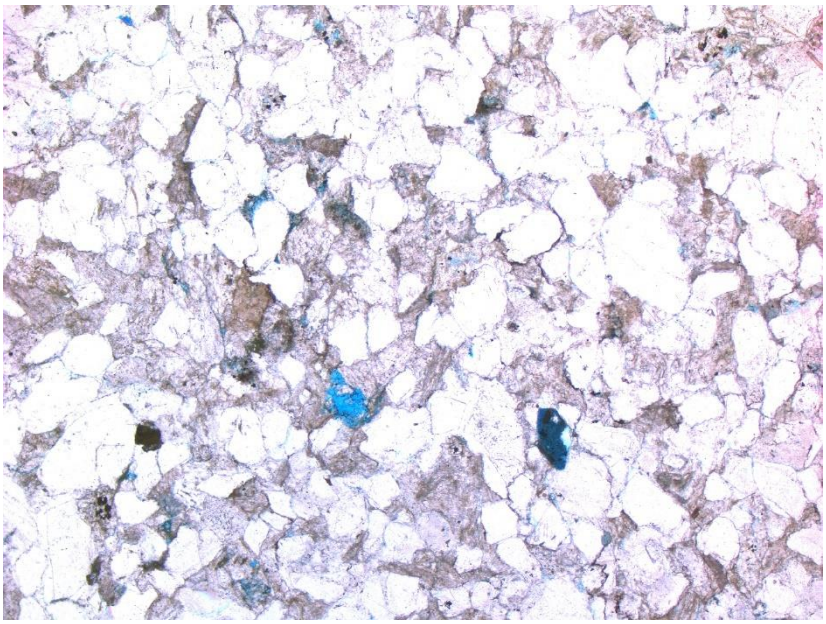
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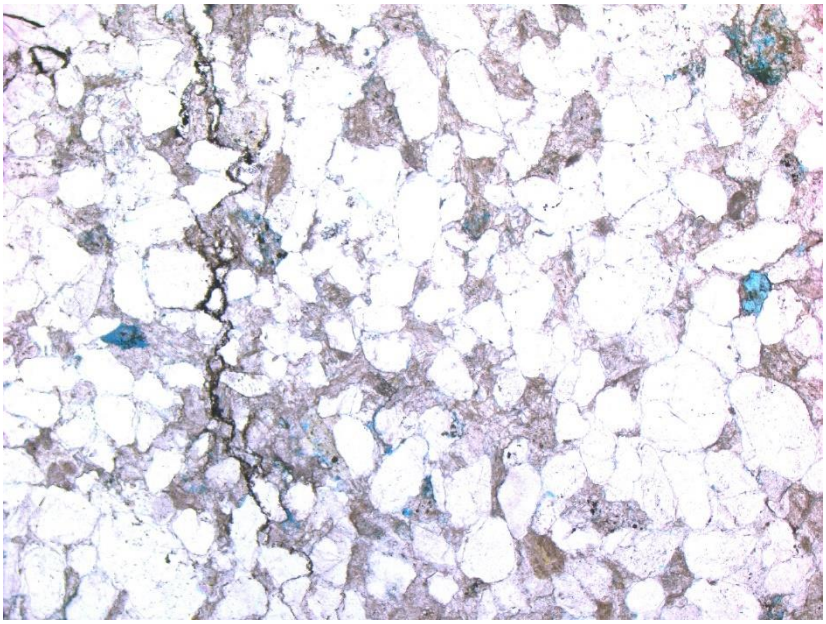
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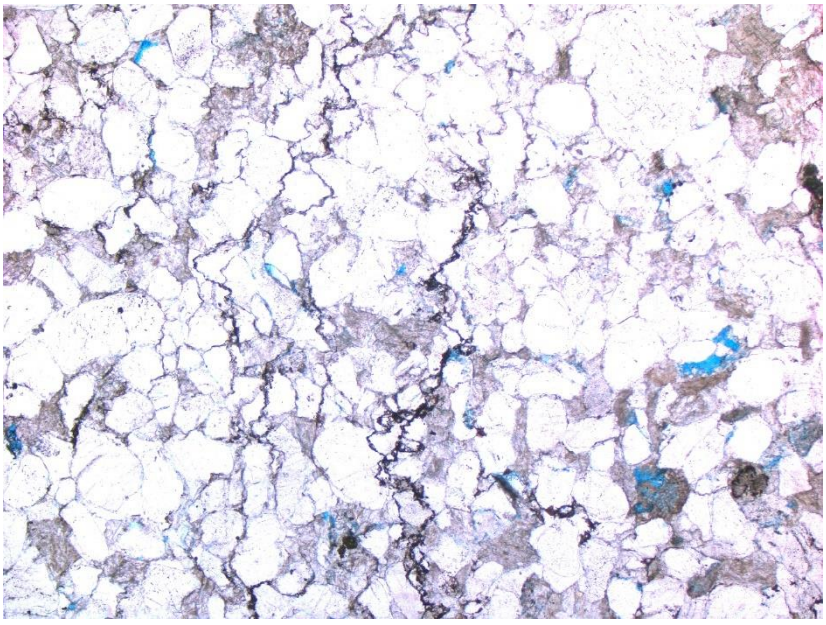
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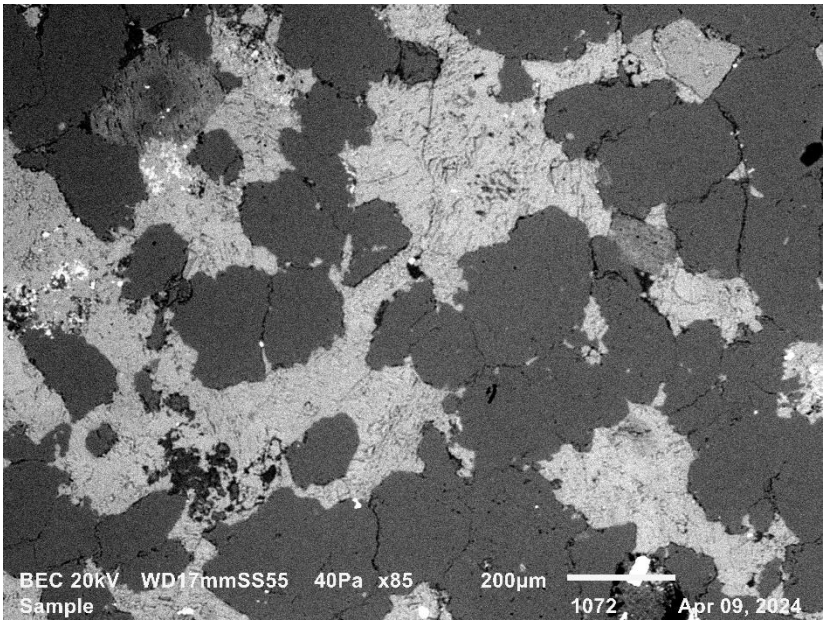
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TSC3B8_8



TSC3B8_9



SEM_TSC3B8_9